PREMIER REFERENCE SOURCE

Production and Manufacturing System Management

Coordination Approaches and Multi-Site Planning

Paolo Renna

Advances in Civil and Industrial Engineering Series

Production and Manufacturing System Management:

Coordination Approaches and Multi-Site Planning

Paolo Renna
University of Basilicata, Italy

ENGINEERING SCIENCE REFERENCE

Managing Director: Lindsay Johnston
Editorial Director: Joel Gamon
Book Production Manager: Jennifer Romanchak
Publishing Systems Analyst: Adrienne Freeland
Development Editor: Austin DeMarco
Assistant Acquisitions Editor: Kayla Wolfe
Typesetter: Travis Gundrum
Cover Design: Nick Newcomer

Published in the United States of America by
Engineering Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Production and manufacturing system management: coordination approaches and multi-site planning / Paolo Renna, editor.
p. cm.
Includes bibliographical references and index.
Summary: “This book presents relevant theoretical frameworks and most recent research findings in this area, providing significant theories for research students and scholars to carry out their continuous research as well as practitioners who aim to improve upon their understanding of distributed production planning”-- Provided by publisher.
ISBN 978-1-4666-2098-8 (hardcover) -- ISBN 978-1-4666-2099-5 (ebook) -- ISBN 978-1-4666-2100-8 (print & perpetual access) 1. Business logistics. 2. Industrial management. I. Renna, P. (Paolo)
HD38.5.P792 2013
658.5--dc23
2012020293

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

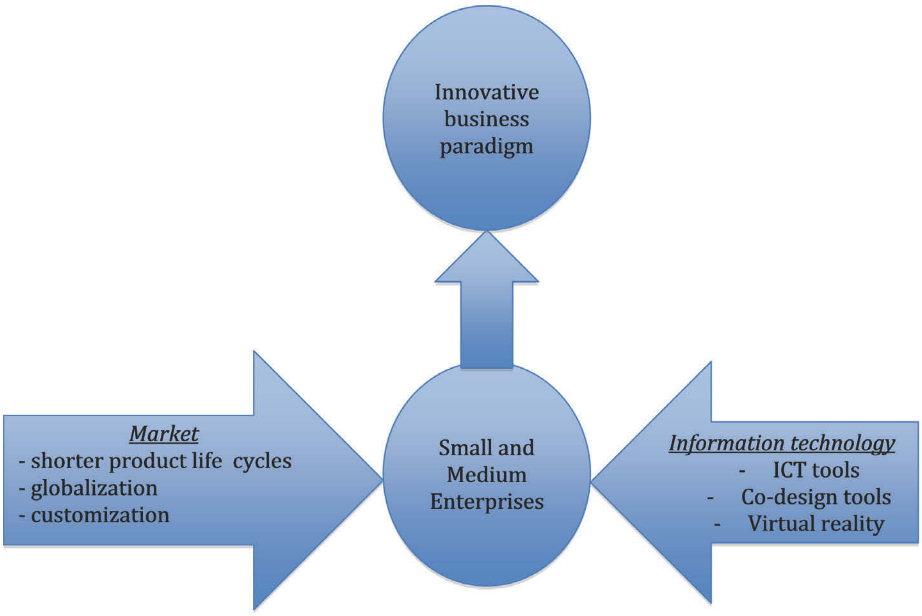
Preface

THE ROLE OF COOPERATION METHODS TO CREATE VALUE ADDED SERVICES IN SMALL AND MEDIUM ENTERPRISES

Introduction

The market globalization and increase of competition forces manufacturing companies to adopt new business organization paradigms. Moreover, Small and Medium Enterprises can compete to a global level if they try to cooperate at different levels as: design, production planning, et cetera. Figure 1 shows the driving forces towards the adoption of cooperation mechanism for the Small and Medium Enterprises (SMEs). The market is characterized by shorter product life cycles, the globalization of the competition, and the higher customization of the products. The rapid development of new technologies as Information and Communication Technology, co-design tools, and virtual reality allow the enterprises to adopt new cooperation mechanism geographically distributed. Therefore, the forces of the market and the new opportunities derived from new technologies can be a relevant opportunity for the SMEs to adopt new

Figure 1. Driving forces towards cooperation mechanism



business paradigm. These new paradigms are important, because the ability to react to continuous and unexpected changes is essential for market success (Wiendahl and Lutz). The competition is changed by these factors. The competition of individual companies is substituted by the competition among supply chain or networks (Carrie, 2000).

Several cooperation configurations have been proposed in scientific literature. Supply chain management is a network of enterprises that focused on their core business in order to integrate the entire business line (Miles and Snow, 1986). Virtual enterprises are characterized by a short-term collaboration among partners focused on their core business to take advantages from a market opportunity (Camarinha-Matos and Afsarmanesh, 2003). The cluster concept has been proposed as a network of companies organized in clusters; each cluster is characterized by hierarchical network of enterprises (Porter, 1998; Carrie, 2000).

The extended enterprises is defined by Childe (1998) as: "*a conceptual business unit or system that consists of a purchasing company and suppliers who collaborate closely in such a way as to maximise the returns to each partner*." Perrone et al. (2005) proposed a set of value added services to support extended enetrprise by multi agent architetture, negotiation tools, production planning and simulation. Many authors discussed the problem of coordination multi facility production problem. Among the recent studies, the following have particular relevance.

Lo Nigro et al. (2003) proposed to model and design coordination problems within production network by using the Multiple Agent Technology. In particular, their paper proposes new strategies for coordinating production-planning activities within production networks. Such models have been developed and tested by using a proper simulation environment developed by using open source code and architecture. The results of the research can be located at two levels: (a) concerning the specific coordination problem addressed, the research provides some insights to make decisions about the choice of coordination approaches to be used in distributed production planning problems; (b) at more strategic level, the paper shows how Agent Technology and discrete event simulation can be used to build up efficient coordination structures for production networks.

Lin and Chen (2007) proposed a monolithic model of the multi-stage and multi-site production planning problem. The contribution of this planning model is to combine two different time scales, i.e., monthly and daily time buckets. Then, the approach is centralized, and the relevance of the case study application of the approach proposed.

Alvarez (2007) discussed some specific characteristics of the planning and scheduling problem in the extended enterprise including an analysis of a case study, and reviewed the available state-of-the-art research studies in this field. Most studies suggest that integrated approaches can have a significant impact on the system performance, in terms of lower production costs, and less inventory levels.

The methodologies proposed to support the cooperation approaches can be classified in these main areas:

- **Multi Agent Technology:** This methodology allows to build an architecture distributed, robust and adaptable to change of the environment. Lima et al. (2006) and Argoneto et al. (2008) proposed multi agent architecture to support production planning activities.
- **Coordination Mechanism:** In order to coordinate two or more actors with conflicting goals. This context proposed negotiation process, game theory, et cetera (Bruccoleri et al., 2005; Argoneto et al., 2008).

- **Discrete Event Simulation:** In order to evaluate the real value added by a tool. Most important, from a strategic point of view, is to understand what kind of coordination policy can lead a better global result for the enterprise within a distributed framework (Renna and Argoneto, 2010).

The cooperation mechanisms have demonstrated to support several areas of SMEs and several fields of applications. The context of SMEs activities concerns the capacity sharing (Renna and Argoneto, 2010b), process planning (Zang et al., 2000), production planning (Argoneto et al., 2008), virtual logistic management systems (Chang et al., 2003).

Moreover, the field of application is not only the SMEs activities context, but several fields of application can use the same methodologies. Some examples are the following: electricity grid (Carvalho et al., 2012), healthcare management systems (Makni et al., 2012), and traffic control system (Wei, 2012).

Scope and Contents of the Book

The edited volume concerns the different aspects of cooperation mainly for SMEs. The objective is to present the studies to develop multi agent infrastructure and models for the coordination activities among the enterprises. This book also presents cooperation models and approaches focused on fields different from the SMEs applications.

The chapters of the book are organized in three sections. Section 1, *Multi-Agent System Applications,* focuses on the application of multi agent methodology to support the distributed architecture in the fields of production planning and supply chain. Section 2, *Distributed Production Planning and Organization,* presents the methodology for the production planning problem and the design/management of distributed organizations. Section 3, *Network Applications,* describes methodologies and applications that can be applied in general network organizations.

Chapter 1 concerns the study of the formation of a consortium to match buyer bid or seller. The chapter proposes heuristics and one of them based on genetic algorithm and compares the performances in auction trading. The proposed approaches are supported by a Multi Agent System. The GA method shown later is less structured and offers more freedom and random selection, as does evolution in nature. In terms of performance, the GA method without any enhancement of the selection criteria is at least as good as the rule-based approach.

Chapter 2 proposes a novel approach based on emergent distributed scheduling to overcome the traditional separation between task scheduling and execution control. The Manufacturing Execution System proposed is able to reject disturbances and successfully handle unforeseen events by autonomic agents implementing the monitor-analyze-plan-execution loop while achieving their corresponding goals. Results obtained for different simulated scenarios indicate that the autonomic MES is robust and stable despite the total autonomy given to order and RAs when negotiating resource usage without resorting to a priori defined schedule.

Chapter 3 presents a multi-agent model aimed to investigate emergent organizational structures in production networks and their reification by means of pheromone-based algorithms. The model considers agents (firms) embedded in a production network, interacting among them through business-to-business relations. The results of the simulations show the impact of the transportation cost and the geographical reach on the regionalization of production and on wealth patterns.

Chapter 4 investigates distributed coordination in dynamic assignment of time-critical entities among multiple sites. An agent-based simulation model is developed, in which each agent applies some adaptive assignment rule to match supplies and demands that are generated at its own site. Two distinct centralized initial assignment rules are considered, and how agents update their rules is assessed. The research evaluates the impact of different agent environments, numbers of supply/demand agents, and ratios of supply/demand rates.

Chapter 5 studies production and transportation problem confronting a specialty chemical company that two manufacturing facilities in which one facility produces intermediate products which are then transported to another facility separated by a distance in which end products are manufactured to meet their customers demand. Real industrial data are used to test and validate the model. Comparing the model's results and the company's actual performance indicates that, if the company implemented the proposed model, significant savings could be achieved.

Chapter 6 examines the recent years of research developed in the field of coordination approaches to support distributed production systems. The papers discussed concern the period of 2004-2010 published in international ISI journals. The research articles are classified according to nine fields of research: operational research models; collaborative architecture; negotiation and bargaining models; capacity exchange; revenue sharing; chemical engineering; electronic approach; general review; case study. The analysis of the literature highlights that the articles are distributed uniformly over the years analyzed. The most fields investigated are the collaborative architecture and operational research models, while emerging fields are the chemical engineering and revenue sharing based approaches. The discussion underlines the limitation of the literature and suggests the directions for future research.

Chapter 7 proposes a modeling by selecting a Fuzzy Hierarchical Production Planning (FHPP) technique with zone covering in the mid-term and long-term time horizons electricity supply modeling in the Iran global compact network. In this research, in combination with the AHP method and linear programming model, environmental pollution, efficiency, proportion in total capacity, and power plant activity in year criteria are considered in addition to the previously considered cost based models.

Chapter 8 deals with description of problems small and medium enterprises (SME's) deal with during project cooperation or using Virtual Enterprise paradigm. A number of important problems are addressed through effective communication and appropriate communication environment in this chapter. By using the proposed communication environment and proper tool, there is no need for unification and big investments in to the information and communication technologies. All information and data exchange is done by email, and since email is a simple and open data format, it can be integrated and processed by any ICT system.

Chapter 9 makes an initiative to interpret prosumer and its connections with some resembling concepts, such as value co-creation, service dominant logics, crowdsourcing, and consumer-based coopetition. This chapter shows that there is still need to continue these discussions and develop further the concepts associated with prosumer. Also, this chapter contributes by providing new perspectives for open - closed innovation strategies by applying (multifaceted) coopetition framework and discussions in the context of collaborative innovation discussions.

Chapter 10 proposes two protocols to reach an agreement between customer and the production network have been proposed: negotiation and an expected profit approaches. Moreover, two coordination strategies have been proposed: index efficiency and ranking price approaches. Finally, the possibility of dividing the orders in lots by the customer is proposed. A simulation environment based on open source code and Multi Agent Architecture has been developed to test the proposed approaches. The experiments have been conducted in different conditions of workload and mar-up; the results of the simulation provide the information necessary to select the suitable coordination and protocol mechanisms in a distributed production planning problem.

Chapter 11 deals with demand uncertainty at the strategic level, the safety stock placement problem in supply chains with limited production capacities. Considering the results from each planning level, an integrated hierarchical approach is proposed in this research. Two phases of integration are considered: (1) the integration of strategic and tactical level planning and (2) the integration between tactical and operational level planning. This collection of models can serve as a basis for further elaborated models to solve more complex problems in a supply chain.

Section 3 discusses the measures of risk in a network and the possible applications of "Second Life" approach.

Chapter 12 proposes a simple measure is used to rank the distribution functions. The proposed distributions which are discussed are: the exponential, Erlang, Uniform, Triangular, Beta, and Beta(PERT) distribution. All suggested distributions fall in the class of NBUE distributions and are considered to be symmetric about their mean. The example network, which is shown in the application, verified the results of theorems discussed in the chapter.

Chapter 13 presents a conceptual-pedagogical "cybernetic" methodology for cyber entities' (avatars') spatial awareness in an innovative way by using Second Life (SL) in the learning process. The main contribution and originality of the research is to highlight the suitability of SL for organizing and conducting courses from a distance. In addition, the contribution and thus the record of the learning through "organizational-teaching" methodology and the main axis is to identify problems that are associated with the acceptance and future development of the leanings communities.

Chapter 14 investigates the new interactive relationship, which arises between cyber entities (avatars) that move around, meet others, and emulate their work in [D-] CIVEs ([Distributed-] Collaborative Immersive Virtual Environments). The original contribution of this effort is to become a highly inexhaustible source of inspiration and awareness for the interactive bibliographic data and interdisciplinary fields of e-learning for the future.

Paolo Renna
University of Basilicata, Italy

REFERENCES

Alkvarez, E. (2007). Multi-plant production scheduling in SMEs. *Robotics and Computer-integrated Manufacturing*, *23*(6), 608–613. doi:10.1016/j.rcim.2007.02.006

Argoneto, P., Perrone, G., Renna, P., Lo Nigro, G., Bruccoleri, M., & Noto La Diega, S. (2008). *Production planning in production networks*. London, UK: Springer-Verlag. doi:10.1007/978-1-84800-058-2

Camarinha-Matos, L. M., & Afsarmanesh, H. (2003). Elements of a base VE infrastructure. *Journal of Computers in Industry*, *51*(2), 139–163. doi:10.1016/S0166-3615(03)00033-2

Carrie, A. (2000). From integrated enterprises to regional clusters: The changing basis of competition. *Computers in Industry*, *42*, 289–298. doi:10.1016/S0166-3615(99)00077-9

Carvalho, M., Perez, C., & Granados, A. (2012). An adaptive multi-agent-based approach to smart grids control and optimization. *Energy Systems*, *3*(1), 61–76. doi:10.1007/s12667-012-0054-0

Chang, E., Dillon, T., Gardner, W., Talevski, A., Rajugan, R., & Kapnoullas, T. (2003). A virtual logistics network and an e-hub as a competitive approach for small to medium size companies. *Web and Communication Technologies and Internet-Related Social Issues, HSI 2003*. *Lecture Notes in Computer Science*, *2713*, 167–168.

Childe, S. J. (1998). The extended enterprise- A concept for co-operation. *Production Planning and Control*, *9*(4), 320–327. doi:10.1080/095372898234046

Lima, R. M., Sousa, R. M., & Martins, P. J. (2006). Distributed production planning and control agent–based system. *International Journal of Production Research, 44*(18 – 19), 3693–3709.

Lin, J. T., & Chen, Y.-Y. (2007). A multi-site supply network planning problem considering variable time buckets - A TFT-LCD industry case. *International Journal of Advanced Manufacturing Technology*, *33*(9-10), 1031–1044. doi:10.1007/s00170-006-0537-z

Lo Nigro, G., Noto La Diega, S., Perrone, G., & Renna, P. (2003). Coordination policies to support decision making in distributed production planning. *Robotics and Computer-integrated Manufacturing*, *19*, 521–531. doi:10.1016/S0736-5845(03)00062-0

Makni, M., Ben Hadj-Alouane, N., Tata, S., & Yeddes, M. (2012). Negotiating deadline constraints in inter-organizational logistic systems: A healthcare case study. *Business Process Management Workshops*. *Lecture Notes in Business Information Processing*, *100*(Part 2), 108–118. doi:10.1007/978-3-642-28115-0_11

Miles, R., & Snow, C. (1986). Organizations: New concepts for new forms. *California Management Review*, *18*(3), 62–73.

Perrone, G., Bruccoleri, M., & Renna, P. (2005). *Designing and evaluating value added services in manufacturing e-market places*. Springer. doi:10.1007/1-4020-3152-1

Porter, M. (1998). Clusters and the new economies of competition. *Harvard Business Review*, *76*, 77–90.

Renna, P., & Argoneto, P. (2010a). Production planning and automated negotiation for SMEs: An agent based e-procurement application. *International Journal of Production Economics*, *127*, 73–84. doi:10.1016/j.ijpe.2010.04.035

Renna, P., & Argoneto, P. (2010b). A game theoretic coordination for trading capacity in multi-site factory environment. *International Journal of Advanced Manufacturing Systems*, *47*(9), 1241–1252. doi:10.1007/s00170-009-2254-x

Wei, X. (2012). Research of highway integrated traffic control system based on multi-agent. *Software Engineering and Knowledge Engineering: Theory and Practice*. *Advances in Intelligent and Soft Computing*, *114*, 17–23. doi:10.1007/978-3-642-03718-4_3

Wiendahl, H.-P., & Lutz, S. (2002). Production in networks. *CIRP Annals- Manufacturing Technology, 51*(2), 573-586.

Zang, Y., Zang, C., & Qang, H. P. (2000). An Internet based STEP data exchange framework for virtual enterprise. *Computers in Industry*, *41*, 51–63. doi:10.1016/S0166-3615(99)00039-1

Table of Contents

Detailed Table of Contents

Section 1
Multi-Agent System Applications

Chapter 1
Alternative Approaches to Auction Trading by Consortia in Multi Agent Systems:
A Comparative Study

Barin N. Nag
Towson University, USA

Dong-Qing Yao
Towson University, USA

Sungchul Hong
Towson University, USA

ABSTRACT

Agent-based auction trading is important in e-Procurement as a part of the supply chain management activity of procurement via the Internet. Participating buyers and sellers are intelligent agents tasked with finding matches with required or offered quantities for best performance. Formation of consortiums offers opportunities in matching trade volumes, but in the real world, there are difficulties in optimizing consortium formation due to lack of perfect information and the dynamic character of the information. Heuristic methods are often the only solution. This chapter shows the impact and capabilities of alternate heuristic models, and compares their performances in auction trading.

INTRODUCTION

Auction trading over the Internet has become a standard procedure for the procurement and electronic acquisition of products and services in a process known otherwise as e-Procurement. Auction trading in its traditional form has long been considered an important part of managing the supply chain in terms of keeping the cost down and the volume high. The Internet made the process faster and more effective reducing the cost and increasing the efficiency. Using the Internet intel-

DOI: 10.4018/978-1-4666-2098-8.ch001

ligent agents can become the trading entities, both buyers and sellers. Agent based auction trading takes the trading process one step further to reduce cost and increase efficiency. The e-Procurement mechanism is enhanced by the procurement of larger volumes at more attractive prices. This has made the e-Procurement mechanism the primary selling mechanism for tier one suppliers giving them the selling advantage of enabling them to move the largest possible volume at the best price. It is equally an advantage for large buyers allowing them access to a large volume of supply at competitive prices. In recognition of the supply chain benefits of the e-trade environment, the European Union has made it mandated for many transactions.

The environment of agent-based auction trading consists of online auctions between web-based buyer agents and web-based seller agents. The trading mechanism works best when there are many buyers and many sellers providing a competitive marketplace and volume economies. The challenge of high performance in a complex and competitive market is to match buyers and sellers. Typically, there are two parameters of a match, price and volume. Price may often be a concern for the feasibility of a trade, *i.e.* a buyer or seller will not trade above or below a certain price. A special type of purchase concerns MRO products used by manufacturing organizations, where MRO stands for "Manufacturing, Repair, and Operations". Typically MRO products are not part of the finished goods that constitute the bulk of the revenue. MRO products may have prevailing market prices and matching prices is automatic. As a first step, we consider matching volumes alone, and compare matching approaches on the basis of trading volumes. The comparison may later be extended to matching in the two dimensions of price and quantity. The volume matching option is especially interesting because volume is subject to an individual agent's bid as a buyer, or offer as a seller. In a traditional trading environment, cooperation and consortium formation is the strategy used to match a larger volume by a collaborative combination of smaller volumes. The focus of this research is to compare alternate methods to replicate the cooperative process of matching and volume generation when the trading entities are agents.

The proposed system studied here is a two-tier e-Procurement or auction trading environment, where the trading entities consist of multiple suppliers, or selling agents, and multiple buyers represented by buying agents. In a *forward auction*, a seller agent proposes a volume of trade and a buyer agent matches the volume, or a consortium of buyer agents, seek to match the seller's volume by a combination of their individual volumes. In a *reverse auction*, a buyer agent proposes a bid volume, and a seller agent matches the volume, or a consortium of seller agents, seek to match the buyer's volume by a combination of individual volumes. While the priority remains on direct matching as the most convenient for buyer and seller alike, cooperative trading has an enormous potential in increasing trading volumes and in reducing waiting times for matches, thereby increasing the efficiency of trading.

Agents working together in a community, making collaborative decisions in auction trading to achieve individual goals, form a *Multi-agent System* (MAS). The information on available trades is freely available to all involved trading agents, and the cooperative actions between them to form consortiums is as important as their decision-oriented actions in the selection and confirmation of the trades. Binbasioglu (1999) proposed an approach to identify a set of problem components to support the progress of understanding and structuring multi-agent software architecture to manage a supply chain for tactical as well as operational decisions. Fox *et al.* (2000) presents in his paper a solution to construct the software to manage the supply chain at tactical and operational levels using agent-based systems. Typically, agent-based systems utilize order acquisition agents, logistic agents, transportation agents, scheduling agents, resources agents, *etc.* Coordination of agent activity is an important aspect of the work done by groups of agents, for which a critical element is the availability of information. Nag (2008) shows a blackboard architecture that makes available to all agents in real time the trading information and the agent information regarding trading availability and trading volumes. All these previous research proposed agent framework for general supply chain network from business process perspective, but not focusing on specific algorithms to match buyer's demand and seller's supply. To this end, in this chapter, we aim to investigate detailed algorithm to agent consortium formation.

It is reasonable to assume that lots and quantities presented for buying and selling will be different, possibly over a wide range of values. It might be expected that individual buyers and sellers will be reluctant to trade mismatched quantities in case of a small deficit or surplus. A consortium of two or more smaller buyers matching the quantity of a large seller will have more trading success, as will a consortium of two or more smaller sellers matching the quantity of a large buyer. There is a variety of research on cooperation and collaboration between agents and on the formation of consortia, some of which are listed here [Aknine *et al*. (2004); Hong *et al*. (2007 and 2008); Kosakaya *et al.* (2001); Zhao *et al*. (2001)], suggesting the improvement in trading from the collaboration. There has been special mention in the research literature of the benefits of multi-agent cooperation in manufacturing systems [Zho *et al.*(2006)].

In a collaborative environment, cooperation between a set of buyer agents to match a trade offered by a seller agent, or conversely, cooperation between a set of seller agents to match a bid offered by a buyer agent, makes it possible to close a trade where no trade would be possible because of the mismatch between buyer's and seller's trading volumes. The question that remains is about methods used to form the consortium, or consortia, in a dynamic trading environment. An objective of maximizing trading volumes benefits all participants regardless of which side of the trade they are on. In the event that there is a trading authority to supervise the exchange, this trading authority can use the full trading information available to them to set up consortia using optimal integer programming tools. This procedure may not be simple in a large market with a large number of participants as integer programming may not be practical for real time optimization.

The last mentioned option is not feasible or not available in the environment we have envisioned where there is no trading authority to supervise and direct trades and the formation of trading consortia. However, in a complete e-marketplace, buyers and sellers are unsupervised but have at all times full access to information on all proposed buy and sell trades in a Blackboard type of architecture similar to that presented in Nag (2008). Thus, individual buyer and seller agents form their own consortia to match specific trades to increase their own trading volume, and to contribute to the aggregate increase in trading volumes. We are comparing in this work an algorithmic approach to consortium formation, the details of which are presented in Hong *et al.* (2008), with an alternate approach based upon the use of *Genetic Algorithms*. The latter is the major contribution of this work and will be described in detail. In summary, Genetic Algorithms, also known as *GA's*, have been used extensively in a variety of applications that include scheduling and matching. The reader can be referred to a variety of work on GA's, one of the most comprehensive of which is that by Michaelewicz (1994).

AGENT AUCTION TRADING MODEL WITH CONSORTIUM

The same model environment is used in the two methods being compared for simplicity and consistency of the comparison and is described here once for both methods. It is extracted from Hong *et al.*(2007). A two-tier supply chain system is considered with a set of m suppliers and a set of n buyers making up the two tiers. There are k products involved in the trading system. There are no intermediaries or negotiators, or other traders not part of the groups of suppliers or buyers. Buyers and sellers transact directly with one another. The simplicity of the model is intentional to focus attention on the complexity of the trading decisions.

There is no trading authority supervising the trades and guiding the traders' decisions. The traders operate in an open Blackboard architecture environment, as described in Nag (2008), with full knowledge of all trades presented in the current period. Thus, all seller agents (suppliers) have full knowledge of all buyer bids on the market at the present time, as well as full knowledge of all other suppliers and their individual trading offers. In the same way, all buyer agents (buyers) have full knowledge of all supplier offers on the market, as well as the identities and requirements of all other buyers on the market at the present time.

The trading decision might appear to be simple, but is complicated because of the total uncertainty about the future. A trading agent, buyer or seller, might want to avoid an imperfect match in the present period and carry the trade over to the next period in the expectation of finding a better match. However, that better match in the next period may not happen because of unsuitable trade offers. A carry over may be necessitated over a number of periods to enable a perfect match, resulting in a large cost of carrying inventory for a seller agent, or a large opportunity cost for a buyer agent. Every trading agent has a real incentive to match trades quickly by forming a consortium.

The volume of trading is evaluated over a whole period, which might be one day. In a totally dynamic trading environment of multi agent systems, trades may be offered and matched, or rejected, minute by minute with a consortium being formed electronically in seconds by intelligent and empowered agents. A situation of this nature is extremely difficult to evaluate. We consider a more stable environment where a large number of buyer bids and seller offers are on the board in a given period and possible matches can be determined more effectively.

A standard set of trading conditions describing the transparency of the trading system is used in most research. In realizing the objective of maximizing the total trading volume, a summary of the trading conditions as listed in Hong *et al.* (2008), are described as follows:

1. A buyer agent is aware of all the selling bids placed by seller agents.
2. A seller agent is aware of all the buying bids placed by buyer agents.
3. A buyer agent is aware of the community of buyer agents and the quantities requested by each buyer agent.
4. A seller agent is aware of the community of seller agents and the quantities offered by each seller agent.

The decision to buy, or sell, or to form a consortium for the purpose, or to reject a trade and wait, is with the individual agent, and must proceed within the community. Maximizing trading volume translates into minimizing trading costs. Rejecting a trade and waiting adds to the trading cost.

The objective of maximizing trading volumes is realized when trading agents in either tier of buying or selling form consortia to match the volume of a trading agent in the other tier. Furthermore, considering the trading mechanism of forward auction initiated by the seller and reverse auction initiated by the buyer, we list four possible situations as follows:

1. **Seller Agent offers a larger quantity than the requirement of a single buyer:**
    a. **Agent Actions:**
        i. Buyer agent proposes part sale that is accepted or rejected by seller agent.
        ii. Buyer agent looks for and finds partner buyer agents to complete the quantity.
2. **Seller Agent offers a smaller quantity than the requirement of a single buyer:**
    a. **Agent Actions:**
        i. Seller agent looks for a partner seller agent to match the required quantity.
        ii. Buyer agent rejects the offer and waits for a better match.
        iii. Buyer agent accepts the offer and waits for a part offer from another seller agent to complete the quantity.
3. **Buyer agent requests a quantity larger than the offer of a single seller:**
    a. **Agent Actions:**
        i. Seller agent looks for a partner seller agent to match the required quantity.
        ii. Buyer agent rejects the offer and waits for a better match.
        iii. Buyer agent accepts the offer and waits for a part offer from another seller agent to complete the quantity
4. **Buyer agent requests a quantity smaller than the offer of a single seller:**
    a. **Agent Actions:**
        i. Buyer agent proposes part sale that is accepted or rejected by seller agent.
        ii. Buyer agent looks for and finds partner buyer agents to complete the quantity.

The decision problem faced by an agent is dynamic and in real time. If it is not completed quickly, a possible partner in a potential consortium may join with another to complete a trade, and the agent is forced to carry over the trade to the next period.

A preferred internal architecture for all participating agents includes *domain knowledge* as a means of understanding the task of trading volume and trading commodity. An integral part of the internal agent architecture is the *communication capability* that enables an agent to communicate with potential collaborators in the agent community to form partnerships and consortiums, by virtue of knowledge of the agent community and their individual trading volumes. The blackboard architecture is the most suitable for this operation. The implementation of an agent is an algorithmic representation in software of a set of priorities and working rules. To implement a consortium an agent needs a map with the information about agents in the surrounding community. The map is a part of the domain knowledge of an agent. The consortium formation is implemented as a combination of the map and message passing.

The decision problem is centered on mismatches between buying and selling quantities. When a seller agent has a selling quantity larger than the buying quantity and is forced to split the trading quantity, it might become difficult to find a buyer for a small remaining quantity. A buyer agent is faced with the same decision problem in reverse order. As there is no central control, there is no concern about scalability and the need for the central authority to manage trading decisions for communities that vary in size from small to large.

Mathematically the matching problem can be represented as a Dynamic Programming formulation that compares current trading conditions with potential future possibilities to arrive at a trading decision. A practical heuristic approach to solve this problem summarizes the decisions in terms of scenarios as listed below (adapted from Hong *et al.*, 2008):

- **Scenario 1:** In case of buyer's intended buying volume is equal to the seller's selling volume, the seller can do transaction without the help of the consortium.
- **Scenario 2:** In case of buyer's intended buying volume does not meet the seller's selling volume and there is no possibility of forming neither seller's consortium nor the buyer's consortium.
- **Scenario 3:** In case of seller's intended selling volume is smaller than a buyer's intended buying volume, the sellers could form a consortium and their collected volume meets the buyer's required volume.
- **Scenario 4:** Since the trading is dynamic, the size of volume is relative. A seller's selling volume could be greater than one buyer's intended buying volume, but smaller than another buyer's volume. Either the seller or the buyer can form consortium regardless of their relative volumes. In case of seller's intended selling volume is relatively greater than a buyer's intended buying volume, the seller tried to form a consortium but fail to meet the buyer's required volume.
- **Scenario 5:** In case of buyer's intended buying volume is smaller than the seller's selling volume, the buyer can form a consortium with the combined volume meeting the seller's volume.
- **Scenario 6:** In case of buyer's intended buying volume is smaller than the seller's selling volume, the buyer tried to form a consortium but fail to meet the seller's volume.

The multiple scenarios represent the various decision conditions addressed in the experiment. These represent both the difficulty of the decision problem, and the adaptive capability of the decision making system to form matches by formation of consortia to increase the volume.

The experiment was a simulation performed in Excel spreadsheet. It was a simple experiment to demonstrate trading matches using random generation of ten seller agents and ten buyer agents, each with randomly generated trading volumes. To be statistically correct, any experiment with random numbers should be repeated multiple times. In this instance, the random number generation was repeated many times, and ten representative cases are reported. Details of these experiments, *e.g.* the exact volume of trade associated with each buyer or seller agent, and exact reports of the matched trades for each case, can be found in Hong *et al.* (2007). A summary table extracted from Hong *et al.* is presented here as Table 1 showing the volumes matched in each of the ten cases as a *direct match* without consortium, and as a *match with consortium*. A factor has been added to show the ratio of matched volumes without and with

Table 1. Summary results for trading volumes with and without consortium

	Matched Volumes									
Method / Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Direct Match (no consortium)	100	170	260	140	410	340	400	180	140	230
With Consortium Formation	800	240	350	280	410	520	450	470	300	490
Volume Ratio: Without Consortium to With Consortium	1:8	1:1.41	1:1,35	1:2	1:1	1:53	1:1.13	1:2.61	1:2.14	1:2.13

consortium. It is clear that consortium never has a volume less than a direct match, and often has a larger volume. The ratio varies with the random generations of trading agents and their volumes. The stability of the consortium evolved over time depends on the relative size of buying volume and selling volume. For example, a consortium may have a core if one agent has a relative large volume in that this agent always remains in the consortium during its evolution.

GENETIC ALGORITHM FOR TRADE MATCHING WITH CONSORTIUM

In the Genetic Algorithm part of the experiment, the model environment for trade matching with consortium is exactly the same as stated in the previous section. It is still a two-tier supply chain system with no intermediaries or negotiators. The buyers and sellers interact directly with each other without a supervising or guiding authority, operating in an open Blackboard architecture environment with full knowledge of all trades presented in the current period, *i.e.* each agent has complete knowledge in the current period of the identities and requirements of all trading agents on either side. As before, all trading decisions relate to one period where there is no advance information regarding future periods and possible trade offerings in future periods. Even the objective remains the same, and is directed towards maximizing the trading volumes of individual traders by consortium formation to match sellers' and buyers' trading volumes, respectively, thereby maximizing the overall trading volume in a process to increase the success and efficiency of the supply chain.

In this second approach to consortium formation, the matching process used is a *Genetic Algorithm* (GA). A detailed exposition of the Genetic Algorithm can be found in a substantial book by Michalewicz (1994). GA is suitable for NP hard problems such as the matching problem that can not be solved with integer programming in this chapter. The advantage of GA is the heuristic solution can be very close to the optimal solution after enough generations of evolution. A recent application of the GA method in the supply chain is described in Chan and Kumar (2009), and another GA application to a traditional scheduling problem in job shop scheduling is described in Moon *et al.* (2008). Another supply chain application is described in Nachiappan and Jawahar (2007). An interesting application is described in Pennisi *et al.* (2008) using simulated annealing, a process that is a variation on the GA method. There are many other examples of application of the GA method in literature. The GA method has been used successfully in many scheduling applications.

A gene defines a sequence of chromosomes each one of which specifies some physical characteristic of a living organism. The gene sequence specifies the complete set of characteristics of the organism. There is always a process of evolution over time as nature keeps changing the gene sequence in a variety of different approaches always with the objective of making the living being stronger with improved capability for survival, or of developing better abilities to perform certain tasks. One of the steps in the evolution process is known as *crossover*, in which a part sequence string from one gene is merged with the corresponding remaining part from another gene to create a new gene. Another step in the evolution is known as *mutation* where some chromosomes are altered to create a new gene with different properties. Each instance of gene modification is followed by an evaluation step, where the new and previous genes are compared with the objective to determine whether there is an improvement or not, to help guiding the next modification.

Natural genes are complicated sequences requiring supercomputers for basic analysis. Simple versions of genes and evolution can be replicated on microcomputers. A Genetic Algorithm is a heuristic algorithm that simulates on a computer the genetic evolution of living organisms. The same crossover technique is used to mix together parts of two genes to create a new gene in a cut and paste approach. Mutations are also used to modify the solution. One difference in the GA from natural evolution is the *seeding* process which randomly generates a chromosome sequence for the gene. Random selection is used to avoid negative biases in gene selection.

In the following GA experiment, there are a set of buyers and a set of sellers. The trading volumes of the buyers and the volumes of the sellers are known, as are their prices. A trade is feasible only when the buyer's offered price is greater than or equal to a seller's offered price. A trade becomes possible when a match is found. A direct match is made when a buyer's volume matches a seller's volume in a feasible state. However, the possibility exists of splitting a buyer's or a seller's volume between two or more of the other kind who form a consortium to match the trading volume. The objective is to match by consortium to maximize the volume of trade. The initial solution of trade match is generated randomly and represented as a two dimensional array in which rows represent buyers and columns represent sellers. Each element of the array is a value of the quantity Trade_{ij}, given as:

$$\mathrm{Trade}_{ij} = \begin{array}{l} 1,\ \text{if } i^{th} \text{seller has trade with } j^{th} \text{buyer} \\ 0,\ \text{otherwise} \end{array}$$

For trading, the maximum value of seller price denoted $SP_{i \in I}$ (I is a set of sellers) $\leq BP_j$ must be satisfied, where BP_j is a buyer price. The seller's consortium can trade with a buyer. To define the feasibility of the trading volumes:

- SV_i: Seller i's volume
- BV_j: Buyer j's volume.

Let us consider a possible feasible trading case stated mathematically as follows:

$$\sum_i SV_i = BV_j \ and \ Max_i(SP_i) \leq BP_j$$

An explanation of the mathematical statement is that the volume of a consortium of seller agents matches with an individual buyer's volume and the highest price in the consortium is less than the buyer's bidding price, the latter half of the statement being a condition of feasibility. The procedure will consist of repeatedly finding similar matches with the formation of consortia on both sides, with the objective of maximizing the trading volume as defined below:

$$Max(\sum_j BV_j) \ where$$
$$\sum_i SV_i = BV_j \ and \ Max(SP_i) \leq BP_j$$

The end result of this decision operation is the desired maximization of the trading volume.

A mathematical representation of the matching process is described below. There are *n* buyers and *m* sellers. Each buyer and each seller has the option of trading with an exact volume match under a condition of price feasibility, or match volumes with consortia formation while maintaining price feasibility.

- $i \in \{ i \mid 1 \leq i \leq m\} = I$
- $j \in \{ j \mid 1 \leq j \leq n\} = J$

- SP_i = price of seller i
- BP_j = price of buyer j
- SV_i = volume of seller i
- BV_j = volume of buyer j
- CB_i = buyer's consortium for seller *i*
- CS_j = seller's consortium for buyer *j*

$$x_{ij} = \begin{cases} 1 \text{ there is a trade between seller } i \text{ and buyer } j \\ 0 \text{ otherwise} \end{cases}$$

$$Goal: \text{Max} \sum_i \sum_j (Min(BV_j, SV_i) \quad \times \quad x_{ij})$$

Constraint:

- $SP_i \leq BP_{j,}$ $\forall j$ for each i, $i \in$ I and $j \in$ J
- $SP_i \leq BP_{j,}$ $\forall i$ for each j, $i \in$ I and $j \in$ J
- $SV_i = \Sigma\, BV_k$, where $k \in CB_i$, for each $i \in$ I
- $VB_j = \Sigma\, VS_p$, where $p \in CS_i$, for each $j \in$ J

A consortium is a subset of buyers or sellers. If all the buyer's set is J then the consortium of buyers can form 2^n where $n = |J|$ number of different subsets. The number of subset will grow exponentially as the number of buyers is increased. Instead of counting all the subsets, this paper propose a heuristic Genetic Algorithm that finds solution heuristically with less checking but does not guarantee the optimal solution.

The algorithmic steps of the decision process are an iterative application of the following step, by a GA or by any other method:

For every j, find out I_j which represents the seller's consortium for buyer j and let's call it Ij_0 (an initial seed for buyer j).

The time complexity of this process is exponential, *i.e.* a power set of the index *i*. The time requirement of an exponential system of matching is very large when the set over which the matching is done is large. These are the problems that come under the category of *NP*, *i.e.* no polynomial solution. The optimal solution mechanism of *Integer Programming* fails in this context because of the large and exponential time requirement. The GA process is heuristic and is not subject to the exponential time commitment. While the heuristic GA process may result in suboptimal solutions, it is fast and therefore better suited to a real world dynamic application.

The GA process begins with an initial *seed*, or a randomly determined initial solution. It will then proceed to develop a feasible set of solutions, attempting iteratively to increase the set of members until an exact match of trading volumes is achieved. An assumption used in the process is that a seller cannot participate in multiple trading. We shall try later to relax this condition. The GA process is stated as follows:

- **Seed:** Develop by a random process an initial solution, or *gene*, showing a set of seller volumes and a set of buyer volumes, and a set of initial assignments of sellers and buyers.
- **Cross Over:** A process of combining gene solutions by an approach similar to *cut and paste*, where a part of one string is combined with the remaining part of another string to create a new solution.
- **Mutation:** A process of modification of the gene sequence to create an improved gene structure that achieves a better fit with the objective.
- **Feasible Solution:** The feasible solution identifies sets of feasible seller's consortium (for each *i*) for each buyer (for each *j*), and is the starting point for solutions with increased trading volume.
- **Evaluation:** Evaluation of gene solutions on the basis of trading volume produced.
- **Selection:** Select gene solutions with the highest values, or the highest potential for improvement, and continue with crossover and mutation until a high value of trading volume is achieved.

It should be noted that the GA process is heuristic and that there is no closure with an optimal solution. In the next section, we present a simple example to illustrate the effectiveness of trading match with GA.

A GA Example

An example is used to illustrate the GA approach. A seed pattern is generated randomly with 10

Figure 1. a) Genetic algorithm sample random initial solution; b) Genetic algorithm sample feasible solution

SV_i	90	75	40	50	15	90	20	90	10	60		
SP_i	5	15	5	10	10	5	15	25	5	5	BV_j	BP_j
	0	0	0	0	0	0	0	0	0	0	20	20
	0	0	0	0	0	0	0	0	0	0	85	20
	0	0	0	0	0	0	0	0	1	0	50	15
	0	1	0	0	0	0	0	0	0	0	35	15
	0	0	0	1	0	0	0	0	0	0	50	20
	0	1	0	0	0	0	0	0	0	1	70	25
	0	1	0	0	0	1	0	0	0	0	105	15
	0	0	0	0	0	0	1	1	0	0	65	10
	0	0	0	0	0	0	0	0	0	0	70	10
	0	0	0	0	0	0	0	0	0	0	80	25

a

SV_i	100	35	45	70	100	75	85	45	60	45		
SP_i	5	20	5	15	5	20	10	20	20	5	BV_j	BP_j
	0	1	0	0	0	0	0	0	0	1	80	25
	0	0	0	0	0	0	0	0	0	0	25	5
	0	0	0	0	0	0	0	0	0	0	55	10
	0	0	1	0	0	0	0	0	0	0	30	10
	0	0	0	0	0	0	0	0	0	0	80	25
	0	0	1	0	0	0	0	0	0	0	15	15
	0	0	0	0	0	1	0	0	0	0	75	25
	0	0	0	0	0	0	0	0	0	0	20	20
	0	0	0	0	0	0	0	0	0	0	40	5
	0	0	0	0	0	0	0	0	0	0	50	15

b

buyers and 10 sellers as shown in Figure 1(a). The GA gene is represented in a two-dimensional array in which rows represent buyers and columns represent sellers. In the content of a cell that is the intersection of a row and a column, a 1 represents a possible trading between a buyer and a seller, while a 0 represents a no match condition. For example, $Trade_{ij}$ represents that i^{th} seller has a trade with j^{th} buyer under the condition of seller-buyer price and trading volume. In the initial random generation of trade schema, some trades are feasible and some are not. The evaluation section of the algorithm removes all the infeasible trading patterns in several iterations. After a number of iterations with the GA algorithm refining the solution each time, the GA finds a good feasible solution shown in Figure 1(b) that might possibly be the optimal.

The initial solution shown in Figure 1(a) has a value of zero as there are no feasible transactions because of mismatch in quantity or price. An example of the infeasibility is the 1 in the 3^{rd} row and 9^{th} column. This trade is not feasible because the price of the seller is 25, but the buyer's price is 15, which is less than the seller's.

Next the crossover and mutation processes create 20 sets. Following the crossover and mutation process the ten best sets are selected based on the feasible trading volume. The feasible sample result shown in Figure 1(b) has an objective value of 10540. The objective value is not the actual trading volume, but an artificial number derived from trading volumes and number of trades. The actual trading volume is 540 units. The large artificial objective is needed to distinguish between different solutions in the evolution process and to differentiate between feasible and infeasible solutions.

An explanation of the feasible solution of Figure 1(b) is given as follows using *trade(i,j)* as the representation by row *i* and column *j* for the matrix elements in the two dimensional gene array where a 0 indicates a trade matching failure, and a 1 indicates a trade matching success. In the first row, trade(1, 2) is 1 representing a match and a trade where the seller's price is less than or equal to the buyer's price. The trading volume is the minimum of seller volume and buyer volume, in this instance the seller volume of 35. After the trade, the 1st buyer will need 45 units as a remainder. This trader will trade with 10th seller for 45 units and buyer 1 bought all his goods. The third seller wants to sell 45 units out. The 4th buyer has trade with the 3rd seller 30 units. Now the third seller has 15 units as remainder. The same seller has transaction with 6th buyer 15 units. Buyer 7 purchased all the goods needed from seller 6 75 units directly.

Notation:

- SV_i: Volume of Seller *i*
- SP_i: Price of Seller *i*
- BV_j: Volume of Buyer *j*
- BP_j: Price of Buyer *j*

The present problem has $i = 1,\ldots,10$ and $j = 1,\ldots,10$

Count = 10

Experimental results of running the Genetic Algorithm coded in Java are shown in Table 2. These are only summary results. All cases used 10 by 10 arrays of trades with ten buyer agents and ten seller agents in each case. The trading quantities of buyer and seller agents were randomly generated for each case. Detailed information about the cases is available with the authors, but was deemed to be overwhelming for the paper. The details include items such as the identities of buyer and seller agents in a direct match or in a match by consortia, quantities of trading volumes direct or otherwise, *etc.*

It is interesting to note that the GA method has one case where there was a zero match with direct trading, and a traded quantity of 105 units in a consortium of sellers #2 and #9 matching the volume of buyer #2. A second interesting observation is that the average ratio of volumes matched with consortium to those matched directly is 2.78 with the GA method including nine cases and excluding the one case with a zero direct match where no ratio can be calculated. In comparison, the ratio of consortia match to direct match for the rule-based approach shown in Table 1 is 2.53. It would appear that the GA method has the ability to produce greater quantities of matched trading volumes. However, it should be noted that too much reliance should not be placed on this observation at this stage in the research.

The application of the GA method for consortium formation has consistently used sets of buyer and seller agents that are each ten in number, and random generation of trading volume for each agent in each case. Whenever random number generation is used there are concerns about the statistical validity of the results. Results that show a successful trend may turn out to be merely "lucky". A solution to this problem is to perform a large number of these experiments with random generation. In general, success in a statistically significant sense is achieved with at least 25 successful experiments, and certainly with 30 successful experiments. These concepts are easily confirmed by a reference to some basic textbooks on Statistics. For example, a T-distribution with a

Table 2. Summary results for trading volumes with and without consortium using genetic algorithm

Method \ Case	Matched Volumes									
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Direct Match (no consortium)	20	20	90	310	100	0	215	165	60	25
With Consortium Formation	110	90	155	385	160	105	215	210	130	125
Volume Ratio: Without Consortium to With Consortium	1:5.5	1:4.5	1:1.72	1:1.24	1:1.6	NA	1:1	1:1.27	1:2.17	1:5

Table 3. Trading volumes with and without consortium using genetic algorithm (30 runs)

Data Set	Direct	GA	Ratio
1	15	80	1:5.3
2	185	185	1:1
3	50	75	1:1.5
4	60	165	1:2.75
5	180	180	1:1
6	0	80	0:80
7	100	185	1:1.85
8	45	130	1:2.89
9	220	325	1:1.48
10	10	60	1:6
11	10	70	1:7
12	75	145	1:1.93
13	240	240	1:1
14	70	125	1:1.79
15	15	95	1:6.33

Data Set	Direct	GA	Ratio
17	175	175	1:1
18	80	180	1:2.25
19	15	15	1:1
20	85	85	1:1
21	0	0	0:0
22	30	30	1:1
23	50	50	1:1
24	65	65	1:1
25	15	110	1:7.33
26	75	200	1:2.67
27	0	100	0:100
28	140	195	1:1.39
29	200	200	1:1
30	100	100	1:1

number of degrees of freedom approximates the general and standard Normal distribution when the degrees of freedom, *i.e.* the number of observations, are in excess of the number 25. Thus, a set of 30 observations of the GA method with random selection of trading volumes were developed. The results of the application of the GA method are shown in Table 3. It may be seen from the table that the GA method remains successful in the long run in producing larger values of matched trading volumes by forming consortia.

CONCLUSION AND FUTURE DIRECTIONS

The formation of a consortium to match a buyer bid or a seller offer remains a difficult task in the rapid pace of a large e-trade exchange, as they are found today in the established world of global online auction trading, but it is an important problem. Online exchanges as used by autonomous and intelligent agents are global in nature, and this fits well with global manufacturing and procurement, and the global supply chain found today in practice. Globalization of the supply chain involves a very large number of manufacturers and suppliers, and a very large number of possible trades in the e-trade exchange in the form of buyer bids and seller offers.

Matching trades in real time by formation of consortia reduces costs in the supply chain and increases the efficiency making business more profitable for all parties involved. It was a conclusion of Hong *et al.* (2008) that there are significant increases in trading volumes with consortium formation. However, heuristic methods are never conclusive about a best solution that can be proved to be so. The contribution of this work is a comparative study of alternate heuristic methods. The first method shown was more structured and rule-based. It has a reasonably good performance in increasing trading volume by formation of consortia. The GA method shown later is less structured and offers more freedom and random selection, as does evolution in nature. In terms of performance, the GA method without any enhancement of the selection criteria is at least as good as the rule-based approach.

The performance of the basic GA method suggests the use of intelligent selection of the genes towards the development of the species most likely to succeed. This is a practice common in nature. There are a variety of different ways in which these concepts can be applied to this work. It will be more complex algorithmically. Like any true scientific experiment, it is totally unclear at this time if the results will be significantly better. However, there is a strong potential for that.

It might appear from small matching examples that the exercise is trivial. It is not so in practice. In general, in the e-trade auction environment as described, an optimal matching of buyer and seller trading volumes by consortium formation would require the execution of an integer programming formulation. In practice, the actors or facilitators of the trading facility are not able to use this function in view of the limitations of time and resources. They have to use heuristic matching procedures. This is the primary content and contribution of our work. We have used alternate heuristic approaches to the problem of matching buyer and seller volumes by forming consortia to enhance the set of possible matches, with the objective of increasing the trading volume, and have compared the approaches with respect to the trading volumes that have been achieved.

REFERENCES

Aknine, S., Pinson, S., & Shakun, M. F. (2004). A multi-agent coalition formation method based on preference models. *Group Decision and Negotiation*, *13*, 513–538. doi:10.1007/s10726-005-3074-5

Binbasioglu, M. (1999). Problem structuring support for collaboration and problem solving. *Journal of Computer Information Systems*, *40*(2), 54–63.

Fox, M., Barbuceanu, M., & Teigen, R. (2000). Agent-oriented supply chain management. *International Journal of Flexible Manufacturing Systems*, *12*(2/3), 165–188. doi:10.1023/A:1008195614074

Hong, S., Nag, B. N., & Yao, D. (2007). Modeling agent auctions in a supply chain environment. *International Journal of Intelligent Information Technologies*, *3*(1), 14–36. doi:10.4018/jiit.2007010102

Hong, S., Nag, B. N., & Yao, D. (2008). Improving e-trade auction volume by consortium. In Sugumaran, V. (Ed.), *Distributed artificial intelligence, agent technologies, and collaborative applications*. Hershey, PA: IGI Global. doi:10.4018/978-1-60566-144-5.ch005

Kosakaya, J., & Yamaoka, K. (2001) Co-operative multi-agent intelligent field terminals. *Proceedings of the Fifth International Conference on Autonomous Agents*, (pp. 348-354).

Michaelewicz, Z. (1994). *Genetic algorithms + data structures = evolution programs*. Berlin, Germany: Springer-Verlag.

Moon, I., Lee, S., & Bae, H. (2008). Genetic algorithms for job-shop scheduling problems with alternative routings. *International Journal of Production Research*, *46*(10), 2695–2705. doi:10.1080/00207540701244820

Nachiappan, S. P., & Jawahar, N. (2007). A genetic algorithm for optimal operating parameters of VMI system in a two-echelon supply chain. *European Journal of Operational Research*, *182*, 1433–1452. doi:10.1016/j.ejor.2006.09.040

Nag, B. (2008). A Blackboard agent community architecture in a supply chain environment. *Design Principles and Practices: An International Journal*, *1*(1), 91–104.

Pennisi, M., Catanuto, R., Pappalardo, F., & Motta, S. (2008). Optimal vaccination schedules using simulated annealing. *Bioinformatics (Oxford, England)*, *24*(15), 1740–1742. doi:10.1093/bioinformatics/btn260

Zhao, G., Deng, J., & Shen, W. (2001). CLOVER: An agent-based approach to systems interoperability in cooperative design systems. *Computers in Industry*, *45*, 261–276. doi:10.1016/S0166-3615(01)00097-5

Zho, S. C., Ramirez-Serrano, A., & Brennan, R. W. (2006). Cooperative multi-agent reconfigurable manufacturing environments. *International Journal of Manufacturing Technology and Management*, *8*, 283–303. doi:10.1504/IJMTM.2006.008799

Chapter 2
Agent-Based Modeling and Simulation of Intelligent Distributed Scheduling Systems

Milagros Rolón
INGAR (CONICET-UTN), Argentina

Ernesto Martínez
INGAR (CONICET-UTN), Argentina

ABSTRACT

For responsiveness and agility, disruptive events must be managed locally to avoid propagating the effects along the value chain. In this work, a novel approach based on emergent distributed scheduling is proposed to overcome the traditional separation between task scheduling and execution control. An interaction mechanism designed around the concept of order and resource agents acting as autonomic managers is described. The proposed Manufacturing Execution System (MES) for simultaneous distributed (re)scheduling and local execution control is able to reject disturbances and successfully handle unforeseen events by autonomic agents implementing the monitor-analyze-plan-execution loop while achieving their corresponding goals. For detailed design of the autonomic MES and verification of its emergent behaviors, a goal-oriented methodology for designing interactions is proposed. Encouraging results obtained for different operating scenarios using a generative simulation model of the interaction mechanism implemented in Netlogo are presented.

INTRODUCTION

There exists a definitive trend towards introducing agility, adaptability, autonomy and flexibility in production systems to face successfully highly dynamic and uncertain environments (ElMaraghy, 2009). Conventional production systems typically works following a two-tier hierarchy comprising of monolithic schedule generation (upper layer) and execution control (lower layer). Scheduling and planning systems are predominantly centralized systems aiming at one-time global optimization

DOI: 10.4018/978-1-4666-2098-8.ch002

of resource usage and processing performance (Valckenaers et al, 2007; Verstraete et al, 2008). Manufacturing execution system (MES) attempts to follow a given schedule as closely as possible. The MES performs this task in a reactive manner, filling-in missing details, providing alternatives for unfeasible assignments, handling auxiliary tasks, and so on based on shop-floor information and real-time control (Kletti, 2007). This quasi-standard of rigid, hierarchical planning and control architectures in today's industry has been unable to cope with the new challenges of agility and self-configuration successfully, since the production schedules and plans are known to become ineffective after a short time on the shop floor. Centralized production planning and control systems are therefore vulnerable to abrupt changes and unforeseen events in production processes. Furthermore, there is an increasing trend towards inter-firm integration through enterprise networking (Ueda, 1992; Warnecke, 1993; Van Brussel et al, 1998; Canavesio and Martínez, 2007; Wiendahl et al, 2007) which gives rise to the need for responsive (re)scheduling using distributed decision-making and local control systems.

For effectiveness, decentralized MES must be designed so as to address disruptive events seeking robustness rather than optimality (Valckenaers et al, 2007). In decentralized MES, production control is not carried out by a central control unit but it is rather an emergence from the actions and interactions of local controllers in the system (Wang and Usher, 2004).

This chapter proposes an entirely new methodology for design and verification of autonomic MES. In each autonomic unit, the agent playing its manager role implements the monitor-analyze-plan-execute (MAPE) loop which comprise of both scheduling and control function for a given order or resource. For detailed design and behavior verification of the autonomic MES, an extension of the Prometheus-Hermes methodology (Cheong and Winikoff, 2006) is proposed by including generative simulation and behavior verification. The design methodology highlights the goal hierarchy, action sequences and a number of failure recovery procedures to provide design guidelines when specifying goal-oriented interactions. The autonomic MES is made up of a society of agents, each one having cognitive capabilities such learning, reasoning and planning which allow the agent to know what it is doing (Brachman, 2002). For behavior verification in a case study, a generative simulated model in Netlogo has been created and some results obtained for normal and disturbed operating scenarios are presented. A remarkable result is the stability of the autonomic MES despite the dynamic complexity resulting from goal-oriented interactions among a number of autonomic agents. Also, emergent behaviors of the interaction mechanism in abnormal scenarios highlight the importance of generative simulation in designing autonomic MES.

BACKGROUND

As a guideline for designing decentralized MES for shop-floor environments several multi-agent architectures have been proposed. An almost pure distributed architecture for MES design is PROSA (Van Brussel et al, 1998). This architecture consists of three types of basic holons (agents) that cover all aspects of heterarchical control and are structured using the object-oriented concepts of aggregation and specialization: order holons, product holons, and resource holons. Also, the concept of staff holons allows for the presence of centralized elements and functionality in the MES architecture. However, staff holons do not introduce hierarchical rigidity into the system since control decisions are made by basic holons. The holonic MES proposed by Hadeli et al (2004) is based on the PROSA architecture augmented with coordination and control mechanisms inspired in natural systems based on stigmergy and future state prediction (Valckenaers, P. & Van Brussel H. (2005). However, a comprehensive verification of emergent behaviors is still due for holonic MES which prevents an assessment of alternative design parameters.

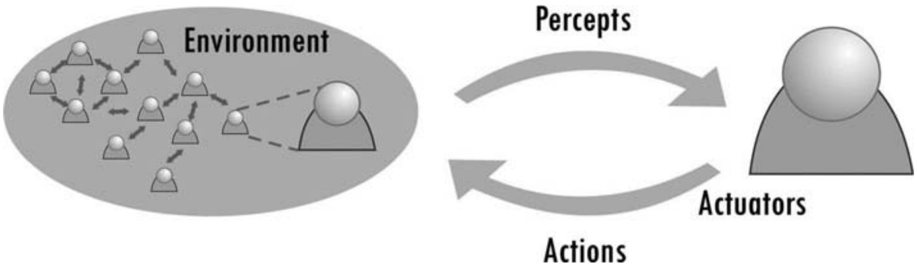
The ADACOR architecture for production control (Leitão et al., 2005) is neither completely decentralized nor purely hierarchical: it alternates between stationary states, where system control relies on supervisors and coordinator levels, and transient situations, triggered by the occurrence of disturbances where the MES switches its decision-making policy to a heterarchical structure. Barata de Oliveira (2004) proposed another hybrid control architecture that is modified according to new processes and equipment items based on the concept of coalitions of manufacturing components. Both architectures have the advantages of being more flexible and adaptable than centralized MES, but as any architecture they need a more detailed design for behavioral verification, including agent's goals specification, interaction mechanisms between the agents and failure recovery procedures. In the case of ADACOR, a Petri Net formalism was used to model the dynamic behavior of the ADACOR holon classes and their interactions, and a prototype in JADE (CSELT, 2009) was implemented, but the holons have not been completely specified and designed in enough details to assess emergent properties and dynamics. Another proposed architecture for holonic MES implementation is the HCBA (Chirn and McFarlane, 2001). HCBA defines two holons: product and resource, one-to-one mapped to their associated physical counterparts in the manufacturing plant with no distinction between holons (agents) as abstract entities and their corresponding objects (products and resources).

A cooperating MES which implements distribution execution control while accounting for an externally supplied schedule was presented by (Valckenaers et al, 2007, Verstraete et al, 2008). The simulation results show that if the disruptive events and disturbances are important, there is no improvement by attempting to follow the original schedule. The same conclusion has been reached by Aytug et al (2005) without simulation, as they set out that if the level of uncertainty is low enough, an optimization-based predictive scheduling algorithm can outperform an on-line dispatching algorithm but as failure rates increase and significant disturbances are present following a priori defined scheduling is inefficient and sometimes impossible. Covanich and McFarlane (2009) implemented both centralized MESs and holonic MESs in a real physical manufacturing system, and concluded that holonic MESs require more efforts to be set up, but substantially less efforts to be reconfigured. So, distributed MESs are fast becoming key components for introducing agility and flexibility at the shop-floor to reject disturbances and handle unplanned events.

In highly competitive global markets characterized by make-to-order production manufacturing companies must meet individual requirements and comply with stringent deadlines while guaranteeing superior quality at low prices. This can be only achieved when production (re)scheduling and execution control are tightly integrated in autonomic MES units. Therefore, an intelligent distributed scheduling system based on interactions between order and resource agents acting as autonomic managers (Kephart and Chess, 2003) was proposed (Rolón et al, 2009, Rolón and Martinez, 2010). These autonomic agents are created by separating the role of the autonomic manager (resource or order agent) from the object being managed (order or resource). This fact is in contrast with the earlier architecture of holonic MES which normally allocate control functionality to tangible objects which correspond to physical machines, intermediate parts or final products (Van Brussel et al., 1998).

In this chapter the autonomic idea depicted in (Rolón and Martinez, 2010) will be used to embrace a total integration of distributed schedule

Figure 1. Agent – environment interaction cycle



generation and local execution control. To carry out this integration the concept of order agents (OAs) and resource agents (RAs) is proposed in a detailed design for behavioral verification. As a result, both scheduling and execution control are bottom-up emergencies from interactions among OAs and RAs in a mechanism designed to abstract relevant decisions to schedule and control dynamic shop-floor environments characterized by a high level of uncertainty.

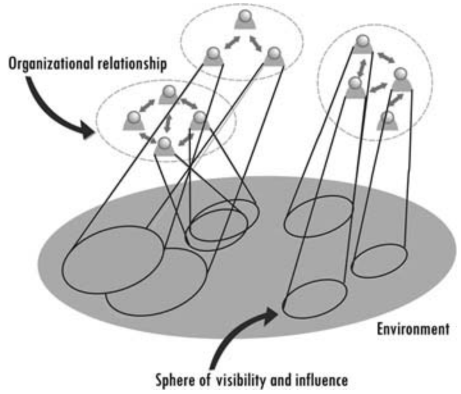
DYNAMIC DISTRIBUTED SCHEDULING

Agent-Based Modeling

Agents are well-suited for achieving goals in uncertain and constrained environments such as electronic markets or manufacturing shop-floors. We consider agents to be autonomic entities that are situated in an environment which is made up of objects (e.g., orders, resources and tasks) and other agents (Bordini et al, 2007). The environment state is perceived by sensors and can be changed by executing actions though actuators available to the agent as it is shown in Figure 1. The essential concepts of agent-based computing, as can be seen at Figure 2, are situated agents, high-level interactions and organizational relationships (Jennings, 2000). Agents are able to interact among them and different agents have different "spheres of influence" in the sense that they are able to influence some parts of the environment (Wooldridge, 2001). The fact that in some cases these spheres of influence may coincide gives rise to conflictive or collaborative relationships among particular agents. That is, situated agents need to interact with one another to achieve goals related to the roles they accept to play. Interactions require a well-defined logic for taking actions and creating communication channels among concerned agents.

When adopting a multi-agent view of distributed MES, it soon becomes apparent that decentralizing scheduling and control is about the design of an artificial society of agents where goal-oriented interactions are the leverage points for emergent behavior (Ferber, 1999). Interactions between agents may consist of data transfer from one agent to another, or much more complicated, involving the passing of messages composed in

Figure 2. Essencial concepts of agent-based computing

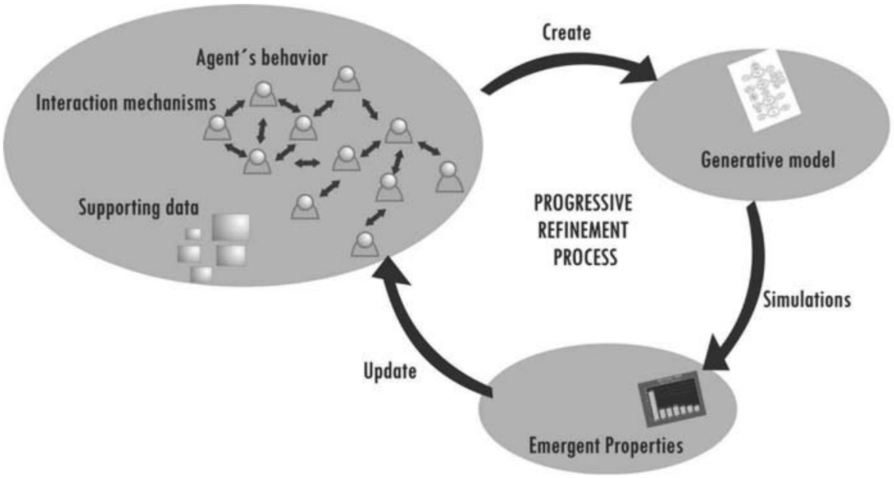


some language, with one agent constructing the message and other interpreting and answering it (Gilbert, 2008). Agents in artificial societies modeling the manufacturing shop-floor (resources and order agents) interact with each other by following well-defined mechanisms allowing them to coordinate and plan their activities so that they can achieve their specific objectives. Essential in this process are the capability and options to negotiate and reach deals with other agents regarding resources usage, order attributes, etc.

Agent-based modeling and simulation (ABMS) is a computational method that enables an analyst to create, analyze and experiment with simulation models composed of agents that interact within a well-defined environment (Gilbert, 2008). One of the advantages of computational modeling is that it forces the modeler to be precise: unlike theories and models expressed in natural language, an interaction mechanism has to be completely and exactly specified if it is to run on a computer. Another advantage is that in silico experiments with a computational model of artificial societies of agents are cheaper or occasionally is the only way to test hypothesis regarding mechanism design. Furthermore, an experiment can be set up and repeated many times, using a range of design parameters or allowing some uncertain factors to vary randomly. ABMS also offers enormous flexibility in reflecting the actual manufacturing setting, and it opens up new possibilities for organizations to take advantage of designed multi-agent systems.

ABMS is able to discover emergent connections between system components, tie trace experience with detailed micro-processes to system-level knowledge and archetype patterns causing emergent behavior, and in this way it may identify possible outcomes that are outside the range of analytical thinking (North and Macal, 2007). To this aim, agent-based modeling must follow an iterative model construction process. This process starts with an initial description of the behavior of individual agent behaviors as well as interaction mechanisms along with supporting data. This conceptual description is then converted to a generative model that can be used to test hypothesis. The resulting model is then simulated and the initial results are examined. The agent internal decision-making policy and the interaction mechanism in the model are then updated based on goals agents must achieve, and the model is simulated again. This progressive refinement process continues until the model reproduces both desirable behaviors and properties of the artificial society, as it is shown in Figure 3.

Figure 3. Iterative process of agent-based modeling and simulation



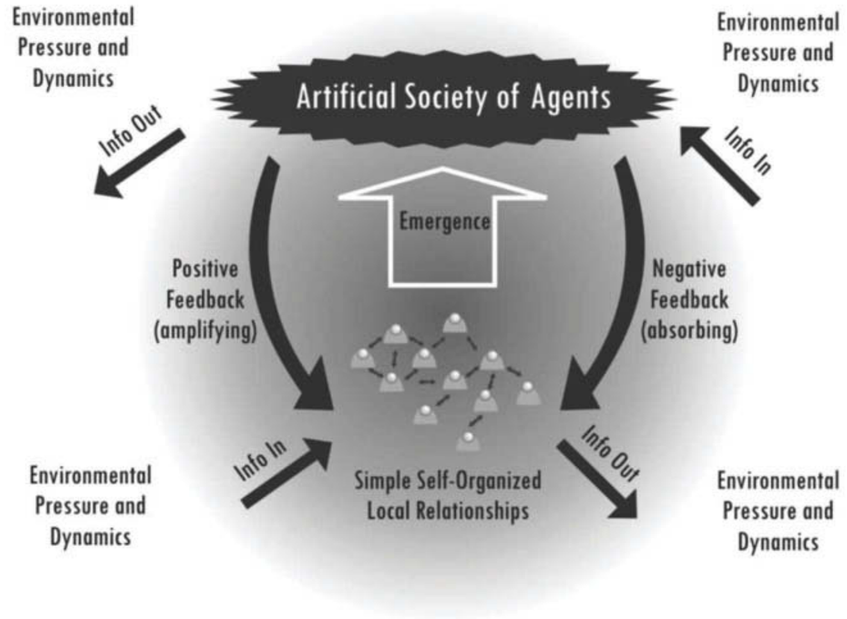
Generative models using agent-based modeling and simulation are very natural means for understanding and designing complex adaptive systems such as autonomic MES. The path from micro worlds to emergent properties (macro behavior) is full of surprises and definitively requires systemic synthesis via simulation rather than reductionist analytical tools (Miller and Page, 2007).

Generative Simulation Modeling

Generative modeling refers to the application of computational models to understand emergence properties of complex social systems (Epstein, 2006). The usual barriers set by the standard modeling tools, such as the need to keep the model within a reasonable size, are overcome with the computational modeling approach. In computational models a controlled micro-world simulation is used to discover macro-level behaviors resulting from on-going interactions on micro-scale interactions. The model serves as a tool to validate the hypothesis (simulated experimentation) and as guideline to improve designs of interaction mechanisms in multi-agent systems (Schelling, 1978). Generative simulation models readily reveal emergent connections between the component systems and make viable the identification of unexpected consequences of agent interactions. Therefore it allows discovering and analyzing the implications of social structures and the properties that can emerge from a given mechanism design.

Contrasting with the traditional top-down approach (see Figure 4 adapted from Epstein and Axtell, 1996, for details), a bottom-up emergence in an artificial society of agents which mainly communicate through the actions taken, define patterns that arise from the chosen mechanism design (e.g., the sugarscape world, Epstein, 2006). Moreover, such aggregate patterns are immune to reasonable variations in the individual agent behavior. Although decision-making policies used by agents might be quite simple, the result of ongoing interactions among them can be very complex and difficult to predict, mainly when

Figure 4. Bottom up emergence of complex adaptive behavior (adapted from Epstein and Axtell, 1996)



agent internals are heterogeneous and each individual agent learns over time based on its unique experience and evaluative feedback.

Most of the existing analytic tools require that interacting agents have a high degree of homogeneity. This homogeneity is not a feature often observed in the world but rather a necessity imposed by the analytical modeling approach (Miller and Page, 2007). Unlike traditional tools, computational methods are able to incorporate heterogeneous agents rather easily. In this way, software agents managing manufacturing objects (resources and orders) can interact with each other and coordinate and plan their activities so that they can achieve their own goals by design. Essential in this process are the abilities to negotiate and reach deals with other agents (resources owners, external clients, raw material suppliers and subcontractors). Thus emergent properties resulting from interactions among heterogeneous agents with different objectives and decision-making policies highlights the importance of resorting to the generative modeling approach of ABMS for learning meta-rules that may change agent behaviors in distributed decision-making. Moreover, collective learning is also the result of information content in exchanged messages, a feature which cannot be easily accounted for by analytical models of agent interactions.

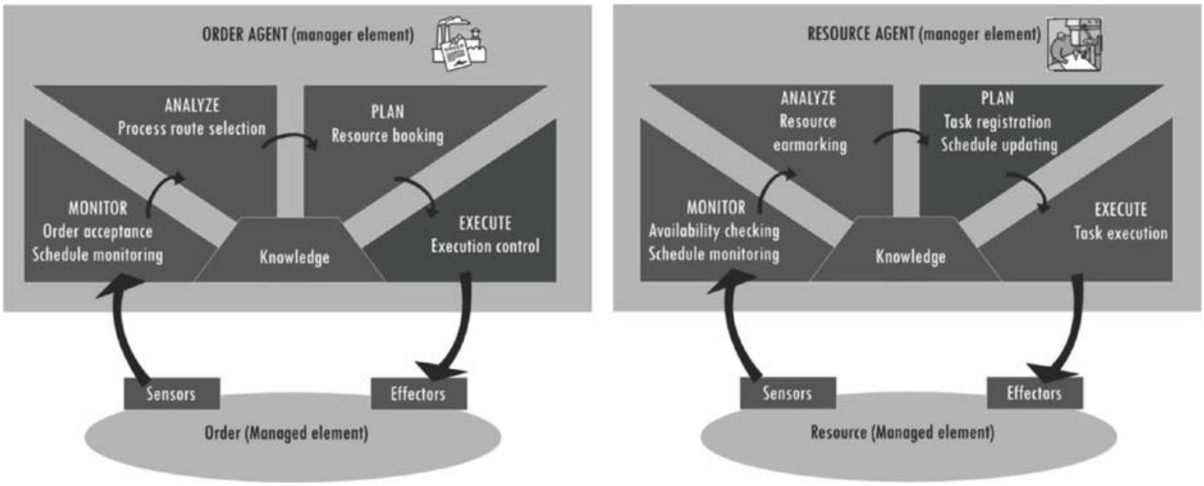
There are some previous works that emphasizes the results obtained by generative modeling in the scheduling topic. Vaario and Ueda (1998) proposed a modeling method for simulating dynamic scheduling where local attraction fields direct transporters carrying jobs to particular machines according to priority rules. The resulting emergence is generated by local interactions among agents through their force fields which cannot be anticipated without carrying the simulation. Ueda et al (2004) introduced an emergent synthesis of a MES decision-making policy based on a system model to predict the effect of alternative control and planning actions in make to order manufacturing environments. Emergence in this case was used to evaluate and control the range of time and cost constraints of the costumer that the system is able to fulfill.

Emergent Distributed Scheduling

The most common approach to monolithic MES implementation is to heavily resort to a given schedule, carried out by a single agent that makes assumption about future environmental states and makes the planning and distribution for each resource so as to focus execution control only on handling details and contingencies in task execution. However, preferring and attempting to follow the given schedule seriously limit the effectiveness of control actions taken by a conventional MES. In this chapter an autonomic MES concept is proposed which emphasizes a total integration of decentralized schedule generation and local execution control for agility and responsiveness. Such integration is carried out through the concept of order and resource agents acting as autonomic managers (Kephart and Chess, 2003; IBM Corp., 2009).

In the proposed autonomic MES, there are two different roles that can be assigned to an agent. It can be either an order agent or a resource agent as shown in Figure 5. The order agent (OA) is responsible for completing the order as required by its attributes (due data, product mix, quality and size) which determines the operations (tasks) for processing the order at the shop-floor. The OA chooses the best processing route and follows up order processing until it is completed. The resource agent (RA) manages the schedule for a resource and registers its usage and failure state. It is responsible for the execution of tasks for different orders. Each agent playing its role implements the monitor-analyze-plan-execute (MAPE) loop which comprise both scheduling and control for a given order or resource. That is, for the autonomic agent to be self-managing

Figure 5. Order agent and resource agent viewed as autonomic managers



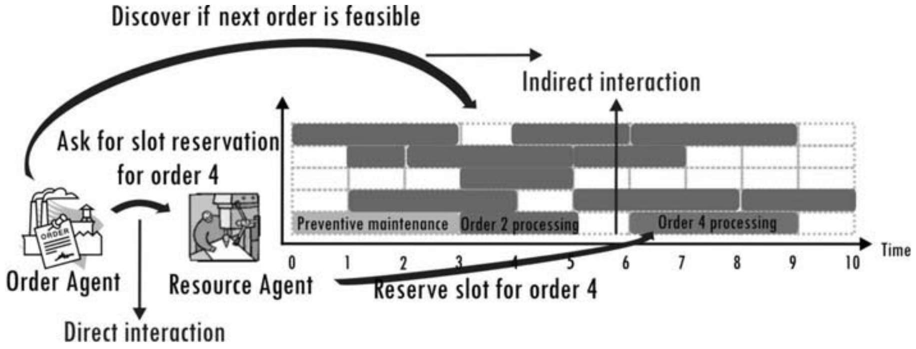
regarding its managed object, it must have an automated method to collect the details it needs from the manufacturing system (monitor function); to analyze those details to determine if something needs to be changed (analyze function); to create a plan, or sequence of actions that specifies the required changes (plan function); and to perform those actions (execute function).

The MAPE loop for both OAs and RAs must be accounted for by the interaction mechanism for distributed scheduling as follows:

- The monitor function includes the schedule monitor functionality, where both order and RAs oversee the Gantt chart looking up for schedule updates (the OA for the current order process route and the RA specifically for its resource), the order acceptance functionality, where the OA finds in the Gantt if a candidate order is feasible and so can be added to the current schedule or otherwise is rejected, and the availability checking functionality, where the RA checks at each step of order processing the chosen resource availability.
- The analyze function comprises the process route selection and resource earmarking functionalities, where the RAs returns the data to constitute the list of alternative solutions from which the top solution will be chosen.
- The plan function includes the resource booking and task registration functionalities, where the OA asks for slot reservation to each RA of the top solution, and the schedule updating functionality, where the RAs reflect resource commitment in the common Gantt chart.
- The execute function for the RA manages the completion of its resource usage plan with due consideration for dynamic updates using the task execution functionality, whereas the execution control functionality of the OA deals with the local solution of disruptive events by order rescheduling.

In the MES architecture there is one RA for each equipment item whereas each OA only deals with orders of a specific type. The communication is achieved through direct contact (messages) among concerned agents and indirect interactions through a dynamic Gantt chart which is used as a blackboard (see Figure 6) for information sharing about the state of shop-floor. The schedule is an emergence of such interactions and is perceived in the dynamic Gantt chart.

Figure 6. Direct and indirect interaction in the dynamic Gantt chart



The above mentioned interactions between the managed elements (orders and resources) are done via their autonomic managers while their spheres of influence partially overlap since a given OA interacts with other OA through RAs. That is, the shop floor environment is jointly controlled by autonomic OAs and RAs acting locally to achieve their goals.

GOAL-ORIENTED INTERACTION MECHANISM

Prometheus and Hermes Design Methodologies

The Prometheus methodology (Padgham and Winikoff, 2004) defines a detailed process for implementing and testing/debugging agent-oriented software systems. It consists of three phases: the system specification phase focuses on identifying the goals and basic functionalities of the multi-agent system, along with inputs (percepts) and outputs (actions) through the development of use-case scenarios characterizing operating conditions or environmental dynamics which the system must be able to handle properly. The architectural design phase uses the outputs from the previous phase to determine which agent types the system will contain and how they will interact. The third phase is the detailed design phase that looks at the internals of each agent and how it will carry out its tasks within the overall machinery of the multi-agent system.

In addition to detailed processes, Prometheus defines a range of design artifacts that are produced along the way. Some of these artifacts are kept (final design artifacts), and some are only used as "stepping stones" (intermediate design prototypes) to move forward onto the design lifecycle. Some artifacts capture the system structure (e.g. system overview diagram) and others describe its dynamic behavior (e.g. interaction diagrams).

Hermes approach to designing agent interactions (Cheong and Winikoff, 2005) uses interaction goals, actions maps/sequences and a number of failure recovery procedures to define a design methodology for multi-agent systems. The methodology follows an incremental waterfall model in which each step is derived from earlier design artifacts.

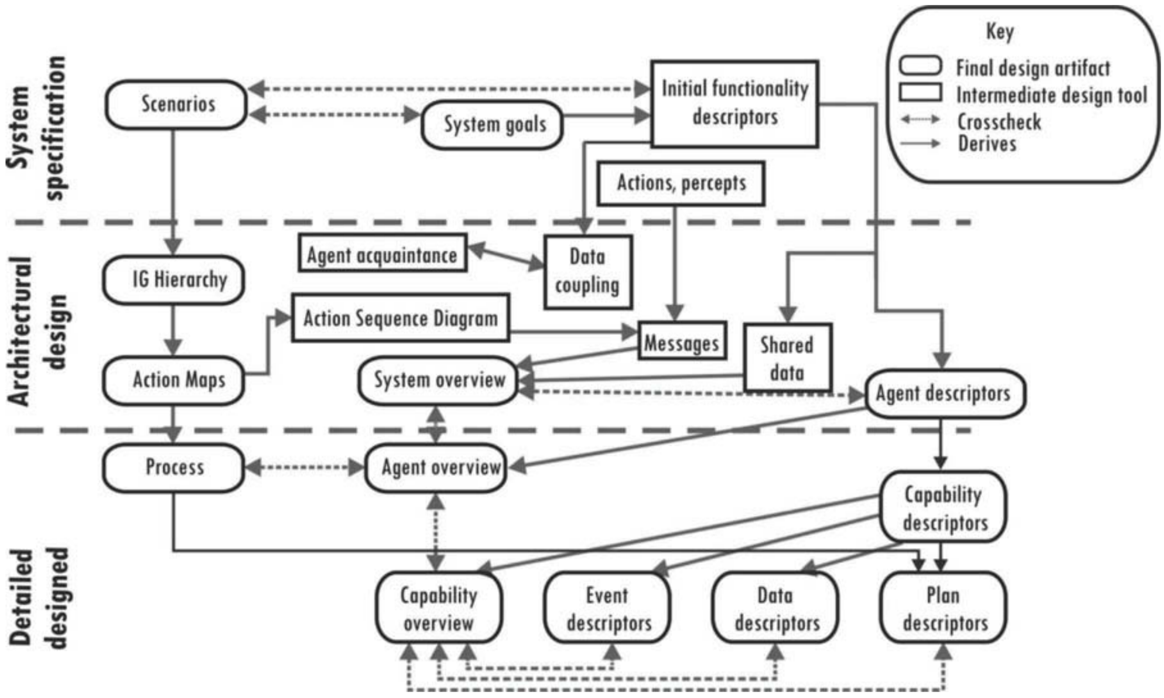
In the interaction goal hierarchy design phase, the designer is concerned with what the interaction is going to achieve and which roles are involved in each interaction. The identified roles and interaction goals are captured and organized into an interaction-goal hierarchy. The action map design phase pinpoints actions which are needed to deploy agent roles and then organized into appropriate execution sequences. These sequences are tested for validity and all possible sequences of actions are defined. In the last phase, the message design phase, the designer's attention shifts from actions to communications among agents, as they required completing the interaction mechanism definition.

In Hermes, early terminations and action retries can be used to handle mechanism failures. In the first case the entire interaction is ended and can be used in situations in which re-attempting the failed action or pursuing an alternative course of action will not result in progressing through the interaction logic. Instead, an action retry allows a failed action to further the interaction by attempting again the same or different action. If an action fails and is not able to be handled by action retries, this lead to an interaction-goal failure. When this happens, the interaction can be either terminated or rolled back to a previous interaction-goal.

Since Hermes has been conceived for interaction design in multi-agent systems, the approach described in (Cheong and Winikoff, 2006), which integrates the two methodologies replacing the typical Prometheus interaction design process with Hermes, was used for the autonomic MES proposed here. An overview of the integrated methodology can be seen in Figure 7.

As shown in Figure 7, the Hermes interaction-goal hierarchy and action maps replace the following Prometheus interaction artifacts: interaction diagrams, interaction protocols and process diagrams. Action maps are a mixture of interaction protocols and process diagrams in which action maps contain both inter- and intra-agent details while interaction protocols comprise of inter-agent communications and process diagrams describing only internal agent processes. Steps which are not involved in interaction design follow the typical Prometheus procedure. On the other hand, identification of Hermes roles is straightforward as they are usually taken from Prometheus agent types. The process of developing the interaction-goal hierarchy and its relevant action maps is more direct and more guided than in the Hermes methodology as the designer is developing these artifacts based on Prometheus´ scenarios. Action sequence diagrams and action message diagrams

Figure 7. The phases of the Prometheus methodology integrated with Hermes (Cheong and Winikoff, 2006)



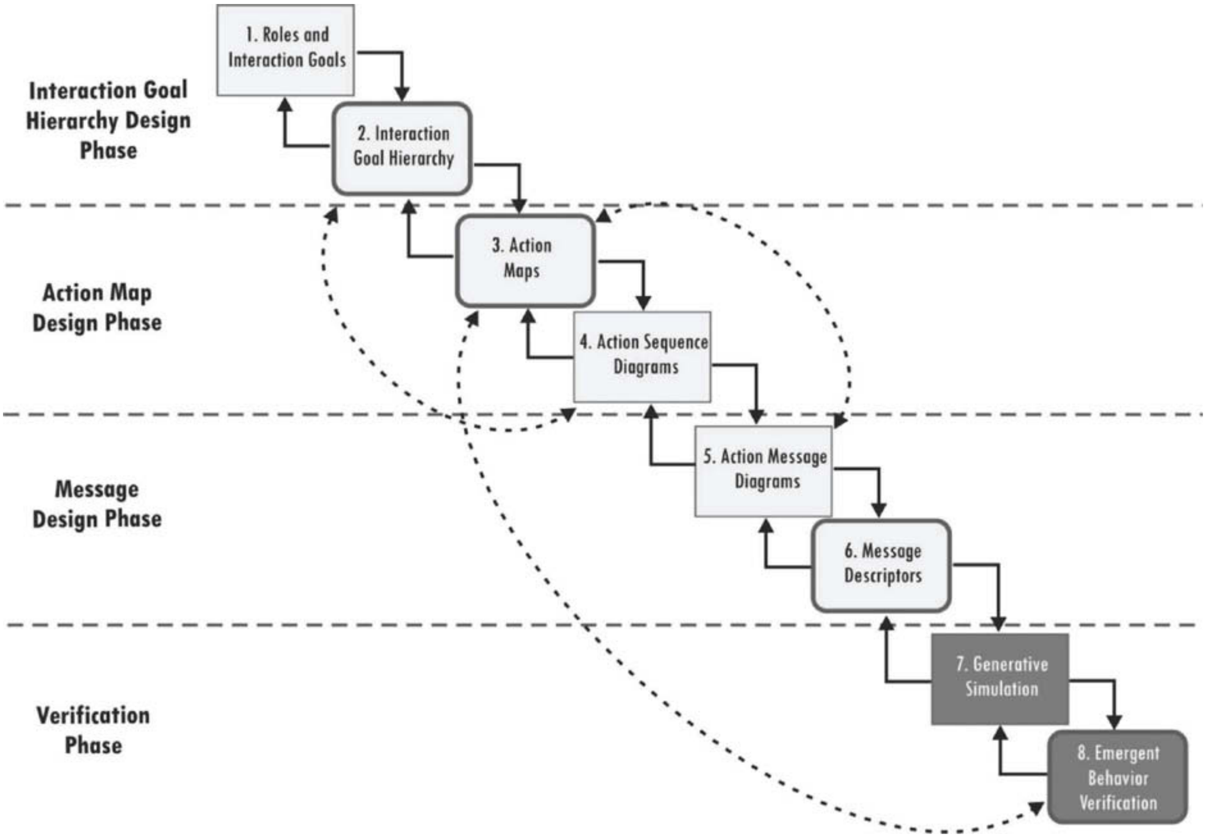
remain unchanged from the original Hermes approach. Moreover, the messages identified from the Hermes design can be carried across and adapted to Prometheus message descriptors as the message descriptors from both methodologies are very similar.

Specifically for the design and specification of the autonomic MES, the incremental waterfall of the Hermes methodology which defines the interaction design of the Prometheus-Hermes methodology has been extended to include a behavioral verification via generative simulation. A fourth phase, the verification phase, is introduced (see Figure 8) not only to validate the appropriate execution sequences but the whole emergent behavior of the distributed scheduling mechanism. Generative simulation will be used here as a computational tool to analyze emergent properties of alternative design of the autonomic MES. It is worth highlighting that mechanism design is about complete protocols for constraining multi-agent interactions such that emergent behavior and dynamics have certain desirable properties (Wooldridge, 2001). The emergent behavior verification will allow spotting goals and action maps that should be changed so as the goals can be achieved.

Design of the Intelligent Distributed Scheduling

For the sake of space only some final design artifacts from the design methodology in Figure 7 will be discussed next. To illustrate the typical running of the proposed autonomic MES, different scenarios consisting of a sequence of steps,

Figure 8. Phases of the extended Hermes methodology



the name of the functionality it belongs to and the information that is used or produced are considered. As an example, the feasible order arrival scenario is shown at Table 1.

In addition to those concrete descriptions of specific yet typical interactions, the defined agent types were developed, including the roles and data contain within. The details for both agents of the autonomic MES and the developing of its descriptors can be found at Table 2.

The interaction-goal hierarchy for the distributed scheduling mechanism is shown in Figure 9, where the undirected lines denote sub-goal relationships and the directed lines depict temporal dependency. The roles involved in the achievement of each goal are shown with the letter R, and it is also identified the initiator agent of each interaction goal with the letter I. As there are some interactions that can be initiated by either the OA or the RA, it is possible to inherit the initiator which is denoted by in Figure 9. Whichever agent initiates the interaction at runtime is inherited by the lower interaction goals.

The overall goal of the intelligent distributed scheduling system is *planning and execution control*. The *scheduling* goal involves both order acceptance and resource commitment. That is, the corresponding OA looks up the Gantt to discover if the order is feasible in the current situation. If so, the order is accepted, and if not, it is returned to the client. If the *order acceptance* goal is achieved, selected RAs are asked to provide different options for probable finalization time at their resources. These options given by selected

Table 1. Feasible order arrival scenario

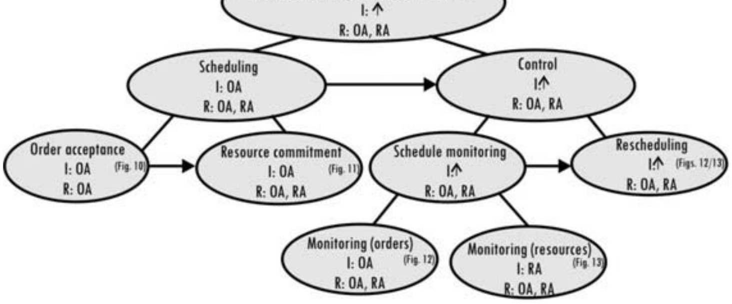
Name: Feasible order arrival scenario					
Trigger: New order arrival					
Description: A new order arrives at the shop floor. If it is feasible, the order is registered in the dynamic Gantt chart					
Steps:					
	Step type	**Step**	**Functionality**	**Data used**	**Data produced**
1	GOAL:	Analyze feasibility	OA	order type, order due date	order feasible notice
2	ACTIVITY:	Accept order	OA	order feasible notice	none
3	ACTIVITY:	Get possible task location (for the tasks involved in the different options of the production formula)	RB	selected dispatching rule	possible location of the task
4	GOAL:	Obtain possible solutions (for the order)	PS	processing times, probable finalization times	list of possible solutions
5	GOAL:	Choose the top solution	PS	list of possible solutions, selection criterion	process route
6	ACTIVITY :	Register the task (for the tasks involved in the process route)	TR	process route, processing times	change at the Gantt chart
Key for functionality: **OA** Order Acceptance - **AC** Availability Checking – TR Task Registration -**TE** Task Execution - **SM** Schedule Monitor - **EC** Execution Control - **RE** Resource Earmarking - **RB** Resource Booking - **PS** Process Route Selection - **SU** Schedule Updating					

Table 2. Order agent and resource agent descriptors

ORDER AGENT
Description This agent holds the order knowledge which determines the operations for the processing of an order. It selects the process route that will be communicated to concerned resource agents as the current order process plan (selecting the best-performing solution) and monitors the progress of order processing.
Cardinality minimum 0
Cardinality maximum many
Lifetime ongoing
Actions accept order, reject order, request location to resource, analize production formula option completeness, analize production formula option compatibility, remove resource earmarking, check remaining options, order materials for each operation, transport materials to next equipment area, check pending stages in the route, store completed order.
Uses data Process knowledge DB, Gantt chart DB, Pending orders DB
Produces data Executed orders DB, Pending orders DB, Non feasible orders DB
Goals Check pending operations, generate list of solutions, choose a solution, evaluate processing result.
Functionalities Order Acceptance, Process route selection, Resource booking, Schedule monitor, Execution control.
Protocols Order arrival protocol, Resource commitment protocol, Processing protocol, Reprocessing protocol.
RESOURCE AGENT
Description This agent manages the schedule for a resource and register its usage and failure state at the Gantt chart. It is the responsible for tasks execution.
Cardinality minimum 1
Cardinality maximum many
Lifetime ongoing
Actions get possible task location, register task on the Gantt chart, detect failure type and probable duration, check next maintenance operations and probable duration.
Uses data Process knowledge DB, Gantt chart DB
Produces data Gantt chart DB
Goals update Gantt chart, execute task, check resource availability.
Functionalities Availavility checking, Schedule monitor, Schedule updating, Resource earmarking, Task registration, Task execution.
Protocols Resource commitment protocol, Processing protocol, Reprocessing protocol, Unavailable resource protocol.

RAs allow the concerned OA to make a list of candidate solutions. Given the different solutions provided by RAs, the OA selects the top one, with the aim of booking the time slot corresponding to the different tasks in the order. When the order execution is monitored, an OA is always the initiator of the top goal, while when the focus is on resource state monitoring the corresponding RA is the agent who starts it. The *control* interaction-goal can then be also initiated by either the OA or the RA. The RA checks resource availability and the OA follow the processing route monitoring order execution. The *rescheduling* interaction-goal is initiated by the agent that detects the disruptive event: the RA updates the Gantt chart according to the execution condition changes and

Figure 9. Goal Hierarchy in the intelligent distributed scheduling system



failure state of the resource and the OA removes those resource earmarked for tasks which are affected.

The generalized action maps showing how each atomic goal of the interaction-goal hierarchy is to be achieved (see right side of each goal at Figure 9) are shown in Figure 10 through Figure 13. These includes data stores and failure handling procedures to face disturbances. Order monitoring and the corresponding rescheduling activity (Figure 12) as well as the resource monitoring and rescheduling activity (Figure 13) due to the disruptive events are described in the same activity map because they are tightly linked through action retries. Regarding data stores, there are five data bases in the distributed intelligent system architecture that made up the shop-floor execution control system: the *process knowledge data base,* containing information about different resources in the manufacturing system, physical connections between them and operations that can be performed by each one of them along with required inputs; the *Gantt chart data base,* holding the current schedule for each resource commited to a group of tasks for a certain time window, and were also the 'broken' or 'in maintenance' indicators for certain resources according to their actual condition; the *executed orders data base,* that has records related to orders that have been recently executed and have already left the system; the *pending orders data base,* containing records associated with outstanding orders within the MES, and the *non feasible orders data base,* containing records of rejected orders. The action maps developed provide flexible and robust interactions among an OA and several RAs (Figures 11 and 12) and a RA with several OAs (Figure 13), including action sequences to deal with failure cases summarized in Table 3.

Figure 10. Action map for order acceptance interaction-goal

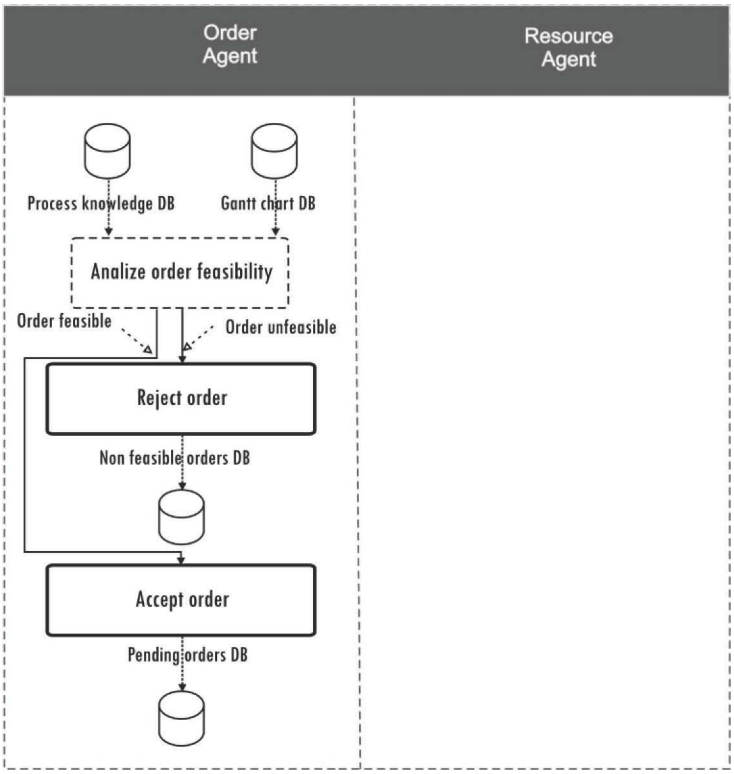


Figure 11. Action map for resource commitment interaction-goal

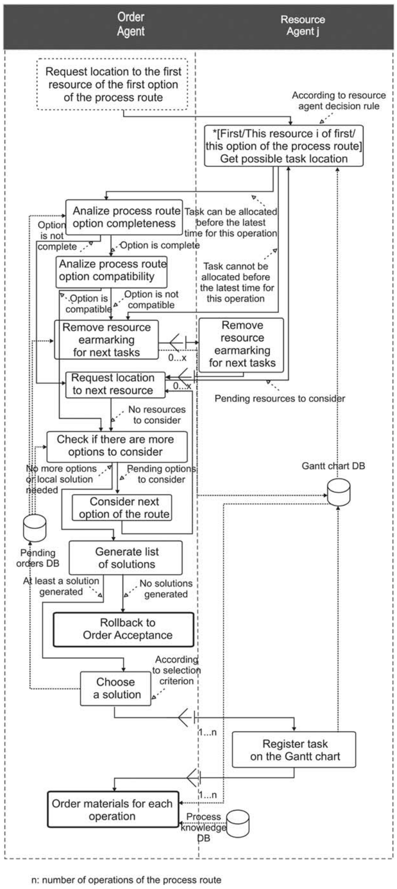
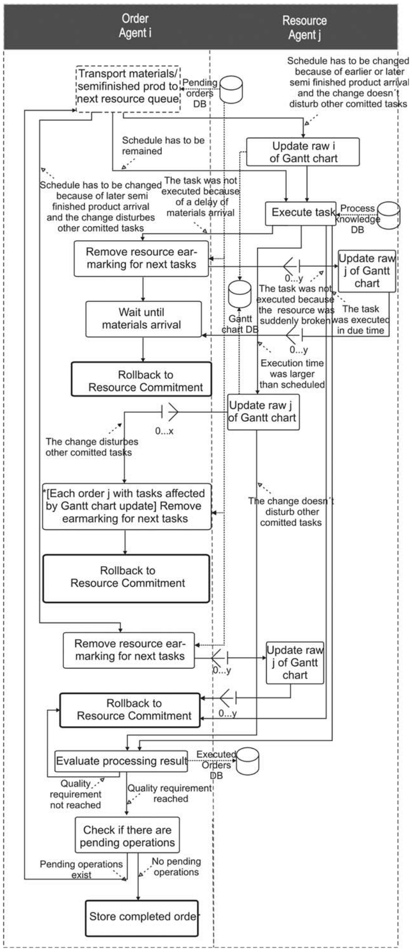


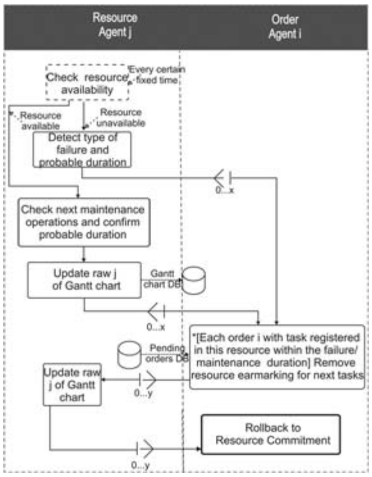
Figure 12. Action map for monitoring (orders) and rescheduling interaction-goals



As it is shown in Figure 10, when a new order arrives at the shop floor, the OA analyze its feasibility through Gantt exploration. If all tasks can be virtually placed in any Gantt location according to the average processing time for each equipment before order due date, the order is accepted and continues to the next interaction-goal in the distributed scheduling system. On the other hand, if the order results infeasible it will be rejected and sent to the ERP level, and in case its due date was modified and sent it back to the shop floor, it would enter in the MES as a new planned order. They incorporate scenario variations and identify possible disruptive events using Hermes´ failure handling procedures to address them: termination and action retry for action failures. For example, in Figure 12, the OA removes earmarking for later resource usages if the task was not executed because of a delay in raw material supply. An example of a rollback for interaction-goal failures can be found at Figure 11, where as the OA cannot generate a solution, the *resource commitment* interaction-goal is rolled back to the *order acceptance* goal that subsequently will be achieved in a different manner and so leads to a different result.

Regarding Figure 11, the OA asks candidate RAs of each option in the production formula a possible task allocation in their resource schedule and probable finalization time along with a due

Figure 13. Action map for monitoring (resources) and rescheduling interaction-goals



date for option acceptance. Each OA have only a limited number of options to consider in order to avoid a combinatorial problem, and OAs assume all processing options given by RAs are valid. These valid options make possible the generation of a list of solutions by the OA. After selecting the process solution for the order, the OA answers received options in due course so as to commit the chosen resources. As a response to the demand for booking of the OA, the RA registers the assigned slot in the Gantt chart. After time slot booking, OA request the raw materials needed in the production formula. Regarding Figure 11, a RA can answer task allocation request for its resource according to local dispatching rules such as SPT (shortest processing time), EDD (earliest due date) and FIFO (first in first out). Moreover, the OA have four different criteria to select the process route, which correspond to minimizing late deliveries (earliest global finalization time), minimizing processing costs (shortest processing time), lowering intermediate product storage cost (shortest time between stages) and decrease the finished product storage cost (largest global finalization time). These different decision-making rules for OAs and RAs results in different design alternatives for the distributed scheduling system.

Table 3. Possible failures at the interaction-goals

#	Action	Possible Failures	Remedial Actions	Interaction-Goal
1	Get possible task location	Task cannot be allocated before the due date	Consider other resource that executes the same task	Resource Commitment
2	Generate list of solutions	No solutions generated	Analyze if the order is still feasible	Resource Commitment
3	Transport materials / semi finished products	Transport delay	Update Gantt chart and remove resource earmarking for next tasks if the change would disturb other tasks	Monitoring (orders) and rescheduling
4	Execute task	Delay of materials arrival	Wait until materials arrival and re-earmark resources	Monitoring (orders) and rescheduling
5	Execute task	Resource breakdown during execution	Execute the operation again in another resource	Monitoring (orders) and rescheduling
6	Execute task	Execution time is larger than scheduled and other committed tasks were disturbed	Change schedule and remove resource earmarking for next tasks	Monitoring (orders) and rescheduling
7	Evaluate processing result	Quality requirement not reached	Reprocess in the same resource or another one	Monitoring (orders) and rescheduling
8	Check resource availability	Resource unavailable	(Re)earmark tasks registered within the failure duration and next tasks	Monitoring (resources) and rescheduling

Order monitoring and the corresponding rescheduling activity due to disruptive events (Figure 12) as well as the resource monitoring and rescheduling (Figure 13) due to the disruptive events are both described in only one activity map because they are tightly linked through action retries. Regarding order execution (Figure 12), an OA requests moving raw materials and semi-finished products to the corresponding resource queue in order to be processed.

At the same time, the involved RA is checking resource availability every certain fixed time and if the resource is not available, it diagnosis a failure type and probable duration of the unavailability. Should there exist planned maintenance operations the concerned RAs have to inform through the Gantt chart registration to allow all the agents to keep it in mind such events when looking up for processing feasibility of future orders. In case there are tasks already registered in that resource over the duration of resource unavailability period, affected Oas involved will have to remove resource earmarking and roll back to the *resource commitment* interaction-goal to reschedule those tasks which have been affected.

If it is time to execute the task and the materials or semi-finished products has arrived to the equipment area, the RA executes the task and informs the processing quality result to the OA who evaluates the processing result comparing the quality requirements for the product with the quality obtained by the operation input. If quality requirements are reached, then the following operations are executed for that order till there are not pending operations in the product recipe. On the other hand, if it is time to execute the task but the materials or semi-finished products haven´t yet arrived to the resource working area, the concerned OA asks for removing the resource earmarking for remaining tasks in the order and once the material arrives it rolls back to the *resource commitement* interaction-goal to reschedule the affected tasks. The RA manages its local schedule, that is, if the resource is idle and the materials and semi-finished products have arrived, it can process the task considering it doesn't disturb other scheduled orders even though if it is earlier than the planned start time for the task. If any changes occur in a resource schedule, the corresponding RA refreshes the Gantt chart. If the change doesn't disturb other committed tasks, next operations are followed and task execution continues as planned. Otherwise, a rollback to *resource commitment* interaction-goal is always needed.

As can be seen in the different action maps presented, they successfully account for alternative scenario variations and identify possible disruptive events using Hermes´ failure handling procedure to address them. For example, in Figure 12, an action retry for an action failure is shown when the OA removes earmarking for later resource usages if the task was not executed because of a delay in raw material supply. In the case of rollbacks for interaction-goal failures (see Figure 11), as the OA cannot generate a solution, the *resource commitment* interaction-goal is rolled back to the Order Acceptance goal which will be achieved in a different manner and so leads to a different result.

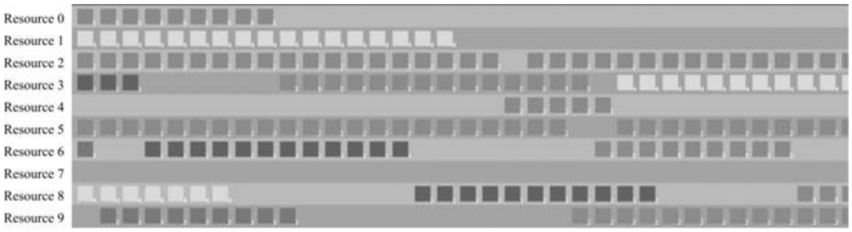
SIMULATION OF THE SCHEDULING SYSTEM

Prototype Implementation in Netlogo

A computational model of the distributed scheduling system was implemented in Netlogo® (Wilensky, 1999), a well suited software environment for modeling complex adaptive systems, or "worlds," and a useful tool in understanding emergent decentralized behaviors in multi-agent systems (Vidal, 2009).

The Netlogo environment is made up of agents. Each agent develops a decision-making policy and carries out its own activity in an asynchronous manner regarding the behavior of other agents. In Netlogo worlds, there can be four types of agents: turtles, patches, links, and the

Figure 14. A view of the resultant dynamic Gantt chart



observer. Turtles are agents that move around in the world. The world is two dimensional and is divided up into a grid of patches. Each patch is a square piece of "ground" over which turtles can move. Links are agents that connect two turtles. The observer doesn't have a ground location, it is constantly looking out over the world of turtles and patches. The different tasks involved in each order production give rise to a number of mobile agents (turtles), one for each time unit, that move over a grid of stationary agents (patches) which represents resource usage times. A set of agents (agentsets) were used to differentiate order types and so the corresponding production formula.

The dynamic Gantt chart of the Figure 14 was made as follows. Instead of moving to the right the time window following the system time, turtles (unit time tasks) are asked to move one unit to the left side and to die when they arrive to the patch in the left corresponding to the current time.

Each resource corresponds to a row in the Gantt chart and there is a dynamic temporal window with a fixed duration from the actual time to the future showing if the resources are reserved for a specific order type (colored box) or not (only the grey row), or whether the resource is unavailable due an unplanned event or it is in the maintenance state (black box).

To program the model, global variables were used whenever the information must be shared (available for every agent), and turtle variables and patch variables when they were sole private information for a single agent or type of agents.

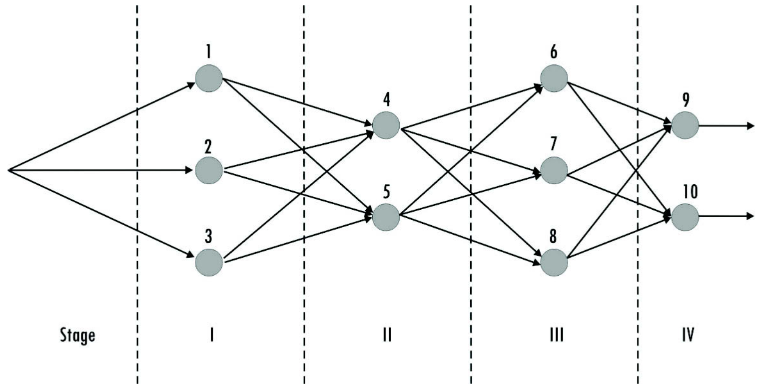
Case Study

To exemplify the proposed approach, let's consider emergent scheduling in a multiproduct batch plant comprising of 4 stages and 10 units to obtain 5 different products (Figure 15). Each order has different attributes such as product type and due date whereas arrival times, processing times and machine failure rates are stochastic. A batch (order) can follow many different routes through the batch plant while using different pieces of equipment. So there is a great deal of

Table 4. Mean process times for the case study

Order Type	Stage I			Stage II		Stage III			Stage IV	
	1	2	3	4	5	6	7	8	9	10
1	15	15	15	14	15	12	12	12	11	11
2	-	-	23	-	5	22	22	22	-	14
3	18	18	18	14	15	24	24	24	9	9
4	21	21	21	11	20	12	12	12	8	8
5	17	17	17	14	15	9	9	9	13	13

Figure 15. Multi-product plant network structure



flexibility in order scheduling and it is not obvious how smoothly each order will flow through the system due to a number of disruptive events and shop-floor constraints.

This case study seeks to assess how the plant will operate under the proposed mechanism for distributed scheduling and to foresee its capacity to reschedule and execution control under unplanned events such as an increase in processing time at a given stage for an order type or an increasing of machine breakdown rates. Also, it is assumed that OAs have the objective of decreasing late deliveries, so they have the same criteria to choose from the list of solutions the one corresponding to earliest global finalization time. Regarding the objectives of RAs, it is considered that all of them use the FIFO dispatching rule (allocating tasks in first available space of their local schedule).

There are two or three pieces of resources in each of the four stages (see Figure 15) and these equipment units sometimes differs by size and product capability, as may be seen at first glance in the mean processing times given in Table 4. Each batch must be processed through each stage and will occupy just one resource in each stage. Batch orders are placed on the plant individually, their size is the same for all of them, and it is assumed that they are released to the plant by the production management system or master production plan at a higher level.

It is difficult to predict without using a generative simulation model when a set of tasks will flow relatively smoothly through the MES, or if an increase in the failure rate of a resource will force delays and lengthen considerably the time required to complete a set of orders. So, the case study objectives are to predict how the plant will

Figure 16. Total processing time for order types 2 and 3 in the normal scenario

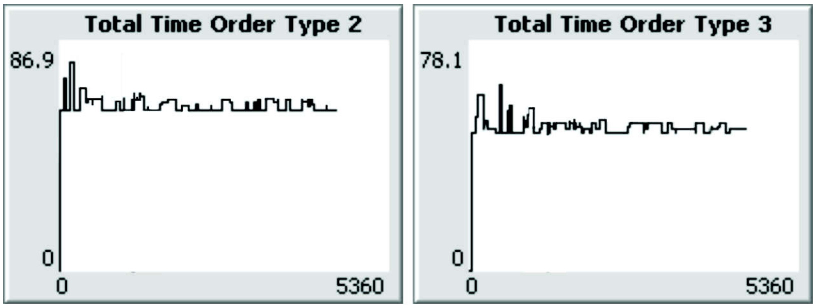
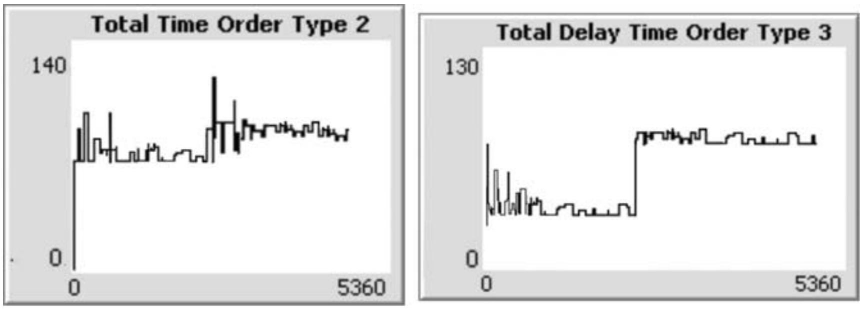


Figure 17. Total processing time for order types 2 and 3 in the scenario when order type 3 becomes more demanding of processing time at stage II since time 2000 min



operate under the proposed mechanism for distributed scheduling and to foresee its capacity to repair locally disturbances in the emergent schedule.

Results

Performance indicators considered for the emergent schedule were total processing times, queuing times and resource utilization. Equipment items are chosen according to the decreasing late delivery criterion, that is, OAs choose the solution with the earliest global finalization time. Figure 16 exhibits the dynamics of the plant for the normal operating scenario. As can be seen the total processing times of both order types shown tend to stabilize roughly after a time equal to 1000 min. This is a very important outcome which highlights that the emergent scheduling mechanism is robust and stable despite the total autonomy given to OA and RA and the lack of a master schedule.

Figure 17 shows the impact of total processing time for the order types 2 and 3 when orders type 3 experiment an instantaneous increment in the processing time at stage II (for example, because of a more demanding quality criterion). The order type 2 has been chosen because as it is appreciated at Table 4, it has a less flexible production formula. Contrasting with this case, the order type 3 can be processed in any equipment, and it has the particularity of demanding the highest production times. The total processing time for the order 2 has important variations in this period, and then tends to stabilize. Other order types are also affected but to a lesser extent, possibly because they have other resource alternatives.

Figure 18. Total processing time for order types 2 and 3 in the scenario where an increase of resource I.1 breakdown rates between 1000 and 2000 min. is simulated

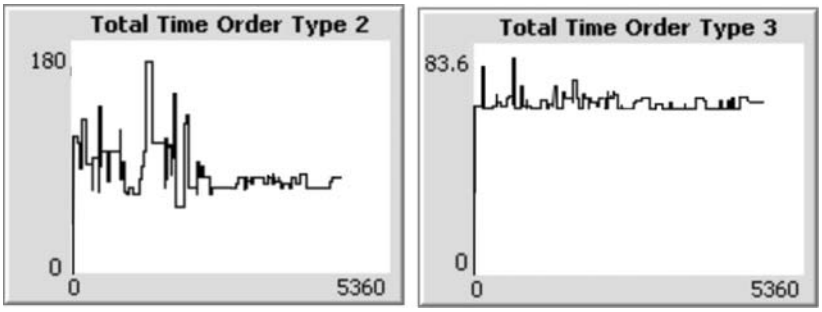


Figure 19. Total processing time for order types 2 and 3 in the scenario where the order type 2 starts becoming rush order from 2000 min. onwards

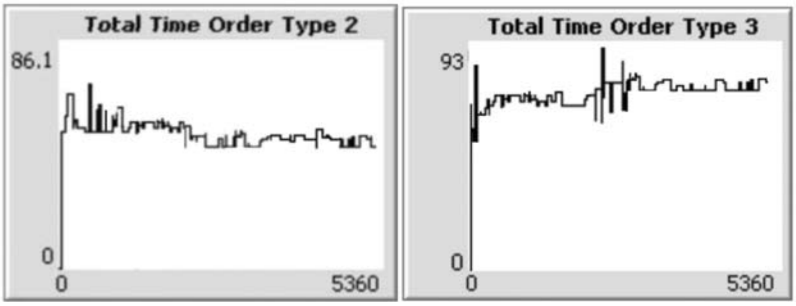


Figure 18 describes the dynamic response of the scheduling mechanism when the resource I.1 experiences a sudden increase in its breakdown rate. Type 3 order are somewhat affected momentarily whereas type 2 orders are severely disrupted in their processing times even when this order type is not processed at this particular resource. At Figure 19, processing times for the same type of orders are shown, for the scenario where orders of type 2 suddenly become rush orders. Type 3 orders are affected by this priority change but then their processing time stabilizes again, yet at a higher average whereas for type 2 orders do not suffer any sudden disruptions and their processing time stabilizes at a lower average.

Table 5 shows the evolution of the utilization in five time intervals over the simulation time horizon. As can be seen how, the increased rate of resource I.1 breakdown gives rise to a displacement of some already scheduled orders to other resources. These results highlights that the proposed approach is capable of handling effectively changes in its environment.

In Figure 20, total averaged queuing times for all order types and for different scenarios are shown. As can be seen orders of type 2 experiment the longest waiting times for resources in each stage of the multiproduct plant in all scenarios. Also, as expected queuing times for resources experiment a significant increase for the breakdown scenario.

Figure 21 shows the averaged queuing times for all order types and for four OA different criteria: decrease late delivery (earliest global finalization time), decrease the process cost (shortest processing time), decrease the intermediate product storage cost (shortest time between stages) and decrease the finished product storage cost

Table 5. Utilization for resources I.1, I.2 and I.3

Normal Scenario	from 0 to 1000	from 1000 to 2000	from 2000 to 3000	from 3000 to 4000	from 4000 to 5000
resource I.1	76,50%	82,52%	87,84%	85,18%	87,51%
resource I.2	64,90%	60,91%	70,13%	65,52%	67,83%
resource I.3	63,43%	66,08%	67,10%	65,69%	66,40%
Increased failure rate of resource I.1	**from 0 to 500**	**from 500 to 1000**	**from 1000 to 1500**	**from 1000 to 1500**	**from 1500 to 2000**
resource I.1	78,15%	12,00%	74,87%	80,88%	86,80%
resource I.2	64,43%	92,77%	76,17%	70,52%	66,91%
resource I.3	67,51%	92,86%	78,15%	69,71%	65,03%

Figure 20. Average queuing times for all order types and for the different scenarios considered

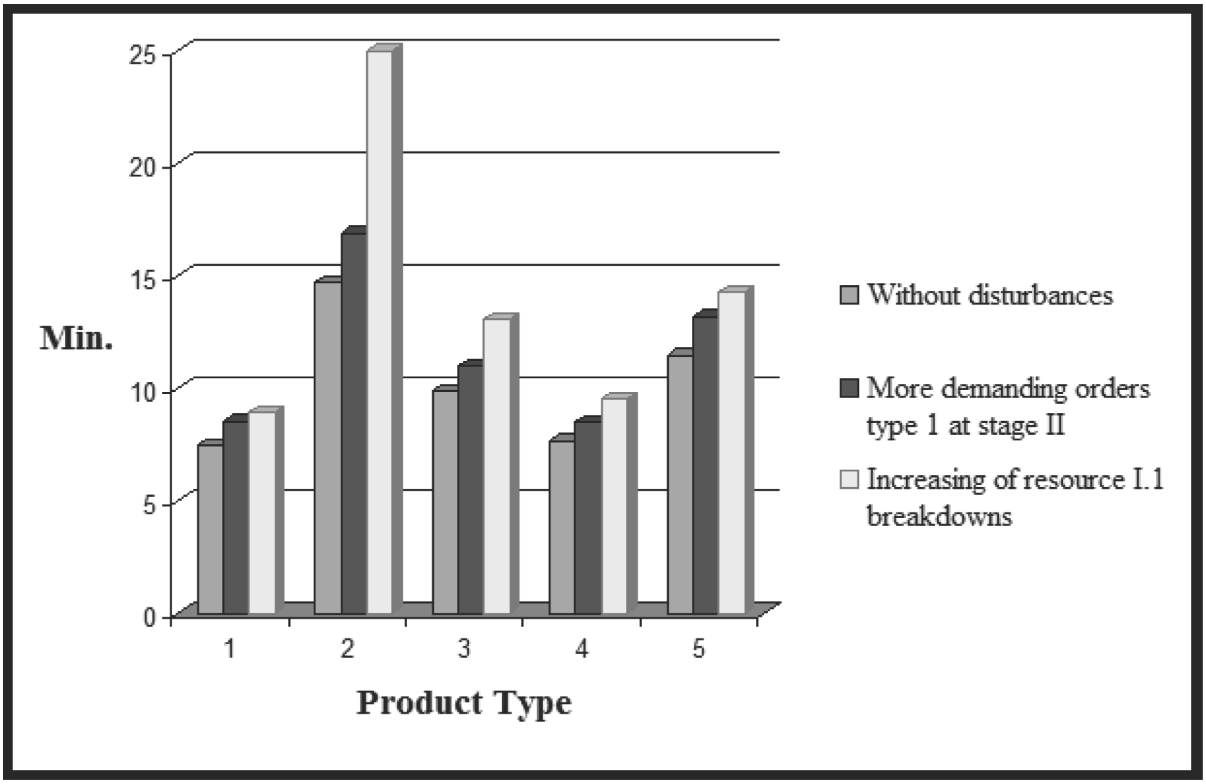
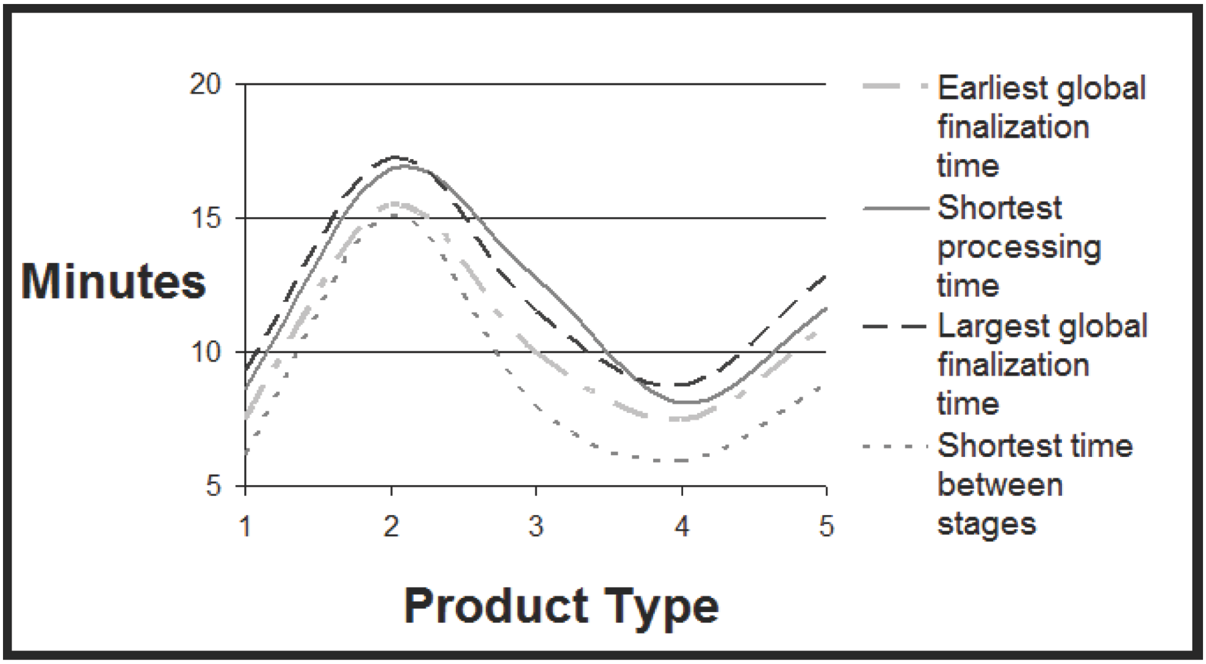


Figure 21. Average queuing times for all the order types and for different OA criteria



(largest global finalization time). It is quite clear that the criterion of decreasing the intermediate product storage cost results in the lowest queuing times for all the order types, and queuing times are not significantly modified with the chosen criterion for the OA.

FUTURE RESEARCH DIRECTIONS

Future research includes the implementation of a more sophisticated prototype with heterogeneous order and RAs having different objectives and strategies to maximize resource usage and minimize processing time. Upcoming work will also address more complex manufacturing systems, for instance related to a more complicated set of equipment interconnections, mixed orders and the need for re-processing operations in order to comply with more stringent quality constraints. Finally, the issue of individual and collective learning is being studied for defining the information content of exchanged messages.

CONCLUSION

A novel design and verification methodology for an intelligent distributed scheduling system based on well-defined interactions between autonomic agents which manage two different types of objects: orders and resources has been proposed. The design methodology highlights goal-oriented interactions among agents as the cornerstone for influencing by design the emergent behavior and dynamics of an autonomic MES. To assess the proposed MES design a generative simulation model has been implemented. Results obtained for different simulated scenarios indicate that the autonomic MES is robust and stable despite the total autonomy given to order and RAs when negotiating resource usage without resorting to a priori defined schedule.

The importance of behavior verification when designing multi-agent systems has been emphasized by expanding the Prometheus-Hermes methodology with a verification phase using generative simulation in the lifecycle of a goal-oriented interaction mechanism. This opens an entirely new approach for model-based design of a society of agents for applications in process systems engineering.

REFERENCES

Aytug, H., Lawley, M., McKay, K., Mohan, S., & Uzsoy, R. (2005). Executing production schedules in the face of uncertainties: A review and some future directions. *European Journal of Operational Research*, *161*, 86–110. doi:10.1016/j.ejor.2003.08.027

Barata de Oliveira, J. (2004). Coalition based approach for shop floor agility: A multiagent approach. PhD Thesis, Universidade Nova de Lisboa.

Bordini, R., Wooldridge, M., & Hübner, J. (2007). *Programming multi-agent systems in AgentSpeak using Jason*. Chichester, UK: John Wiley & Sons. doi:10.1002/9780470061848

Brachman, R. (2002). Systems that know what they're doing. *IEEE Intelligent Systems*, *17*(6), 67–71. doi:10.1109/MIS.2002.1134363

Canavesio, M., & Martinez, E. (2007). Enterprise modeling of a project-oriented fractal company for SMEs networking. *Computers in Industry*, *54*, 794–813. doi:10.1016/j.compind.2007.02.005

Cheong, C., & Winikoff, M. (2005). Hermes: Designing goal-oriented agent interactions. In *Proceedings of the 6th International Workshop on Agent-Oriented Software Engineering*.

Cheong, C., & Winikoff, M. (2006). Improving flexibility and robustness in agent interactions: Extending Prometheus with Hermes. *Software Engineering for Multi-Agent Systems*, *6*, 189–206. doi:10.1007/11738817_12

Chirn, J., & McFarlane, D. (2001). Building holonic systems in today's factories: A migration strategy. *Journal of Applied Systems Studies: Special Issue on Holonic and Multi-Agent Systems*, *2*, 82–105.

Corporation, I. B. M. (2006). *An architectural blueprint for autonomic computing*. Retrieved May 14, 2010, from http://www-01.ibm.com/software/tivoli/autonomic/pdfs/AC_Blueprint_White_Paper_4th.pdf

Covanich, W., & McFarlane, D. (2009). Assessing ease of reconfiguration o conventional and Holonic manufacturing systems: Approach and case study. *Engineering Applications of Artificial Intelligence*, *22*(7), 1015–1024. doi:10.1016/j.engappai.2009.01.001

CSELT. (2009). *Java agent developed framework*. Retrieved May 14, 2010, from http://jade.cselt.it

El Maraghy, H. (2009). The cognitive factory. In El Maraghy, H. (Ed.), *Changeable and reconfigurable manufacturing systems* (pp. 355–371). London, UK: Springer. doi:10.1007/978-1-84882-067-8

Epstein, J., & Axtell, R. (1996). *Growing artificial societies. Social science from the bottom-up*. Washington, DC: Brooking Institution Press.

Epstein, J. M. (2006). *Generative social science: Studies in agent-based computational modeling*. Princeton, NJ: Princeton University Press.

Ferber, J. (1999). *Multi-agent systems. An introduction to distributed artificial intelligence*. Boston, MA: Addison-Wesley.

Gilbert, N. (2008). *Agent-based models*. London, UK: Sage Publications.

Hadeli, K., Valckenaers, P., Kollingbaumb, M., & Van Brussel, H. (2004). Multi-agent coordination and control based on stigmergy. *Computers in Industry*, *53*, 75–96. doi:10.1016/S0166-3615(03)00123-4

Jennings, N. (2000). On agent-based software engineering. *Artificial Intelligence*, *117*, 277–296. doi:10.1016/S0004-3702(99)00107-1

Kephart, J., & Chess, D. M. (2003). The vision of autonomic computing. *Computer*, *36*(1), 41–50. doi:10.1109/MC.2003.1160055

Kletti, J. (2007). *Manufacturing execution systems – MES*. Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-540-49744-8

Leitão, P., Colombo, A., & Restivo, F. (2005). ADACOR: A collaborative production automation and control architecture. *IEEE Intelligent Systems*, *20*, 58–66. doi:10.1109/MIS.2005.2

Miller, J., & Page, S. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton, NJ: Princeton University Press.

North, M., & Macal, M. (2007). *Managing business complexity: Discovering strategic solution with agent-based modeling and simulation*. Oxford, UK: Oxford University Press.

Padgham, L., & Winikoff, M. (2004). *Developing intelligent agent systems: A practical guide*. Chichester, UK: John Wiley & Sons. doi:10.1002/0470861223

Rolón, M., Canavesio, M., & Martinez, E. (2009a). Agent based modelling and simulation of intelligent distributed scheduling systems. *Computer Aided Chemical Engineering*, *26*, 985–990. doi:10.1016/S1570-7946(09)70164-6

Rolón, M., & Martinez, E. (2010), Agent-based simulation modeling of an interaction mechanism for detailed design of autonomic manufacturing execution systems. *Proceedings of the 43rd CIRP International Conference on Manufacturing Systems* (pp. 1036 -1043). Vienna, Austria: Vienna University of Technology and Fraunhofer Austria Research GmbH.

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York, NY: Norton.

Ueda, K., Fujii, N., & Inoue, R. (2004). Emergent synthesis approaches to control and planning in make to order manufacturing environments. *CIRP Annals - Manufacturing Technology, 53*(1), 385-388.

Ueda, N. (1992). A concept for bionic manufacturing systems based on DNA-type information. In *Proceedings of the IFIP TC5 / WG5.3 Eight International PROLAMAT Conference on Human Aspects in Computer Integrated Manufacturing, B-3* (pp. 853-863).

Vaario, J., & Ueda, K. (1998). An emergent modelling method for dynamic scheduling. *Journal of Intelligent Manufacturing*, *9*(2), 129–140. doi:10.1023/A:1008863811960

Valckenaers, P., & Van Brussel H. (2005). Holonic manufacturing execution systems. *CIRP Annals - Manufacturing Technology, 54*(1), 427-432.

Valckenaers, P., Van Brussel, H., Verstraete, P., & Saint Germain, P., & Hadeli. (2007). Schedule execution in autonomic manufacturing execution systems. *Journal of Manufacturing Systems*, *26*, 75–84. doi:10.1016/j.jmsy.2007.12.003

Van Brussel, H., Wyns, J., Valckenaers, P., & Bongaerts, L. (1998). Reference architecture for holonic manufacturing systems: PROSA. *Computers in Industry*, *37*, 255–274. doi:10.1016/S0166-3615(98)00102-X

Verstraete, P., Valckenaers, P., Van Brussel, H., Saint Germain, B., Hadeli, K., & Van Belle, J. (2008). Towards robust and efficient planning execution. *Engineering Applications of Artificial Intelligence*, *21*, 304–314. doi:10.1016/j.engappai.2007.09.002

Vidal, J. (2009). *Fundamentals of multiagent systems with netlogo examples*. Unpublished textbook. Retrieved May 14, 2010, from http://www.scribd.com/doc/2094479/Fundamentals-of-Multiagent-Systems

Wang, Y., & Usher, J. (2004). Application of reinforcement learning for agent-based production scheduling. *Engineering Applications of Artificial Intelligence*, *18*, 73–82. doi:10.1016/j.engappai.2004.08.018

Warnecke, H. J. (1993). *The fractal company: A revolution in corporate culture*. Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-642-55776-7_3

Wiendahl, H., El Maraghy, H., Nyhuis, P., Zäh, M., Wiendahl, H., Duffie, N., & Brieke, M. (2007), Changeable manufacturing – Classification, design and operation. *CIRP Annals - Manufacturing Technology, 56*(2), 783-809.

Wilensky, U. (1999). *Netlogo modeling environment*. Retrieved May 14, 2010, from http://ccl.northwestern.edu/netlogo/download.shtml

Wooldridge, M. J. (2001). *Multi-agent systems: An introduction*. Chichester, UK: John Wiley & Sons.

KEY TERMS AND DEFINITIONS

Agent: Autonomous entity capable of achieving a goal by choosing an action policy. For this reason, it has reactivity capabilities (it perceives the environment and answers to changes that occur in it), social skills (it communicates with other agents, users or systems to fulfill its tasks) and learning abilities (it is able to adapt itself to the environment through different techniques).

Agent-Based Modeling: Computational technique that allows the study of social phenomena and allow us to discover the social structures and behavior that emerge from the interaction of agents.

Autonomic Systems: Dynamic organizations of autonomous entities with self-configuration, self-optimizing, self-reconfiguration and self-protection capabilities. Their architecture implements the monitor-analyze-plan-execution loop.

Emergent Behavior: Complex behavior that emerges as the aggregation of individual behaviors of the agents that are part of a multi-agent system.

Intelligent Systems: Systems that learn from their experience, and use their knowledge to make decisions.

Interaction: Dynamic relationship of two or more agents producing actions and reactions, which in turn influence their future behavior.

Scheduling: Timeline of resource usage in a set of tasks, according to constraints of parallelism and synchronization.

Chapter 3
A Multi-Agent System for Production Networks Simulation:
Toward a Pheromone-Based Model for Agents' Coordination

Samir Hamichi
Laboratoire d'Informatique de Paris 6, France

Diana Mangalagiu
University of Oxford, UK & Reims Management School, France

Zahia Guessoum
Laboratoire d'Informatique de Paris 6, France &
University de Reims Champagne Ardenne, France

ABSTRACT

In this chapter, the authors present a multi-agent model aimed to investigate emergent organizational structures in production networks and their reification by means of pheromone-based algorithms. The model considers agents (firms) embedded in a production network, interacting among them through business-to-business relations. The evolution of the network structure is endogenous, as it takes into account the individual behavior of the firms and their interactions. The firms are adaptive agents taking investment decisions according to their business efficiency. They adapt their prices to be competitive and get a larger share of the market. Also, they adapt their business relations with their suppliers in order to reduce costs of inputs and get orders satisfied. The agent's proactivity, with very simple decision mechanisms at the micro level, leads to the emergence of meta-stable business clusters and supply chains at the macro level. Pheromone-based algorithms reify dynamically these clusters as explicit graphs. The results of the authors' simulations show the impact of the transportation cost and the geographical reach on the regionalization of production and on wealth patterns. Individual firms, with local B2B interactions and decisions, form stable production systems based on the supply/demand and market growth mechanisms leading to the maturation of the market.

DOI: 10.4018/978-1-4666-2098-8.ch003

INTRODUCTION

Over the last decade, the complex dynamics of supply chains (SC) and production networks of firms had received considerable attention in the literature [Carbonara et al. (2002); Dyer et al. (2000); Harland et al. (2001); Swink et al. (2007)]. The complexity of such systems comes from the large number of heterogeneous actors they involve and from the spatial distribution and interdependence of these actors. However, a particularly interesting aspect received little attention in the literature: the exploration of the dynamics at the firm level in the particular context of a supply/production network.

In a production network, firms' interaction (through buying and selling transactions) may take several forms, produce several types of benefits and lead to increased competition and possibly increased economic performance. This forces firms to adopt new strategies such as privileging partnerships and distributed production approaches and leads to interesting emergent behaviors at a macro level. The emergence of hybrid organizational forms such as clusters of firms in industry is one of the observed macro-level behaviors, which is the focus of the present chapter.

This chapter is organized as follows: after a brief introduction describing the general perspective and objective of the chapter, we first provide the background of the production networks of firms and emergence of supply-chains as distributed systems. We review the literature and the current issues on the interaction between firms through simple business-to-business (B2B) relations leading to the emergence of production districts. We introduce different views on the efficiency and robustness of these networks and on how they relate to organizational performance. Then we discuss the insight agent-based modeling approach brings to the understanding of these issues. We briefly review agent-based models of self-organization in production network issues and coordination mechanisms, which could lead to a better performance for the firms within a distributed framework.

In the second part of the chapter, we present the Multi-Agent System (MAS) of adaptive production networks we have developed combining both micro->macro and emergent-macro->micro approaches simultaneously. In the model, at the micro level, the firms interact locally, leading to the emergence of some macro level structures of supply-chains. We use a pheromone-based mechanism to develop explicit graphs that capture the endogenous emergent macro level structures (emergence of efficient supply chains). The firms capture these emergent macro level effects, which affect their behavior. This reproduces the real world behavior, where the agent (the firm, in our case) observes and interprets what it sees. These new structures influence the local firms and the interactions between them, changing the cooperation and the coordination of the production. Finally, we provide concluding remarks and future research directions.

BACKGROUND

In this section we introduce the main definitions and concepts needed to understand the interactions taking place between organizations in order to capture complex dynamics, structures, routines and performance of organizations and organizational arrangements such as industrial clusters.

Theories of Industrial Districts and Clusters

Alfred Marshall, in the nineteenth century, coined the term 'Industrial Districts' when remarking that industries tend to concentrate in specific geographical areas [Marshall, (1890)]. As examples of industrial districts, Marshall referred to straw plaiting in Bedfordshire and cutlery in Sheffield, pointing out that geographical proximity provides specialized labor, nurtures subsidiary industries, stimulates innovative activity and enables technological spillovers. Contemporary management scientists such as Michael Porter - using the term 'cluster' instead of 'district' - stress that competition between neighboring rivals and availability of sophisticated customers stimulates innovation and engenders positive feedback for all firms in a cluster [Porter, (1990)].

According to Belussi (2006), theoretical basis for the literature on industrial districts and clusters has its roots in five main approaches: 1) Marshallian theory; 2) Location theory; 3) Transaction cost and institutional theory; 4) International business theory; 5) Regional studies. Belussi (2006) classified the modern developments of neo/post-Marshallian school along three main streams: 1) The analysis of the resurgence of the model of the small firm based on flexible specialization. 2) The examination of social interactions at regional/local level that leads to proximity benefits. The approach has been developed within the category of the phenomena related to "local or localized learning" [Becattini, (1990) & Antonelli, (2000)]. 3) Finally, the integration to the Schumpeterian concepts of competition, innovation, and evolutionary economics.

Our focus in this chapter is self-organization mechanisms for agents' coordination. The concept of organization has received wide interest in the MAS community [Mathieu et al. (2002)], but these works seldom reify this notion.

According to the industrial district theory, firms organize themselves in clusters in order to reduce transaction costs [Belussi, (2006)], i.e. in a MAS perspective, agents organize themselves in order to optimize agents' interactions and to deal with the free entry/exit of agents. Without any central control of the organization, the local decisions and interactions of the firms lead the implicit organization they belong to, to reach a meta-stable state. Moreover, each agent (firm) has a level of perception of its environment.

Related Work

Agent-based modeling and simulation are regarded as one of the best candidates for addressing different aspects of production and supply networks. Much of the work in the literature focuses on MAS integrating the entire supply chain as a network system of independent agents while taking into account the spatial distribution of the agents. Using physics and statistical mechanics methods, one stream of literature investigates the firm's behavior within production networks as a dynamic system. Battiston et al. (2007) identified mechanisms, which reproduce qualitatively the main stylized facts of industrial districts of firms and supply chains such as firm's size distributions and the correlation of output, growth and bankruptcy across firms. They also show that the aggregate variables of the whole network of firms can be traced back to the direct firm-firm interdependence. Weisbuch and Battiston (Weisbuch, (2006) & Weisbuch et al. (2007)], using a similar very simple framework, investigated wealth concentration and production regionalization as self-organized behavior of the system. They show how local production failures can result in avalanches of shortage and bankruptcies across the network and lead to separate economic regions into poor and rich regions with scale free distribution of regions' wealth.

While the models developed in [Battiston et al. (2007); Weisbuch, (2006); Weisbuch et al. (2007)] are very simple and reproduce well known stylized facts, some of the underlying assumptions are very strong and don't convince the economists. The first one regards the pricing mechanism. In fact, the price in these studies is not related to the firms' activity (costs, efficiency and markup) or to the market taking into account the demand and supply. The second is about the topology of the networks. The topology of the networks studied is fixed and doesn't change over time, which leads to assume a firm connected to the same suppliers and customers over time. The third assumption is about the homogeneity of firms' behavior. The firm is assumed to have a capital as production capacity, investing all profits in extra production capacity at each time step without any adaptation or investment strategy.

Ikeda et al. [Ikeda et al. (2007, 2007b)] investigated, from the standpoint of econophysics, interacting firms rationally investing in a production facility to maximize net present value. They estimate parameters used in the model through empirical analysis of financial and transaction data. They propose two different methods (analytical and regression methods) to obtain an interaction matrix of firms. On a subset of a real transaction network, they simulate, using the estimated parameters, the dynamics of firm's revenue, cost, and fixed asset, which is the accumulated investment for the production facility. The simulation reproduces the quantitative behavior of past revenues i.e. the cumulative probability distribution of the firms' revenue. They also studied the correlation of firms' performance on a transaction network and found that statistically significant correlation coefficients are obtained as evidence for the firm interactions [Ikeda et al. (2008)].

Again, these models reproduce stylized facts, but are based on strong assumptions about the investment behavior. They assume perfect information, a simple production function and a static topology of the network. First, the study doesn't extend the production function with multiple variables, (i.e. fixed assets and labor costs) and the asymmetric treatment of revenue and material costs (i.e., only revenue is described by the time-evolution equation), which leads to non-realistic cumulative probability distribution of material costs. The second question concerns the static view of the firm network, i.e., the list of linked firms is obtained by analyzing the transaction data of a certain fiscal year and is not updated during the simulation. In fact, the functional form of interaction is analogous to the inter-atomic force of crystal lattice, where the equilibrium position of the atom is assumed. Network analysis of multi-year transaction data and flexible mechanisms of dynamic networks are necessary for this purpose. Some other issues of their agent-based model regard the capabilities of simulating large-scale transaction networks and verifying the reliability of the model.

Few of the models proposed in the literature combine both micro->macro and emergent-macro->micro simultaneously [Conte et al. (2007), Gilbert (2002)]. The MAS paradigm offers very powerful tools to improve the understanding of distributed production among firms and compare coordination mechanisms and strategies impact on the global performance of the network its impact on the firms' performance.

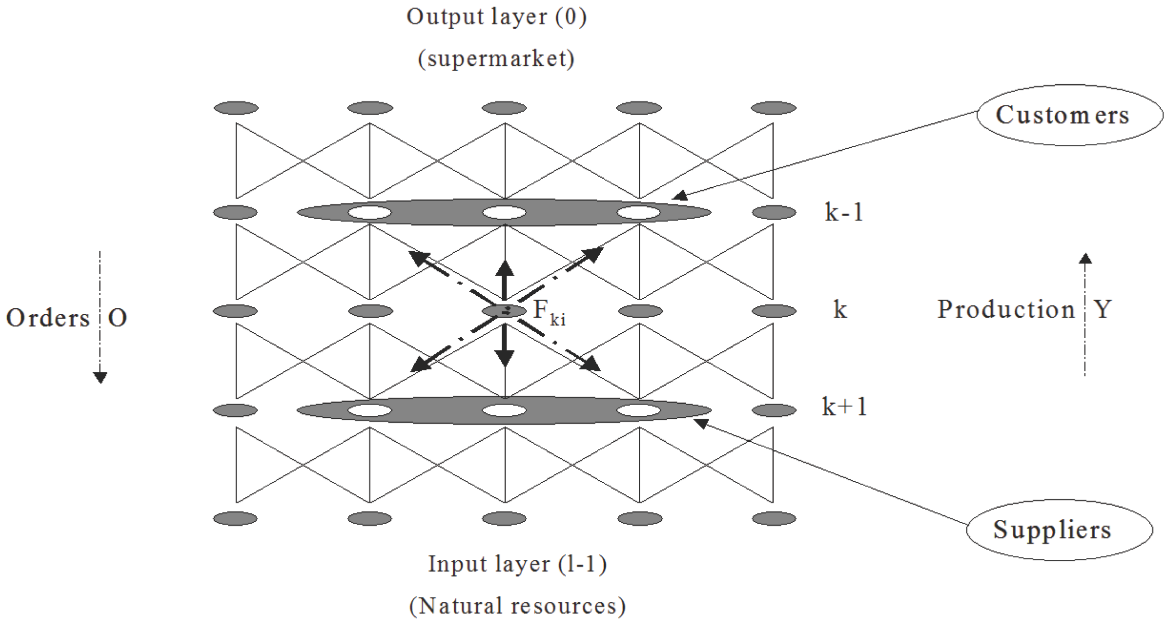
MULTI-AGENT MODEL

The authors' model is based on the model developed by Weisbuch and Battiston [Weisbuch et al. (2007)] (W&B model) as a network of firms having business-to-business relations.

The W&B model belongs to a large class of non-linear systems called reaction-diffusion systems brought from chemical physics [Shnerb et al. (2000)]. The reaction part here is the autocatalytic loop of production and capital growth coupled with capital decay and death processes. The characteristics of the model are: a dynamical behavior with spatio-temporal patterns (emergence of very productive regions), well characterized dynamical regimes (decay/grow) separated in the parameter space by transitions or crossovers, and scale free distributions since the dynamics is essentially multiplicative and noisy.

The W&B model, with its strong assumptions regarding the topology of the network, the orders from the market, the non-existence of pricing mechanisms and investment strategies, is far from taking into account important economic features. Indeed, firms are considered to behave uniformly, while in real markets, firms are very heterogeneous.

Figure 1. Network of firms



Our approach is to start with this simple model characterized by well known stylized facts and to use the MAS paradigm in order to evolve towards a more realistic and flexible model allowing us to further study important issues about production network and supply chains.

In this section, we describe the model with all extensions. In the model, we introduced a pricing mechanism calculated endogenously from the micro variables (costs, markup). The firm is able to decide which strategy to adopt in various circumstances; supply: order distribution (diversification), changing suppliers (efficiency), extending production capacity (investment).

The Network

We consider a production network $N_{l,m}$ as a regular grid with l layers of m firms. The network is oriented from an input layer $l-1$ (natural resources) towards an output layer 0 (supermarkets) (see Figure 1).

In each node of the grid we place a firm such as each firm $F_{k,i}$ is localized at position i in a given layer k. The network is initialized with $n=l*m$ firms. Each firm $F_{k,i}/k\in[1,l-2]$ is linked to its customers in the layer $k-1$ and its suppliers in the layer $k+1$.

The input to the production network enters only through the firms in the input layer, at zero cost. The output from the network is sold only by firms in the output layer at a price determined by a market clearing mechanism explained in the next section.

We define the cost of transportation c^T per unit of distance between suppliers and customers in any layer except the input layer, where firms are assumed to be located at the source of their resources.

Firms are located at the nodes of the lattice. Orders (O) flow from the output layer $(k=0)$ to the input layer $(k=l-1)$; supply (Y) flows from the input layer to the output layer.

The Firm

The variables we use to describe a firm $F_{k,i}$ located in the position *(k,i)* in the network are:

- $A_{k,i}(t)$: Production capacity at time t.
- $L_{k,i}(t)$: Liquid assets at time t.
- $S_{k,i}(t)$: Suppliers list at time t.
- $C_{k,i}(t)$: Customers list at time t.
- $O_{k,i}(t)$: Orders to its suppliers at time t.
    - $O_{k,i}^{k+1,j}(t)$: Orders sent to the supplier $F_{k+1,j}$ at time t.
- $Y_{k,i}(t)$: Production at time t.
    - $Y_{k,i}^{k-1,j}(t)$: Production delivered to the firm $F_{k-1,j}$ at time t.
- $c_{k,i}^{u}(t)$: Cost of one unit of product at time t.
- $p_{k,i}(t)$: Sale price of one unit of product at time t.
- $\Pi_{ki}(t)$: Profit at time t.

Capital: Each firm $F_{k,i}$ has a capital $K_{k,i}$. In W&B's model the capital is defined as the firm's production capacity $A_{k,i}$. Thus, each production cycle, the whole profit is invested to increase capacity. We revised the definition of the capital to allow further possibilities for the firm as investment strategies according to efficiency and production capacity utilization.

The capital is defined as:

$$K_{k,i}(t)=A_{k,i}(t) + L_{k,i}(t)$$

where $L_{k,i}$ is the liquid assets of the firm $F_{k,i}$ which does not depreciate in time and $A_{k,i}$ is the production capacity (taking into account land, warehouses, machines, labor, etc.), which depreciate in time with a rate λ.

Startup and Bankruptcy: Each firm $F_{k,i}$ enters the market with an initial capital. During its lifetime, it has a production process converting Y^{In} units of inputs bought from firms in layer $k+1$ into Y units of output. The production function is described later in the next section. A firm can go bankrupt and disappear if it's capital goes under zero. In case of bankruptcy, a new firm is created in the same location after a time lag τ. This parameter influences the avalanche of bankruptcies, as studied by [Weisbuch et al. (2007)]. The study shows that avalanches occur across the network as the time lag increases.

Business-to-Business Relations (B2B): Links in the production network represent the B2B relations between firms (customer-supplier relationship). Inspired from cellular automata, W&B model defined the network as a two dimension static lattice with "pseudo-periodic" boundary conditions. One dimension is considered as layers of the production chain (input to the output layer). The second dimension is considered as a geographical proximity with periodic boundary conditions.

In W&B model, each firm is linked to three firms considered as its suppliers from the upstream layer (except for the firms in the last layer upstream) and to three other firms considered as its customers from the downstream layer (except for the last downstream layer). These links are fixed all the time, which means that firms can change neither suppliers nor customers over time. Even after creation of a new firm i.e. after a bankruptcy, the new firm will have the same links as the bankrupted firm.

We extended the model to include dynamics to the process of network formation: agents (firms) follow a set of protocols while interacting with each other. This extension allows simulating real situations where the firm is able to perceive its environment and rationalize its decisions following strategies. The environment is impacted by firms' decisions.

The Firms' Environment

A firm's environment is its market: from the upstream side the firm gets inputs and to the downstream side it sells products. Therefore, the firm interacts only with firms within its environment. Regarding the output layer (k=0) as a final market, the firms in this layer sell the production directly to the final consumers. We assume that all the production $Y_0(t) = \sum_{i=1..m} Y_{0,i}(t)$ will be sold (absorbed by the market).

The pricing mechanism is based on a function of demand and supply of the production. This mechanism is a market clearing mechanism which confronts the aggregate production $Y_0(t)$ to a demand curve and sets the market price $p^m(t)$ for the firms in the market where the aggregate production is sold.

The Dynamics of the Model

The production process is based on business-to-business interactions and is executed within each time step *t*. One time step represents a full production process:

1. Each firm places orders. A firm receiving an order calculates its needed inputs for production and then places orders to its suppliers.
2. Once orders propagated till the input layer, each firm produces and delivers.
3. After delivery, each firm calculates its profit, invests part of its profit in production capacity if needed and retains the rest as liquid assets.

Bellow, we describe all processes executed by each firm in a time step.

Order Placement and Production

Orders $O_{0,i}(t)$ placed by a firm in the output layer: We use the following simplifying assumptions for the model, inspired from [Delli Gatti et al. (2005)] and assumed in many production network models [Weisbuch, (2006); Weisbuch et al. (2007), Hamichi et al. (2009a, 2009b)], which keep a reasonable level of realism of the model.

- The orders are limited only by the production capacity of the firm.
- At the level of the output layer, all output production is sold. Consequently, the firms in the output layer place orders for full production, i.e. limited by its capacity $A_{0,i}$:

  $O_{0,i}(t) = q.A_{0,i}(t)$

  where q is the technological coefficient which gives the amount of product per unit of evaluated production capacity.
- We set $q=1$ for all the firms.

Orders $O_{k,i}(t)$ placed by the firm $F_{k,i}$ at the intermediate levels ($k=1...l-1$): At the initial time step, firms in layer *k*, including the output layer, divide equitably and transfer orders upstream to get products from layer (k + 1) allowing suppliers to produce. The firm $F_{k,i}$($k=1..l-1$) calculates the quantity to produce by summing all received orders from customers and comparing it to its production capacity

$$O_{k,i}(t) = \min\left(q.A_{k,i}(t), \sum_{j|F_{k-1,j} \in C_{k,i}} O_{k-1,j}^{k,i}(t) \right)$$

where $O_{k-1,j}^{k,i}(t)$ is the order of the customer $F_{k-1,j}$ placed with firm $F_{k,i}$.

Then, the firm $F_{k,i}$($k=0..l-2$) places orders to each one of its suppliers, according to a strategy which takes into account the unit price and the distance to each of them.

At the initialization stage, all firms follow a supplier diversification strategy, i.e. they follow the same ordering process. In subsequent steps, firms take into account the reliability of different suppliers and order at time *t* from each supplier proportionally to the production received at time $t-1$.

Orders $O_{l-1,i}(t)$ at the input layer: Firms at the input layer $k=l-1$ are not required to order any input. We assume that they have unlimited and zero cost access to needed raw materials. The costs incured will be extraction costs.

Production: The production process starts from the input layer, each firm starting producing according to the inputs received Y^{in}.

$$Y_{l-1,i}^{in}(t) = \min\left(q.A_{l-1,i}(t), O_{l-1,i}^{in}(t)\right)$$

At other layers $k=0..(l-2)$, the production is:

$$Y_{k,i}^{in}(t) = \sum_{j|F_{k+1,j} \in S_{k,i}} Y_{k+1,j}^{k,i}(t)$$

where $Y_{k+1,j}^{k,i}(t)$ is the input products received by the firm $F_{k,i}$ from the supplier $F_{k+1,j}$. Firm's goal is to produce $Y_{k,i}(t) = O_{k,i}^{in}(t)$ but its real production depends on events happening during the production process with a probability P (taken from a uniform distribution), resulting in losing a random fraction $\varepsilon(t)$ of its production.

The production function including exogenous and unplanned events is:

$$Y_{k,i}(t) = \alpha.Y_{k,i}^{in}(t).(1 - \varepsilon(t))$$

where α is a transformation coefficient.

We define Z as the production efficiency ratio used by the firm to define its investment strategy according to its capacity utilization.

$$Z_{k,i}(t) = \frac{Y_{k,i}(t)}{q.A_{k,i}(t)}$$

Costs and Prices

- **Total and Unit Cost:** At the firm level, we take into account fixed costs (plants, machinery, warehouses, etc.) and variable costs (labor, inputs, etc.). The total cost c^t is defined as the sum of all costs while the unit cost c^u is the average cost per unit of output.

The total cost of the firm $F_{k,i}$ at period t consists of input cost, labor cost and depreciation cost as follows:

- **Input Cost:** Money paid for inputs including transportation.

$$c_{k,i}^{in}(t) = \sum (p_j + c_T.d_j).Y_{k+1,j}^{k,i}(t)$$

where
  - p_j the sale price of the supplier $F_{k+1,j}$
  - $Y_{k+1,j}^{k,i}(t)$ is the production delivered by the firm $F_{k+1,j}$ to the firm $F_{k,i}$
  - c_T is the transportation cost of one unit of product per unit of distance
  - d_j is the geographical distance between the firms $F_{k+1,j}$ and $F_{k,i}$
- **Labor Cost:** The percentage of labor in production capacity.

$$c_{k,i}^{l}(t) = \omega.A_{k,i}(t)$$

where ω is the relative cost of labor. We consider ω the same for all firms. We note that a firm has to pay labor cost even if it doesn't produce anything.
- Transformation cost depending only on the quantity produced.

$$c_{k,i}^{p}(t) = \gamma.Y_{k,i}(t)$$

where γ is the cost of producing one unit of product.

From the costs equations we deduce the unit cost:

$$c_{k,i}^{u}(t) = \frac{c_{k,i}^{in}(t) + c_{k,i}^{l}(t) + c_{k,i}^{p}}{Y_{k,i}(t)}$$

Markup pricing mechanism: We calculate the price at the firm level according to one of the most common pricing mechanism used in economics, cost-plus pricing, which doesn't take into account the demand.

$$p_{k,i}(t) = c^u_{k,i}(t).(1 + M_{k,i}(t))$$

where $M_{k,i}(t)$ is the markup of the firm $F_{k,i}$ at time t.

Market clearing mechanism: We also set a market clearing mechanism in the system. We consider the output layer as the final market where the products are sold to the end customers: firms at this layer will not sell the production with the price calculated in the previous equation, but with a market price set by the demand function through supply and demand confrontation (Figure 2). The price is set to clear the market and the demand curve[1] is assumed to be:

$$p^m.Y_0 = D$$

where p^m is the market price for the final product (output layer price) and Y_0 is aggregate production of final product (output layer production).

Profit

The profit is defined as total revenue minus cost:

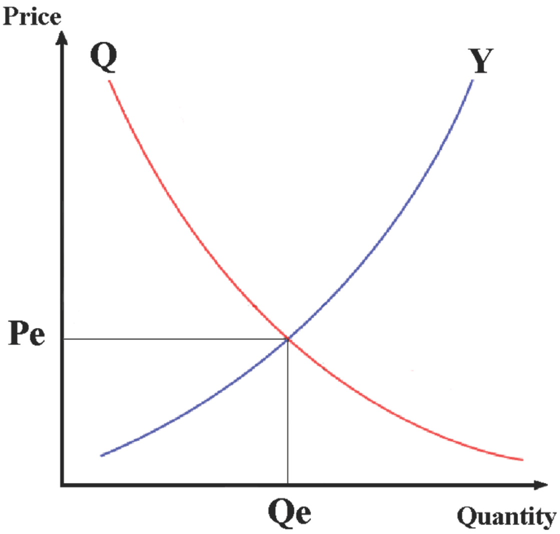
$$\Pi_{k,i}(t) = (p_{k,i}(t) - c^u_{k,i}(t)).Y_{k,i}(t)$$

Investment

The firm makes investments in order to maximize its future value. In our model, we assume that all capital investments in production capacity are irreversible investments.

We consider that the firm $F_{k,i}$ will invest its profit in liquid assets. When the firm reaches very high utilization regime, it invests part of the liquid assets in production capacity, thus increasing it with a certain percentage θ. Therefore, the production capacity decreases with rate λ due to depreciation and increases with θ according to the investment decisions (see Algorithm 1).

Figure 2. Market Clearing (demand and supply curves)



Customer/Supplier Relation

We consider the firm as the basic entity of our MAS. The firm interacts with other firms in its environment following B2B rules. In the model, the firm has a dynamic set of suppliers and customers with which it interacts. Firms change suppliers over time depending on their economic performance. The firm, by assessing its business exchanges, adapts its relations with its partners: suppliers in its supply side and customers in its market (upstream / downstream).

In a previous study [Hamichi et al. (2009b)], we have designed a mechanism for supplier substitution based only on the price of the inputs (including geographical distance). The mechanism is based on the principle that a firm continues to order inputs from profitable suppliers and proceeds to substitute the less profitable ones by seeking new suppliers offering best prices. In this sourcing adaptation process, the firm is aware of the price, *Algorithm 1. Investment*

Requires: Production capacity A, liquid assets L, profit Π, utilization ratio Z **Ensure:** Investment of profit
1: **if** $(Z_{k,i}(t)=1$ *and* $\Pi_{k,i}(t)>0)$ **then** 2: $L_{k,i}(t+1)=L_{k,i}(t)+\Pi_{k,i}(t)-\theta.A_{k,i}(t)$ $A_{k,i}(t+1)=A_{k,i}(t).(1-\lambda+\theta)$ 3: **else** 4: $L_{k,i}(t+1)=L_{k,i}(t)+\Pi_{k,i}(t)$ $A_{k,i}(t+1)=A_{k,i}(t)(1-\lambda)$ 5: **end if** where θ is the investment fraction

the geographical distance and the production capacities of all the firms in its supply side that are within its geographical reach. It sorts them by unit cost including transportation cost. It takes then the decision to substitute the higher cost supplier by the firm with the minimum unit cost. So the firm adapts its list following the algorithm 2.

To reach its goal, the firm has to take decisions according to strategies. As a supplier, the firm has to practice competitive prices in order to get more customers. Therefore, the firm adapts its fixed markup in its pricing policy. This local adaptation leads to changes in the form of the organizational structure in which the firm is involved by gaining or losing customers. Using these decision mechanisms at the firm (micro) level, we are interested in the effect of these decisions on the production regionalization and the economic performance of the whole system (macro-level).

SIMULATION AND RESULTS

The results of simulations were obtained, using the multi-agent platform DIMA [Guessoum et al. (1999)], for a production network with 1250 nodes in five layers, run for 10000 time steps. The initial wealth is uniformly and randomly distributed among firms:

$$A_{k,i}(t=0) \in [1.0, 1.1]$$

$$L_{k,i}(t=0) = 0$$

Emergent Patterns

Using the model, the study of economic performance of the system under different conditions shows the impact of geographical reach of the firm on the number of production clusters that emerge across the network and the impact of transportation costs on this regionalization [Hamichi et al. (2009b)]. Our simulations show, in all the cases studied, that the firms self-organize into regions and spatial patterns such as productive and metastable production chain emerge.

Aggregate Economic Performance

For the economic performance at the macro level, the aggregate values of the global system (market price, aggregate production and total growth of the capital) show how the market evolves from an early development stage (with the demand much higher than the offer) to a mature stage. As the production initially is not high enough to satisfy the demand, the market price is largely higher than the average unit cost at the end of the production chain. Firms in the output layer take advantage of this situation, selling all their production with very high profit. This leads them to increase production capacity, investing part of liquid assets as previously described. Firms at the output layer share the market in proportion to their respective production capacity, while firms in intermediate layers sell production with a fixed margin. These two simplified behaviors are realistic. The profits of the firms in intermediate layers are influenced by their suppliers' prices and by the quantities of products ordered by their customers.

The investment fraction θ parameter has an impact on the global performance of the system.

Algorithm 2. Substitute a supplier

Ensure: Substitution of a supplier

if ($\dfrac{Y_{k,i}^{in}(t)}{O_{k,i}^{out}(t)} < satThresh$) **then**

for $F_{k+1,j} \notin S_{k,i}(t) \mid j \in [1..m]$ **do**

return *j* with $\min(p_j + c^T.d_{(i,j)})$;

end for

for $F_{k+1,h} \in S_{k,i}(t) \mid h \in [1..m]$ **do**

return *h* with $\max(p_j + c^T.d_{(i,h)})$;

end for

if $(p_h + c^T.d_{(i,h)} > p_j + c^T.d_{(i,j)})$ then

$S_{k,i}(t+1) = S_{k,i}(t) - F_{k+1,h} + F_{k+1,j}$;

end if

else

$S_{k,i}(t+1) = S_{k,i}(t)$

End if

where

p_j (resp. p_h) is the unit price of the firm $F_{k+1,j} \notin S_{k,i}$ (resp. $F_{k+1,h} \in S_{k,i}$)

c^T is the transportation cost of unit of production per unit of distance

$d_{(i,j)}$ (resp. $d_{(i,h)}$) is the geographical distance between firm $F_{k,i}$ and firm $F_{k+1,j}$ (resp. between firm $F_{k,i}$ and firm $F_{k+1,h}$

Coupled to the capacity decay λ, the two parameters separate the growth regime mainly into three regimes:

1. **$\theta =< \lambda$:** Decay regime with decay of the global production capacity (Figure 4. Case of $\theta = 0.01$ and $\lambda = 0.01$).
2. **$\theta > \lambda$:** Growing regime with stable production capacity (Figure 4. Case of $\theta = 0.02$ and $\lambda = 0.01$).
3. **$\theta >> \lambda$:** Growing regime with shocks (Figure 4. Case of $\theta = 0.05$ and $\lambda = 0.01$) and instabilities during the process due to avalanches of bankruptcies raised by the failure of big firms that invested more than required in production capacity. Figure 3 shows the sensitivity of the global performance of the system to these two parameters.

Toward A Pheromone-Based Model for Agents' Coordination

In a second stage of our investigation, we introduced a pheromone-based model in order to detect emergent structures (clusters of firms) and take into account feedback to the firms' perception. The model is based on stigmergy principles [Grasse, (1959, 1984)] using agents' environment as medium for coordination. We use digital pheromones in the stigmergic mechanism for coordinating firms production organization. The supply links are the place where the pheromone is deposited (pheromone field). The deposit reinforces the supply links according to the production quantities exchanged between the extremities of the links (B2B). Modeled on the pheromone fields that many social insects use to coordinate their

Figure 3. Regime diagram in the capacity decay (λ) vs. investment rate (θ)

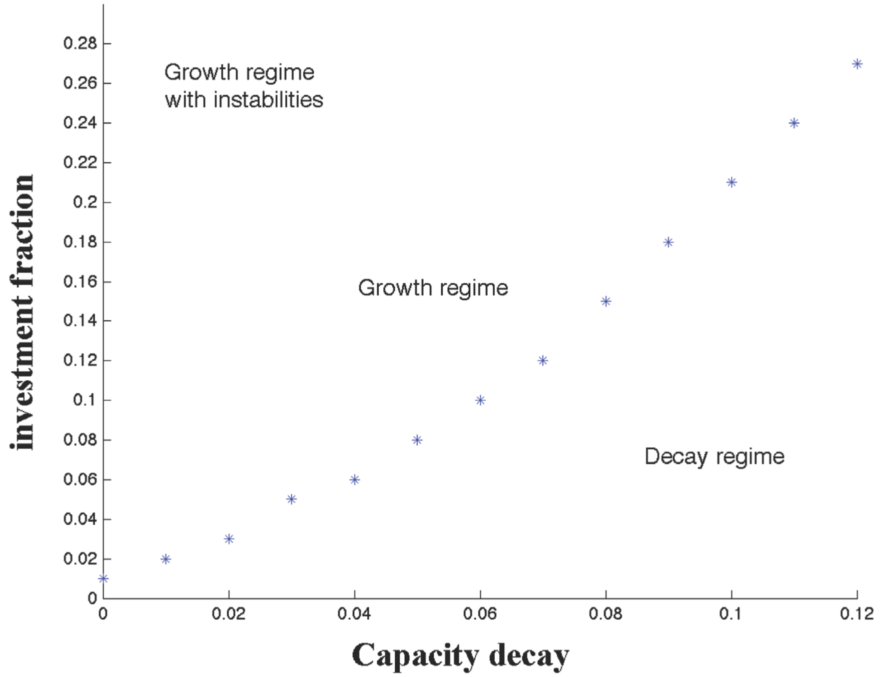
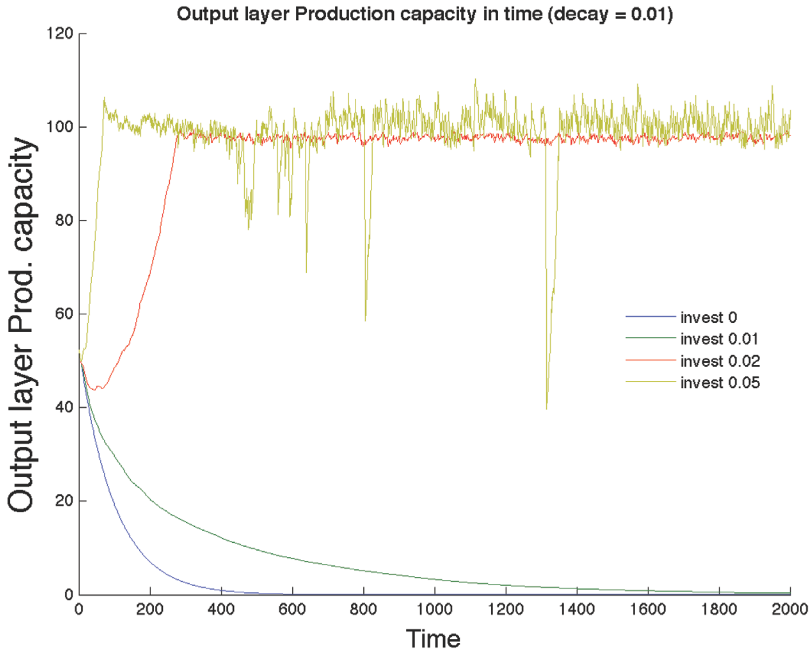


Figure 4. Evolution of the production capacity (decay, growth, and growth with shocks)



behavior. The digital pheromones support the primary operations, inspired by the dynamics of chemical pheromones:

- They can be deposited and withdrawn from an area. Deposits of a certain flavor are added to the current amount of that flavor of pheromone located at that place.
- They are evaporated over time. This serves to forget old information that is not refreshed.
- They propagate from a place to its neighboring places. The act of propagation causes pheromone gradients to be formed.

Structures Reification

Pheromones are modeled as equations across a network of nodes linked by mean of B2B links at which agents can deposit and sense increments to scalar variables representing the pheromones.

In this version of our model, we define the location of the firm (agent) with a position in the geographical space coupled with a position in the product space. Each firm has dynamic portfolios of B2B partners: upstream (suppliers) and downstream (customers). The firms agree with each other for a partnership contract (link between supplier and customer). As firms interact according to these contracts, they give positive feedback to these links by mean of deposit and withdraw of pheromone quantities according to the exchanges accruing between them. The accumulation of the pheromone quantity determines the strength of the link.

At the micro level, the firm can use this information (pheromone strength) to make decisions. A firm uses an interpreting equation to weight the pheromone that it perceives in the links and makes decisions according to this interpretation. The interpreting equation assigns a scalar value ($V(p)$) to the current pheromone place.

At the macro level, the pheromone information is used to reify the structures corresponding to the meta-stable rich and productive chains of the firms. To do so, we introduced an algorithm that filters the whole network, taking into account only links with pheromone strength above a certain threshold (fraction of the average). Then, we use a structure detection algorithm that detects the connected components of the network. These structures are reified and given as the firm's perception. At micro level, the firm uses the information perceived from the macro level to shape its strategies.

Pheromone Mechanism

Each B2B link maintains a scalar variable corresponding to the pheromone flavor. It performs the basic functions of aggregation, evaporation, and propagation. The parameters governing the pheromone field are:

- $p_i \in P =$ set of agents.
- $r_{p_i,p_{i'}} \in R : P \rightarrow P =$ neighbor relation between agents.
- $s(\Omega_f, r_{p_i,p_{i'}}, t) =$ strength of pheromone flavor f characterizing the link $r_{p_i,p_{i'}}$ at time t.
- $d(\Omega_f, r_{p_i,p_{i'}}, t) =$ sum of external deposits of pheromone flavor f within the interval $(t\text{-}1, t]$ at the relation $r_{p_i,p_{i'}}$.
- E_f *in* $(0,1)$ = evaporation factor for flavor f.

The underlying mathematics of the field developed by such a network of locations rests on following equation.

Evolution of the strength of a single pheromone flavor at a given location.

$$s(\Omega_f, r_{p_i,p_{i'}}, t) = (1 - E_f) *$$
$$(s(\Omega_f, r_{p_i,p_{i'}}, t-1) + d(\Omega_f, r_{p_i,p_{i'}}, t)$$

Algorithm 3. Pheromone update (Firm p_i)

Requires: $Y^{in} > 0$
Ensure: The firm p_i updates all $r_{p_i, p_{i'}} \mid p_{i'} \in S_{p_i}$

for each supplier $p_{i'} \in S_{p_i}$ **do**

$$s(\Omega_{Q_s}, r_{p_i, p_{i'}}, t) = (1 - E_{Q_s}).s(\Omega_{Q_s}, r_{p_i, p_{i'}}, t-1) + \frac{Q.Y^{in}_{p_{i'}, p_i}(t)}{\sum_{j|p_j \in S_{p_i}} Y^{in}_{p_j, p_i}(t)};$$

end for

where
Q is the quantity of pheromone deposited by the firm $p_{i'}$.
$Y^{in}_{p_{i'}, p_i}(t)$ production quantity delivered to the firm $p_{i'}$ to the firm p_i

where E_f models the evaporation rate of the pheromone. $s(\Omega_f, r_{p_i, p_{i'}}, t)$ represents the amount of pheromone from the previous cycle, $d(\Omega_f, r_{p_i, p_{i'}}, t)$ represents the total deposits made since the last update cycle Propagation received from the neighboring location agents.

Reification of the Organization Structure

Pheromone algorithms perform the functions identified above. We use one pheromone Ω_{Q_s} (Quantity of Supply): the amount of product received by the firm from its supplier.

Parameters of the Pheromone

- Ω_{Q_s} : Quantity of pheromone of flavor Q_s that each firm has to deposit after each production cycle.
- τ_{Q_s} : Update cycle time: the time interval between deposit and evaporation for flavor $Q_{s.}$
- E_{Q_s} : Evaporation factor is the fraction of the pheromone that remains after the evaporation phase.
- T_{Q_s} : Threshold below which $s(\Omega_{Q_s}, r_{p_i, p_{i'}}, t)$ is set to zero.

Perception Function

Perception function consists on the perception of one or more areas of interest (pheromone place) with a certain revisit frequency:

$$percept(\Omega_{Q_s}) = s(\Omega_{Q_s}, r_{p_i, p_{i'}}, t)$$

Pheromone Update Algorithm

See Algorithm 3.

Stable Structure Detection

Across the network, each m time steps, all the links weighted under a threshold T_f are excluded from the structures. Depending on the value of the threshold, the number of links of the network taken into account varies. We propose an algorithm (Algorithm 4) to detect the emerging structures and study their stability over time.

Algorithm 4. Filtered set of links for structures detection

Requires: Pheromone threshold T_{Q_s} as fraction of the average pheromone quantity
Ensure: Filtered set R'

for each link $r_{p_i,p_{i'}} \in R$ **do**
  if $(s(\Omega_{Q_s}, r_{p_i,p_{i'}}, t) > T_{Q_s})$ **then**
    $R' = R' + r_{p_i,p_{i'}}$;
  End if
end for

Algorithm 5. Connected components

Requires: Filtered network R'
Ensure: Connected components *comp*

Comp =1
for each firm $p_i \mid (r_{p,p_i} \in R')$ or $(r_{p_i,p} \in R')$ **then**
  CComponent(*R', p_i, comp*);
end for

Algorithm 6. CComponent(R, p, comp); // Connected component function

Requires: *R (set of links), p (firm), comp (component)*
Ensure: connected component *comp*

C_p = *comp;*
for each firm $p_i \mid (r_{p,p_i} \in R)$ or $(r_{p_i,p} \in R)$ **then**
  if $(C_{p_i} == 0)$ **then**
    $C_{p_i} = comp$;
    for each $p_{i'} \mid (r_{p_i,p_{i'}} \in R)$ or $(r_{p_{i'},p_i} \in R)$ **do**
      CComponent(*R, p_i, comp*);
    end for
    Comp++;
  End if
end for

CONCLUSION

In this chapter, we have introduced a MAS investigating production networks and supply chains using particular mechanisms for the coordination of the agents. Inspired by a very simple production network model (W&B model), the MAS we propose is designed in a way which allows to alleviate shortcomings of the original framework and its strong assumptions (Hamichi et al., 2009b).

Our objective is to increasingly move towards a more realistic model of production networks starting from a simple one that includes standard economic principles. We have integrated price mechanisms into the model and reproduced stylized facts such as the regionalization of production and wealth with heterogeneous and adaptive agents. The results of our simulations show the impact of the transportation cost and the geographical reach on the shape of the regionalization production and wealth patterns. These results have shown that the individual firms, with local B2B interactions and decisions, form stable production systems based on the supply/demand and market growth mechanisms leading to the maturation of the market. In a second stage, we have developed a pheromone-based mechanism for agents' coordination using reification of the emergent structures. Our preliminary results show that the reified graphs obtained are consistent with the wealth and production patterns we have obtained in previous simulations. The firms have a new perception of their environment as each firm - based on the pheromone mechanism - perceives the production network it belongs to. From these preliminary results, we envisage to further investigate the impact of this perception as macro level feedback on firms' coordination.

REFERENCES

Antonelli, C. (2000). Collective knowledge, communication and innovation: The evidence of technological districts. *Regional Studies*, *34*(6), 535–547. doi:10.1080/00343400050085657

Battiston, S., Delli Gatti, D., Gallegati, M., Greenwald, B., & Stiglitz, J. (2007). Credit chains and bankruptcy propagation in production networks. *Journal of Economic Dynamics & Control*, *31*(6), 2061–2084. doi:10.1016/j.jedc.2007.01.004

Becattini, G. (1990). The Marshallian industrial district as a socio-economic concept. In Pyke, F., Becattini, G., & Sengenberger, W. (Eds.), *Industrial districts and inter-firm cooperation in Italy* (pp. 37–51). Geneva, Switzerland: International Institute for Labour Studies.

Belussi, F. (2006). In search of a theory of spatial clustering: agglomeration versus active clustering. In Asheim, B., Cooke, P., & Martin, R. (Eds.), *Clusters and regional development* (pp. 69–89). London, UK: Routledge.

Carbonara, N., Giannoccaro, I., & Pontrandolfo, P. (2002). Supply chains within industrial districts: A theoretical framework. *International Journal of Production Economics*, *76*(2), 159–176. doi:10.1016/S0925-5273(01)00159-1

Conte, R., Andrighetto, G., Campennì, M., & Paolucci, M. (2007). Emergent and immergent effects in complex social systems. *Proceedings of AAAI Symposium, Social and Organizational Aspects of Intelligence,* Washington DC.

Das, A., Narasimhan, R., & Talluri, S. (2006). Supplier integration – Finding an optimal con□guration. *Journal of Operations Management*, *24*(5), 563–582. doi:10.1016/j.jom.2005.09.003

Delli Gatti, D., Di Guilmi, C., Gaffeo, E., Gianfranco, G., Gallegati, M., & Palestrini, A. (2005). A new approach to business fluctuations: heterogeneous interacting agents, scaling laws and financial fragility. *Journal of Economic Behavior & Organization*, *56*(4), 489–512. doi:10.1016/j.jebo.2003.10.012

Dyer, J., & Nobeoka, K. (2000). Creating and managing a high-performance knowledge-sharing network: The Toyota case. *Strategic Management Journal*, *21*(3), 345–367. doi:10.1002/(SICI)1097-0266(200003)21:3<345::AID-SMJ96>3.0.CO;2-N

Gilbert, N. (2002). *Varieties of emergence*. Paper presented at the Agent Conference: Social agents: Ecology, Exchange, and Evolution, Chicago.

Guessoum, Z., & Briot, J. P. (1999). From active object to autonomous agents. *IEEE Concurrency*, *7*(3), 68–78. doi:10.1109/4434.788781

Hamichi, S., Brée, D., Guessoum, Z., & Mangalagiu, D. (2009). A multi-agent system for adaptive production networks. In G. Di Tosto & H. V. D. Parunak (Eds.), *Multi-Agent-Based Simulation Vol. 5683 of Lecture Notes in Computer Science* (pp. 49-60). Berlin, Germany Springer.

Hamichi, S., Guessoum, Z., & Mangalagiu, D. (2009). A multi-agent system of adaptive production networks. In S. Decker, J. Sichman, C. Sierra, & C. Castelfranchi (Eds.), *Proceedings of 8th Int. Conf. on Autonomous Agents and Multiagent Systems* (pp. 1311-1312). Budapest, Hungary.

Harland, C. M., & Knight, L. A. (2001). Supply network strategy: Role and competence requirements. *International Journal of Operations & Production Management*, *21*(4), 476–489. doi:10.1108/01443570110381381

Ikeda, Y., Aoyama, H., Iyetomi, H., Fujiwara, Y., & Souma, W. (2008). Correlated performance of firms in a transaction network. *Journal of Economic Interaction and Coordination*, *3*(1), 73–80. doi:10.1007/s11403-008-0035-5

Ikeda, Y., Aoyama, H., Iyetomi, H., Fujiwara, Y., Soumad, W., & Kaizoji, T. (2007b). Response of firm agent network to exogenous shock. *Physica A: Statistical Mechanics and its Applications, 382*(1), 138-148.

Ikeda, Y., Souma, W., Aoyama, H., Iyetomi, H., Fujiwara, Y., & Kaizoji, T. (2007). Quantitative agent-based firm dynamics simulation with parameters estimated by financial and transaction data analysis. *Physica A: Statistical Mechanics and its Applications, 375*(2), 651-667.

Marshall, A. (1890). *Principles of economics* (Guillebaud, C. W., Ed.). MacMillan.

Mathieu, P., Routier, J.-C., & Secq, Y. (2002). Principles for dynamic multi-agent organizations. In K. Kuwabara & J. Lee, (Eds.), *Intelligent Agents and Multi-Agent Systems, Vol. 2413 of Lecture Notes in Computer Science,* (pp. 663-670). Berlin, Germany Springer.

Porter, M. (1990). *The competitive advantage of nations. MacMillan*. The MIT Press.

Shnerb, N. M., Louzoun, Y., Bettelheim, E., & Solomon, S. (2000). The importance of being discrete: Life always wins on the surface. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(19), 10322–10324. doi:10.1073/pnas.180263697

Swink, M., Narasimhan, R., & Wang, C. (2007). Managing beyond the factory walls: Effects of four types of strategic integration on manufacturing plant performance. *Journal of Operations Management*, *25*(1), 148–164. doi:10.1016/j.jom.2006.02.006

Weisbuch, G. (2006). Self-organized patterns in production networks. *Complexus*, *2*, 217–227. doi:10.1159/000093692

Weisbuch, G., & Battiston, S. (2007). From production networks to geographical economics. *Journal of Economic Behavior & Organization*, *64*(3-4), 448–469. doi:10.1016/j.jebo.2006.06.018

ENDNOTES

[1] In the current model, we assume an exogenous demand curve, which does not change over time.

Chapter 4
Assessing Multi-Site Distributed Coordination in Dynamic Assignment of Time-Critical Entity via Agent-Based Simulation

Yu Teng
Purdue University, USA

Nan Kong
Purdue University, USA

ABSTRACT

This chapter investigates distributed coordination in dynamic assignment of time-critical entities among multiple sites. The authors develop an agent-based simulation model in which each agent applies some adaptive assignment rule to match supplies and demands that are generated at its own site. They assume each agent has autonomy to design its hierarchical assignment rule and update it based on periodical review of its assignment performance. The authors model the benefit of each assignment based on the life spans of the resource and the need, and a distance measure between them. They consider two distinct centralized initial assignment rules and assess how agents update their rules. The authors also evaluate the impact of different agent environments, numbers of supply/demand agents, and ratios of supply/demand rates.

DOI: 10.4018/978-1-4666-2098-8.ch004

INTRODUCTION

In general term, dynamic assignment deals with the problem of assigning resources from suppliers to needs from recipients over time. The amount of available resources on the supplier side and the needs on the recipient side for the resources are given at each time point although they may vary over time. The problem intends to dynamically update the assignment in a way that one or several of the following goals are achieved.

1. **Overall Benefit:** The total benefit generated by the assignments should be maximized.
2. **Recipient Fairness:** The deviation on the relative amount of resource given to the recipients should be kept as small as possible. By "relative amount of resource", we mean the amount of resource a recipient receives divided by the amount of resource it demands. This is one possible way to describe consumer fairness in a dynamic assignment problem.
3. **Supplier Fairness:** The deviation on resource utilization among the suppliers should be kept as small as possible. As in the previous goal, this is also a fairness measure, but from the supplier side.

The problem arises in many applications in manufacturing (Harris, Cook, & Lewis, 1998; Sennott, 2006), transportation (Powell, 1996; Psaraftis, 1980; Yang, Ye, Tang, & Wong, 2003), and telecommunication (Buddhikot, 2007; Everitt & Manfield, 1989; Zhao & Sadler, 2007). It is common to assume that the arrivals of resources and needs are random (e.g., known only through a probability distribution) over time. It is also often the case that resources and needs are only available for a period of time, and the quality and desirable level of a resource varies over time. Each assignment generates a contribution to benefits, which may also be random. In a centralized allocation system, the assignment activities follow some centralized rule, which is either predetermined or varies according to the resource and need conditions. However, the rule is determined by a centralized decision maker and specified uniformly to all suppliers and to all recipients. On the other hand, in a decentralized allocation system, the assignment activities can follow different rules specified by individual suppliers and recipients. These entities in the system may take an adaptive approach to modify their own rules with the changes in the assignment environment. Even though each entity designs its own assignment rule adaptively, system-wide coordinative behavior may gradually emerge. Research on coordination and distributed resource allocation has been extended in the design of future-generation wireless networks who must cope with the scarcity of the spectral resource in areas with heavy user demand. We refer interest readers to a tutorial by (Gesbert, Kiani, Gjendemsjø, & Øien, 2007).

In this chapter, we apply agent-based simulation to investigate distributed coordination in dynamic resource assignment and sharing within a multi-site system, in which both resources and needs can arrive at any site. We assume that suppliers and recipients are each characterized by a set of possible unique attributes, where the contribution generated by an assignment depends on the attributes of the involved supplier and recipient. One important attribute is the location of the supplier or the recipient. We also assume that the benefit of an assignment decreases with increased delay along the assignment process, which is commonly made for time-critical resources and needs.

We consider two distinct assignment rules as the initial rules, with which suppliers either behave according to their own interests (egoism) or according to the overall societal interest (altruism). We next explore the impact of decentralized rules that are adaptive and can be different across the sites. We assume that only the supplier at each site has the autonomy to alter its assignment rule by a simple rational decision making process, depending on the assignment performance at the site.

Given the complexity of the studied system, it is unlikely to attain analytical solutions. Therefore, we resort to agent-based modeling and simulation (ABMS) for modifying agents' behaviors and assessing decentralized assignment rules.

The remainder of this chapter is organized as follows. In background, we 1) introduce agent-based modeling and simulation, 2) state more formally the generic version of the dynamic assignment problem, and 3) provide a motivating example on geographic sharing of cadaveric organs. In the following sections, we describe an adaptive hierarchical assignment rule in the dynamic assignment problem, present the conceptual design and implementation of our developed agent-based simulation model, and report our preliminary simulation experiments. In the last section, we draw conclusions and point out future research directions.

BACKGROUND

Agent-Based Modeling and Simulation (ABMS)

ABMS is a relatively new approach to modeling complex system composed of interacting, autonomous decision-making entities called agents (Bonabeau, 2002). Based on a set of rules, each agent individually assesses its situation, makes decisions, and executes various behaviors. ABMS has its historical roots in the study of complex adaptive systems (CAS), which was originally motivated by investigations into the adaptation and emergence of biological systems (Macal & North, 2010). ABMS builds upon proven, highly successful techniques such as discrete-event simulation and object-oriented programming. Discrete-event simulation provides an established mechanism for coordinating the interaction of individual agents within simulation, while object-oriented programming provides frameworks to organize agents based on their behaviors. ABMS combines these techniques with a focus on bottom-up model construction (Macal & North, 2010). We have witnessed rapid growth of ABMS applications in recent years, which include the modeling of stock markets (Arthur, Durlauf, & Lane, 1997; LeBaron, 2002), supply chains (Fang, Kimbrough, Pace, Valluri, & Zheng, 2002; Macal, 2004), spread of epidemics (Bagni, Berchi, & Cariello, 2002; Huang, Sun, Hsieh, & Lin, 2004), threat of bio-warfare (Carley, 2006), growth and decline of ancient civilizations (Kohler, Gumerman, & Reynolds, 2005); consumer purchasing behavior (North et al., 2010), adaptive human immune system (Folcik & Orosz, 2006), engagement of forces on the battlefield (Moffat, Smith, & Witty, 2006) and at sea (Hill, Carl, & Champagne, 2006), and many others.

In this work, we take a first step towards understanding of distributed coordination in the generic setting of dynamic assignment with agent-based simulation. Existing literature on ABMS has investigated dynamic assigment in traffic network (Park & Kim, 2001), rescource allocation in healthcare systems (Giesen, Ketter, & Zuidwijk, 2009), and collaborative behaviors in social network (Madey, Freeh, Tynan, Gao, & Hoffman, 2003). Unlike the previous work spotted in various literature areas put strong emphasis on the applications, in this chapter we conduct a systematic investigation on collaborative behavior in a generic decentralized resouce allocation system. Our primary contribution is the development of the modeling and analysis framework that helps reveal the emergence of collaborative actions in the system when decentralized decision makers take adpative hierarchical assignment rules.

Description of Decentralized Dynamic Assignment

Consider an undirected graph $G = (V, E)$. For each node $i \in V$, we define its neighbors as the nodes that are connected to i with some edge in E, i.e., for node $j \in V$, if $(i,j) \in E$, then j is a neighbor of i.

For each node $i \in V$, we consider two independent stochastic arrival processes for the two types of entities (called types A and B). We in this work assume that either arrival process is identical across all nodes in V. We associate a time tag t with each generated entity. For each entity either of type A or B, we assign two attributes: location and life span.

Once a type A entity a becomes available, we assign it to a type B entity b based on some assignment rule. Following the considered assignment rule, each assignment is influenced by the membership of each node. In the simplest case, each node belongs to two sets, one of which is the singleton set containing only the node and the other of which is the set containing all the nodes in the graph. In more complex cases, a node may belong to three sets. In addition to the aforementioned two, it may select a subset of the nodes and form coalition with them. The resultant assignment process is hierarchical as it is natural for each node to prioritize the formed coalition over the other nodes. For each assignment , we assign a benefit based on the spatial relationship between the two nodes, denoted by , and the life spans of the two entities involved in the assignment. Along a predetermined time horizon, a number of assignments are made and some overall system performance is assessed. Furthermore, each agent is allowed to execute autonomy to modify its own assignment rule in a decentralized system. For such system dynamics, an analytic solution is not attainable. Therefore, we resort to agent-based simulation that can capture agents' adaptations during the assignment process.

A Motivating Example

In this section we use an example in organ allocation to motivate the idea of dynamic assignment. Deceased organ transplantation is the only effective therapy for almost all patients with diseases that cause organ dysfunction. Unfortunately, it is hindered by donor scarcity in many countries around the world. Furthermore, many types of organs (e.g., livers, hearts, and lungs) are often underutilized due to various clinical factors. Due to these reasons, organ transplantation and allocation has been a contentious issue in the U.S for decades.

Currently, there are nearly 60 local organ procurement organizations (OPOs) responsible for matching organs with patients. Typically, each of these local organizations is only interested in maintaining good allocation performance in its own service area. It is often the case that an OPO is egoistic, i.e., reluctant to assign procured organs to other OPOs even though patients from other OPOs are clearly in greater need of the organ. However, it is also often the case that an OPO cannot find a good match among the patients who reside in its own service area within the organ's allowable time window (i.e., many types of organs decay rapid and soon become non-transplantable).

To facilitate organ sharing at the national level, the United Network for Organ Sharing (UNOS) (www.unos.org) was established to preside the assignment of organs to patients in a centralized manner. The UNOS takes an altruism approach, i.e., assigning procured organs to the patients who need the organs the most regardless of their locations.

In recent years, a compromise is reached between local OPOs and UNOS by allowing an additional allocation tier between the local level and the national level. The formed hierarchical allocation process still grants individual OPOs the highest priority in terms of organ allocation. However, it prioritizes a group of neighboring OPOs over the rest. With the hierarchical process, each OPO has a better chance to find a good match with the region it belongs. At the same time, sharing is achieved to some degree. Unfortunately, the OPO grouping and coordination was designed and executed by UNOS in an ad-hoc manner. Certain OPOs, especially those net suppliers (i.e., denote more organs to other OPOs than receiving), voice their dissatisfaction on the new centralized system. The research question arises whether better grouping and coordination can be achieved in a decentralized fashion by granting autonomy to the OPOs. For more information on organ allocation, we refer to the website of UNOS (www.unos.org) and (Kong, Schaefer, Hunsaker, & Roberts, 2010).

It is clear that organ allocation can be formulated as a dynamic assignment problem under uncertainty. Organs and patients are regarded as types A and B entities. The two arrival processes are stochastic. Each entity is associated with a number of attributes, e.g., locations, blood types, and life spans for both donors and patients. The transplant efficiency is dependent upon the donor-patient pair, for which an important factor is the distance between the donor and the patient.

There have been several simulation models that are used to examine how alternative allocation policies can affect system outcomes (Pritsker et al., 1995; Shechter et al., 2005; Taranto et al., 2000; van den Hout et al., 2003). However, to the best of our knowledge, no model is agent based. It prohibits us from understanding the changes of the practices in OPOs and policies in UNOS. We in this chapter investigate the generic dynamic assignment problem in a decentralized environment. With valuable insight, we can focus on decentralized organ allocation policy and explore distributed coordination in organ allocation in future research.

ADAPTIVE HIERARCHICAL ASSIGNMENT

In each assignment cycle $t = 1,\ldots,T$, and at each node , we rank all type A entities and type B entities separately based on their arrival times. The ones with earlier arrival times are given higher priority than the ones with later arrival times. In an assignment cycle t, once a type A entity arrives at a node , we follow some assignment rule applicable in cycle t at node i to determine how to assign the type A entity. Once an assignment is made, some assignment benefit, depending on the locations of the type A and B entities and their life spans, is realized. Each node periodically reviews its assignment performance to decide if it needs to join new coalitions or leave the current coalition.

In this section, we describe several assignment rules, a form of assignment benefit, and an assignment rule adaptation mechanism. We first introduce two basic assignment rules as the initial rules, each of which is applied by all nodes at the beginning (from $t = 0$ to the point the assignment rule at node i is updated).

Ra_0 (Egoism Oriented Assignment): Once a type A entity arrives, it is assigned to the type B entity *at the same node* with the highest priority among the entities in the node. If no type B entity waits at the same node, the type A entity is assigned to the type B entity waiting *at the neighboring nodes* with the highest priority.

Rb_0 (Altruism Oriented Assignment): Once a type A entity arrives, it is assigned to the type B entity *at the same node* with the highest priority. If no type B entity waits at the same node, it is assigned to a type B entity *in the entire system* with the highest priority among all entities in the system.

Note that if there is a tie between two type B entities for an assignment, we break the tie randomly. During the assignment process, each node adapts certain hierarchical assignment rule. The node gives itself the highest priority. Then it gives the members in the coalition the second highest priority, and finally the neighboring nodes of the coalition the lowest priority. We state the hierarchical assignment rule formally.

R(t) (Balanced Assignment): Once a type A entity arrives at time t, it is first assigned to the type B entity at the same node with the highest priority. If no type B entities wait at the same node, the type A entity is assigned to the type B entity in the coalition that the node generating the type A entity belongs to. Again the type B entity must be of the highest priority among all type B entities available in the coalition. If no type B entity from the coalition awaits, the type A entity is assigned to the type B entity at the neighboring nodes of the coalition with the highest priority.

Noting that rule $R(t)$, regarded as a three-tiered hierarchical assignment rule, can be easily generalized. We can further prioritize the nodes in the coalition and outside the coalition. Hence, the subset of the nodes within the coalition enlarges at any later level than earlier level along the hierarchy.

Once an assignment is made, some assignment benefit is assigned to it, based on the locations and life spans of the entity pair. The assignment benefit is inversely affected by the life span of the type A entity and the distance between the type A entity and the type B entity. We set the environment to be a 2D grid, and use (x_A,y_A) and (x_B,y_B) to denote the locations of the type A entity and the type B entity, respectively. We use $lifespan_A$ to denote the life span of the type A entity, and use and $lifespan_{MAX}$ to denote the maximum life span of type A entity. The assignment benefit can be expressed by:

$$0.2 * \left(lifespan_{MAX} - lifespan_A\right) * \max(1 - 0.05 * \left(\left|x_A - x_B\right| + \left|y_A - y_B\right|\right), 0).$$

Note that with the 2D grid, we consider the Manhattan distance between the two entities, which is $\left|x_A - x_B\right| + \left|y_A - y_B\right|$.

In the chapter, we assume that each node updates its assignment rule $R(t)$ by periodically reviewing its assignment performance and modifying the coalition at the second tier of the assignment hierarchy. First we define two terms, *outflow assignment* and *inflow assignment*. An assignment is an outflow assignment to a node i if a type A entity at node i is assigned to a type B entity at node $j \neq i$. An assignment is an inflow assignment to a node i if a type A entity at node $j \neq i$ is assigned to a type B entity at node i. We also assume a *net supply* node (i.e., at the node, the arrival rate of type A entity is higher than the arrival rate of type B entity) intends to join a coalition (we allow isolated coalition, i.e. a coalition containing only one node) with the highest average net inflow benefit, while a *net recipient* node (i.e., at the node, the arrival rate of type B entity is higher than the arrival rate of type A entity) intends to join a coalition with the highest average net outflow benefit.

To achieve the objective of maximizing its individual benefit, each node conducts periodical review of 1) recent average performance of its own; and 2) recent average assignment performance of the coalitions containing itself and its neighbors.

Figure 1. Conceptual design of the agent-based simulation model

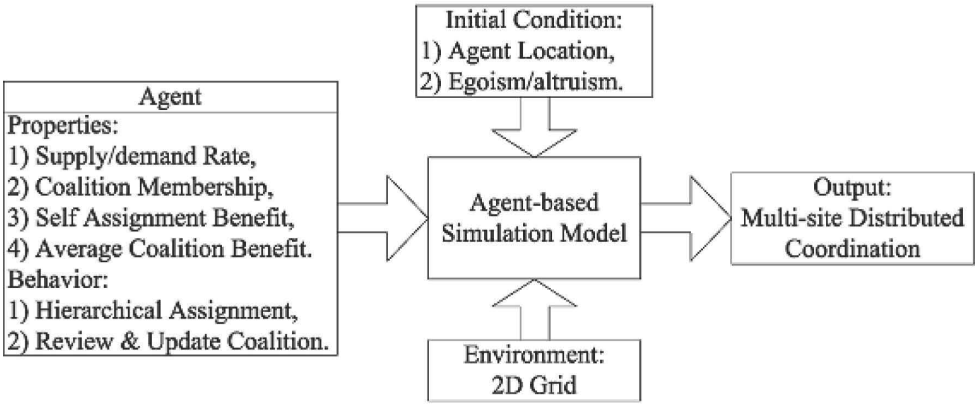


Figure 2. Agent environment specified in repast symphony

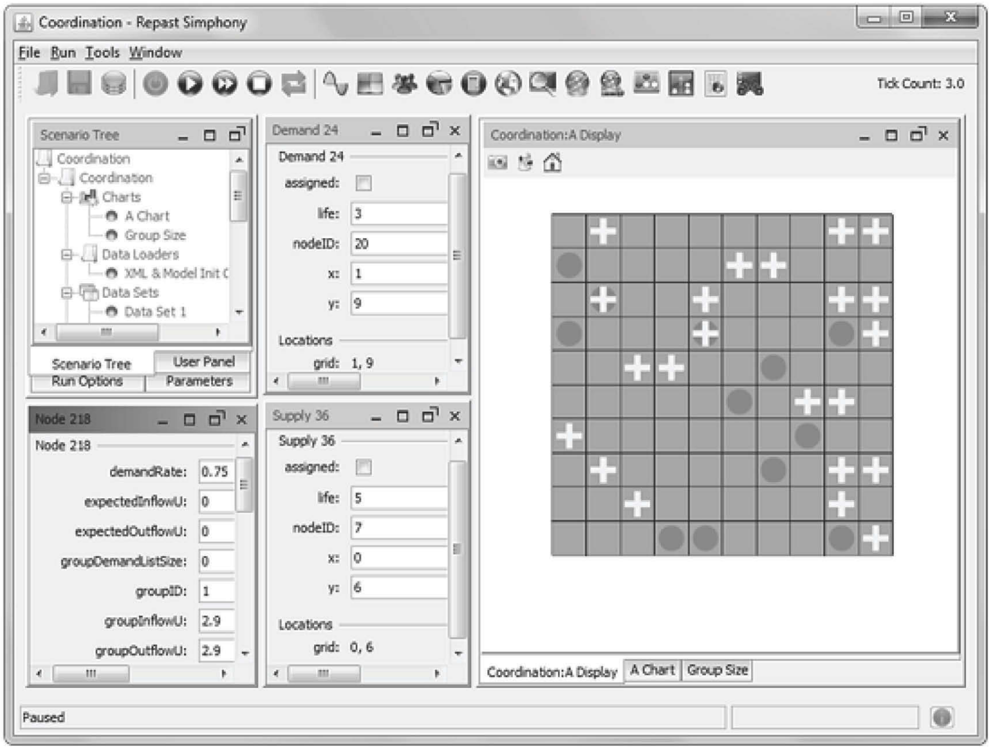
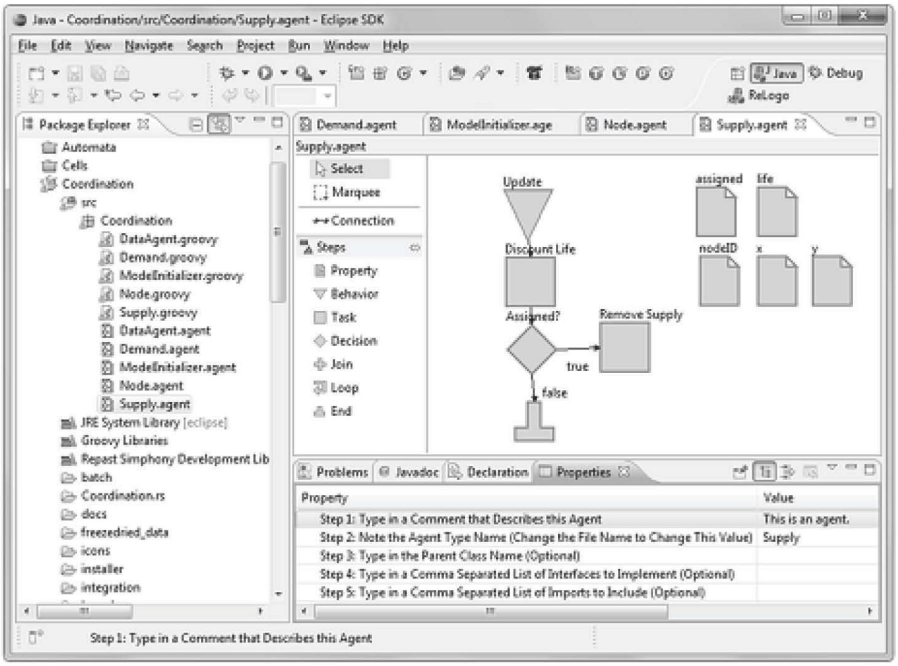


Figure 3. Node agent behavior modeling within the model development environment



After the review, if the node's own recent assignment performance is no worse than the best of the recent average assignment performance of all observed coalitions, the node will stay as (or turn into) an isolated coalition. Otherwise, the node will join (or switch to) the coalition with the best recent average assignment performance. We use the outflow and inflow benefits to distinguish between grouping a net supply node into a coalition with net inflow and grouping a net recipient node into a coalition with net outflow.

AGENT-BASED SIMULATION DESIGN AND IMPLEMENTATION

Conceptual Design

To build the agent-based simulation model, we need to specify agent properties, agent behaviors, an environment for the agents to interact with each other, and the initial condition for the system dynamics. The key model components in the conceptual design are shown in Figure 1.

Model Implementation

The environment for implementing the agent-based simulation is Repast Symphony 2.0 beta (http://repast.sourceforge.net). Repast Symphony is a free and open source ABMS toolkit developed by the Repast group in the Division of Decision and Information Science at the Argonne National Laboratory. It is designed to include advanced point-and-click features for agent behavioral specification and dynamic model self-assembly. The model components can be developed using any mixture of Java, Groovy, and flowcharts (Macal & North, 2004; Macal & North, 2010; North & Macal, 2007).

For the convenience of display and analysis, we set the environment to be a 10 by 10 2D square lattice. Each node takes a Moore neighborhood to identify neighbors, i.e., each node considers the eight nodes surrounding itself to be its neighbors on the 2D grid. The grid display of the model is shown in Figure 2, where the squares represent the nodes, the circles represent the supplies and the crosses represent the demands.

In the agent-based simulation model, we model nodes as the decision making agents that execute assignment and coordination activities. The properties for node agents are: 1) location, 2) rate to generate supply/demand, 3) coalition membership, 4) review cycle and review starting time, 5) recent local assignment benefit (includes inflow and outflow benefits), and 6) recent average assignment benefit (inflow and outflow) for members in the coalition. The behaviors for node agents are: 1) at each tick (assignment cycle), generate type A entity and type B entity with the supply/demand rate; 2) at each tick, assign available local type A entities to type B entities in the system according to hierarchical assignment rule R(t), and record assignment benefit; 3) at the end of each review cycle, make observations on recent local assignment benefit and recent average assignment benefit of adjacent coalitions, and update the coalition membership. A screenshot of the node agent behavior modeling and the model development environment is shown in Figure 3.

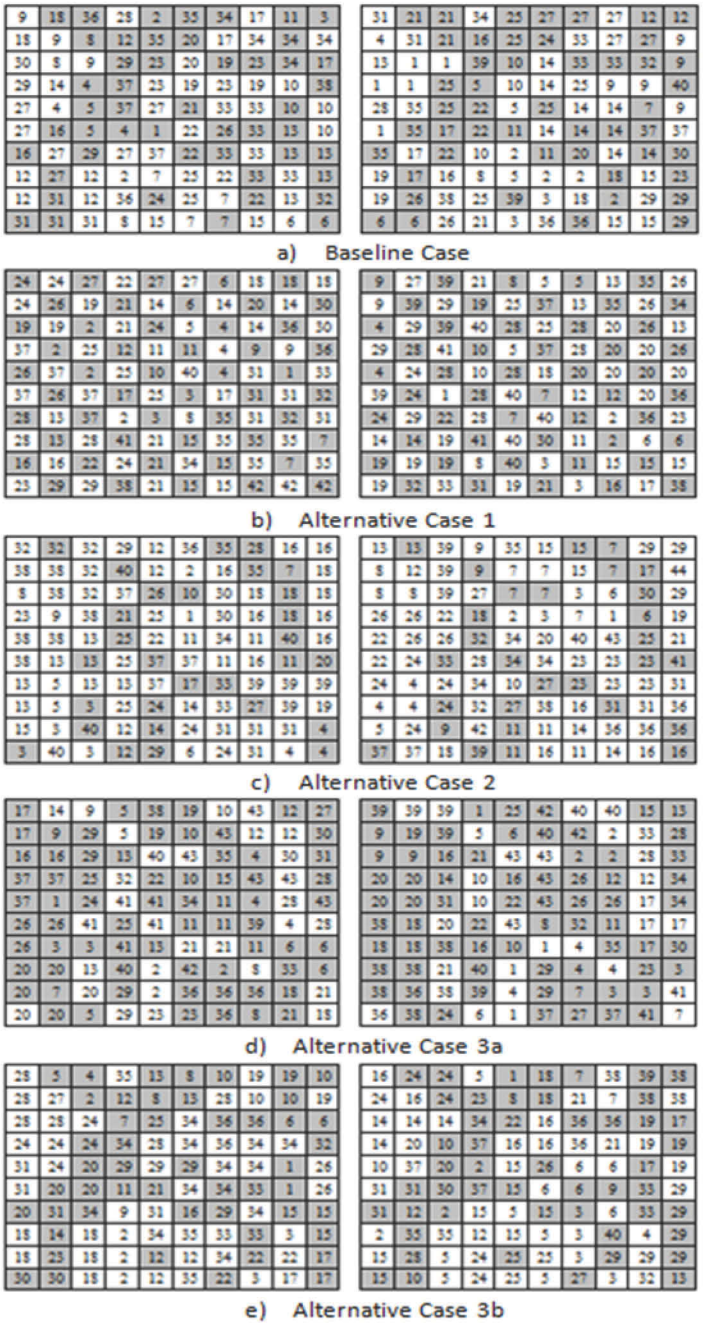
From a simulation model implementation viewpoint, we also model type A and type B entities as agents. These agents have location, life span and maximum life span as properties. The entity agents have two simple behaviors: 1) increase its life span after each tick, and 2) remove itself from the system when an assignment involving it occurs or its maximum life span is reached.

COMPUTATIONAL EXPERIMENTS

Experiment Design and Setup

We consider an agent environment with 100 node agents on a 10 by 10 2D square lattice. We assume the arrivals of the entities with each type

Figure 4. Group index of each node at the end of the simulation run



across nodes are independent and follow identical Bernoulli processes. We further assume each node can be either a net supply node or a net demand node. In the baseline case, we assume a ratio of 2, which specifies that each net supply node has a supply (type A entity) arrival probability of 10% per tick and a demand (type B entity) arrival probability of 5% per tick, while each net demand node has supply arrival probability of 5% per tick and demand arrival probability of 10% per tick. In an alternative case (called Alternative Case 1), we assume the ratio is 3, which specifies that each net supply node has a supply (type A entity) arrival probability of 11.25% per tick and a demand (type B entity) arrival probability of 3.75% per tick, while each net demand node has supply arrival probability of 3.75% per tick and demand arrival probability of 11.25% per tick.

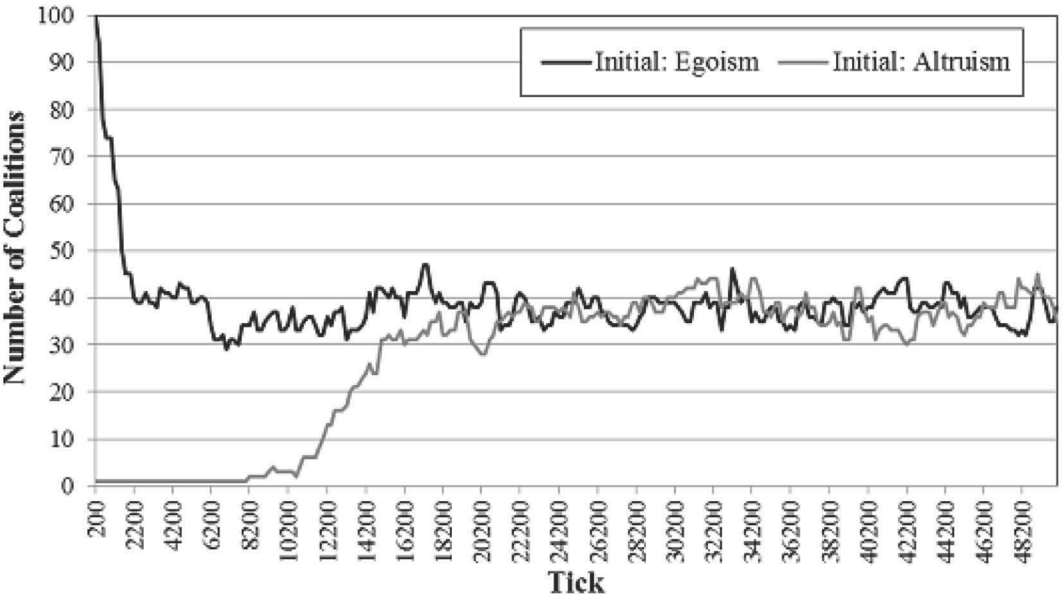
In addition, we specify in the baseline case that the location pattern of net supply and net demand to be 50% net supply nodes and 50% net demand nodes that are randomly distributed on the grid. In several alternative cases, we consider 50% net supply nodes and 50% net demand nodes that are arranged in alternating pattern (called Alternative Case 2); 70% net supply nodes and 30% net demand nodes, randomly distributed on the grid (called Alternative Case 3a); and 30% "net supply" nodes and 70% "net demand" nodes, randomly distributed on the grid (called Alternative Case 3b).

Finally, we assume the maximum life span of both supply and demand to be 5 ticks (5 assignment cycles). We assume each node agent has a fixed review cycle and a fixed review starting time, both are drawn independently from a discrete uniform distribution ranging between 200 and 2000 ticks, with a 200-tick interval. We assume at the end of each review cycle, each agent can only observe the average assignment benefit of the previous 200 ticks, and use the observation to update its coalition membership. For each configuration, we run the simulation for 50000 ticks.

Simulation Results

We report the grouping results for the baseline case in Figure 4a and the alternative cases in Figure 4b-4e. In each subfigure, the cells in grey indicate net supplier nodes, the cells in white indicate net recipient nodes, and the number in each cell labels the group index at the end of the simulation run. There are two subfigures for each case. In the subfigures on the left, the initial assignment rule is Ra_0, egoism oriented assignment. In the subfigure on the right, the initial assignment rule is Rb_0, altruism oriented assignment. In

Figure 5. Dynamics in the number of groups for the baseline case



these subfigures, we record the group index for each node at the end of the simulation run. Our preliminary simulation experiments seem to suggest that 1) more groups would be formed when the initial assignment rule is altruism oriented (comparing the two subfigures on the same row); 2) more groups would be formed as the agent environment becomes more organized, i.e., supplier and recipient node agents are organized side by side (comparing the baseline case and alternative case 2); 3) more groups would be formed if the difference between the numbers of supplier and recipient node agents is relatively larger (comparing the baseline case and alternative cases 3a and 3b); and 4) the group number is insensitive to the increase in the supply/demand ratio (comparing the baseline case and alternative case 1). These observations are in consistency with our intuitions. However, more simulation runs must be conducted in order to draw conclusions with sufficient statistical significance.

Finally we show in Figure 5 the dynamics in the number of groups for the baseline case. The figure shows that the number of groups is gradually stablized, which helps us argue that our simulation duration is sufficiently long. We observe similar trend of stabilization in other cases. We also observe that the number of groups is roughly identical in various tested cases.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This chapter presents an agent-based simulation modeling and analysis framework for studying distributed coordination in generic dynamic assignment. In the simulation, we incorporate a set of realistic agent behaviors. With the simulation, we evaluate a number of cases that differ in the agent environment, the supply/demand ratio, and the difference in the numbers of supply and demand nodes.

The development of the agent-based simulation model offers many opportunities for us to explore in the future on agent behaviors in dynamic assignment. We plan to conduct more comprehensive simulation studies to draw conclusions of statistical significance. We plan to study the cases where agents apply different assessment performance metrics to the system; the cases where agents conduct periodical assessment with different frequencies; and the cases where agents have different levels of information regarding the system and other agents' behaviors. We also plan to further formalize the studied assignment rules along the direction of spatial prioritization. Finally, we plan to consider simulation optimization tools to develop optimal assignment rules in the decentralized system.

REFERENCES

Arthur, W. B., Durlauf, S. N., & Lane, D. A. (Eds.). (1997). *The economy as an evolving complex system II. Santa Fe Institute Studies in the Science of Complexity*. Reading, MA: Addison-Wesley.

Bagni, R., Berchi, R., & Cariello, P. (2002). A comparison of simulation models applied to epidemics. *Journal of Artificial Societies and Social Simulation*, *5*(3).

Bonabeau, E. (2002). *Agent-based modeling: Methods and techniques for simulating human systems* (*Vol. 99*, pp. 7280–7287). National Academy of Sciences. doi:10.1073/pnas.082080899

Buddhikot, M. M. (2007). Understanding dynamic spectrum access: Models, taxonomy, and challenges. *2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks* (DySPAN) (pp. 649-663).

Carley, K. (2006). *Biodefense through city level multi-agent modeling of bio and chemical threats*. Paper presented at the Arizona Spring Biosurveillance Workshop.

Everitt, D., & Manfield, D. (1989). Performance analysis of cellular mobile communication systems with dynamic channel assignment. *IEEE Journal on Selected Areas in Communications*, *7*(8), 1172–1180. doi:10.1109/49.35562

Fang, C., Kimbrough, S. O., Pace, S., Valluri, A., & Zheng, Z. (2002). On adaptive emergence of trust behavior in the game of stag hunt. *Group Decision and Negotiation*, *11*(6), 449–467. doi:10.1023/A:1020639132471

Folcik, V., & Orosz, C. G. (2006). *An agent-based model demonstrates that the immune system behaves like a complex system and a scale-free network*. Paper presented at the SwarmFest 2006.

Gesbert, D., Kiani, S. G., Gjendemsjø, A., & Øien, G. E. (2007). Adaption, coordination, and distributed resource allocation in interference-limited wireless networks. *Proceedings of the IEEE*, *95*(12), 2393–2409. doi:10.1109/JPROC.2007.907125

Giesen, E., Ketter, W., & Zuidwijk, R. (2009). *An agent-based approach to improving resource allocation in the Dutch youth health care sector*. Paper presented at the European Conference on Information Systems (ECIS), Verona, Italy.

Harris, B., Cook, D. J., & Lewis, F. (1998). Machine planning for manufacturing: dynamic resource allocation and on-line supervisory control. *Journal of Intelligent Manufacturing*, *9*(5), 413–430. doi:10.1023/A:1008888215052

Hill, R. R., Carl, R. G., & Champagne, L. E. (2006). Using agent-based simulation to empirically examine search theory using a historical case study. *Journal of Simulation*, *1*(1), 29–38. doi:10.1057/palgrave.jos.4250003

Huang, C.-Y., Sun, C.-T., Hsieh, J.-L., & Lin, H. (2004). Simulating SARS: Small-world epidemiological modeling and public health policy assessments. *Journal of Artificial Societies and Social Simulation*, *7*(4).

Kohler, T. A., Gumerman, G. J., & Reynolds, R. G. (2005). Simulating ancient societies. *Scientific American*, *293*(1), 76–84. doi:10.1038/scientificamerican0705-76

Kong, N., Schaefer, A. J., Hunsaker, B., & Roberts, M. S. (2010). Maximizing the efficiency of the U.S. liver allocation system through region design. *Management Science*, *56*(12), 2111–2122. doi:10.1287/mnsc.1100.1249

LeBaron, B. (2002). *Short-memory traders and their impact on group learning in financial markets* (*Vol. 99*, pp. 7201–7206). National Academy of Sciences. doi:10.1073/pnas.072079699

Macal, C. M. (2004). *Emergent structures from trust relationships in supply chains*. Paper presented at the Agent 2004 Conference on Social Dynamics: Interaction, Reflexivity and Emergence, Chicago, IL.

Macal, C. M., & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation*, *4*, 151–162. doi:10.1057/jos.2010.3

Madey, G., Freeh, V., Tynan, R., Gao, Y., & Hoffman, C. (2003). *Agent-based modeling and simulation of collaborative social networks*. Paper presented at the Americas Conference on Information Systems AMCIS 2003.

Moffat, J., Smith, J., & Witty, S. (2006). Emergent behaviour: Theory and experimentation using the MANA model. *Journal of Applied Mathematics and Decision Sciences*, *2006*, 1–13. doi:10.1155/JAMDS/2006/54846

North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent-based modeling and simulation*. New York, NY: Oxford University Press.

North, M. J., Macal, C. M., Aubin, J. S., Thimmapuram, P., Bragen, M., & Hahn, J. (2010). Multiscale agent-based consumer market modeling. *Complexity*, *15*(5), 37–47.

Park, K., & Kim, W. (2001). A systolic parallel simulation system for dynamic traffic assignment: SPSS-DTA. *Expert Systems with Applications*, *21*(4), 217–227. doi:10.1016/S0957-4174(01)00041-0

Powell, W. B. (1996). A stochastic formulation of the dynamic assignment problem, with an application to truckload motor carriers. *Transportation Science*, *30*(3), 195–219. doi:10.1287/trsc.30.3.195

Pritsker, A. A. B., David, L. M., Janet, S. R., Mary Ann, W., Daily, O. P., Ann, M. H., et al. (1995). Organ transplantation policy evaluation. *Proceedings of the 27th Conference on Winter Simulation*, (pp. 1314-1323).

Psaraftis, H. N. (1980). A dynamic programming solution to the single vehicle many-to-many immediate request dial-a-ride problem. *Transportation Science*, *14*(2), 130–154. doi:10.1287/trsc.14.2.130

Sennott, L., Vanoyen, M., & Iravani, S. (2006). Optimal dynamic assignment of a flexible worker on an open production line with specialists. *European Journal of Operational Research*, *170*(2), 541–566. doi:10.1016/j.ejor.2004.06.030

Shechter, S. M., Bryce, C. L., Alagoz, O., Kreke, J. E., Stahl, J. E., Schaefer, A. J., et al. (2005). *A clinically based discrete-event simulation of end-stage liver disease and the organ allocation process* (Vol. 25, pp. 199-209).

Taranto, S. E., Harper, A. M., Edwards, E. B., Rosendale, J. D., McBride, M. A., Daily, O. P., et al. (2000). Developing a national allocation model for cadaveric kidneys. *Proceedings of the 26th Conference on Winter Simulation,* (pp. 1971-1977).

van den Hout, W. B., Smits, J. M., Deng, M. C., Hummel, M., Schoendube, F., & Scheld, H. H. (2003). The heart-allocation simulation model: a tool for comparison of transplantation allocation policies. *Transplantation*, *76*(10), 1492–1497. doi:10.1097/01.TP.0000092005.95047.E9

Yang, H., Ye, M., Tang, W. H., & Wong, S. C. (2003). Modeling urban taxi services: A literature survey and an analytical example. In Lam, W. H. K., & Bell, M. G. H. (Eds.), *Advanced modeling for transit operations and service planning* (pp. 257–286). Oxford, UK: Pergamon.

Zhao, Q., & Sadler, B. M. (2007). A survey of dynamic spectrum access: Signal processing, networking, and regulatory policy. *IEEE Signal Processing Magazine*, *24*(3), 79–89.

ADDITIONAL READING

Arnheiter, T. (2000). Modeling and simulation of an agent-based decentralized two-commodity power market. *Proceedings of the Fourth International Conference on MultiAgent Systems*, (pp. 361-362).

Bonabeau, E., Dorigo, M., & Theraulaz, G. (1999). *Swarm intelligence: From natural to artificial systems*. New York, NY: Oxford University Press.

Caplat, P., Anand, M., & Bauch, C. (2008). Symmetric competition causes population oscillations in an individual-based model of forest dynamics. *Ecological Modelling*, *211*(3–4), 491–500. doi:10.1016/j.ecolmodel.2007.10.002

Cetin, N., Burri, A., & Nagel, K. (2003). A large-scale agent-based traffic microsimulation based on queue model. *Proceedings of Swiss Transpor t Research Conference (STRC)*.

Chan, W. K. (2008). *An analysis of emerging behaviors in large-scale queueing-based service systems using agent-based simulation.* Paper presented at the Proceedings of the 40th Conference on Winter Simulation, Miami, Florida.

El Rhalibi, A., & Taleb-Bendiab, A. (2006). Harnessing agent-based games research for analysis of collective agent behavior in critical settings. In Hinchey, M., Rago, P., Rash, J., Rouff, C., Sterritt, R., & Truszkowski, W. (Eds.), *Innovative concepts for autonomic and agent-based systems* (*Vol. 3825*, pp. 286–298). Berlin, Germany: Springer. doi:10.1007/11964995_26

Eymann, T., Reinicke, M., Ardaiz, O., Artigas, P., Freitag, F., & Navarro, L. (2003). Decentralized resource allocation in application layer networks. *Proceedings of the 3rd IEEE/ACM International Symposium on Cluster Computing and the Grid*, (pp. 645-650).

Giancarlo, F., Alfredo, G., & Wilma, R. (2005). *A discrete-event simulation framework for the validation of agent-based and multi-agent systems*. Paper presented at the Workshop on Objects and Agents.

Hadzibeganovic, T., Stauffer, D., & Schulze, C. (2009). Agent-based computer simulations of language choice dynamics. *Annals of the New York Academy of Sciences*, *1167*(1), 221–229. doi:10.1111/j.1749-6632.2009.04507.x

Holland, J., & Miller, J. (1991). Artificial adaptive agents in economic theory. *The American Economic Review*, *81*(2), 365–370.

Huddleston, S. H., Learmonth, G. P., & Fox, J. (2008). *Changing knives into spoons.* Paper presented at the 2008 IEEE Systems and Information Engineering Design Symposium, Charlottesville, VA

Hutzschenreuter, A. K., Bosman, P. A. N., Blonk-Altena, I., & La Poutré, H. (2008). Agent-based patient admission scheduling in hospitals. *Proceedings of the 7th International Joint Conference on Autonomous Agents and Multiagent Systems: Industrial Track*, (pp. 45-52).

Kasaie, P., Kelton, W. D., Vaghefi, A., & Naini, S. (2010). Toward optimal resource-allocation for control of epidemics: An agent-based-simulation approach. *Proceedings of the 2010 Winter Simulation Conference* (pp. 2237-2248).

Law, A. M., & Kelton, W. D. (2000). *Simulation modeling and analysis* (3rd ed.). Boston, MA: McGraw-Hill.

Lima, F. W. S., Hadzibeganovic, T., & Stauffer, D. (2009). Evolution of ethnocentrism on undirected and directed Barabási–Albert networks. *Physica A: Statistical Mechanics and its Applications, 388*(24), 4999-5004.

Moser, T., Merdan, M., & Biffl, S. (2010). A pattern-based coordination and test framework for multi-agent simulation of production automation systems. *2010 International Conference on Complex, Intelligent and Software Intensive Systems*, (pp. 526-533).

Nagel, K., & Flötteröd, G. (2009). *Agent-based traffic assignment: Going from trips to behavioral travelers.* Paper presented at the 12th International Conference on Travel Behaviour Research, Jaipur, India.

Niazi, M., & Hussain, A. (2009). Agent-based tools for modeling and simulation of self-organization in peer-to-peer, ad hoc, and other complex networks. *IEEE Communications Magazine*, *47*(3), 166–173. doi:10.1109/MCOM.2009.4804403

Niazi, M., Hussain, A., Baig, A. R., & Bhatti, S. (2008). Simulation of the research process. *Proceedings of the 40th Winter Simulation Conference*, 1326 - 1334.

North, M. J., & Macal, C. M. (2009). Foundations of and recent advances in artificial life modeling with Repast 3 and Repast Simphony. In Adamatzky, A., & Komosinski, M. (Eds.), *Artificial life models in software* (2nd ed.). Springer. doi:10.1007/978-1-84882-285-6_2

Siddiqa, A., Niazi, M., Mustafa, F., Bokhari, H., Hussain, A., Akram, N., et al. (2009). A new hybrid agent-based modeling & simulation decision support system for breast cancer data analysis. *International Conference on Information and Communication Technologies, ICICT '09*, (pp. 134-139).

Spivey, M. Z., & Powell, W. B. (2004). The dynamic assignment problem. *Transportation Science*, *38*(4), 399–419. doi:10.1287/trsc.1030.0073

(2006). InTesfatsion, L., & Judd, K. L. (Eds.). Handbook of computational economics: *Vol. 2*. *Agent-based computational economics*. Amsterdam, The Netherlands: North Holland.

Toffoli, T., & Margolus, N. (1987). *Cellular automata machines: A new environment for modeling*. MIT Press.

Wolfram, S. (1983). Universality and complexity in cellular automata. *Physica D. Nonlinear Phenomena*, *10*(1-2), 1–35. doi:10.1016/0167-2789(84)90245-8

KEY TERMS AND DEFINITIONS

Adaptive Hierarchical Assignment: An allocation rule that first satisfies local demand, then satisfies demand from members in the coalition, and at last satisfies demand from neighbors of the coalition. The coalition membership may change over time when agents (supply/demand entities) try to maximize their own benefits after periodical assessment of the recent performance of adjacent coalitions.

Agent-Based Modeling and Simulation: Agent-based modeling and simulation (ABMS) models a system as a collection of autonomous decision-making entities called agents. Based on a set of rules, each agent individually assesses its situation, makes decisions, and executes various behaviors.

Altruism Oriented Assignment: An allocation rule that first satisfies local demand, and then satisfies the demand from the whole system.

Centralized Allocation System: An allocation system where all supply/demand entities follow some centralized allocation rule, which is determined by a centralized decision maker and specified uniformly to all suppliers and to all recipients.

Decentralized Allocation System: An allocation system where the supply/demand entities can update their own allocation rules adaptively, according to their observations in the system and their decision mechanisms.

Dynamic Assignment Problem: Dynamic assignment problem deals with dynamically assigning resources from suppliers to needs from recipients over time.

Egoism Oriented Assignment: An allocation rule that first satisfies local demand, and then satisfies the demand from neighbors.

Emergent Phenomena in ABMS: Complex patterns arise out of an ABMS model, as a result of interactions of individual agents.

Section 2
Distributed Production Planning and Organization

Chapter 5
Production and Inter-Facility Transportation with Shipment Size Restrictions

Mohamed K. Omar
Nottingham University Business School, Malaysia

ABSTRACT

This chapter studies production and transportation problem confronting a speciality chemical company that has two manufacturing facilities. Facility I produces intermediate products which are then transported to Facility II where the end products are to be manufactured to meet customers' demand. The author formulated the problem as a mixed integer programming (MIP) model that integrates the production and transportation decisions between the two facilities. The developed MIP aims to minimize the production, inventory, manpower, and transportation costs. Real industrial data are used to test and validate the developed MIP model. Comparing the model's results and the company's actual performance indicate that, if the company implemented the proposed model, significant costs savings could be achieved.

INTRODUCTION

Batch production is widely used throughout the chemical industry when fine chemicals of high commercial values are to be manufactured. The batch production has been long accepted for the manufacturing of many types of chemicals, practically those which are produced in small quantities. Due to the multiproduct nature of this industry, it is important that sufficient manufacturing flexibility is available to avoid loss of potential customers.

Since multiproduct chemical plants in the process industry such as speciality chemicals plants and pharmaceutical firms employ batch processing concepts that involve production of small quantities of products but with high varieties. Then, as a result, products are often of incompatible nature, where an intensive setup is incurred, each time a

DOI: 10.4018/978-1-4666-2098-8.ch005

production change from one product to another. Such process characteristics are distinct and predominate in the process industry.

Another important characteristic need to be understood is the fact that firms in the speciality chemical industry compete to a larger degree with the ability to deliver finished products on a timely basis. Finished products are also relatively costly to store. Moreover, there is less customer loyalty due to the fact that the product tends to belong to the commodity end of the product spectrum, and if any firm can attain a price reduction for any reason, the other competitors must follow suit or loss the market share. Due also to the short production lead-time involved, and little or no price and quality differentiation, most of the speciality chemical firms focus on service and availability.

Consequently, short term timing and control of production takes on a more critical role in the process. In addition, firms involve in speciality chemical industry must account for a host of peculiar factors when planning the use of their systems. The nature of the production process results in varying yields due to variations in the process control. The production lead-time is short due to the fact that there is little or no in-process storage and also due to the short process time necessary in many cases to produce products.

The speciality chemical plant or also known as *multi-purpose* plants, production equipments are classified into two categories: pressure vessels (reactors) where the intermediate products are made, and atmospheric vessels (blenders) where different intermediate products are mixed with some chemical solvents to produce finished products. It is common in the speciality chemical industry that firms may temporarily store intermediates for later sale or they may continue to be processed further to more finished products. In addition, intermediate products may be transferred to other facilities within the firm or sold to customers to be used as intermediate products for their end product production.

The case addressed by this chapter involves a speciality chemical company in which intermediate products are produced at one production facility and transported to another facility where the intermediate products are processed further to end products to meet customers' demand. The production and transportation decisions have been dealt with separately and the practice of the company is that production plan is first developed and then transportation plan is worked out by the transportation department. Like many companies with a similar situation, transition between the two functions relies on inventory buffers. Moreover, like many other companies in the industry, there is management pressure for the company to reduce inventory and to adopt the just-in-time concepts as much as they could. Nowadays, it has become essential for companies to explore closer coordination between production and distribution functions.

This study focuses on the coordination of production planning of intermediate products, end products and transportation decisions over two manufacturing facilities, separated and located at two different locations. This research, addresses a speciality chemical manufacturing company that produces intermediate products at one location and then transport the intermediate products to another facility where the end products are produced. Therefore, this research reports on the coordination of production-planning and transportation decisions surrounding a speciality chemical company that has all the characteristics of a typical multiproduct batch chemical plants. This research proposes an integrated approach to coordinate and synchronize the production and transportation planning decisions between the manufacturing facilities subject to some constraints and restrictions.

The reminder of the chapter is organized as follows. In the next section, the literature review and production environment are presented. Challenges and solution approach and model formulation are then presented. Finally, computational results, illustrative example, conclusions and suggestion for future research are presented.

LITERATURE REVIEW

In this section of the chapter, the literature review will focus on the reported research that attempt to couple production and transportation activities. In addition, we will focus on research work that uses exact methods as a solution methodology for integration of production and transportation decisions. However, interested readers are referred to the comprehensive reviews provided by Erengüç et al. (1999), Goetschalckxet al. (2002) and Chen (2004). Moreover, the author intends to provide the reader with some of the recent works that uses non exact methods to provide solution for integrating scheduling and transportation activities.

Perhaps, the earliest work that proposed an exact method that attempt to integrate production and transportation decisions was by Geoffrin and Graves (1974).A Mixed Integer Programming (MIP) was presented to deal with production and distribution system for multiple plants with the objective to minimize production and transportation costs. Another interesting work is that reported by Williams (1983) when a dynamic programming model was developed for solving production of batches and distribution decisions. Cohen and Lee (1989) developed a non-linear MIP model that aims to maximize the profit for several facilities and distribution centres. Haq et al. (1991) proposed an MIP model that determines production and distribution batch sizes for a multi-stage production-inventory-distribution system. The authors considered a three echelon system with one production facility, several warehouses and several retailers.

Pyke and Cohen (1993) developed a mathematical model for a single product three- level supply chain and its performance characteristics of the model were examined. In their extension of their previous work, Pyke and Cohen (1994) developed a mathematical model for integrating production and distribution system that compromised of a single model factory, a stockpile of finished goods and a single retailer. Arntzen et al. (1995) developed an MIP model that aims to minimize production, inventory, material handling, overheads and transportation costs over the supply chain. Camm et al. (1997) developed an MIP for determining location and distribution centres that aims to minimize the cost involved in location and distribution centres.

Vidal and Goetschalckx (1997) present a review of models on global logistics systems. They state that most comprehensive strategies problem is the optimization of complete supply chain. In their definition, strategic production-distribution model is the problem that requires concerns managers to compute the number, location, capacity and type of manufacturing plants and warehouses to use. In addition, the authors addressed the strategic production planning models, with emphasis on MIP, including the terms considered in the objective functions, the constraints and the specific characteristics of the methods of solution and computational experience.

Barbarosoglu and Ozgur (1999) developed an integrated analysis of production distribution function in a two-echelon system. A single plant that produces several products distributed to several depots, and from depots to customers with time varying known demand requirement. The problem was expressed as an MIP model with the objective function set to minimize the total fixed and variable costs associated with production, inventory holding and two stage distribution systems.

Dogan and Goetschalckx (1999) proposed an MIP model that can deal with multi-periods production-distribution systems for the case of seasonal customer demand. Dhanenens-Flipo and Finke (2001) modelled a combined production-distribution problem in the form of a network flow problem. The proposed model was designed to handle multi-site, multi-product and multi periods problems. Jayaraman and Pirkul (2001) developed an MIP model for location and distribution facilities in multi echelon environment. The authors proposed a Lagrangian relaxation approach and an efficient heuristic solution procedure that utilizes the solution generated from the Lagrangian relaxation problem. The integrated model has proven to be cost minimization procedure for analyzing facility logistics strategies in the context of production and distribution design studies. Garcia et al. (2004) presented a model that deals with scheduling of orders and vehicle assignment for production and distribution planning in a scenario of no-wait, immediate delivery to the customer site. It is assumed that all requests are known in advance. They have a set of production plants with a production capacity, for the manufacturing of orders and fixed number of delivery vehicles. The problem is presented as an MIP model with the objective function that aims to maximize the profit obtained for selected orders.

Matta and Miller (2004) address the problem of coordinating the short-term production and inter-facility transportation scheduling decisions. The problem addressed by the authors consists of two plants, a plant that produces intermediates and another that produces finished products. The problem was formulated as an MIP model that simultaneously determine the cost minimizing quantities of products an intermediate plant must produce and ship to a finishing plant using different transportation modes. Moreover, the model simultaneously finds the cost minimizing quantities of product that the finishing plant must produce to meet its customer demand on time. Kanyalkar and Adil (2005) consider production planning of multi site production facility and propose a linear programming model to develop the time and capacity aggregated plan and detailed plan for the problem considered.

Recently, there are many publications that attempt to integrate scheduling and transportation activities using non exact methods. The motivation of using non exact methods is the fact that the coupling of scheduling and transportation is an NP-Hard problem (see Cheng and Kovalyov (2001), and Li, and Sivakumar (2008)) and as a result, there is large number of published papers that uses heuristics and metaheuristics as methodology to provide a solution for integrating production and transportation problems. Examples of heuristics, the readers are referred to Chang and Lee (2004), Park (2005), Gupta and Sivkumar (2006), Li et al. (2006) and for metaheuristics such as simulated annealing readers are referred to the work of Li et al. (2008), Genetic Algorithms (Lee et al. (2002), Chan et al. (2005), Ko and Evans (2007) and Zegordi et al. (2010).

Although research works indicate that a great opportunity for cost saving exists when coupling production and transportation decisions, however, Bonfill et al. (2008) state that only few publications have been reported so far in this direction and as a result, the efficient coordination of production and distrbution systems remain an open area for research, with an increasing interest as companies move towards higher collaboration and competitive environments.

As it can been seen from the presented literature review that MIP modelling approach have been used to provide solution for integration of production and transportation problems, however, the MIP model presented in this research exhibits some characteristics that has not been reported in the literature. Among the unique characteristics common in the speciality chemical industry reported in this research are the batch size restriction for both intermediates and finished products, the need to compute the number of batches for intermediates and finished products, yield percentage from intermediate to finish products and shipment size restrictions. With those characteristics in mind, the author propose and tested new MIP model that attempts to provide a solution to production and transportation problem confronted a speciality chemical company. In the next section of this chapter, the production environment is presented.

PRODUCTION ENVIRONMENT

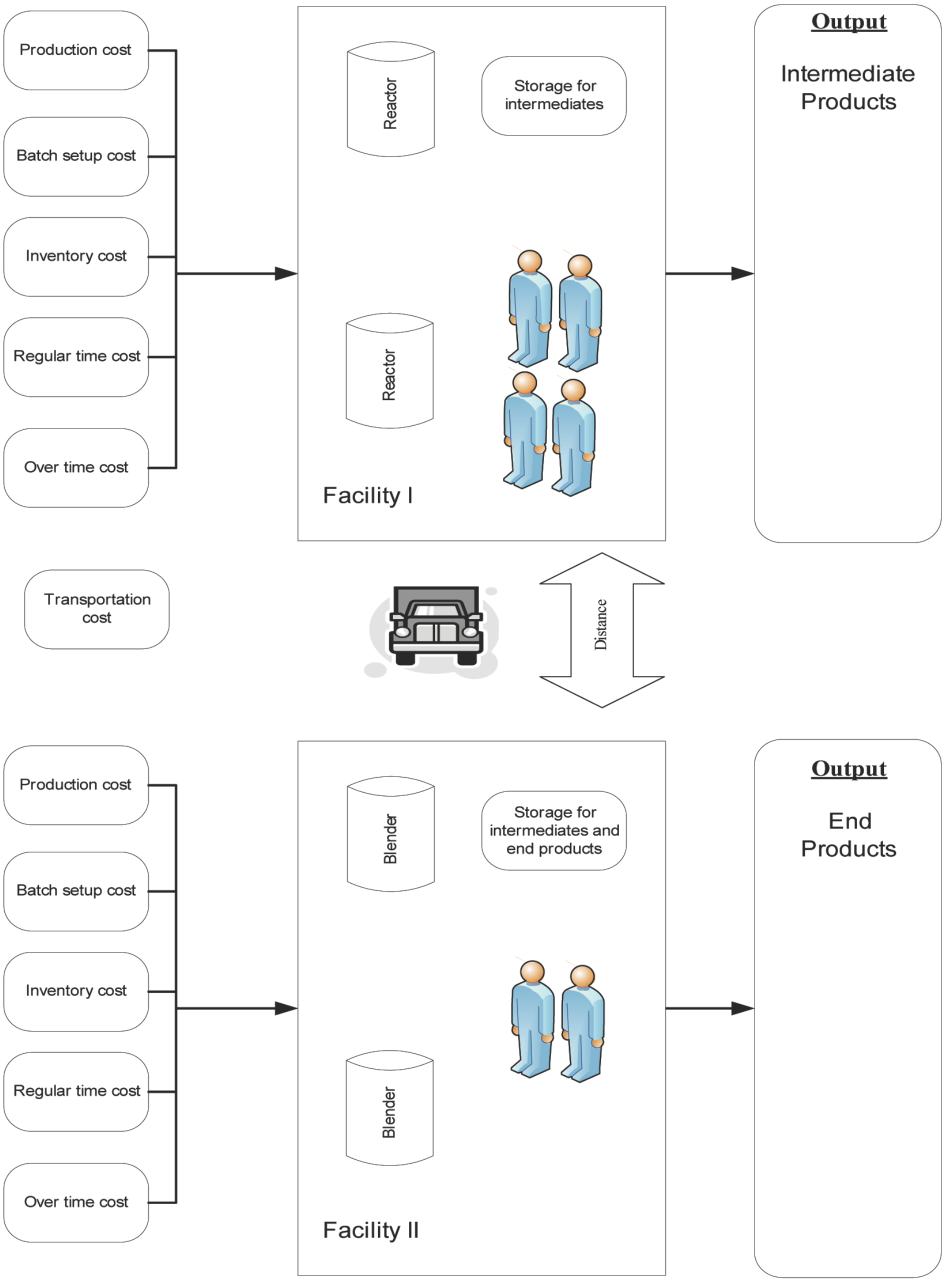
This research considers coordination of production planning and transportation decisions among two production facilities, a common planning and coordination problem in the process industry. The problem considered by this chapter can be described in the following way: A speciality chemical manufacturing company has two production facilities, I and II. Production facility I produce range of incompatible intermediate products that need to be transported to facility II for further processing into end products. At production facility I, there are serial of production vessels (Reactors) with batch size restriction configuration where the intermediate products are produced, while producing intermediate products, considerable setup activities are needed every time the production run is switched from one intermediate product into another. Facility II consists of serial of atmospheric pressure vessels (Blenders) with batch size restrictions configurations where end products are manufactured. In similar manner, end products manufactured in facility II are incompatible and considerable setup activities are needed every time the production run is switched from one end product into another. Distilled water which constitutes a good portion in making end products is produced at facility II at a known fixed cost. Intermediate products are packed in 150 kg steel drums and when needed, they are transported by trucks with limited truck load of 112 drums per trip. Figure 1 shows the layout of two production facilities and the inter-facility transportation. It is worth noting that the company currently have 37 active end products that require exactly 50 intermediate products to be manufactured. Moreover, the 37 end products are offered to the customers at different concentrates choices based on their application and obviously at different price and as a result the end product list would reach a figure of 50 products.

In terms of the production and transportation planning activities, once the planner at production facility II receives customers' requirements of end products (quantity and type), he/she starts to work on three challenges, first is to convert the required end products into the exact portions of each intermediate products needed and taken into account the yield issue. Secondly, compute the number of batches need for each end product. Finally, determine the needed production leadtime. Upon completion of these challenges, the planner at facility II forwards the answers of the challenges to facility I where the intermediate products are manufactured. In similar manner, the planner at facility I converts the quantities of the intermediate products into number of workable batches needed to be produced and coordinate intermediate products transportation to facility II through the transportation department. Both planners in each of the manufacturing facility must consider the constraints imposed on batch size, inventory levels and transportation load and develop a plan for intermediate products production, transportation and production of end products that ensure meeting the customers' demand. The speciality chemical manufacturing company wanted a solution to their production and transportation planning problem between the two facilities that takes all planning complexity into consideration and minimizes the total cost. As a result of the above, the ultimate objective of this research work is to develop suitable optimization model that can deal with all the planning complexity and provides minimum cost plans for intermediates and end products manufacturing and transportation activities.

CHALLENGES AND SOLUTION APPROACH

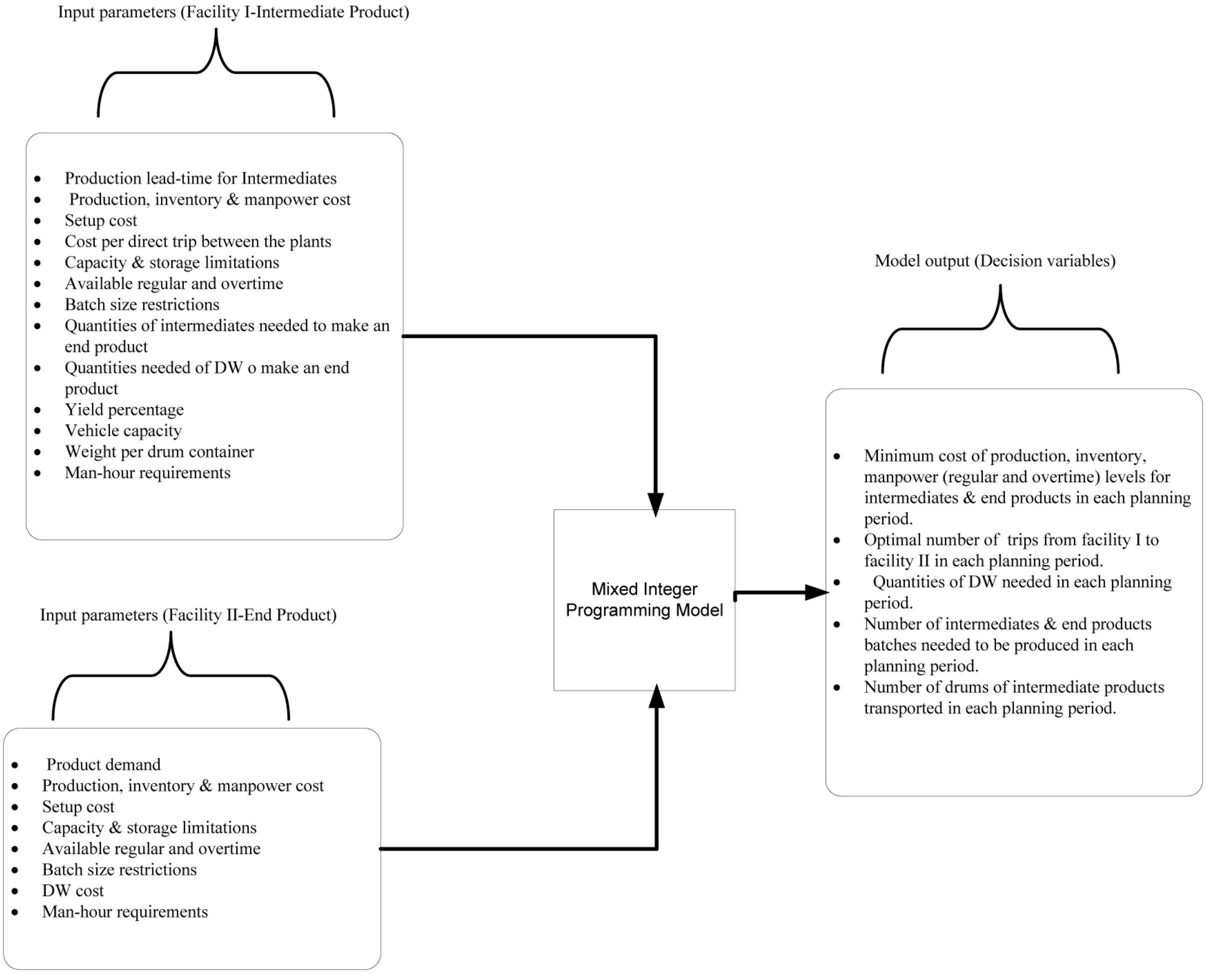
Discussions with the production and transportation planning management reveal that while the planning department is coping with the planning activities using spreadsheet software, there are complex tasks that any developed model should

Figure 1. Layout of the two manufacturing facilities



address and provide solutions to such problems. First, they highlight the complexity of the end product compositions (ingredients). In other words, the model should be developed in such a way to enable the user to input the demand of the end products, and then the model should compute the exact amount of intermediate products and distilled water needed to satisfy the input demand with the yield requirements. Secondly, the planning department experienced great difficulties with the batching problem. Batching activities is the process of transforming customers' product orders

Figure 2. Input and output data for the MIP model



into set of batches to be planned and subsequently each one to be assigned due dates. This process is commonly practiced in the chemical industry, since the batch frequently shared by several other orders, with the earliest one determining the batch due date. In addition, the company is concern with the inventory levels at both facilities and therefore, the model should be developed in such a way that it ensures minimum inventory levels at both facilities.

The planning department expressed their wish to know the exact number of drums containers of intermediate products transported per planning period so that a control policy could be set to deal with this issue. As a result of the discussions with the planning management, the solution proposed for this situation is to develop an MIP model that can generate optimal plans for production, inventory and manpower levels at the two facilities and deal with the transportation decisions.

Figure 2 shows the required input data needed for the MIP model and the results output once the MIP model determine either an optimal or feasible solution to the production and transportation problem considered. In the next section, the details of the MIP model are presented.

MODEL FORMULATION

In this section, the developed MIP model that aims to provide a solution to the integration of production and transportation decisions is presented. First the indices are presented and then followed by model parameters, decision variables and finally, the objective functions and constraints equations.

Indices

- i: Index of end product type i at facility II
- k: Index of intermediates type k at facility I
- t:Index of time period t

Model Parameter

Facility I: Manufacturing of Intermediates

T	Length of planning horizon
$\hat{C}_{kt}$	Production cost per unit of intermediate product *k* in period *t*
$\hat{S}_{kt}$	Set up cost per batch for intermediate *k* in period *t*
$\hat{h}_{kt}$	Inventory carrying cost per unit of intermediate product *k* per period *t*
$\hat{r}_t$	Cost per man-hour of regular time labour in period t in facility I
$\hat{o}_t$	Cost per man-hour of overtime labour in period t in facility I
$\hat{B}_{kt}^{\min}$	Minimum batch size of intermediate product *k* in period *t*
$\hat{B}_{kt}^{\max}$	Maximum batch size of intermediate product *k* in period *t*
$\hat{rm}_t$	Total regular time hours available in period *t* in facility I
$\hat{om}_t$	Total overtime hours available in period *t* in facility I
$\hat{m}_k$	Man-hour required to produce one unit of intermediate product *k*
$\hat{os}_{kt}$	Overstock limit for intermediate product *k* in period *t*
$\hat{a}_{ik}$	Number units of intermediate product k required to produce one unit of end product *i*
$\hat{PC}_t$	Available capacity in production facility I in period *t*
$\hat{SC}_t$	Available storage capacity in facility I in period *t*
L	Production lead-time for intermediates
ϖ	Weight per drum container in kilogram

Transportation

C_t	Cost per direct trip in period *t* from facility I to facility II
C	Vehicle capacity

Facility II: Manufacturing of End Products

d_{it}	Demand for end product *i* in period *t*
C_{it}	Production cost per unit of end product *i* in period *t*
S_{it}	Set up cost per batch for end product *i* in period *t*
h_{it}	Inventory carrying cost per unit of product *i* per period *t*
r_t	Cost per man-hour of regular time labour in period t in facility II
o_t	Cost per man-hour of overtime labour in period t in facility II
$B_{it}^{\min}$	Minimum batch size of end product *i* in period *t*
$B_{it}^{\max}$	Maximum batch size of end product *i* in period *t*
rm_t	Total regular time hours available in period *t* in facility II
om_t	Total overtime hours available in period *t* in facility II
m_i	Man-hour required to produce one unit of end product *i*
os_{it}	Overstock limit for end product *i* in period *t*
Y_i	Yield percentage from intermediate products to end product *i*
PC_t	Available production capacity in facility II in period *t*

SC_t Available storage capacity in facility II in period t

C_t^{DW} Production cost per unit DW per period t

a_i^{DW} Number units of DW required to produce one unit of end product i

Decisions Variables

Facility I: Manufacturing of Intermediates

D_{kt} Demand of intermediate type k in period t.

$\hat{X}_{kt}$ Number of units of intermediate product k to be produced in period t

$\hat{\eta}_{kt}$ Number of batches of intermediate product k to be produced in period t

$\hat{I}_{kt}$ Ending inventory in units of intermediate product k in period t

$\hat{R}_{kt}$ Regular time in hours used in producing intermediate product k in period t

$\hat{O}_{kt}$ Overtime in hours used in producing intermediate product k in period t

I_{kt}''' Ending inventory in units of intermediate product k at facility II in period t

Transportation

$\hat{d}r_{kt}$ Number of drums of intermediate product k transported in period t

W_t The number of direct trips from facility I to the facility II in period t

$\hat{SM}_{kt}$ Total amount of k intermediate product transported from facility I to facility II in period t

Facility II: Manufacturing of End Products

X_{it} The number of units of end product i to be produced in period t

η_{it} The number of batches of end product i to be produced in period t

I_{it} Ending inventory in units of end product i in period t

R_{it} Regular time in hours used in producing end product i in period t

O_{it} Overtime in hours used in producing end product i in period t

D_t^{DW} Demand of DW in period t

Objective Function

$$Minimize$$

$$\sum_{t=1}^{T}\sum_{i=1}^{I}(C_{it}X_{it} + h_{it}I_{it} + S_{it}\phi_{it} + r_tR_{it} + o_tO_{it}) + \sum_{t=1}^{T-L}\sum_{k=1}^{K}(\hat{C}_{kt}\hat{X}_{kt} + \hat{h}_{kt}\hat{I}_{kt} + S_{kt}\phi_{kt} + \hat{r}_t\hat{R}_{kt} + \hat{o}_t\hat{O}_{kt}) + \sum_{t=1}^{T}C_t^{DW}D_t^{DW} + \sum_{t=1}^{T-L}C_tW_t \tag{1}$$

Set of Constraints

Facility I: Manufacturing of Intermediates

$$\hat{I}_{k(t-1)} + \hat{X}_{kt} - \hat{SM}_{kt} = \hat{I}_{kt} \quad \forall k,\ t = 1, 2\ldots \text{T-L} \tag{2}$$

$$\sum_{k=1}^{K}\hat{R}_{kt} \le \hat{rm}_t \quad t = 1, 2\ldots \text{T-L} \tag{3}$$

$$\sum_{k=1}^{K}\hat{O}_{kt} \le \hat{om}_t \quad t = 1, 2\ldots \text{T-L} \tag{4}$$

$$m_k\hat{X}_{kt} = \hat{R}_{kt} + \hat{O}_{kt} \quad \forall k,\ t = 1, 2\ldots \text{T-L} \tag{5}$$

$$\hat{I}_{kt} \le \hat{os}_{kt} \quad \forall k,\ t = 1, 2\ldots \text{T-L} \tag{6}$$

$$\sum_{k=1}^{K}\hat{X}_{kt} \le \hat{PC}_t \quad t = 1, 2\ldots \text{T-L} \tag{7}$$

$$\sum_{k=1}^{K}\hat{I}_{kt} \le \hat{SC}_t \quad t = 1, 2\ldots\text{T-L} \tag{8}$$

$$\hat{SM}_{kt} = \varpi\,\hat{dr}_{kt} \quad \forall k,\ t = 1, 2\ldots \text{T-L} \tag{9}$$

$$\hat{\eta}_{kt}\,\hat{B}_{kt}^{\min} \le \hat{X}_{kt} \le \hat{\eta}_{kt}\,\hat{B}_{kt}^{\max} \quad \forall k,\ t = 1, 2\ldots \text{T-L} \tag{10}$$

Transportation

$$W_t \ge w \sum_{k=1}^{K} \hat{dr}_{kt} \Big/ C \quad \forall k,\ t = 1, 2\ldots\text{T-L} \tag{11}$$

Facility II: Manufacturing of End Product

$$I_{i(t-1)} + X_{it} - I_{it} = d_{it} \quad \forall i,\ t = 1, 2\ldots\text{T} \tag{12}$$

$$\sum_{i=1}^{I} R_{it} \le rm_t \quad t = 1, 2\ldots\text{T} \tag{13}$$

$$\sum_{i=1}^{I} O_{it} \le om_t \quad t = 1, 2\ldots\text{T} \tag{14}$$

$$m_i X_{it} = R_{it} + O_{it} \quad \forall i,\ t = 1, 2\ldots\text{T} \tag{15}$$

Facility II: Manufacturing of End Product

$$I_{it} \le os_{it} \quad \forall i,\ t = 1, 2\ldots\text{T} \tag{16}$$

$$\sum_{i=1}^{I} X_{it} \le PC_t \quad t = 1, 2\ldots\text{T} \tag{17}$$

$$\sum_{i=1}^{I} I_{it} \le SC_t \quad t = 1, 2\ldots\text{T} \tag{18}$$

$$\hat{SM}_{kt} + I'''_{k(t+L-1)} - D_{kt} = I'''_{k(t+L)} \quad \forall k,\ t = 1, 2\ldots\text{T-L} \tag{19}$$

$$I'''_{kt} \le \varpi \quad \forall k,\ t = 1, 2\ldots\text{T} \tag{20}$$

$$D_{kt} = \sum_{i=1}^{I} \frac{\hat{a}_{ik}\, X_{i(t+L)}}{Y_i} \quad \forall k,\ t = 1, 2\ldots\text{T} \tag{21}$$

$$D_t^{DW} = \sum_{i=1}^{I} \frac{a_i^{DW} X_{it}}{Y_i} \quad t = 1, 2\ldots\text{T} \tag{22}$$

$$\eta_{it} B_{it}^{\min} \le X_{it} \le \eta_{it} B_{it}^{\max} \quad \forall i\ \text{I},\ t = 1, 2\ldots\text{T} \tag{23}$$

$$X_{it}, I_{it}, R_{it}, O_{it}, \hat{X}_{kt}, \hat{I}_{kt}, \hat{R}_{kt}, \hat{O}_{kt}, I'''_{kt}, D_t^{DW}, \hat{SM}_{kt} \ge 0 \tag{24}$$

$$\eta_{it}, \hat{\eta}_{kt}, \hat{dr}_{kt}, W_t \ge 0 \text{ and integers} \tag{25}$$

$$\phi_{it}, \phi_{kt} \in \{0,1\} \tag{26}$$

In the above formulation, Equation 1 represents the objectives function which calls for minimizing its four terms. The first and second terms quantify the production, inventory, setup, regular and overtime costs at production facility I and II respectively. The third term quantifies the distilled water cost at facility II and the fourth term quantifies the transportation costs. Equation 2 is the demand; inventory transportation relationship for intermediate products at facility I. Equations 3 and 4 state the regular and overtime limitations at facility I. Equation 5 presents the workforce limitations, while Equation 6 enforces the overstock limitations for intermediate products. Equations 7 and 8 state production capacity and storage limitations at facility I. Equation 9 converts quantities of intermediate products to be transported into number of drum containers to be transported. Equation 10 enforces minimum and maximum batch size requirements for intermediate products manufacturing. Equation 11 defines the relationship between number of transportation trips, capacity of the vehicle and the number of drums to be transported per planning period. Equation 12 is the demand, inventory relationship for end products at facility II. Equations 13 and 14 state the regular and overtime limitations at facility II. Equation 15 presents the workforce limitations, while Equation 16 enforces the overstock limitations for end products. Equations 17 and 18 state the production capacity and storage limitations at facility II. Equation 19 is the transportation, demand, inventory relationship for intermediate products at facility II. Equation 20 represents the restrictions imposed on the level of quantities of intermediate products to be stored at facility II per period. Equation 21 determines the quantities of each intermediates needed for each end product to be manufactured in each period. Equation 22 determines the quantities of distilled water needed for end products manufacturing. Equation 23 enforces minimum and maximum batch size requirements for end products manufacturing. Equation 24 represents the non-negativity constraint. Equation 25 describes the integer variables. Equation 26 defines ϕ_{it}, ϕ_{kt} as binary variables.

COMPUTATIONAL RESULTS

Our model was formulated using OPL-Studio version 3.7.1 and solved using CPLEX version 9.1. The model was executed with Intel Pentium (R) process 1.86 GHz, 2MB RAM. Microsoft Excel spreadsheet 2007 was used to enable the model to import its input data (model parameters) and then export the results back to Microsoft Excel. The model was used to solve 6 weeks horizon problem for the entire 37 end products that require 50 intermediate products to be manufactured. In order to compare the performance of the proposed model with the current planning practice in terms of cost, 6 weeks actual demand of end products, the set limit of intermediate products, initial and ending inventories at facility I and facility II, the set limit of end products initial and ending inventory at facility II together with all other parameters needed for the proposed model were taken from the company.

In the first case of our computational work, we restrict the integer variables requirements for the whole time horizon of 6 weeks. In this case, CPLEX was terminated after 4380 seconds without finding feasible solution with an optimality gap of 0.05% and obviously, this means that the integer restriction for all considered planning horizon is making the MIP model to be a hard problem to solve. One good solution for this problem is the fact that most the companies use the rolling horizon concept in their operational planning. The rational for such operational strategy is the fact that customers' orders additions and cancelation foresees companies to review their operational planning quite often. Based on this concept and bearing in mind the lead times requirements for raw materials and other planning issues, we decided to impose integer restriction for the first 3 weeks and remove the integer restriction for the other 3 weeks of the planning horizon. Using this concept, the model generated around 3511 variables, 506 of which were integer variables, and around 5249 constraints. The model was solved only in 210 seconds and we were able to find a feasible solution with an optimality gap of 0.0071%.

The solution obtained from the MIP model showed that the total cost for integrating production and transportation for the 3 weeks considered has been reduced by about 5% of the actual cost for the same planning time horizon. Obviously, actual value cannot be disclosed for confidentially issues; however, the company reveals that reduction in cost was significant. Since we have developed the model in way that allows CPLEX to export the results to Microsoft Excel, it was not difficult to conduct some analysis to the components that constitute the total costs. Our analysis indicate that the production costs for end product was found to be around 50.14% of the total costs and the production costs for intermediate products was found to be around 46.17% of the total costs. The costs of ending inventory for end products was about 0.12% of the total costs, while the costs of the ending inventory of intermediates was around 0.35% of the total cost. Moreover, the setup costs at both plants was found to be almost the same and equal to 0.06% of the total costs and the transportation costs was found to be around 0.09% of the total costs, while remaining percentages were for the other cost components.

From the analysis carried out, that the production costs at both facilities constitute a far larger proportion of the total costs than the transportation costs. Interestingly, the model managed to keep a lower inventory levels for both facilities owing to the limitation imposed on restriction the ending inventory level at both facilities. We thought that It would have been very interesting to compare our findings with the actual total cost components computed by the company, unfortunately, the author was not granted an access to the data and as it seems, the company consider this issues as highly confidential. However, the management indicated that model have provided them with some insights regarding the total cost components. It is important to highlight at this junction that the MIP model might not be able to obtain an optimal solution to the production and transportation problem across the two manufacturing facilities when longer time horizon is considered for the entire products list. However, the management indicated that they are practicing the concept of rolling horizon for planning the customers' orders and as a result, the developed model will improve their production and transportation planning decisions.

Illustrative Example

Since it was difficult to display the full results obtained from running the model with the full range of the products, the author believe that it would be a good idea to provide an illustrative example that help the reader to understand the complexity of the case study and show part of optimal solution results. The case considered here consists of five end products that are produced as a result of using eleven intermediate products and portion of the distilled water which can be described in the following manner: Product IT1 is a lubricant agent that can be produced as a result of blending three intermediate products (J1, J8, R003). The second product is IT2, a water soluble corrosion inhibitor that requires four intermediate products to be blended with distilled water (J6, J7, R003, R019, DW). The third end product IT3 is a sulphuric lubricant that can be produced by blending six intermediate products (J1, J4, J5, J8, R003, R048).Product IT4 is an anti foaming product which is manufactured as a result of blending two intermediate products and distilled water (J1, J3, DW). The fifth product IT6; is a corrosion inhibitor that requires three intermediate products to be blended (J7, R007, R048).Figure 3 illustrates intermediate products and solvents as composition of the end products used in this illustrative example. In addition, Table 1 was developed to show the exact portions of each intermediates used in making an end product and at the same time shows the estimated yield for each end product. It is worth to remind the reader that intermediate products are manufactured in facility I and then transported to facility II for further processing (blending) into end products.

Results and Discussions

Using OPL-Studio version 3.7.1 and solved using CPLEX version 9.1 to execute the model, the model had 695 variables of which 200 were integer, around 974 constraints and the author was able to obtain an optimal solution in few seconds. In the illustrative example, 6 weeks time horizon were used, however, in displaying the results, we have only shown 2 weeks due to the limitations of space requirements in this chapter. The part of the results of the illustrative example for the intermediate products production planning and transportation decisions are shown in Tables 2 and 3, while results for the end product production planning decisions are shown in Table 4. In addition, Table 5 shows weekly number of intermediate products transported from facility I to facility II together with the weekly truck trips between the two facilities.

Upon deciding about the type and quantity of the demand of the end products as indicated in Table 4 (row 2), the planner will use this information as an input to the model. Now, referring to Table 2, the model will compute the exact intermediate products per planning period as shown in row 2, once the demand of intermediate product demands per planning period is realized, the

Figure 3. Example of intermediate products and solvent as composition of end products

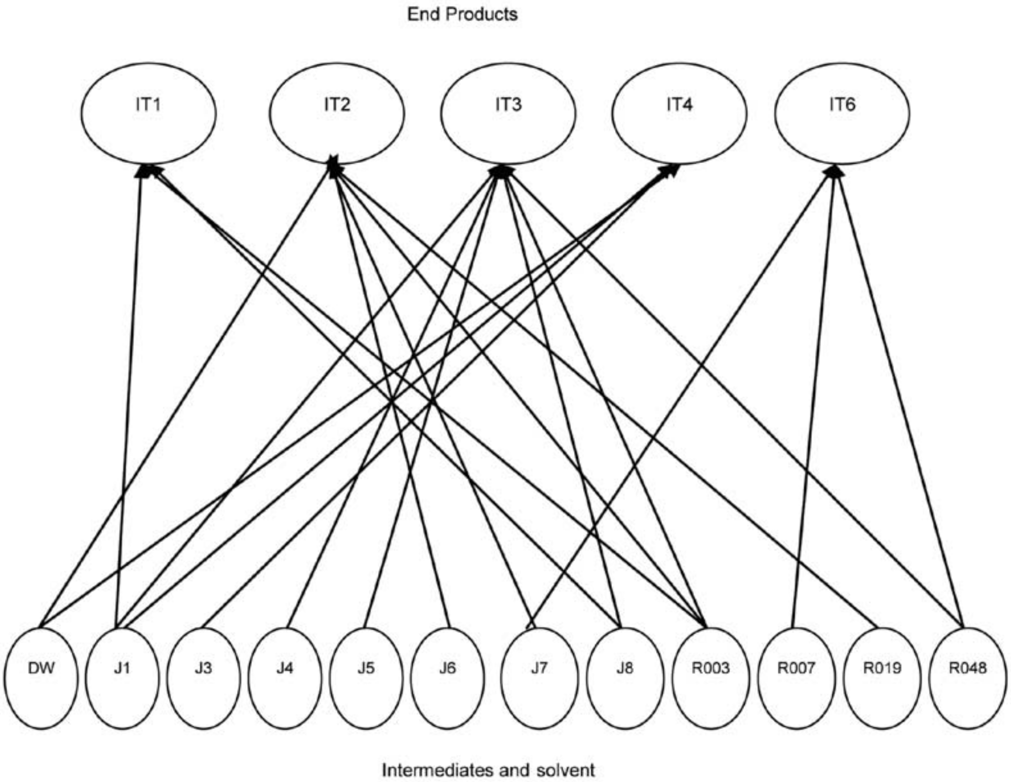


Table 1. End product, intermediate and distilled water composition

Components	IT1	IT2	IT3	IT4	IT6
DW	0%	61.15%	0%	28%	0%
J1	3.40%	0%	1.70%	2%	0%
J3	0%	0%	0%	70%	0%
J4	0%	0%	5%	0%	0%
J5	0%	0%	25%	0%	0%
J6	0%	10%	0%	0%	0%
J7	0%	15%	0%	0%	17.50%
J8	66.60%	0%	33.30%	0%	0%
R003	30%	11.25%	15%	0%	0%
R007	0%	0%	0%	0%	7.50%
R019	0%	2.60%	0%	0%	0%
R048	0%	0%	20%	0%	75%
Yield	85%.	90%	90%	86%	87%

Table 2. MIP optimal results for decisions variables at facility I

	J1		J3		J4		J5		J6		J7	
Week	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
D_{kt}	1498.5	0	13050	18080	900	750	4500	3750	51666.7	4533.77	11250	9950.6
$\hat{X}_{kt}$	5000	0	13050	18150	5000	0	5000	5000	5663	0	5269	9900
$\hat{\eta}_{kt}$	1	0	1	1	1	0	1	1	1	0	1	1
$\hat{R}_{kt}$	14.9	0	34.85	48.46	10.25	0	12.85	12.85	14.61	0	14.59	27.423
$\hat{O}_{kt}$	0	0	0	0	0	0	0	0	0	0	0	0
BIP1	1525	5025	0	0	0	3950	0	350	4087	4500	6131	0
$\hat{I}_{kt}$	5025	2775	0	0	3950	3200	350	1600	4500	0	0	0
BIP2	0	0	0	0	0	0	0	0	0	0	0	0
I'''_{kt}	0	1.446	0	0	0	150	0	150	0	83.33	0	150
$\hat{SM}_{kt}$	1500	2250	13050	18150	1050	750	4650	3750	5250	4500	11400	9900
$\hat{dr}_{kt}$	10	15	87	121	7	5	31	25	35	30	76	66

BIP1=Beginning inventory of intermediate products at plant I and BIP2= Beginning inventory of intermediate products at plant 2.

model computes the quantity of intermediate products to be produced per period as shown in row 3, the number of batches needed per planning period as shown in row 4, the regular and overtime used per planning period as shown in rows 5,6, the beginning inventory and ending inventory levels of intermediate products per planning period is shown in rows 7,8, the beginning inventory and ending inventory levels of intermediate products per planning period is shown in rows 9,10, the total quantities of intimidates transported in kg per planning period as in row 11 and finally the amount of drums of intermediates transported per planning period as shown in row 12. Table 3 shows the results of the remaining of the intermediate products for the illustrative example and the results could be interpreted in a similar manner. Table 4 was constructed to show the results of the production and inventory levels per planning period for the end products which are displayed in rows 3, 7 and 8, while the number of batches per planning period are shown in row 4 and regular and overtime per planning period are shown in rows 5, 6. In Table 5, the optimal number of intermediate products drums transported and the required truck trips are displayed.

Table 3. MIP optimal results for decisions variables at facility I

		J8		R003		R007		R019		R048	
W	W	1	2	1	2	1	2	1	2	1	2
D_{kt}		22050	33237.5	15744.9	20072.36	1500	1350	1343.33	1178.78	18600	16500
$\hat{X}_{kt}$		0	25487	0	17800	6600	0	5000	5000	18600	16650
$\hat{\eta}_{kt}$	NB	0	1	0	1	1	0	1	1	1	1
$\hat{R}_{kt}$	RT	0	59.38	0	42	13.46	0	14.05	14.05	76.446	68.43
$\hat{O}_{kt}$	OT	0	0	0	0	0	0	0	0	0	0
BIP1	BIP1	29863	7663	18050	2300	0	5100	1063	4713	0	0
$\hat{I}_{kt}$	EIP1	7663	0	2300	0	5100	3600	4713	8513	0	0
BIP2	BIP2	0	0	0	0	0	0	0	0	0	0
I'''_{kt}	EIP2	0	150	0	5.06	0	0	0	60666	0	0
$\hat{SM}_{kt}$	Shkg	22200	33150	15750	20100	1500	1500	1350	1200	18600	16650
$\hat{d}r_{kt}$	Shdr	148	221	105	134	10	10	9	8	124	111

BIP1=Beginning inventory of intermediate products at plant I and BIP2= Beginning inventory of intermediate products at plant 2.

Table 4. MIP optimal results for decisions variables at facility II

	IT1		IT2		IT3		IT4		IT6	
W	1	2	1	2	1	2	1	2	1	2
d_{it}	48187	45280	30626	43642	17275	15458	19626	16041	12387	16254
X_{it}	85077.85	20491.88	30626	46500	17275	16200	19634.15	16032.85	12387	17400
η_{it}	3	1	1	2	1	1	1	1	1	1
R_{it}	199.95	28.89	45.63	69.28	22.28	20.89	25.131	20.52	10.99	17.92
O_{it}	0	0	0	0	0	0	0	0	1.76	0
BIP1	0	36890	0	0	0	0	0	8.147	0	0
I_{it}	36890.85	12102.74	0	2858	0	742	8.147	0	0	1146

Table 5. Weekly drums of intermediates products produced and transported

	Number of drums transported and number of trips	
	Week 1	Week 2
J1	10	15
J3	78	121
J4	7	5
J5	31	25
J6	35	30
J7	76	66
J8	148	221
R003	105	134
R007	10	10
R019	9	8
R048	124	111
Total number of drums	642	746
Total trips	6	7

CONCLUSION

In this chapter, an approach that calls for integration of production and transportation in a speciality chemical firm was discussed. A mixed integer programming model was developed to formulate the production and transportation between two manufacturing facilities separated by a distance. Facility I produces the intermediate products which are basically the ingredients of the finished products. Then the intermediates are then transported to facility II for further possessing into end products. The model was formulated based on the company's systems structure and production and transportation practices. The performance of the integrated approach has been compared with the company's actual performance. The results showed that the proposed approach have improved the quality of the decisions, since the proposed approach indicates that if the company implements the approach, significant cost savings could be achieved. Moreover, the author provides an illustrative example that includes five end products that require eleven intermediate products and a portion of the distilled water to be manufactured. Many benefits can be expected from implementing the proposed approach that include the fact that more profit could be achieved since the cross functions between the two facilities could be optimized and the planning decisions will be more accurate since they are supported by the well developed mathematical model. The proposed model assumes deterministic demand rates and market conditions and therefore an obvious extension would be to include some elements of stochastic conditions when developing the MIP. Another opportunity for further research is the use of metaheuristics as a solution approach for solving a very large real-life instance with hundreds of end products for the same production environment.

REFERENCES

Arntzen, B. C., Brown, G. G., Harrison, T. P., & Trafton, L. L. (1995). Global supply chain management at digital equipment corporation. *Interface*, *25*, 69–93. doi:10.1287/inte.25.1.69

Barbarosoglu, G., & Ozgur, D. (1999). Hierarchical design of two-echelon distribution system. *European Journal of Operational Research*, *118*, 464–484. doi:10.1016/S0377-2217(98)00317-8

Bonfill, A., Espuna, L., & Puigjaner, L. (2008). Decisions support framework for coordination production and transport scheduling in SCM. *Computers & Chemical Engineering*, *32*, 1206–1224. doi:10.1016/j.compchemeng.2007.04.020

Camm, J. D., Chorman, T. E., Dull, F. A., Evans, J. R., Sweeney, D. J., & Wegryn, G. W. (1997). Blending OR/MS judgement, and GIS: Restructuring P &G's supply chain. *Interfaces*, *27*(1), 128–142. doi:10.1287/inte.27.1.128

Chan, F. T. S., Chung, S. H., & Chan, P. L. Y. (2005). An adaptive genetic algorithm with dominated genes for distrbution scheduling problems. *Expert Systems with Applications*, *29*(2), 364–371. doi:10.1016/j.eswa.2005.04.009

Chang, Y. C., & Lee, C. Y. (2004). Machine scheduling with job delivery coordination. *European Journal of Operational Research*, *158*, 470–487. doi:10.1016/S0377-2217(03)00364-3

Chen, Z. L. (2004). *Integrated production and distribution operations: Taxonomy models and review*. Kluwer Academic Publishers.

Cheng, T. C. E., & Kovalyov, M. Y. (2001). Single supplier scheduling for multiple deliveries. *Annals of Operations Research*, *107*, 51–63. doi:10.1023/A:1014938712999

Cohen, M. A., & Lee, H. L. (1989). Resource deployment analysis of global manufacturing and distribution networks. *Journal of Manufacturing Operations and Management*, *2*, 81–104.

Dhaenens-Flipo, C., & Finke, G. (2001). An integrated model for an industrial production-distribution problem. *IIE Transactions*, *33*, 705–715. doi:10.1080/07408170108936867

Dogan, K., & Goetschalckx, M. (1999). A primal decomposition method for the integrated design of multi-period production-distribution systems. *IIE Transactions*, *31*, 1027–1036. doi:10.1080/07408179908969904

Erengüç, S. S., Simpson, N., & Vakharia, A. (1999). An integrated production/distribution planning in supply chains: An invited review. *European Journal of Operational Research*, *115*, 219–236. doi:10.1016/S0377-2217(98)90299-5

Garcia, J. M., Lozano, S., & Canca, D. (2004). Coordinated scheduling of production and delivery from multiple plants. *Robotics and Computer-integrated Manufacturing*, *20*, 191–198. doi:10.1016/j.rcim.2003.10.004

Geoffrion, A. M., & Graves, G. W. (1974). Multicommodity distribution design by Benders decomposition. *Management Science*, *20*(5), 822–844. doi:10.1287/mnsc.20.5.822

Goetschalckx, M., Vidal, J., & Koray, D. C. (2002). Modelling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. *European Journal of Operational Research*, *143*, 1–18. doi:10.1016/S0377-2217(02)00142-X

Gupta, A. K., & Sivakumar, A. I. (2006). A job shop scheduling techniques in semiconductor manufacturing. *International Journal of Advanced Manufacturing Technology*, *27*, 1163–1169. doi:10.1007/s00170-004-2296-z

Haq, A. N., Vrat, P., & Kanda, A. (1991). An integrated production inventory and distrbution model for manufacturing of urea: A case. *International Journal of Production Economics*, *25*, 39–50. doi:10.1016/0925-5273(91)90129-H

Jayaraman, V., & Prikul, H. (2001). Planning and coordination of production and distribution facilities for multiple commodities. *European Journal of Operational Research*, *133*, 394–408. doi:10.1016/S0377-2217(00)00033-3

Kanyalkar, A. P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 4431–4454. doi:10.1080/00207540500142332

Ko, H. J., & Evans, G. W. (2007). A genetic algorithm based heuristic for the dynamic integrated forward/reverse logistic network for 3PLs. *Computers & Operations Research*, *34*(2), 346–366. doi:10.1016/j.cor.2005.03.004

Lee, Y. H., Jeong, C. J., & Moon, C. (2002). Advanced planning and scheduling with outsourcing in manufacturing supply chain. *Computers & Industrial Engineering*, *43*(1-2), 351–374. doi:10.1016/S0360-8352(02)00079-7

Li, K., Ganesan, V. K., & Sivakumar, A. I. (2006). Scheduling of single stage assembly with air transportation in a consumer electronic supply chain. *Computers & Industrial Engineering*, *51*, 264–278. doi:10.1016/j.cie.2006.02.007

Li, K., Ganesan, V. K., & Sivakumar, A. I. (2008). Complexity and algorithms for synchronised scheduling of parallel machine assembly and air transportation in consumer electronics supply chain. *European Journal of Operational Research*, *187*, 442–455. doi:10.1016/j.ejor.2007.03.006

Matta, R., & Miller, T. (2004). Production and inter-facility transportation scheduling for a process industry. *European Journal of Operational Research*, *158*, 72–88. doi:10.1016/S0377-2217(03)00358-8

Park, Y. B. (2005). An integrated approach for production and distribution planning in supply chain management. *International Journal of Production Research*, *43*(6), 1205–1224. doi:10.1080/00207540412331327718

Pyke, D. F., & Cohen, M. (1993). Performance characteristics of stochastic integrated production-destruction systems. *European Journal of Operational Research*, *68*, 23–48. doi:10.1016/0377-2217(93)90075-X

Pyke, D. F., & Cohen, M. (1994). Multiproduct integrated production-distribution systems. *European Journal of Operational Research*, *74*, 18–49. doi:10.1016/0377-2217(94)90201-1

Vidal, C., & Goetschalckx, M. (1997). Strategic production–distribution models: A critical review with emphasis on global supply chain models. *European Journal of Operational Research*, *98*, 1–18. doi:10.1016/S0377-2217(97)80080-X

Williams, J. F. (1983). A hybrid algorithm for simultaneous scheduling of production and distribution in multi-echelon structure. *Management Science*, *29*, 77–92. doi:10.1287/mnsc.29.1.77

Zegordi, S. H., Kamal Abadi, I. N., & Beheshti, M. A. (2010). A novel genetic algorithm for solving production and transportation scheduling in a two-stage supply chain. *Computers & Industrial Engineering*, *58*, 373–381. doi:10.1016/j.cie.2009.06.012

ADDITIONAL READING

Bilgen, B., & Ozkarahan, I. (2007). A mixed-integer linear programming model for bulk grain blending and shipping. *International Journal of Production Economics*, *107*, 555–571. doi:10.1016/j.ijpe.2006.11.008

Eksioglu, S. D., Eksioglu, B., & Romeijn, H. E. (2007). A Lagrangean heuristic for integrating production and transportation planning in a dynamic, multi-item, two-layer supply chain. *IIE Transactions*, *39*, 191–201. doi:10.1080/07408170600733244

Jans, R., & Degrave, Z. (2008). Modelling industrial lot sizing problem: a review. *International Journal of Production Research*, *46*(6), 1619–1643. doi:10.1080/00207540600902262

Liang, T. F., & Cheng, H. W. (2008). Application of fuzzy sets to manufacturing/ distrbution planning decisions with multi-product and multi-time period in supply chains. *Expert Systems with Applications*, *36*, 3367–3377. doi:10.1016/j.eswa.2008.01.002

Mula, J., Peidro, D., Diaz-Madronero, M., & Vicens, E. (2010). Mathematical programming models for supply chain production and transportation. *European Journal of Operational Research*, *201*, 377–390. doi:10.1016/j.ejor.2009.09.008

Rizk, N., Martel, A., & D'amours, S. (2006). Multi-item dynamic production-distrbution planning in process industries with divergent finishing stages. *Computers & Operations Research*, *33*, 3600–3623. doi:10.1016/j.cor.2005.02.047

Sabri, E. H., & Beamon, B. M. (2000). A multi-objective approach to simultaneous strategic and operational planning in supply chain design. *Omega-International Journal of Management Science*, *28*, 581–598. doi:10.1016/S0305-0483(99)00080-8

Chapter 6
A Review of Research of Coordination Approaches in Distributed Production Systems

Paolo Renna
University of Basilicata, Italy

ABSTRACT

The increasing of global competition and the need for rapid response to market changes drive manufacturing enterprises to adopt new business models. This chapter examines the recent years of research developed in the field of coordination approaches to support distributed production systems. The papers discussed concern the period of 2004-2010 published in international ISI journals. The research articles are classified according to nine fields of research: operational research models; collaborative architecture; negotiation and bargaining models; capacity exchange; revenue sharing; chemical engineering; electronic approach; general review; case study. The analysis of the literature highlights that the articles are distributed uniformly over the years analyzed. The most fields investigated are the collaborative architecture and operational research models, while emerging fields are the chemical engineering and revenue sharing based approaches. The discussion underlines the limitation of the literature and suggests the directions for future research.

INTRODUCTION

Manufacturing enterprises have face to high and global competitive markets that force to change towards new organizational structure. The driving forces can be classified in two categories: market characteristics and Information and Communication Technology (ICT) developments. The market has been continuously changing in terms of demand volatility, shorter production cycles, rapid introduction of new product and introduction of new technologies. From the point of view of ICT,

DOI: 10.4018/978-1-4666-2098-8.ch006

the development of ICT technologies offer the possibility to support the cooperation of distributed production entities. These driving allow the manufacturing enterprises to develop new form of organization for integration and cooperation among several actors of a supply chain obtaining a production network structure. The manufacturing enterprises that operate in a production network are able to focus on their core competence, react to market changes with more flexibility of the organizational structure and more efficiency of the value chain. The production networks need coordination tools to support the activities of the network and the performance of the structure heavy depend on the methodologies used to develop these tools. (Wiendahl and Lutz, 2002). Basically, two approaches are available for managing production networks: a centralized approach, where a unique entity has got all the necessary information to make planning decisions for the entire network; On the other hand, a decentralized approach can be used; in this case, each entity in the network has the necessary information and knowledge to make autonomous planning decisions, while, the common goal is reached through a cooperation among all the network actors (Lo Nigro et al., 2003). It has been quite acknowledged that, while centralized approaches are theoretically better in pursuing global system performance, they have several drawbacks concerning operational costs, reliability, reactiveness, maintenance costs and so forth (Ertogral and Wu, 2000). Generally, it can be distinguished between two levels of coordination (Bhatnagar et al., 1993): the general level coordination can be seen in terms of integrating decisions of different functions (facility location, distribution, marketing, etc.); the second level regards the coordination problem within the same function (production planning, capacity allocation, etc.). Alvarez(2007) stated that companies are shifting from single manufacturing facilities to multi-factory in order to gain competitive advantages in the international economic arena. The objectives are to adopt models of coalition of enterprises able to rapidly react and adapt to market changing requirements. Some example of new business paradigms have benne proposed as Virtual Enterprises, Virtual Organization, Fractal Enterprises and extended enterprises. However, coordination models have to be identified within these organizations. The objective of this chapter is to review the literature related to the second level. The rest of this chapter is organized as follows. In Section 2 the methodology used to review the literature is explained. In Section 3, the review of the literature has been classified. In Section 5 the discussion of the literature with the future research paths are provided, Finally, in Section 6 the conclusions are discussed.

RESEARCH METHODOLOGY

The aim of this research is to classify cooperation in distribution production systems research conducted over recent years. Moreover, the research intended to identify the strengths and weaknesses of the literature themes investigated and the emergence of new themes, and trends in publication quantity. Articles for analysis were gathered from leading information system journals for the 5 year period 2004–2009 including the first part of 2010.

The number of journals selected was to 115 containing coordination tool in distributed production systems. Table 1 reports the list of journals that contains at least two papers dealing with the coordination in distribution production systems.

The articles were searched within journal with impact factor and the identification of articles within the journal list involved keyword searches and an exhaustive search on contents pages of the journals. Articles that appeared to fit into the distributed production planning category were verified by firstly reading the abstract and then the entire article to extract the main findings and emphasis of the article. Moreover, the books

Table 1. Reviewed journals and number of articles by year

Journal title	2004	2005	2006	2007	2008	2009	2010	No. of articles	% of total
Books	1	1	5	1	5	1	1	15	13.04%
Other journals	1	5	3	1		2	2	14	12.17%
International Journal of Production Economics	2	2	3		2	3	1	13	11.30%
International Journal of Production Research		5	2	2	2	2		13	11.30%
Computers and chemical engineering	2	1		1	4	2	1	11	9.57%
European Journal of operational research	2	2	1	2	1		1	9	7.83%
CIRP Annals - Manufacturing Technology	1	1	3	1	2	1		9	7.83%
Robotics and Computer Integrated Manufacturing	1			1		2	1	5	4.35%
Production Planning & Control	3	2						5	4.35%
Expert systems with applications				1		1	2	4	3.48%
Journal of intelligent manufacturing systems		1		1		1	1	4	3.48%
Computers in industry	2			1				3	2.61%
Engineering Application of Artificial Intelligence						3		3	2.61%
OMEGA				1	2			3	2.61%
Computers and industrial engineering			1			1		2	1.74%
International Journal of Advanced Manufacturing Technology				1			1	2	1.74%
									(100.00%)
Total	15	20	18	14	18	19	11	115	Stdv. 4.88

published on the distributed production planning issue were studied. Papers that investigated the integration of distributed production planning with other issues (as inventory management, bullwhip effect, horizontal cooperation, etc.) where the main issue isn't the distributed production planning are omitted.

Table 1 reports the percentage of the papers investigated for each journal and the deviation standard (Stdv.). The number of articles for each year is major or equal 14 (except 2010 year partially explored) that show a continuous attention of researchers in this field. The largest number of articles published regards the books on this research field over the last six years (13.04%). The international journal of production research and international journal of production economics are the journals with higher number of articles (11.30%). A significant remark can be made concerning the journal of Computers and Chemical Engineering that published more articles on distributed production planning systems (9.57%) in recent years. However, the low value of standard deviation of 4.88 show that the articles are distributed over the all journals discussed.

CLASSIFICATION OF LITERATURE

In this section the literature described in the above section are classified by journals, by year and according to their focus. The articles are classified from the grounded analysis into main nine high-level conceptual categories (Table 2):

1. Operational research models.
2. Collaborative architecture.
3. Negotiation and bargaining models.
4. Capacity exchange.
5. Revenue sharing.
6. Chemical engineering.
7. Electronic approach.
8. General review.
9. Case study.

Some articles that don't have a specific focus (many categories integrated among them), they are assigned to the main theme discussed.

Table 2 reports the percentage of the articles in each theme defined. Figure 1 shows the percentage of the articles analyzed among the research categories above introduced. As the reader can notice, two main themes are more discussed in recent years: collaborative architecture and operational research models. Then, negotiation and bargaining models is received a medium attention by researches, while the others themes have the same relevance.

Table 2. Number and percentage of articles in the major themes

Theme	No. of articles	% of articles
Collaborative architecture	35	30.43%
Operational research models	29	25.22%
Negotiation and bargaining models	11	9.57%
Electronic approaches	8	6.96%
Revenue sharing	7	6.09%
General review	7	6.09%
Chemical engineering	6	5.22%
Case study	6	5.22%
Capacity exchange	6	5.22%
total	115	100.00%

Each category is deeply described in the following sub-sections.

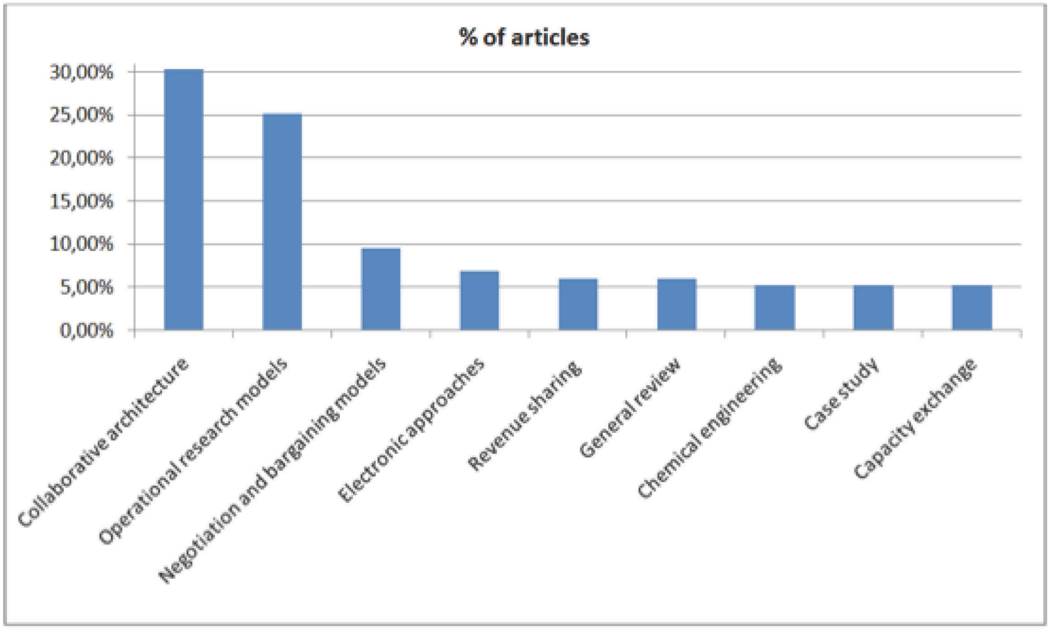
Collaborative Architecture

A major category of literature in distributed production planning research investigated the frameworks and architectures for collaborative mechanism in decentralized environment.

Some research papers deal with distributed architectures. Verwijmeren (2004). Windt and Hulsmann (2007) discussed the problems of the shift from conventional control to autonomous cooperation and control. Monostori et al. (2006), Lu and Wang (2008) developed Multi agent and software component architecture dedicated to supply chain coordination, which supports distributed and cooperative organizations. Valckenaers et al. (2004) proposed a multi agent architecture coordinated by stigmergy approach. Jia et al. (2004) proposed an agent architecture for product development and manufacture in a decentralized environment. Carvalho et al. (2005) propose an organization concept, the Autonomous Production System (APS), as the base unit to build autonomous and reconfigurable production systems. The APS unit has, simultaneously, the characteristic of the whole and of the part like Holons and the holarchy in the Holonic Manufacturing System. The PPC model proposed is related to the hierarchical PPC concept. These studies concerns the conceptual devolvement of Multi Agent Architectures that can be used in generalized problems.

More papers proposed Multi Agent Architectures in specific fields of applications. Lu et al. (2005) propose an agent-based collaborative production framework where orders, sub-assemblies, production lines and cells are modeled as agents that interact with each other in a collaborative

Figure 1. Distribution of the articles among the themes



way. Anussornnitisarn et al. (2005) developed a model of distributed resource allocation by applying market-based pricing and costing approach in the coordination network participants' decisions, a monetary unit is chosen as common medium of exchange for the coordination process. Dudek (2004), Schneeweiss and Zimmer (2004), Li and Wang (2007), Albino et al. (2007), Chiarvesio and Di Maria (2009) considered operational coordination mechanisms within a supply chain. In describing a particular link within an entire network, we employed main concepts of the theory of hierarchical planning and identified the top-level with the producer and the base-level with the supplier. Maritan et al. (2004), Monteiro et al. (2007) proposed an approach of coordination of decisions in a multi-site system. It is based this approach on a multi-agent concept and on the principle of distributed network of enterprises. For this purpose, each enterprise is defined as autonomous and performs simultaneously at the local and global levels.

Several studies was proposed to investigate the dynamics of the collaboration based on Multi Agent Systems. Caridi et al. (2004; 2005), Monostori et al. (2004) studied the collaborative planning and forecasting replenishment (CPFR) process and, in particular, the exceptions regarding sales and order forecast by means of a multi-agent system. The proposed system is composed of an 'advanced' model and a 'learning' model. The advanced model is able to recognize and dynamically solve the exceptions according to the criteria threshold values set in the front-end agreement between partners. The learning model, which is an evolution of the advanced model, allows the criteria threshold values to be updated by the model itself through the analysis of historical data. Experimental results indicate better performance, in terms of total costs (by comparison with CPFR without intelligent agents), inventory level and stock-out level and sales. Lima et al. (2006), Azevedo et al. (2004), Frayret et al. (2004) presented a model of an Agent-based Production Planning and Control (PPC) system that can be dynamically adaptable to local and distributed utilization of production resources and materials. Nof et al. (2006) studied the collaboration in a multi-enterprise environment. Allwood and Lee (2005) present an agent model that could be used to study the supply-chain network dynamics. The agent model has a strategic level and an operational level. The first is responsible for determining the prices and target inventory levels, ranking customers, and evaluating suppliers. The second is responsible for demand management, production planning and control, materials management, and accounting. Vancza et al. (2008), Duffie et al. (2008), Camarinha-Matos et al. (2005, 2007, 2008a, 2008b, 2009), Mahdavi et al. (2009) presented a coordination mechanism where sharing information truthfully and planning local production optimally serve both system-wide and individual objectives in a production network environment. Wagner and Nyhuis (2009) presented an approach to design a production network. Nair and Closs (2006) investigated the impact of coordinated operational policies like transportation expediting and replenishment, and pricing markdowns in a short lifecycle retail setting. Gunasekaran et al. (2008), Rudberg and West (2008), Abele et al. (2008) investigated the competitive strategies in production networks.

From the above review three sub- themes can be pointed out: general framework, MAS for specific fields and dynamics of the MAS. All these sub-themes are investigated over the horizon considered, but the dynamics issue is the more analyzed in recent years.

Key Research Questions

The issue of collaborative framework is the most investigated by researches (see Table 2), but some research questions can be highlighted.

- What are the technical implication for implement a real Multi Agent Architecture in Distributed Production Planning enterprises?
- How do the Agent based platform toolkits available can be used for industrial cases?
- How does the information exchange among agents can be relevant in real case application?

Operational Research Models

Significant works have been conducted on the development of operational models for distributed production planning. The aim of these models is to coordinate distributed planning with a collaborative approach based on operational models. Each partner, supplier or producer, is described in the mathematical model by an objective function.

Voß and Woodruff (2006), Schenk et al. (2010) described the factory planning process with its manifold practical characteristics. The model discussed is the practical production planning methodologies, while the cooperation among enterprises don't deeply discussed. van Wezel et al. (2006), Puigjaner L., Heyen G., (2006) discussed the models and support systems for production planning for multi-plant environment, where the plants operate in the same enterprise or with long-term stable collaboration.

The first sub-field concerns the development of mathematical models. Kanyalkar and Adil (2005) consider production planning of multi-site production facilities with substitutable capacities serving multiple-selling locations where the supplying plant is dynamically determined. A linear programming model is developed to produce the time and capacity aggregated plan and the detailed plan simultaneously to overcome the drawback of the hierarchical planning approaches of not yielding a feasible and/or an optimal lower-level plan. Kallrath (2005), Kallrath and Maindl (2006) developed a multisite, discrete-time planning model which divides the planning horizon into commercial periods and then further discretizes those commercial periods into production periods. Both the discrete-time nature of the model, as well as the limitation of one product changeover per production period can lead to the given planning model underestimating the true production capacity of the supply chain, but these two features are common within many planning models found in both academia and industry. Ryu and Pistikopoulos (2007) proposed a multiperiod planning model for a supply chain. The proposed framework decomposes the management of the supply chain into two optimization problems where first demands are aggregated and allocated to certain production facilities based in part upon geographic considerations. Then, individual planning problems are solved for each production facility. Chung et al. (2009) This paper studied a multi-factory production scheduling problem, which was structured in a series model. The model is subject to capacity constraints, precedence relationship, and alternative machines with different processing time. The objective function is to minimize the makespan, which consists of the processing time, the transportation time between resources either within the same factory or across two different factories, and the machine set-up time among operations. Jolayemi and Olorunniwo (2004) developed a deterministic model for planning production and transportation quantities in multi-plant and multi-warehouse environment with extensible capacities. Tsiakis and Papageorgiou (2008) proposed a model to determine the optimal configuration of a production and distribution network subject to operational and financial constraints. A mixed integer linear programming (MILP) model is proposed to describe the optimisation problem. Leung et al. (2006, 2007) developed robust optimization models for multi-site production planning problem. Gottlich et al. (2010) proposed a mathematical description that captures the dynamic behavior of the system by a coupled system of ordinary differential delay equations. The underlying optimization problem is solved using discretization techniques yielding a mixed-integer programming problem. Moon and Seo (2005), Caricato and Grieco (2009) considered a problem that is typical of companies that manufacture products in production plants placed in different production areas worldwide. A solution framework for the production allocation and balancing problems based on mathematical programming is proposed. Its computational efficiency is improved using techniques from constraint programming.

The second sub-fields regards the model solved by heuristic approaches. Park (2005) presents a heuristic solution for integrating production and distribution planning that is tested through a computational study in a multi-plant, multi-retailer, multi-item, multi-period logistic environment where the objective is to maximize the total net profit. Lee and Kwon (2010) proposed a tabu search and decomposed optimization for distribution centres operation. Hsu and Li (2009) proposed a Mixed Integer Program (MIP) and simulated annealing to optimal plant capacity, and the production amount among the plants of different-sized. Bilgen (2010) discussed the above problem by a fuzzy mathematical programming approach. Sauer (2006) proposed several methods for the problem of multi-site scheduling. Savkin adn Somlo (2009) considered a class of flexible manufacturing networks. They employed hybrid dynamical systems to model such networks. The main and new achievement of the paper is that they proposed a distributed implementable in real time scheduling rule such that the corresponding closed-loop system is stable and optimal. Sambasivan and Yahya (2005) proposed a lagrangian-based heuristic for multi-plant, multi-item, multi-period capacited lot-sizing problems with inter-plant transfers. Torabi and Hessani (2009) proposed a fuzzy goal programming approach for multi-site production environment.

Huang et al. (2008) suggested an order confirmation mechanism that allows synchronizing the available capacities over the supply network. Tseng and Huang (2009) proposed a model to produce an assembled product, the components need to be manufactured within the allocated tolerances such that the assembly operations can be performed to produce the final product. In a collaborative manufacturing environment, the components of a product may be manufactured at different plants distributed at various locations. Aprile et al. (2005) take into account two main aspects: the process flexibility of each Supply Chain (SC) firm and the logistics flexibility concerning the possible connections between suppliers, assemblers and markets. Different configurations of an SC are proposed, in correspondence to different degrees of the process and logistics flexibility. Ambruster et al. (2006) proposed a model for autonomous control in production networks using an approach based on pheromone. Lan et al. (2010) proposed a mathematical model for fuzzy multi-period production planning. It can be notice, that the heuristic approaches in recent years are more sparse among several methodologies.

Key Research Questions

- How the mathematical models can be used when the plants are independent, and therefore with reduced information sharing?
- What are the advantages/drawbacks of the heuristic approaches compared among them?
- How neural network and simulation can be a valid approach?
- How the mathematical model can investigate the dynamicity of a network?

Negotiation and Bargaining Models

In particular, the paper (Lo Nigro, 2006) suggests a production planning architecture able to highlight relationships among subtasks' variables in which mechanisms assure consistency among solutions of different planning levels. Moreover, the paper proposes negotiation frameworks as effective tools to manage production planning subtasks. Walther et al. (2008) proposed a negotiation approach implemented via Lagrangian relaxation and subgradient optimisation which only requires a minimum data exchange. Lee and Kumara (2007) designed multiple auctions and each auction coordinates the plans of a supplier and its customers by trading the right of managing the supplier's inventory plan. Wang et al. (2004) proposed a coordination mechanism based on game theory between two echelon decentralized supply chain. Chen et al. (2008) proposed a negotiation approach for trading capacity between two autonomous factory. Vancza and Egri (2006) proposed a contract-based approach to coordinate a supply networks. Chen and Wang (2009) developed a game theory approach to allocate orders in a multi-facility environment. Wang et al. (2009) proposed an agent based negotiation and decision making for the design of a supply chain. Beaudoinc et al. (2010) developed a negotiation approach for a multi-firm environment in the wood procurement planning case. Dudek and Stadler (2005) Dudek (2009) discussed the negotiation approaches for collaborative planning in supply chains. The negotiation methodologies are more investigated in recent years; the game theory approach in this fields is not deeply investigated.

Key Research Questions

- What are the advantages/drawbacks of game theory compared to classical negotiation approaches?
- How do negotiation strategies can influence the performance of distribute production planning?
- What is the difference among auction protocols?

Electronic Approaches

Ulieru and Cobzaru (2005) propose a Holonic supply-chain management system for the Telephone Manufacturing Industry. The MAS is based on the following agents: Logistics, Order Manager, Customer, Transport, Bank, and several Plant agents representing the assembly plant and various suppliers. Hausen et al. (2006), Friz and Hausen (2009) discussed the potential of electronic supply network coordination. Kim and Park (2008) suggest a conceptual framework for aligning the strategic issues and the structural issues of supply chain management based on e-business application. Argoneto and Renna (2010) developed an e-business model based on production planning and negotiation tools for orders allocation. Zhang et al. (2006) proposed an approach for integration in supply chain based on multi agent systems and electronic infrastructure. Chen et al. (2009) discussed the collaboration in production networks by electronic approach. Perrone at al. (2005) discussed end proposed innovative tools for managing operations in enterprise networks.

Key Research Questions

- How electronic approaches ca support the dynamic production networks?
- How electronic infrastructures can be used as integration among several levels of production networks?
- What are the real economic benefits of electronic approaches?

General Review

Several papers discussed the review of different problem of the issue discussed in this chapter. A large literature review on this area can be found in the paper of Stadtler (2005). Mula et al. (2006) discussed the models for production planning in uncertainly environment. Alvarez (2007) presented a review of production scheduling in multi-site environment for Small and Medium Enterprises. Varma et al. (2007) discussed an overview of emerging research challenge and opportunities for optimizing and modeling in distributed enterprise environment. Grunow et al. (2007) analyzed the evolution of production networks structure. Mazzola et al. (2009) discussed the most significant theories on firm networking are reviewed and an innovative strategic framework that mainly underlies at firm networks organisation is proposed. Very briefly, it is argued that networks are differently organised according to three basic strategic objectives: to gain efficiency; to collect knowledge; to pursue globalization. The proposed framework has been tested within the manufacturing industry through an empirical survey conducted on 93 case studies. Leitao (2009) discussed the state of the art related to the use of Multi Agent architecture in distributed manufacturing control.

Key Research Questions

- What are the research approaches implemented in real cases?

Capacity Sharing

Bruccoleri et al. (2005) Argoneto et al. (2006) proposed approaches to coordinate a production network made of different and geographically dispersed plants that, in case of unpredictable market changes, can be reconfigured in order to gather a specific production objective. Bruccoleri proposed a negotiation approach, while Argoneto a game theory approach. Wu and chang (2007) proposed a model for capacity trading among semiconductor fabs. Ahlert et al. (2009) analyzed the problem of sizing the network capacity pool by a decentralised planning process applying the top-down/bottom-up principle. Argoneto et al. (2008), Renna and Argoneto (2010) proposed research develops a distributed approach, for a network of independent enterprises, able to facilitate the capacity process by using a multi-agent architecture and a cooperative protocol. The last one is based on game theory and, in particular, on Nash bargaining solution. The above papers show how the capacity sharing among plants is a very interesting fields of research in recent years.

Key Research Questions

- What are the benefits of integration between capacity and production exchange?
- How the capacity exchange can affect the capacity expansion decisions?
- What are the advantages/drawbacks of heuristic approaches?

Case Study

In this section are reported the papers in which application in real case are discussed. Levis and Papageorgiou (2004), Meijboom and Obel (2007) proposed a solution for capacity planning in multi site pharmaceutical industry. Ceroni and Nof (2005) presented a case study in the shoe industry for task allocation. Lin and Chen (2007) developed a multi-plant planning model which deals in part with the distribution of demands among the various production facilities. The planning model simultaneously takes into account two different time scales (i.e., monthly and daily time scales) by means of varying time buckets within the formulation. Taking into account multiple time scales can become vital when dealing with products which have varying distributions of demand due dates. However, the issue of intermediate demand due dates was not explicitly addressed within the formulation. The approach is applied in TFT-LCD industry. Sousa et al. (2008) discussed the supply chain design and planning problems in process industry. Sousa, Shah, and Papageorgiou (2008) proposed a multilevel planning framework for an industrial supply chain. The first-level aggregate planning model determines the active nodes within the supply chain, as well as the allocation of customer demands among the various active production facilities. The second-level planning model more rigorously takes into account the production capacity of the supply chain, and with the supplied information from the first-level aggregate planning model, it determines the detailed production and distribution profile for the supply chain. This approach requires additional computational time to solve two planning models as opposed to one for the time horizon of interest. As evidenced by the various multisite planning models summarized above, the effective operational planning of a supply chain requires one to explicitly take into account the transportation between production and distribution centers; however, supply chain production capacity considerations cannot be neglected either. If the multisite operational planning model does not provide a tight upper bound on the production capacity of each production facility within the supply chain, then resources may be inefficiently allocated and orders may go unnecessarily unsatisfied. It is important that the multisite planning model takes into account the production capacity of each production facility, as well as the interplay between the customer distribution centers and each product facility within the supply chain. The length of the operational planning horizon makes the rigorous modeling of the supply chain's production capacity computationally prohibitive, and as a result, several aggregation schemes have been adopted. The quality of the aggregation scheme is ultimately measured by its ability to supply a tight upper bound on the true production capacity of the supply chain. Several planning level aggregation schemes will be presented in the sequel to show how this modeling obstacle has been previously addressed.

Key Research Questions

- What are the most promising fields of applications?

Chemical Engineering

In recent years several application for multi-site planning have been developed in chemical industries. Verderame al. (2009), Behdania et al. (2010), Dondo et al. (2008), Al-Qathani and Elkamel (2008) have been proposed model for management of planning and logistic activities in multi-site environment. Chen and Lee (2004) proposed a multi-objective optimization model in a supply chain networks. Varma, Reklaitis, Blau, and Pekny (2007) provided an overview of the potential research avenues present within the field of enterprise-wide modeling and optimization. A summary of several multisite planning models will be presented in order to provide a basis for the contribution of this paper.

Key Research Questions

- How the approaches proposed for discrete manufacturing systems can be implemented in chemical industries?

Revenue Sharing

Lots of works have been devoted to employing revenue sharing mechanism to coordinate a decentralized supply chain. Most of them focus on designing the revenue sharing schemes to improve the SC profits, such as Chauhan and Proth (2005) and Gupta and Weerawat (2006). However, it remains unclear that how transfer pricing heuristics in practice impact on the coordination and their interactions with the revenue sharing rates in a decentralized supply chain with multi-plants, multiperiods and finite capacity. The considered decentralized supply chain consists of manufacturer and distributor echelons. The two echelons interact with each other through the transfer price and the product order. The transfer price is a key variable in the coordination. The transfer price determines the order quantity for the distributors and then affects the total SC profits. In addition, the revenue sharing rate can affect the manufacturer for determining the transfer prices. Understanding the effects of these pricing heuristics and their interactions with revenue sharing rate can help us design better revenue sharing mechanism to put into practice. Cachon and Lariviere (2005) proved that revenue sharing contracts are equivalent to buy back contracts in the fixed-price newsvendor environment; and are equivalent to price discounts in the pricesetting newsvendor. However, there are some cases in which revenue sharing contracts are not appropriate, as pointed out by Cachon and Lariviere. Firstly, while revenue sharing contracts coordinate retailers to compete on quantity, it does not coordinate retailers to compete both on price and quantity. Secondly, when the earnings from the revenue sharing contract do not cover the additional administrative expense incurred by such a contract, it is not appropriate to employ revenue sharing contracts to coordinate a supply chain. Thirdly, the revenue sharing contract may not be attractive if retailers can take action to influence demand. The revenue sharing contract has been designed from many perspectives in the literature. Chauhan and Proth have studied the revenue sharing contract that is proportional to the risks undertaken by the involved parties (Chauhan and Proth, 2005). Gupta and Weerawat (2006) investigated three types of revenue sharing contracts for supplier-manufacturer coordination. The first kind of contract is that revenue sharing depends on the supply lead time. In the second kind of contract, the supplier guarantees a delivery lead time to the manufacturer and incurs an expedited shipping charge if the supplier cannot meet the promised lead time. In the last kind of contract, the revenues shared to the supplier rely on the supplier's inventory level. Giannoccaro and Pontrandolfo (2004) built revenue sharing models for two-and three-stage supply chains. Their analytical solutions showed that the transfer price for the distributor equals the revenue keep rate times the marginal cost in the two-stage supply chain. In a revenue sharing contract, the buyer reimburses the seller some of its revenues for the discount on the wholesale prices (Simchi-Levi et al., 2008).

Key Research Questions

- Is revenue sharing alternative to other approaches?
- What are the benefits of integration among revenue sharing and other approaches?

DISCUSSION

The recent five years of distributed production system research have been studied. The classification of the literature presented in this article has proposed nine research areas. All the nine research areas have received the same attention during the years analyzed. Two areas of research are predominant: collaborative and operational models. Although there have been a considerable number of articles published in leading journals on these issues there are still many unanswered questions and areas that lack clarity. Many articles have focused on multi agent architecture, but few articles have investigated the implication of real application of multi agent toolkits and the barriers to the adoption of them. In the area of operational research, few papers investigated the application of mathematical model when independent enterprises are involved and therefore the centralized information is reduced. Moreover, several research issues can be deeply investigated as the comparison of heuristic with mathematical approaches in different environmental conditions, integration between simulation and heuristic approaches.

Few articles have been proposed in the other areas of research. Among them, some emerged areas in recent years can be pointed out. In recent years (2007-2010) the application of multi-plant coordination methodologies in chemical industries have received more attention. This interest is, also, confirmed by some papers of case study presented in chemical and pharmaceutical industries (Meijboom and Obel, 2007; Sousa et al., 2008;). Another new research area is the cooperation at capacity level. Some recent articles investigated the possibility to exchange capacity among multi-plant environment. This research issue can divided in two sub-issues: if the plants operate in the same enterprise or the plants are independent. The information available to develop cooperation approach have to take into account this aspect.

A promising area of research is the revenue sharing approach; the main aspects investigated regard the cooperation among retailers in supply chains. These approaches can be most promising also in other cooperation mechanism of production networks.

Limitations and Future Research Paths

From the analysis of the above literature several questions research are opened (described in the above paragraphs). The main limit is the development of different approaches of cooperation that can be integrated among them. The mature subjects as mathematical, heuristic, fuzzy, etc. have been investigated individually, but the integration among them can be a relevant improvement in cooperation mechanism. A significant research area can be represent by the vertical integration of different level of cooperation. In particular three main areas of a supply chain can be interested: capacity exchange; production planning; distributed centres. The performance investigation of a top-down structure in which the first activity is the cooperation of capacity, then the production planning distribution and finally the cooperation among distribution centres. How the classical cooperation methodologies operate in a distributed environment with several methodologies interconnected. Moreover, it has to be notice that the first two levels (capacity and production planning) were investigated, while the cooperation among distribution centres is an area of research with very few attentions. In briefly, the future research paths highlighted are the following:

- Investigation of approaches with integration of different methodologies in the area of operational research.
- Study of the interaction of cooperation models applied in different levels of the enterprises (capacity, production planning and distribution centres).
- Development of cooperation models in the area of distribution centres.
- How the revenue sharing methodologies can support and improve the cooperation models developed.
- What are the real advantages of application of production networks cooperation in real application?

CONCLUSION

The chapter deals with the analysis of the recent literature on the cooperation mechanism in distributed production systems. The analysis has been conducted over the period 2004-2010 and pointed out the specific research areas. The papers discussed show how the research on these fields is uniformly distributed over the years investigated. The research articles are classified according to nine fields of research: operational research models; collaborative architecture; negotiation and bargaining models; capacity exchange; revenue sharing; chemical engineering; electronic approach; general review; case study. Finally, the future research paths are proposed. However, this review of distributed production planning research has been restricted to journals with impact factor. This means that it may not be representative of all articles published, because proceeding of conferences are excluded. This is the main limit of the review presented in this chapter.

REFERENCES

Abele, E., Meyer, T., Näher, U., Strube, G., & Sykes, R. (Eds.). (2008). *Global production: A handbook for strategy and implementation*. Berlin, Germany: Springer.

Ahlert, K.-H., Corsten, H., & Gossinger, R. (2009). Capacity management in order-driven production networks— A flexibility-oriented approach to determine the size of a network capacity pool. *International Journal of Production Economics*, *118*, 430–441. doi:10.1016/j.ijpe.2008.11.013

Al-Qahtani, K., & Elkamel, A. (2008). Multisite facility network integration design and coordination: An application to the refining industry. *Computers & Chemical Engineering*, *32*, 2189–2202. doi:10.1016/j.compchemeng.2007.10.017

Albino, V., Carbonara, N., & Giannoccaro, I. (2007). Supply chain cooperation in industrial districts: A simulation analysis. *European Journal of Operational Research*, *177*(1), 261–280. doi:10.1016/j.ejor.2005.12.007

Allwood, J. M., & Lee, J.-H. (2005). The design of an agent for modelling supply chain network dynamics. *International Journal of Production Research*, *43*, 4875–4898. doi:10.1080/00207540500168295

Alvarez, E. (2007). Multi-plant production scheduling in SMEs. *Robotics and Computer-integrated Manufacturing*, *23*, 608–613. doi:10.1016/j.rcim.2007.02.006

Anussornnitisarn, P., Nof, S. Y., & Etzion, O. (2005). Decentralized control of cooperative and autonomous agents for solving the distributed resource allocation problem. *International Journal of Production Economics*, *98*(2), 114–128. doi:10.1016/j.ijpe.2004.05.015

Aprile, D., Garavelli, A. C., & Giannoccaro, I. (2005). Operations planning and flexibility in a supply chain. *Production Planning and Control*, *16*(1), 21–31. doi:10.1080/09537280412331313348

Argoneto, P., Bruccoleri, M., Lo Nigro, G., Perrone, G., Noto La Diega, S., Renna, P., & Sudhoff, W. (2006). High level planning of reconfigurable enterprises: A game theoretic approach. *CIRP Annals - Manufacturing Technology, 55*(1), 509-512.

Argoneto, P., Perrone, G., Renna, P., Lo Nigro, G., Bruccoleri, M., & Noto La Diega, S. (2008). *Production planning in production networks models for medium and short-term planning*. Springer.

Argoneto, P., & Renna, P. (2010). Production planning, negotiation and coalition integration: A new tool for an innovative e-business model. *Robotics and Computer-integrated Manufacturing*, *26*(1), 1–12. doi:10.1016/j.rcim.2009.01.001

Armbruster, D., Beer, C., de Freitag, M., Jagalski, T., & Ringhofer, C. (2006). Autonomous control of production networks using a pheromone approach. *Physica A*, *363*(1), 104–114. doi:10.1016/j.physa.2006.01.052

Azevedo, A. L., Toscano, C., Sousa, J. P., & Soares, A. L. (2004). An advanced agent-based order planning system for dynamic networked enterprises. *Production Planning and Control*, *15*(2), 133–144. doi:10.1080/09537280410001662538

Beaudoinc, D., Frayretb, J.-M., & LeBela, L. (2010). Negotiation-based distributed wood procurement planning within a multi-firm environment. *Forest Policy and Economics*, *12*(2), 79–93. doi:10.1016/j.forpol.2009.07.007

Behdania, B., Lukszo, Z., Adhitya, A., & Srinivasanb, R. (2010). Performance analysis of a multi-plant specialty chemical manufacturing enterprise using an agent-based model. *Computers & Chemical Engineering*, *34*(5). doi:doi:10.1016/j.compchemeng.2010.01.020

Bhatnagar, R., Chandra, P., & Goyal, S. K. (1993). Models for multi-plant coordination. *European Journal of Operational Research*, *67*(2), 141–160. doi:10.1016/0377-2217(93)90058-U

Bilgen, B. (2010). Application of fuzzy mathematical programming approach to the production allocation and distribution supply chain network problem. *Expert Systems with Applications*, *37*, 4488–4495. doi:10.1016/j.eswa.2009.12.062

Bruccoleri, M., Lo Nigro, G., Perrone, G., Renna, P., & Noto La Diega, S. (2005). Production planning in reconfigurable enterprises and reconfigurable production systems. *CIRP Annals - Manufacturing Technology, 54*(1), 433-436.

Cachon, G., & Lariviere, M. (2005). Supply chain coordination with revenue sharing contracts: Strengths and limitations. *Management Science*, *51*, 30–44. doi:10.1287/mnsc.1040.0215

Camarinha-Matos, L. M., & Afsarmanesh, H. (2005). Collaborative networks: A new scientific discipline. *Journal of Intelligent Manufacturing*, *16*(4–5), 439–452. doi:10.1007/s10845-005-1656-3

Camarinha-Matos, L. M., & Afsarmanesh, H. (2007). A comprehensive modeling framework for collaborative networked organizations. *Journal of Intelligent Manufacturing*, *18*(5), 529–542. doi:10.1007/s10845-007-0063-3

Camarinha-Matos, L. M., & Afsarmanesh, H. (2008). *Collaborative networks – Reference modeling*. New York, NY: Springer.

Camarinha-Matos, L. M., Afsarmanesh, H., Galeano, N., & Molina, A. (2009). Collaborative networked organizations – Concepts and practice in manufacturing enterprises. *Computers & Industrial Engineering*, *57*, 46–60. doi:10.1016/j.cie.2008.11.024

Camarinha-Matos, L. M., Afsarmanesh, H., & Ollus, M. (2008). *Methods and tools for collaborative networked organizations*. New York, NY: Springer. doi:10.1007/978-0-387-79424-2

Caricato, P., & Grieco, A. (2009). A DSS for production planning focused on customer service and technological aspects. *Robotics and Computer-integrated Manufacturing*, *25*(6), 871–878. doi:10.1016/j.rcim.2009.06.003

Caridi, M., & Cavalieri, S. (2004). Multi-agent systems in production planning and control: An overview. *Production Planning and Control*, *15*(2), 106–118. doi:10.1080/09537280410001662556

Caridi, M., Cigolini, R., & De Marco, M. (2005). Improving supply-chain collaboration by linking intelligent agents to CPFR. *International Journal of Production Research*, *43*(20), 4191–4218. doi:10.1080/00207540500142134

Carvalho, J. D., Moreira, N., & Pires, L. C. M. (2005). Autonomous production systems in virtual enterprises. *Journal of Computer Integrated Manufacturing*, *18*, 357–366. doi:10.1080/09511920500081445

Ceroni, J. A., & Nof, S. Y. (2005). Task parallelism in distributed supply organizations: A case study in the shoe industry. *Production Planning & Control: The Management of Operations*, *16*(5), 500–513. doi:10.1080/09537280500121851

Chauhan, S. S., & Proth, J.-M. (2005). Analysis of a supply chain partnership with revenue sharing. *International Journal of Production Economics*, *97*, 44–51. doi:10.1016/j.ijpe.2004.05.006

Chen, C. L., & Lee, W. C. (2004). Multi-objective optimization of multiechelon supply chain networks with uncertain product demands and prices. *Computers & Chemical Engineering*, *28*(6–7), 1131–1144. doi:10.1016/j.compchemeng.2003.09.014

Chen, J. C., Wang, K. J., Wang, S. M., & Jang, S. J. (2008). Price negotiation for capacity sharing in two-factory environment using genetic algorithm. *International Journal of Production Research*, *46*(7), 1847–1868. doi:10.1080/00207540601008440

Chen, W.-L., Huang, C.-Y., & Lai, Y.-C. (2009). Collaborative e-work networks in industrial engineering. *Computers & Industrial Engineering*, *57*(1), 61–72. doi:10.1016/j.cie.2008.08.012

Chen, Y. J., & Wang, W.-L. (2009). Orders dispatching game for a multi-facility manufacturing system. *Expert Systems with Applications*, *36*(2), 1885–1892. doi:10.1016/j.eswa.2007.12.040

Chiarvesio, M., & Di Maria, E. (2009). Internationalization of supply networks inside and outside clusters. *International Journal of Operations & Production Management*, *29*(11). doi:10.1108/01443570911000186

Chung, S. H., Lau, H. C. W., Choy, K. L., Ho, G. T. S., & Tse, Y. K. (2009). Application of genetic approach for advanced planning in multi-factory. *International Journal of Production Economics*, *127*(2). doi:doi:10.1016/j.ijpe.2009.08.019

Dondo, R., Mendez, C. A., & Cerda, J. (2008). Optimal management of logistic activities in multi-site environments. *Computers & Chemical Engineering*, *32*, 2457. doi:10.1016/j.compchemeng.2007.10.002

Dudek, G. (2004). *Collaborative planning in supply chains*. Berlin, Germany: Springer.

Dudek, G. (2009). *Collaborative planning in supply chains: A negotiation-based approach* (2nd ed.). Springer. doi:10.1007/978-3-540-92176-9

Dudek, G., & Stadler, H. (2005). Negotiation based collaborative planning between supply chains partners. *European Journal of Operational Research*, *163*, 668–687. doi:10.1016/j.ejor.2004.01.014

Duffie, N. A., Roy, D., & Shi, L. (2008). Dynamic modeling of production networks of autonomous work systems with local capacity control. *CIRP Annals - Manufacturing Technology, 57*, 463–466.

Ertogral, K., & Wu, S. D. (2000). Auction-theoretic coordination of production planning in the supply chain. *IIE Transactions*, *32*, 931–940. doi:10.1080/07408170008967451

Frayret, J.-M. D., & Montreuil, B. (2004). Co-ordination and control in distributed and agent-based manufacturing systems. *Production Planning and Control*, *15*(1), 1–13. doi:10.1080/09537280410001658344

Fritz, M., & Hausen, T. (2009). Electronic supply network coordination in agrifood networks- Barriers, potentials, and path dependencies. *International Journal of Production Economics*, *121*, 441–453. doi:10.1016/j.ijpe.2007.02.025

Giannoccaro, I., & Pontrandolfo, P. (2004). Supply chain coordination by revenue sharing contracts. *International Journal of Production Economics*, *89*, 131–139. doi:10.1016/S0925-5273(03)00047-1

Göttlich, S., Herty, M., & Ringhofer, C. (2010). Optimization of order policies in supply networks. *European Journal of Operational Research*, *202*, 456–465. doi:10.1016/j.ejor.2009.05.028

Grunow, M., Günther, H. O., Burdenik, H., & Alting, L. (2007). Evolving production network structures. *CIRP Annals - Manufacturing Technology, 56*(1), 427-430.

Gunasekaran, A., Lai, K.-H., & Edwin Cheng, T. C. (2008). Responsive supply chain: A competitive strategy in a networked economy. *Omega*, *36*(4), 549–564. doi:10.1016/j.omega.2006.12.002

Gupta, D., & Weerawat, W. (2006). Supplier-manufacturer coordination in capacited two-stage supply chains. *European Journal of Operational Research*, *175*, 67–89. doi:10.1016/j.ejor.2005.04.021

Hausen, T., Fritz, M., & Schiefer, G. (2006). Potential of electronic trading in complex supply chains: An experimental study. *International Journal of Production Economics*, *104*, 580–597. doi:10.1016/j.ijpe.2005.04.010

Hsu, H.-C., & Li, H.-C. (2009). An integrated plant capacity and production planning model for high-tech manufacturing firms with economies of scale. *International Journal of Production Economics*, *118*(2), 486–500. doi:10.1016/j.ijpe.2008.09.015

Huang, C. Y., Huang, C. C., & Liu, C. Y. (2008). Order confirmation mechanism for collaborative production networks. *International Journal of Production Research*, *46*(3), 595–620. doi:10.1080/00207540600844019

Jia, H. Z., Ong, S. K., Fuh, J. Y. H., Zhang, Y. F., & Nee, A. Y. C. (2004). An adaptive and upgradable agent-based system for coordinated product development and manufacture. *Robotics and Computer-integrated Manufacturing*, *20*(2), 79–90. doi:10.1016/j.rcim.2003.08.001

Jolayemi, J., & Olorunniwo, F. (2004). A deterministic model for planning production quantities in a multi-plant, multi-warehouse environment with extensible capacities. *International Journal of Production Economics*, *87*(2), 99–113. doi:10.1016/S0925-5273(03)00095-1

Kallrath, J. (2005). Solving planning and design problems in the process industry using mixed integer and global optimization. *Annals of Operations Research*, *140*, 339. doi:10.1007/s10479-005-3976-2

Kallrath, J., & Maindl, T. I. (2006). *Real optimization with SAP-APO*. Heidelberg, Germany: Springer.

Kanyalkar, P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 31–54. doi:10.1080/00207540500142332

Kim, S. W., & Park, S. (2008). Development of a three-echelon SC model to optimize coordination costs. *European Journal of Operational Research*, *184*(3), 1044–1061. doi:10.1016/j.ejor.2006.11.033

Lan, Y., Liu, Y., & Sun, G. (2010). An approximation-based approach for fuzzy multi-period production planning problem with credibility objective. *Applied Mathematical Modelling*, *34*(11). doi:10.1016/j.apm.2010.02.013

Lee, S., & Kumara, S. (2007). Decentralized supply chain coordination through action markets: Dynamic lot-sizing in distribution network. *International Journal of Production Research*, *45*, 4715–4733. doi:10.1080/00207540600844050

Lee, Y. H., & Kwon, S. G. (2010). The hybrid planning algorithm for the distribution center operation using tabu search and decomposed optimization. *Expert Systems with Applications*, *37*(4), 3094–3103. doi:10.1016/j.eswa.2009.09.020

Leitão, P. (2009). Agent-based distributed manufacturing control: A state-of-the-art survey. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.005

Leung, S. C. H., Tsang, S. O. S., Ng, W. L., & Wu, Y. (2007). A robust optimization model for multi-site production planning problem in an uncertain environment. *European Journal of Operational Research*, *181*(1), 224–238. doi:10.1016/j.ejor.2006.06.011

Leung, S. C. H., Wu, Y., & Lai, K. K. (2006). A stochastic programming approach for multi-site aggregate production planning. *The Journal of the Operational Research Society*, *57*(2), 123–132.

Levis, A. A., & Papageorgiou, L. G. (2004). A hierarchical solution approach for multi-site capacity planning under uncertainty in the pharmaceutical industry. *Computers & Chemical Engineering*, *28*(5), 707–725. doi:10.1016/j.compchemeng.2004.02.012

Li, X., & Wang, Q. (2007). Coordination mechanisms of supply chain systems. *European Journal of Operational Research*, *179*(1), 1–16. doi:10.1016/j.ejor.2006.06.023

Lima, R. M., Sousa, R. M., & Martins, P. J. (2006). Distributed production planning and control agent-based system. *International Journal of Production Research*, *44*(18), 3693–3709. doi:10.1080/00207540600788992

Lin, J. T., & Chen, Y. (2007). A multi-site supply network planning problem considering variable time buckets—A TFT-LCD industry case. *International Journal of Advanced Manufacturing Technology*, *33*, 1031. doi:10.1007/s00170-006-0537-z

Lo Nigro, G., Bruccoleri, M., & Perrone, G. (2006). Negotiation in distributed production planning environments. *International Journal of Production Research*, *44*(18), 3743–3758. doi:10.1080/00207540600575787

Lo Nigro, G., Noto La Diega, S., Perrone, G., & Renna, P. (2003). Coordination policies to support decision making in distributed production planning. *Robotics and Computer-integrated Manufacturing*, *19*, 521–531. doi:10.1016/S0736-5845(03)00062-0

Lu, L., & Wang, G. (2008). A study on multi-agent supply chain framework based on network economy. *Computers & Industrial Engineering*, *54*, 288–300. doi:10.1016/j.cie.2007.07.010

Lu, T. P., Chang, T. M., & Yih, S. (2005). Production control framework for supply chain management—an application in the elevator manufacturing industry. *International Journal of Production Research*, *43*(20), 4219–4233. doi:10.1080/00207540500142167

Mahdavi, I., Mohebbi, S., Zandakbari, M., Cho, N., & Mahdavi-Amiri, N. (2009). Agent-based web service for the design of a dynamic coordination mechanism in supply networks. *Journal of Intelligent Manufacturing*, *20*(6). doi:10.1007/s10845-008-0173-6

Maritan, C. A., Brush, T. H., & Karnani, A. G. (2004). Plant roles and decision autonomy in multi-national plant networks. *Journal of Operations Management*, *22*, 489–503. doi:10.1016/j.jom.2004.05.007

Mazzola, E., Bruccoleri, M., & Perrone, G. (2009). A strategic framework for firm networks in manufacturing industry: An empirical survey. *CIRP Annals - Manufacturing Technology, 58*(1), 387-390.

Meijboom, B., & Obel, B. (2007). Tactical coordination in a multi-location and multistage operations structure: A model and a pharmaceutical company case. *Omega*, *35*, 258–273. doi:10.1016/j.omega.2005.06.003

Monostori, L., Csaji, B. C., & Kadar, B. (2004). Adaptation and learning in distributed production control. *CIRP Annals Manufacturing Technology*, *53*(1), 349–352. doi:10.1016/S0007-8506(07)60714-8

Monostori, L., Vancza, J., & Kumara, S. (2006). Agent-based systems for manufacturing. *CIRP Annals Manufacturing Technology*, *55*(2), 697–720. doi:10.1016/j.cirp.2006.10.004

Monteiro, T., Roy, D., & Anciaux, D. (2007). Multi-site coordination using a multi-agent system. *Computers in Industry*, *58*, 367–377. doi:10.1016/j.compind.2006.07.005

Moon, C., & Seo, Y. (2005). Evolutionary algorithm for advanced process planning and scheduling in a multi-plant. *Computers & Industrial Engineering*, *48*, 311–325. doi:10.1016/j.cie.2005.01.016

Mula, J. (2006). Models for production planning under uncertainty: A review. *International Journal of Production Economics*, *103*, 271–285. doi:10.1016/j.ijpe.2005.09.001

Nair, A., & Closs, D. J. (2006). An examination of the impact of coordinating supply chain policies and price markdowns on short lifecycle product retail performance. *International Journal of Production Economics*, *102*(2), 379–392. doi:10.1016/j.ijpe.2005.04.009

Nof, S. Y., Morel, G., Monostori, L., Molina, A., & Filip, F. (2006). From plant and logistics control to multi-enterprise collaboration. *Annual Reviews in Control*, *30*(1), 55–68. doi:10.1016/j.arcontrol.2006.01.005

Park, Y. B. (2005). An integrated approach for production and distribution planning in supply chain management. *International Journal of Production Research*, *43*(6), 1205–1224. doi:10.1080/00207540412331327718

Perrone, G. (2005). Manufacturing e-marketplaces: innovative tools for the extended enterprise. In Perrone, G., Bruccoleri, M., & Renna, P. (Eds.), *Designing and evaluating value added services in manufacturing e-marketplace*. Berlin, Germany: Springer. doi:10.1007/1-4020-3152-1_1

Puigjaner, L., & Heyen, G. (2006). *Computer aided process and production engineering*. Wiley & Son. ISBN: 9783527308040

Renna, P., & Argoneto, P. (2010). A game theoretic coordination for trading capacity in multi-site factory environment. *International Journal of Advanced Manufacturing Technology*, *47*(9), 1241–1252. doi:10.1007/s00170-009-2254-x

Rudberg, M., & West, M. (2008). Global operations strategy: Coordinating manufacturing networks. *Omega*, *36*, 91–106. doi:10.1016/j.omega.2005.10.008

Ryu, J., & Pistikopoulos, E. N. (2007). Multiperiod planning of enterprise-wide supply chains using an operation policy. *Industrial & Engineering Chemistry Research*, *46*, 8058. doi:10.1021/ie070508b

Sambasivan, M., & Yahya, S. (2005). A Lagrangean-based heuristic for multi-plant, multi-item, multi-period capacitated lot-sizing problems with inter-plant transfers. *Computers & Operations Research*, *32*, 537–555. doi:10.1016/j.cor.2003.08.002

Sauer, J. (2006). Modeling and solving multi-site scheduling problems. In van Wezel, W., Jorna, R. J., & Meystel, A. M. (Eds.), *Planning in intelligent systems: Aspects, motivations and methods* (pp. 281–299). Hoboken, NJ: John Wiley & Sons. doi:10.1002/0471781266.ch9

Savkin, A. V., & Somlo, J. (2009). Optimal distributed real-time scheduling of flexible manufacturing networks modeled as hybrid dynamical systems. *Robotics and Computer-integrated Manufacturing*, *25*(3), 597–609. doi:10.1016/j.rcim.2008.04.004

Schenk, M., Wirth, S., & Müller, E. (2010). *Factory planning model: Situation-driven production facility planning*. Springer.

Schneeweiss, C., & Zimmer, K. (2004). Hierarchical coordination mechanisms within the supply chain. *European Journal of Operational Research*, *153*, 687–703. doi:10.1016/S0377-2217(02)00801-9

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2008). *Designing and managing the supply chain: Concepts, strategies and case studies*. McGraw- Hill Inc.

Sousa, R., Shah, N., & Papageorgiou, L. (2008). Supply chain design and multilevel planning—An industrial case. *Computers & Chemical Engineering*, *32*, 2643. doi:10.1016/j.compchemeng.2007.09.005

Stadtler, H. (2005). Supply chain management and advanced planning – Basics, overview and challenges. *European Journal of Operational Research. Supply Chain Management and Advanced Planning*, *163*(3), 575–588.

Torabi, S. A., & Hassani, E. (2009). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19), 5475–5499. doi:10.1080/00207540801905460

Tseng, Y.-J., & Huang, F.-Y. (2009). A multi-plant tolerance allocation model for products manufactured in a multi-plant collaborative manufacturing environment. *International Journal of Production Research*, *47*(3), 733–749. doi:10.1080/00207540701528792

Tsiakis, P., & Papageorgiou, L. G. (2008). Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics*, *111*, 468–483. doi:10.1016/j.ijpe.2007.02.035

Ulieru, M., & Cobzaru, M. (2005). Building holonic supply chain management systems: An e-Logistics application for the telephone manufacturing industry. *IEEE Transactions in Industrial Informatics*, *1*, 18–30. doi:10.1109/TII.2005.843827

Valckenaers, P. H., Kollingbaum, M., & Van Brussel, H. (2004). Multiagent coordination and control using stigmergy. *Computers in Industry*, *53*, 75–96. doi:10.1016/S0166-3615(03)00123-4 van Wezel, W., Jorna, R., & Meystel, A. (2006). *Planning in intelligent systems*. Wiley & Son. ISBN: 9780471734277

Vancza, J., & Egri, P. (2006). Coordinating supply networks in customized mass production—A contract-based approach. *CIRP Annals Manufacturing Technology*, *55*(1), 489–492.

Vancza, J., Egri, P., & Monostori, L. (2008). A coordination mechanism for rolling horizon planning in supply networks. *CIRP Annals - Manufacturing Technology, 57*, 455–458.

Varma, V. A., Reklaitis, G. V., Blau, G. E., & Pekny, J. F. (2007). Enterprise-wide modeling & optimization—An overview of emerging research challenges and opportunities. *Computers & Chemical Engineering*, *31*, 692. doi:10.1016/j.compchemeng.2006.11.007

Verderame, P. M., & Floudas, C. A. (2009). Operational planning framework for multisite production and distribution networks. *Computers & Chemical Engineering*, *33*, 1036–1050. doi:10.1016/j.compchemeng.2008.09.008

Verwijmeren, M. (2004). Software component architecture in supply chain management. *Computers in Industry*, *53*, 165–178. doi:10.1016/j.compind.2003.07.004

Voß, S., & Woodruff, D. L. (2006). *Introduction to computational optimization models for production planning in a supply chain* (2nd ed.). Springer.

Wagner, C., & Nyhuis, P. (2009). A systematic approach to analysis and design of global production networks. *Production Engineering and Research Development*, *3*, 295–303. doi:10.1007/s11740-009-0167-z

Walther, G. (2008). Negotiation-based coordination in product recovery networks. *International Journal of Production Economics*, *111*, 334–350. doi:10.1016/j.ijpe.2006.12.069

Wang, H. W., Guo, M., & Efstathiou, J. (2004). A game-theoretical cooperative mechanism design for a two-echelon decentralized supply chain. *European Journal of Operational Research*, *157*(2), 372–388. doi:10.1016/S0377-2217(03)00233-9

Wang, M., Wang, H., Vogel, D., Kumar, K., & Chiu, D. K. W. (2009). Agent-based negotiation and decision making for dynamic supply chain formation. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.001

Wang, M., Wang, H., Vogel, D., Kumar, K., & Chiu, D. K. W. (2009). Agent-based negotiation and decision making for dynamic supply chain formation. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.001

Wiendahl, H. P., & Lutz, S. (2002). Production networks. *Annals of CIRP on Manufacturing Technologies*, *51*(2), 573–586. doi:10.1016/S0007-8506(07)61701-6

Windt, K., & Hülsmann, M. (2007). Changing paradigms in logistics - Understanding the shift from conventional control to autonomous cooperation and control. In Hülsmann, M., & Windt, K. (Eds.), *Understanding autonomous cooperation & control - The impact of autonomy on management, information, communication, and material flow* (pp. 4–16). Berlin, Germany: Springer. doi:10.1007/978-3-540-47450-0_1

Wu, M. C., & Chang, W. J. (2007). A short-term capacity trading method for semiconductor fabs with partnership. *Expert Systems with Applications*, *33*(2), 476–483. doi:10.1016/j.eswa.2006.05.012

Zhang, D. Z. W., Anosike, A. I., Lim, M. K., & Akanle, O. M. (2006). An agent-based approach for e-manufacturing and supply chain integration. *Computers & Industrial Engineering*, *51*(2), 343–360. doi:10.1016/j.cie.2006.02.012

Chapter 7
A New Modeling and Application of Hierarchical Production Planning Approach

Reza Tanha Aminlouei
University of Tehran, Iran

ABSTRACT

In real power systems, power plants are not in the equal space from the load center, and their fuel cost is different. With common utilization conditions, production capacity is more than total load demand and losses. Therefore, there are different criteria for active and inactive power planning in each power plant. The best selection is to choose a framework in which the utility cost is minimized. On the other hand, planning in power systems has different time horizons; thus, for effective planning in power systems, it is very important to find a suitable mathematical relationship between them. In this chapter, the authors propose a modeling by selecting a Fuzzy Hierarchical Production Planning (FHPP) technique with zone covering in the mid-term and long-term time horizons electricity supply modeling in the Iran global compact network.

INTRODUCTION

Describe the general perspective of the chapter. Toward the end, specifically state the objectives of the chapter.

Electricity production planning which is called generation planning in power systems is divided into: long-term, mid-term and short-term planning (Alonso, etc. 1992). Planning and operating modern electric power systems involve several interlinked and complex tasks. Optimizing a production plan, however, is difficult for thermal and hydro power plants, which could be solved with proper computer tools.

Long-term energy generation planning is of key importance to the operation of electricity

DOI: 10.4018/978-1-4666-2098-8.ch007

generation. It is employed for strategic planning, budgeting, and fuel acquisitions and to provide a framework for short-term energy generation planning.

A long-term planning period (one year) is usually subdivided into shorter intervals of weeks or months, for which parameters like load–duration curve should be predicted, and variables like expected energy generations for each plant unit must be optimized. The Load–Duration Curves (LDC's) predicted for each interval are used as input data, which are equivalent to load-survival functions. This is appropriate since load uncertainty can be suitably described using the LDC. It is assumed that the probability of failure for each thermal unit is known.

In power system management, the problem of planning production for the next 10–30 days is known as the mid-term planning problem. Production planning problems with up to one week time horizon is known as short-term planning.

The short-term and mid-term planning problems could be principally considered alike, except in some specific conditions, when the problems are more or less relevant to the variety of time horizons. Since uncertainty exists in prediction of electricity demand as well as electricity price, the prediction of the mid-term problem can become difficult. On the other hand, the short-term model can be detailed due to the relatively good predictions that can be derived for the next few days. This high level of detail implies that in practice a short-term model, can only implement one district heating system at a time. Another purpose of the mid-term model is the model restrictions that connect the different systems. For example in principal planning procedure, the outputs of solved mid-term problems are used as the inputs to the short-term problems.

Production planning in the electricity industry and PPGP problems are very complex with extensive features. Also, due to the specific condition of respective product, electricity generation planning is mainly different from the other production planning problems that have specific characteristics. Some of these characteristics are:

- Not being able to suppose the backorder state.
- Generating electricity in a specific time period for use in future time periods is not directly possible.
- Flexible and specific electricity generation planning generate more electricity than predicted output to satisfy the expected demand.

An appropriate approach to alleviate this deficiency is to use FHPP by introducing imprecise/fuzzy data along with soft constraints, allowing some minor deviations from the outputs of the upper level while making a decision in the lower level.

A rigorous mathematical analysis of Hierarchical Production Planning (HPP) is found in the pioneering work of Hax and Meal (Hax & Meal, 1975). Theoretical work on the topic has followed (Golovin, 1975), (Bitran & Hax, 1981) and (Ozdamar, etc. 1996). Nowadays, HPP method is used as a structured method in various fields.

In previous studies of power systems, there is very little attention to the hierarchical structure aspects of power system production planning. Also in previous studies there is a lack of a proper updating feedback system to increase reliability and developing performance of the power system production planning on different horizons of planning. A feedback system allows decision makers not only to have very flexible production plans but also to revise the model easily into different levels of long-term, mid-term and short-term levels of electricity planning with the inputs like 'any unexpected events', 'upper manager decision makers' and 'actual data which is gained with time lapse'. Moreover in the previous studies, objective functions used in power system production planning models were based on cost, and other criteria of power production such as environmental pollution, proportion in total capacity and so on, were not considered together with economic criterion.

The main purpose of this paper is to improve the performance of the power system generation planning structure practically on different horizons of planning (long-term, mid-term and short-term electricity planning). A feedback system of FHPP is applied with multi objective functions for power production planning. The imprecise input parameters along with some soft constraints are introduced in the model formulation instead of using the crisp data and imposing hard constraints to provide required consistency between decisions of different levels. In practice the result of production plans through FHPP would be more feasible and compatible.

The rest of the paper is organized as follows: The relevant literature is presented in Section 2. The overall structure of the proposed FHPP model along the corresponding fuzzy mathematical models is illustrated in Section 3. In Section 4, the proposed fuzzy HPP structure is elaborated applying appropriate strategies and the associated fuzzy linear programming models are converted into the equivalent auxiliary crisp models. The proposed FHPP structure is implemented for a real power system in Iran. The case study and the obtained results as well as some managerial implications are provided in Section 5. There it is indicated that applying FHPP as a new approach for PPGP, will be conducted toward effective structured and efficient power system as concluding remarks in section 6.

BACKGROUND

Based on the main characteristics of the research problem, as explained in more detail in the next section, the most relevant and recent literature in three different but somewhat close streams of: 1- Production planning in power systems and 2- Applications of fuzzy modeling in production planning are studied.

Production Planning in Power Systems

The long-term problem is a well-known stochastic optimization problem, as several of its parameters are only known as probability distributions, such as load, the availability of thermal units, hydrogenation and energy generations from renewable sources in general. Bloom and Gallant (1994) proposed a linear model with an exponential number of inequality constraints and used an active set methodology (Gill, etc. 1981) to find the optimal way of matching the LDC of a single interval using thermal unit in the presence of load-matching and other operational non-load-matching constraints.

The Bloom and Gallant model has been successfully extended to multi-interval long-term planning problems, using the active-set method (Nabona, etc. 2001), the Dantzig–Wolfe column generation method (Dantzing & Wolfe, 1960; Perez & Conejo, 2000) or the Ford–Fulkerson column-generation method (Ford & Fulkerson, 1958; Page, 2002). A quadratic model to formulate the long-term profit maximization of generation companies in a liberalized market has been proposed (Nabona & Page, 2002) and column generation procedures have been employed to solve it (Page & Nabona, 2002; Nabona & Page, 2004).

Mid-term planning does not frequently appear in the literature. However, the closely related short-term planning, which considers similar questions over a time horizon of up to one week, is well known. The most common version of the short-term planning problem, also known as the unit commitment problem, considers planning of power producing units in a power grid.

Rong et al. (2009) introduced in their research the DRDP-RSC algorithm, which is a dynamic regrouping based dynamic programming algorithm based on linear relaxation of the ON/OFF states of the units, sequential commitment of units in small groups. This research addresses the Unit Commitment (UC) in multi-period Combined Heat and Power (CHP) production planning under the deregulated power market.

Currently, the solution approaches to UC of CHP systems are limited to some general-purpose methods. The research follows two lines. The first line applies decomposition techniques such as Lagrangian relaxation (LR) (Dotzauer, 2001; Thorin, etc. 2005) and DP based algorithms (Rong, etc. 2008; Rong, etc. 2009; Hakonen, 1996). The second line treats the overall problem as an entity and resorts to a general solver possibly with some modifications such as the Branch and Bound algorithm (Illerhaus & Verstege, 1999) to solve a MILP formulation of the problem. The application of simulation approaches (Eriksen, 2001; Ummels, etc. 2007) and artificial intelligence techniques such as genetic algorithms (Sakawa, etc. 2002) should be placed under this category. It is undoubted that the Interior Point Method (IPM) (Medina, etc. 1999) and the improvement of the formulation for the UC problem (Carrion & Arroyo, 2006) can also be applied to CHP systems. Youakim (2008) presented necessary and sufficient conditions for the feasibility of unit combinations that can be checked off-line that is, before the start of the unit commitment algorithm, and thus before any economic dispatches are performed, thereby rendering a very efficient unit scheduling algorithm in terms of computer memory and execution time. Patra and Goswami (2009) proposed a dynamic programming technique with a fuzzy and simulated annealing based unit selection procedure for the solution of the UC problem.

Jalilzadeh et al. (2009) presented a new method with integration of generation and transmission network reliability for the solution of UC problem. In fact, in order to have a more accurate assessment of system reserve requirement, in addition to unavailability of generation units, unavailability of transmission lines are also taken into account. Gomes and Saraiva (2009) described the formulations and the solution algorithms developed to include uncertainties in the generation cost function and in the demand on DC OPF studies. The uncertainties are modeled by trapezoidal fuzzy numbers and the solution algorithms are based on multi parametric linear programming techniques. Goransson and Johnsson (2009) used a Mixed Integer Programming (MIP) approach to determine the power plant dispatch strategy which yields the lowest systems costs. In the model, each large thermal plant is described separately, including properties such as start-up time, start-up cost and minimum load level. Kumar and Naresh (2009) proposed an efficient optimization procedure based on Real Coded Genetic Algorithm (RCGA) for the solution of Economic Load Dispatch (ELD) problem with continuous and non-smooth/ non-convex cost function considering various constraints. The effect of the proposed algorithm has been demonstrated on different systems considering the transmission losses and valve point loading effect in thermal units. For the solution of corresponding optimization problems, several methods have been suggested and implemented, including algorithms based on branch-and-bound (Cohen & Yoshimura, 1983), dynamic programming (Hobbs, etc. 1988; Snyder, etc. 1987), Lagrangian relaxation (Muckstadt & Koenig, 1977; Virmani, etc. 1989; Zhuang & Galiana, 1988) and genetic algorithms (Cheng, etc. 2000; Kazarlis, etc. 1996). Surveys are given in (Sen & Kothari, 1998; Sheble & Fahd, 1994).

Applications of Fuzzy Modeling in Production Planning

The fuzzy set theory has been used considerably for modeling and solving the different variants of production planning and scheduling problems in uncertain environments. Hsu and Wang (2001) developed a Possibilistic Linear Programming (PLP) model based on Lai and Hwang's (1992) approach to determine appropriate strategies regarding the safety stock levels for assembly materials, regulating dealers' forecast demands and numbers of key machines in an assemble-to order environment. Fung et al. (2003) presented a Fuzzy Multi-Product Aggregate Production Planning (FMAPP) model to cater different scenarios under various decision-making preferences by applying integrated parametric programming and interactive methods. Wang and Liang (2004) developed a fuzzy multi-objective linear programming model with piecewise linear membership function to solve multi-product Aggregate Production Planning (APP) problems in a fuzzy environment. In another research work, they (2005) presented an interactive possibilistic linear programming model using Lai and Hwang's (2004) approach to solve the multi-product aggregate production planning problem with imprecise forecast demand, related operating costs and capacity. Moreover, in mid-term supply chain planning domain, Torabi and Hassini (2008) presented a novel multi-objective possibilistic mixed integer linear programming model for a Supply Chain Master Planning (SCMP) problem consisting of multiple suppliers, one manufacturer and multiple distribution centers which integrates the procurement, production and distribution aggregate plans considering various conflicting objectives simultaneously as well as the imprecise nature of some critical parameters such as market demands, cost/time coefficients and capacity levels. In another research work (Torabi & Hassini, 2008b), the authors extended the above model to multi-site production environments and proposed an interactive fuzzy goal programming solution approach for the problem. Other relevant literature may include (Wang & Fang, 1997; Wang & Fang, 2001; Tang, etc. 2000; Tang, etc. 2003). It is noteworthy that there are some other research works applying stochastic model to solve the production planning problems in uncertain environments. For a recent review of different approaches for dealing with uncertainty in production planning problems especially HPP approach, an interested reader is referred to Mula et al. (2006).The literature review regarding the application of fuzzy approach in production planning and scheduling problems reveals the lack of using fuzzy sets theory in modeling HPP structures.

The proposed fuzzy HPP which has been stimulated by a real industrial case of an Iranian power network consists of three decision-making levels. Monthly consumption of 20 future years is forecasted in the first level. In second level, forecasted demand is allocated to different methods of electricity generation for an aggregate period. Structure of the proposed Fuzzy Aggregate Production Planning (FAPP) model could be considered as a fuzzy linear programming model which generates an optimal production plan to satisfy the aggregate forecasted demands of electricity. Two objective functions are: 1- minimizing the cost of electricity generation by different methods of generation and 2- maximizing the total preference weights of projects that are calculated by Analytical Hierarchy Process (AHP). In the third (disaggregation) level, similar model is applied to determine the production plan at the monthly periods. The next section provides the detailed fuzzy models in the proposed FHPP framework.

THE PROPOSED FUZZY HIERARCHICAL PRODUCTION PLANNING MODEL

Because of insufficient or inaccessible data and also the information acquiring high costs, the modeling parameters for PPGP are usually imprecise. In other words, competitive market persuades managers to implement precise and reliable production plans which could not be achieved with inaccurate and fuzzy market data. Also implementation of production plans with imprecise crisp data and crisp models is very difficult. One of the main motivations of this study is fuzziness. Which made the extracted results from the proposed FHPP to be more accurate, reliable and increase the efficiency of production planning, therefore it will be convenient to obtain production planning model that could handle fuzzy and uncertain data from the market. Fuzzy constraints should be used to increase the efficiency and compatibility among different levels of planning. Hence more optimal and feasible results could be obtained. The integrated problem of PPGP is divided into three levels of: 1- Demand level 2- Aggregate level, and 3- Disaggregate or allocation level presented in Figure 1.

First Level (Demand Forecast)

The demand forecasting method presented by Sadeghi, et al. (2009) is applied in this study. The amount of monthly demand for 20 future years is forecasted for planning, and then an optimal planning model is developed to satisfy the demand.

Second Level (Demand Allocation to the Generation of Different Methods)

The forecasted demand in the first level is allocated to different aggregate methods of electricity generation for seasonal aggregate periods in 20 future years. Different methods of electricity generation can be divided into different features. For example we can divide them according to the technology applied such as Fossil, Nuclear, Combine cycle, Small hydro, big hydro, Micro hydro, Wind turbine, PV, Mono crystalline, Multi crystalline and Geothermal. Some of these technologies are not employed in Iran. The most common technologies of 1- Gas 2- Steam 3- Combine cycle 4- Hydro are considered for electricity generation.

Mixed Method of AHP with FAPP

AHP is applied to obtain total preference weights for each method of electricity generation in Iran using Expert Choice software. Then FAPP is applied to maximize total preference weights, to determine the best combination of generation methods and to satisfy power plant production demand in Iran using Lingo software (Figure 2).

Assigning Score to Each Generation Method

For each method of electricity generation in Iran (Gas, Steam, Combine Cycle and Hydro) a score is given based on the following criteria.

Figure 1. Hierarchical structure of problem solving

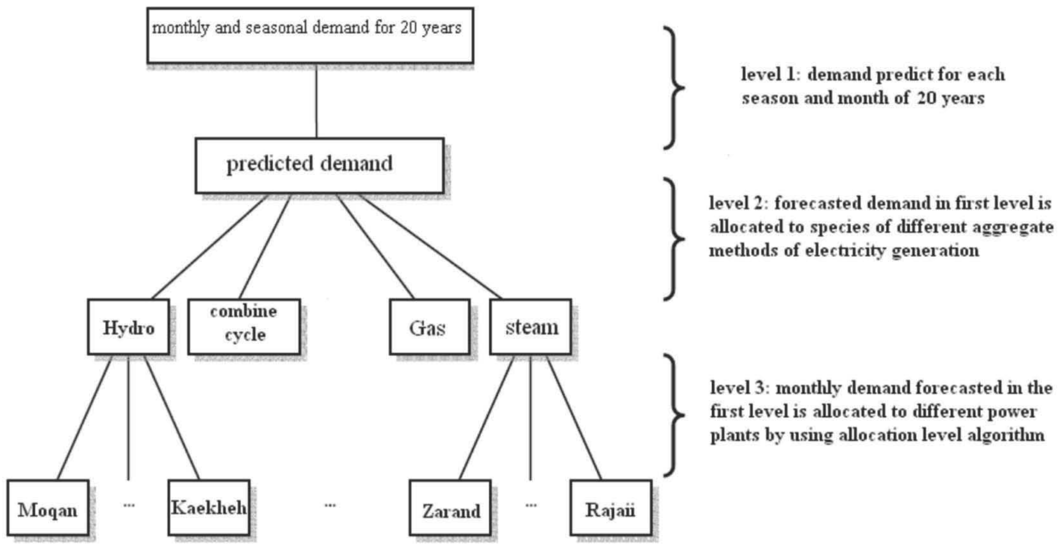
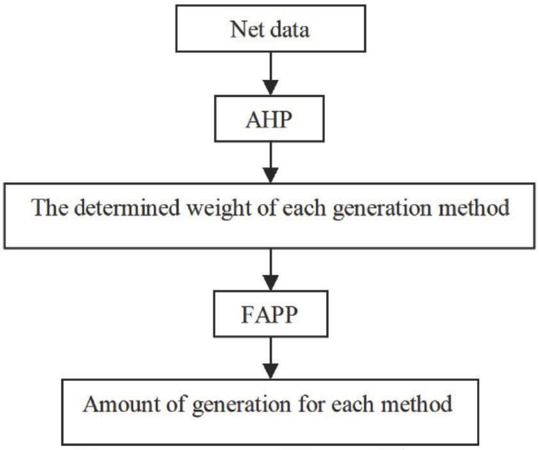


Figure 2. Mixed method of analytical hierarchy process with fuzzy aggregate production planning



- Amount of environmental pollution in production procedure including SO2, NOx and CO2.
- The share of each method capacity compared with the total capacity.

Forecasted aggregate seasonal demand for 20 future years is assigned to the different methods of generation by applying heuristic mathematical model. The above criteria are used to rank different production methods, in a hierarchical structure (Figure 3).

FAPP of Proposed Structure to Electricity Generation Planning

The proposed FAPP model is used to provide an optimal aggregate production plan. Then it can satisfy the dynamic demands of electricity over a given long-term planning horizon involving the above mentioned outputs. The main characteristics and assumptions considered in the FAPP formulation are as follows:

- A four-power plant situation is considered.
- There is a seasonal period on 20 future years planning horizon.
- Forecasted demand in seasonal period ts of year ty in zone z and peak demand of year ty in zone z are assumed fuzzy.
- Reliability, autonomy and balance constraints are assumed fuzzy.

The indices, parameters and variables used to formulate the FAPP model are:

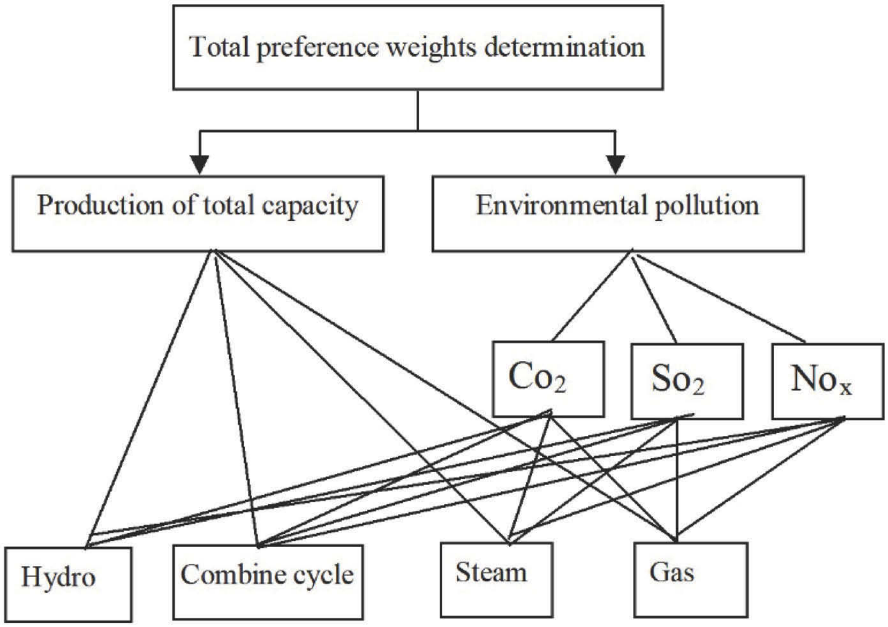
Indices:

- i : Index of aggregate power plant families (i =1, …, 4).
- t_s : Index of aggregate time periods (seasonal, t_s =1,…, 4).
- t_y : Index of time horizon planning (annual, t_y =1,…, 20).
- z, z_p : Index of Electricity zones of Iran (z, z_p =1, …, 15).

Parameters:

- $fp(z,i)$: Fuel cost of old power plant i in zone z in base year (Rial/MW).
- $HR(z,i)$: Heat rate of old power plant i in zone z in base year (constant).
- $fpesc(z,i)$: Regulation rate of old power plant i in zone z in each year toward before year (%).
- $OM(z,i)$: Variable operation and maintenance costs of old power plant i in zone z (Rial/MW).
- $fpN(z,i)$: Fuel cost of new power plant i in zone z in base year (Rial/MW).
- $HRN(z,i)$: Heat rate of new power plant i in zone z in base year (constant).
- $fpescN(z,i)$: Regulation rate of new power plant i in zone z in each year toward before year (%).
- $OMN(z,i)$: Variable operation and maintenance costs of new power plant i in zone z (Rial/MW).

Figure 3. Hierarchical structure to rank production methods



- $UE\cos t(z)$: Unsaved energy cost per blackout (MW) in zone *z* (Rial/MW).
- $UM\cos t$: Unmet reserve requirements cost per MW (Rial/MW).
- W_{zi} : Total preference weights of projects that are calculated by AHP (constant).
- $\tilde{D}(t_y, t_s, z)$: Amount of electricity demand in zone z in season t_s of year t_y (MW).
- $\tilde{D}_{peak}(z, t_y)$: Amount of peak electricity demand in zone z of year t_y (MW).
- $PGLoss(z,i)$: Inner consumption factor of old power plant *i* in zone *z* (%).
- $PGNLoss(z,i)$: Inner consumption factor of new power plant *i* in zone *z* (%).
- $PG\exp step(z,i)$: Capacity mounted in each developing step in old power plant *i* in zone *z* (MW).
- $PGN\exp step(z,i)$: Capacity mounted in each developing step in new power plant *i* in zone *z* (MW).
- $PG\max(z,i)$: Upper bound of total development in all years in old power plant *i* in zone *z*.
- **Decay:** Reduction capacity in each year toward before year (%).
- $PG_{init}(z,i)$: Amount of total nominal power of power plants *i* in zone *z* (MW).
- $PFLoss(z, z_p)$: Loss percentage between two zones (%).
- $PF_{init}(z, z_p)$: Amount of initial capacity for lines between two zones (MW).
- $AF(z, t_y)$: Autonomy factor for zone *z* and in year t_y.
- $Cos\theta$: Coefficient of line power that is allocated to active flow (%).
- $RESPP(z,i)$: Bound of reserve for power plant *i* in zone *z* (%).
- $crf(z)$: Capital recovery factor for old power plant in zone *z* (constant).
- $PG\exp\cos t(z,i)$: Fixed cost for developing in old power plant *i* in zone *z* (Rial/MW).

- $PGN\exp\cos t(z,i)$: Fixed cost for making new power plant *i* in zone *z* (Rial/MW).
- $PFN\cos t(z,z_p)$: Fixed cost for making new transmission lines between zones *z* and z_p (Rial/MW).
- $crfPNF(z,z_p)$: Capital recovery factor for new transmission lines between zones *z* and z_p (constant).
- **Disc:** Interest rate in any year of planning horizon for all zones (constant).

Variables:

- $PG(t_y,t_s,z,i)$: Production amount of old power plant *i* in zone *z* and in season t_s of year t_y (MW).
- $PGN(t_y,t_s,z,i)$: Production amount of new power plant *i* in zone *z* and in season t_s of year t_y (MW).
- $PG\exp(t_y,z,i)$: Number of units that add in old power plant *i* in zone *z* and in year t_y.
- $PGN\exp(t_y,z,i)$: Number of units that add in new power plant *i* in zone *z* and in year t_y.
- $PF(t_y,t_s,z,z_p)$: Amount of old transitive power between two zones and in season t_s of year t_y (MW).
- $PFN(t_y,t_s,z,z_p)$: Amount of new transitive power between two zones and in season t_s of year t_y (MW).
- $PFN\exp(t_y,z,z_p)$: Amount of capacity made of new lines between zones *z* and z_p in year t_y (MW).
- $F_{Max}(t_y,z,z_p)$: Amount of capacity that a zone has reserved for other zone in year t_y (MW).
-
- $UM(z,t_y)$: Amount of unmet reserve requirements in zone *z* in year t_y (MW).
- $UE(t_y,t_s,z)$: Amount of unsaved energy in zone *z* and in season t_s of year t_y (MW).

Based on the above notations, the FAPP model is formulated as shown in the following sections.

Objective Functions

Minimizing the cost of electricity generation using different ranges of technologies is considered as the first objective (Z1), and the second objective function (Z2) is to maximize the total preference weights of projects which are calculated by AHP. Knowing the model is long-term projection; total costs in planning horizons of all years. Thus we change the value of the total costs of each year to money value in base year (see Box 1).

Fuel and operational cost for old power plants

Production cost of total old power plants with each technology in all zones in ty year is equal to Equation 2 in Box 2.

Fuel and operational cost for new power plants

Production cost of total new power plants with each technology in all zones in ty year is equal to Equation 3 in Box 3.

Blackout costs (Unsaved Energy and Unmet Reserve)

Blackout costs in total zones in ty year are equal to Equation 4 in Box 4.

Capital costs as for developing old power plants

The cost of all total development for all total old power plants in all total zones in ty year and considering capital recovery factor is equal to Equation 5 in Box 5.

Capital costs as for developing new power plants

The cost of making power plants for all total new power plants in all total zones in ty year and considering capital recovery factor is equal to Equation 6 in Box 6.

Box 1. Equation 1

$$Min \qquad Z_1 = \sum_{t_{yb}=1}^{20} \frac{C_{PG}\left(t_{yb}\right) + C_{PGN}\left(t_{yb}\right) + C_U\left(t_{yb}\right)}{\left(1+disc\right)^{\left(t_{yb}-1\right)}} + \sum_{t_{yb}=1}^{20} \sum_{tc_y=t_{yb}}^{20} \frac{Ccap_{PG}\left(t_{yb}\right) + Ccap_{PGN}\left(t_{yb}\right) + Ccap_{PFN}\left(t_{yb}\right)}{\left(1+disc\right)^{\left(tc_y-1\right)}}$$

$$Max \quad Z_2 = \sum_{t_y=1}^{20} \sum_{t_s=1}^{4} \sum_{z=1}^{15} \sum_{i=1}^{4} W_{zi} \times PG\left(t_y, t_s, z, i\right) \tag{1}$$

Box 2. Equation 2

$$C_{PG}\left(t_y\right) = \sum_{t_s=1}^{4} \sum_{z=1}^{15} \sum_{i=1}^{4} PG\left(t_y, t_s, z, i\right) \times \left[OM\left(z,i\right) + HR\left(z,i\right) \times fp\left(z,i\right) \times fpesc\left(z,i\right)^{t_y}\right] \tag{2}$$

Box 3. Equation 3

$$C_{PGN}\left(t_y\right) = \sum_{t_s=1}^{4} \sum_{z=1}^{15} \sum_{i=1}^{4} PNG\left(t_y, t_s, z, i\right) \times \left[OMN\left(z,i\right) + HRN\left(z,i\right) \times fpN\left(z,i\right) \times fpescN\left(z,i\right)^{t_y}\right] \tag{3}$$

Box 4. Equation 4

$$C_U\left(t_y\right) = \sum_{t_s}^{4} \sum_{z=1}^{15} \left[UE\left(t_y, t_s, z\right) \times UE\cos t\left(z\right)\right] + \sum_{z=1}^{15} UM\left(z, t_y\right) \times UM\cos t \tag{4}$$

Box 5. Equation 5

$$Ccap_{PG}\left(t_y\right) = \sum_{i=1}^{4} \sum_{z=1}^{15} PG\exp step\left(z,i\right) \times PG\exp\left(t_y, z, i\right) \times PG\exp\cos t\left(z,i\right) crf\left(z\right) \tag{5}$$

Capital costs that are related to developing new transfer lines

The cost of all total developments for all total new transfer lines between all of the zones of the country in ty year and considering capital recovery factor is equal to Equation 7 in Box 7.

Constraints

For each period, the following constraints are considered:

1. **The capacity constraints of old power plants generation (see Equation 8 in Box 8).** The amount of electricity product of old power plant i in season ts of year ty in zone z cannot be more than the amount of the total primary mounted capacity plus added capacity until ty year (by reduction alignment due to decay).
2. **Max development of old power plants constraint.** Each productive power plant that is made at first has known measurements and physical close. So the number of all units that can mounted in one power plant, in time horizon is limited. It means that the power plant i in zone z and in all total duration, have known amount of Max output for development. Thus maximum development of old power plants constraint in 20 years time horizon is equal to Equation 9 in Box 9.
3. **The capacity constraints of new power plants generation.** According to zones geography condition and their abilities to work professionally, construction of different power plants in several zones with their own characteristic presented in the offering projects list is given to the model. By solving the model, the order is determined according to zones demand and costs and other technological and economical problems. The amount of electricity generation in new power plant i in season ts of year ty in zone z cannot be more than the amount of total new mounted capacity by reduction alignment due to decay (see Equation 10 in Box 10).
4. **The capacity constraints of old transmission lines.** Development of the old lines between the two zones of the country cannot be possible due to the elimination of the filling capacity of power station at the two ends of the lines. Thus the new lines should be developed by Max capacity assuming their development in future is not commercially feasible. The exchange amount between z and zp zones in season ts of year ty related to old lines can be less than or equal to the mounted capacity. So this capacity constraint for the old transferring lines is in shown as Equation 11 in Box 11.
5. **The capacity constraints of reserve exchange.** In the peak hours, each zone can make part of its capacity as reserve for the other zone named reserve capacity. The reserved capacity should be smaller than initial capacity of transmission lines between two zones, which is necessary to be guaranteed with a constraint (see Equation 12 in Box 12).
6. **The capacity constraints of new transmission lines.** In the transferring lines, that capacity development is possible with each amount of the capacity, when provided continuously. By spotting PFNexp(ty,z,zp) variable, which determine the amount MW development between two zp and z zones in season ts of year ty, and with spotting the capacity reduction of exhaustion that the Decay parameter show the amount of that, capacity constraint for the new lines is equal to Equation 13 in Box 13.
7. **The reliability constraints.** Each zone should have a defined reserve bound for main supply source (power plants). The reserve

Box 6. Equation 6

$$Ccap_{PGN}\left(t_y\right)=\sum_{i=1}^{4}\sum_{z=1}^{15} PGN\exp step\left(z,i\right)\times PGN\exp\left(t_y,z,i\right)\times PGN\exp\cos t\left(z,i\right)crf\left(z\right) \tag{6}$$

Box 7. Equation 7

$$Ccap_{PFN}\left(t_y\right)=\sum_{z=1}^{15}\sum_{z_p=1}^{15} PFN\exp\left(t_y,z,z_p\right)\times PFN\cos t\left(z,z_p\right)\times\left(0.5\right)\times crfPNF\left(z,z_p\right) \tag{7}$$

Box 8. Equation 8

$$PG\left(t_y,t_s,z,i\right)\leq\left\{PG_{init}\left(z,i\right)\times\left(1-Decay\right)^{ty}+\sum_{tyb=1}^{ty} PG\exp step\left(z,i\right)\times PG\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}$$
$$\times\left(1-PGLoss\left(z,i\right)\right)\qquad\forall t_y,t_s,z,i \tag{8}$$

Box 9. Equation 9

$$\sum_{ty=1}^{20} PG\exp step\left(z,i\right)\times PG\exp\left(t_y,z,i\right)\leq PG\max\left(z,i\right)\qquad\forall z,i \tag{9}$$

Box 10. Equation 10

$$PGN\left(t_y,t_s,z,i\right)\leq\left\{\sum_{tyb=1}^{ty} PGN\exp step\left(z,i\right)\times PGN\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}$$
$$\times\left(1-PGNLoss\left(z,i\right)\right)\qquad\forall t_y,t_s,z,i \tag{10}$$

Box 11. Equation 11

$$PF\left(t_y,t_s,z,z_p\right)\leq\left\{PF_{init}\left(z,z_p\right)\times\left(1-Decay\right)^{ty}\right\}\times\left(1-PFLoss\left(z,z_p\right)\right)\times Cos\theta\qquad\forall t_y,t_s,z,z_p \tag{11}$$

Box 12. Equation 12

$$F_{Max}\left(t_y, z, z_p\right) \leq \left\{PF_{init}\left(z, z_p\right) \times \left(1-Decay\right)^{ty} + \sum_{tyb=1}^{ty} PFN\exp\left(t_{yb}, z, z_p\right) \times \left(1-Decay\right)^{(ty-tyb)}\right\}$$
$$\times\left(1-PFLoss\left(z, z_p\right)\right) \times Cos\theta \qquad \forall t_y, z, z_p \tag{12}$$

Box 13. Equation 13

$$PFN\left(t_y, t_s, z, z_p\right) \leq \left\{\sum_{tyb=1}^{ty} PFN\exp\left(t_{yb}, z, z_p\right) \times \left(1-Decay\right)^{(ty-tyb)}\right\} \times \left(1-PFLoss\left(z, z_p\right)\right) \times Cos\theta \qquad \forall t_y, t_s, z, z_p \tag{13}$$

Box 14. Equation 14

$$\sum_{i=1}^{4} \frac{\left\{PG_{init}\left(z, i\right) \times \left(1-Decay\right)^{ty} + \sum_{tyb=1}^{ty} PG\exp step\left(z, i\right) \times PG\exp\left(t_{yb}, z, i\right) \times \left(1-Decay\right)^{(ty-tyb)}\right\} \times \left(1-PGLoss\left(z, i\right)\right)}{1+RESPP\left(z, i\right)}$$
$$+\sum_{i=1}^{4} \frac{\left\{\sum_{tyb=1}^{ty} PGN\exp step\left(z, i\right) \times PGN\exp\left(t_{yb}, z, i\right) \times \left(1-Decay\right)^{(ty-tyb)}\right\} \times \left(1-PGNLoss\left(z, i\right)\right)}{1+RESPP\left(z, i\right)} +$$
$$\sum_{z_p=1}^{15}\left\{F_{Max}\left(t_y, z_p, z\right) \times \left(1-PFLoss\left(z_p, z\right)\right)\right\} + UM\left(z, t_y\right) \tilde{\geq} \sum_{z_p=1}^{15} F_{Max}\left(t_y, z, z_p\right) + \tilde{D}_{peak}\left(z, t_y\right) \qquad \forall t_y, z \tag{14}$$

Box 15. Equation 15

$$\sum_{i=1}^{4} PG\left(t_y, t_s, z, i\right) + PGN\left(t_y, t_s, z, i\right) + UE\left(t_y, t_s, z\right) + \sum_{z_p=1}^{15} PF\left(t_y, t_s, z_p, z\right) \times \left(1-PFLoss\left(z_p, z\right)\right) +$$
$$\sum_{z_p=1}^{15} PFN\left(t_y, t_s, z_p, z\right) \times \left(1-PFNLoss\left(z_p, z\right)\right) \cong \tilde{D}\left(t_y, t_s, z\right) + \sum_{z_p=1}^{15} PF\left(t_y, t_s, z, z_p\right)$$
$$+\sum_{z_p=1}^{15} PFN\left(t_y, t_s, z, z_p\right) \quad \forall \quad t_y, t_s, z \tag{15}$$

Box 16. Equation 16

$$\left\{PG_{init}\left(z,i\right)\times\left(1-Decay\right)^{ty}+\sum_{tyb=1}^{ty}PG\exp step\left(z,i\right)\times PG\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times$$
$$\left(PGLoss\left(z,i\right)\right)+\left\{\sum_{tyb=1}^{ty}PGN\exp step\left(z,i\right)\times PGN\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times\left(PGNLoss\left(z,i\right)\right)$$
$$\tilde{\geq} AF\left(z,t_y\right)\times\tilde{D}_{peak}\left(z,t_y\right)\qquad\forall t_y,z,i \tag{16}$$

Box 17. Equation 17

$$PG\left(t_y,t_s,z,i\right),PGN\left(t_y,t_s,z,i\right),UE\left(t_y,t_s,z\right),F_{Max}\left(z,z_p\right),PF\left(t_y,t_s,z,z_p\right),PFN\left(t_y,t_s,z,z_p\right),$$
$$PG\exp\left(t_y,z,i\right),PGN\exp\left(t_y,z,i\right),PFN\exp\left(t_y,z,z_p\right),UM\left(z,t_y\right)\geq 0\qquad\forall t_s,z,z_p,i \tag{17}$$

bound with RESPP parameter can be model for thermal power plants for all zones which is typically 0.1 and 0.16 for hydro power plant for all zones. Model for raising reliability of system always has more capacity for network than demand. Certainly if this additional capacity do not supply, amount of network reliability will be less. UM(z,ty) variable show the amount of network unmet reserve MW in zone z and in ty year, so for reliability constraint we have is shown as Equation 14 in Box 14.

8. **The Balance constraints.** Each zone if cannot perform the demand by choosing the blackouts that enter to the supply of the demand/supply balance equation, then the unbalance problem of demand/supply should be solved. UE(ty,ts,z) variable represent the amount of MW blackout in zone z and each time (see Equation 15 in Box 15).
9. **Autonomy constraints.** In addition by spotting system reliability, because of non-technological, political, and economical reasons, it is better to preserve the internal capacity in the determinate fraction of internal peak demand, uninterested to economical profits of "cheap power importation" or "reserve capacity importation". Autonomy factor AF(z, ty)>=0, returns the percent of autonomy of each zone. Thus if it want to be completely autonomy should AF≥1 and if it want to be completely attached to the fixed importation is the peak time, to be economically safe it is AF=0 and for the remains between 0<AF<1. So the production autonomy constraint is demonstrated in Equation 16. (see Box 16).
10. **Non-negativity constraint.** Equation 17 is a non-negativity constraint (see Box 17).

Third Level (Different Methods of Production Allocation to Dependent Power Plants)

In the third level of hierarchical structure, monthly demand forecasted in the first level is allocated to different power plants using allocation level algorithm as follows.

Mixed Method of AHP with Fuzzy Disaggregate Production Planning

AHP is applied to obtain total preference weights for each power plant by using Expert Choice software. Then Fuzzy Disaggregate Production Planning (FDPP) is applied to maximize the total preference weights, to determine the best combination of power plants and to satisfy production demand in Iran using Lingo software.

Ranking Power Plants that Produce Electricity by the Same Method

To rank power plants, AHP method is used as illustrated in the Figure 4. Two criteria are used to score each power plant:

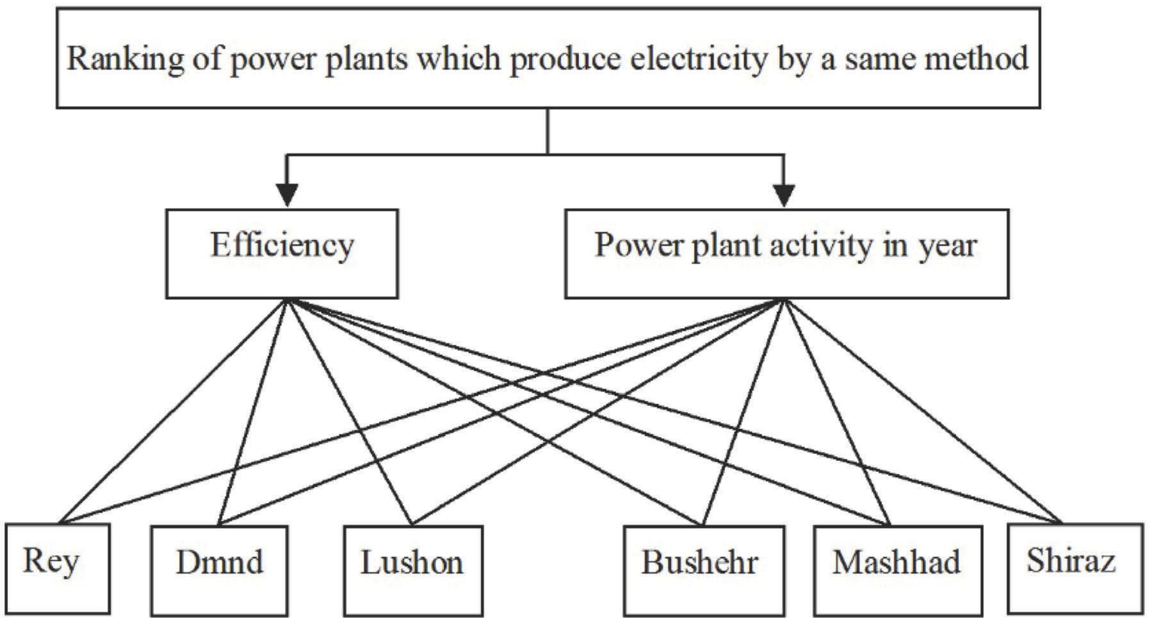
- Efficiency of different power plants.
- Power plant activity in a year.

After ranking of different power plants using the above method, the forecasted monthly demand for first season of the first year should be satisfied with allocation of the demand to the power plants, using FDPP. FDPP model is as follows:

FDPP of Proposed Structure for Electricity Generation Planning

The aggregate production plan generated by FAPP model cannot be implemented in practice because of its aggregate nature regarding both the power plants and time periods. Therefore, in order to develop a detailed production plan, disaggregated model is required to provide a master production plan (MPS). Thus, another fuzzy linear programming model (FDPP) is proposed in which its main assumptions and structure are similar to those of FAPP model. FDPP model must be solved separately for each period of FAPP model. It means that we should solve one FDPP model for each season of 20 future years. For example, we solved

Figure 4. Hierarchical structure to rank power plants which produce electricity by the same method



the FDPP model for autumn (ts=3) of first year. After solving the aggregate model, and specified the amount of generation of Steam, Gas, Combine Cycle and Hydro power plants in each season of 20 years planning horizon, then the disaggregate model for the first season of first year should solve the disaggregate model for the first season of first year to determine the monthly production rate of each final power plants. Then do the same calculation with the result for other seasons of first year by using the obtained results from the previous stages which should do the necessary reforms for future stages to get the monthly production planning of power plants for first year. This calculation should work for the next 20 years horizon by spotting the previous year's results and planning the necessary reforms. This work in hierarch planning is named rolling horizon approach that the regulation and correction is always based on previous results. Here we perform the sample of autumn season of first year of disaggregate model.

The main characteristics and assumptions considered in the FDPP formulation are as follows:

- There is a three-period planning horizon that each period is a month.
- Forecasted demand in period tm of zone z and peak demand in zone z are assumed fuzzy.
- Reliability and balance constraints and forced constraints (24-26) of aggregate planning level are assumed fuzzy.

The indices, parameters and variables used to formulate the FDPP model are as follows:

Indices:

- i : Index of aggregate power plant families ($i = 1, \ldots, 4$).
- t_s : Index of aggregate time periods (t_s =1, …, 4).
- z, z_p : Index of Electricity zones of Iran (z, z_p =1, …, 15).
- k : Index of Disaggregate power plant (k =1,…, n_i).
- t_m : Index of Disaggregate period (t_m =1,…,3).

Parameters:

- $FC(z,i,k)$: Fuel cost of power plant k of i family in zone z (Rial/MW).
- $OM(z,i,k)$: Variable operation and maintenance costs of power plant k of i family in zone z (Rial/MW).
- $UE\cos t(z)$: Unsaved energy cost per outage (MW) in zone z (Rial/MW).
- $UM\cos t$: Unmet reserve requirements cost per MW (Rial/MW).
- W_{zik} : Total preference weights of power plant k of i family that are calculated by AHP (Constant).
- $\tilde{D}(t_m, z)$: Amount of electricity demand per zone for per season of next year (MW).
- $\tilde{D}_{peak}(z)$: Amount of peak electricity demand per zone of next year (MW).
- $PGLoss(z,i,k)$: Inner consumption factor of power plant k of i family in zone z (%).
- $PG_{init}(z,i,k)$: Amount of total nominal power of power plants k of i family in zone z (MW).
- $PFLoss(z, z_p)$: Loss percentage between two zones (%).
- $PF_{init}(z, z_p)$: Amount of initial capacity for lines between two zones (MW).
- $Cos\theta$: Coefficient of line power that is allocated to active flow (%).
- $RESTHM(z,i,k)$: Bound of reserve for power plant k of i family in zone z (%).

Variables:

- $PG\left(t_m, z, i, k\right)$: Production amount of power plant k of i family in zone z and in period t_m (MW).
- $PF\left(t_m, z, z_p\right)$: Amount of transitive power between two zones and in period t_m (MW).
- $F_{Max}\left(z, z_p\right)$: Amount of capacity that a zone has reserved for other zone (MW).
- $UM\left(z\right)$: Amount of unmet reserve requirements in zone z (MW).
- $UE\left(t_m, z\right)$: Amount of unsaved energy in zone z and in period t_m (MW).

Based on the above notations, the FDPP model is formulated as Equations 18-27 (see Box 18).

Objective Functions (18)

Minimizing the cost of electricity generation by different power plants is considered as the first objective (Z1), and the second objective function (Z2) is to maximize the total preference weights of power plants which are calculated by AHP.

Constraints

For each period, the following constraints are considered:

1. **The capacity constraints of power plant generation (Equation 19):**
   Production amount of power plant k of i family in zone z and in period tm should not be greater than the amount of total nominal power of power plants k of i family in zone z.
2. **The capacity constraints of transmission lines (Equation 20):**
   The amount of exchange that can be transited between two zones is smaller or equal to installed lines capacity between two zones.
3. **The capacity constraints of reserve exchange (Equation 21):**
   In the peak hour, each zone can make part of its capacity as reserve for the other zone named reserve capacity, which is smaller than the initial capacity of transmission lines between two zones. It is necessary to be guaranteed with a constraint.
4. **The reliability constraints (Equation 22):**
   Reliability constraints guarantee the existence of a suitable reserve bound between installed capacity and peak period demand.
5. **The Balance constraints (Equation 23):**
   Load balance forces the supply and demand to be equal in each period.
6. **Forced constraints of aggregate planning level (Equations 24-26):**
   The solution of a higher level subsystem represents a constraint to be imposed on the next level subsystem and thus, decisions at each level constitute a chain. Moreover, in the HPP problem, solutions of higher level subsystem are considered as inputs of the next level subsystem. Hence it is important to create suitable compatibility among the levels of subsystem. Crisp constraints reduce flexibility of HPP problems and the probability of having a feasible solution in any level whereas by using fuzzy constraints, flexibility of HPP problems increases, put a suitable compatibility between each level, and increases the probability of having a feasible solution for the problem (Tanha & Ghaderi, 2007).

SOLUTION PROCEDURE

In order to reach a preferred solution of the proposed FHPP structure, the associated mathematical programming models should be converted into the equivalent crisp ones. In this regard, three main

Box 18. Equations 18-27

$$Min \quad Z_1 = \sum_{t_m=1}^{3}\sum_{z=1}^{15}\sum_{i=1}^{4}\sum_{k=1}^{n_i} PG\left(t_m,z,i,k\right)\times\left[OM\left(z,i,k\right)+FC\left(z,i,k\right)\right]+$$
$$\sum_{t_m=1}^{3}\sum_{z=1}^{15}\left[UE\left(t_m,z\right)\times UE\cos t\left(z\right)\right]+\sum_{z=1}^{15} UM\left(z\right)\times UM\cos t$$
$$Max \quad Z_2 = \sum_{t_m=1}^{3}\sum_{z=1}^{15}\sum_{i=1}^{4}\sum_{k=1}^{n_i} W_{zik}\times PG\left(t_m,z,i,k\right) \tag{18}$$

$$PG\left(t_m,z,i,k\right)\le PG_{init}\left(z,i,k\right)\times\left(1-PGLoss\left(z,i,k\right)\right) \qquad \forall \quad t_m,z,i,k \tag{19}$$

$$PF\left(t_m,z,z_p\right)\le PF_{init}\left(z,z_p\right)\times\left(1-PFLoss\left(z,z_p\right)\right)\times C0s\theta \qquad \forall \qquad t_m,z,z_p \tag{20}$$

$$F_{Max}\left(z,z_p\right)\le PF_{init}\left(z,z_p\right)\times\left(1-PFLoss\left(z,z_p\right)\right)\times Cos\theta \qquad \forall \quad z,z_p \tag{21}$$

$$\sum_{i=1}^{4}\sum_{k=1}^{n_i}\frac{PG_{init}\left(z,i,k\right)\times\left(1-PGLoss\left(z,i,k\right)\right)}{1+RESPP\left(z,i,k\right)}+\sum_{z_p=1}^{15}\left\{F_{Max}\left(z_p,z\right)\times\left(1-PFLoss\left(z_p,z\right)\right)\right\}$$
$$+UM\left(z\right)\tilde{\ge}\sum_{z_p=1}^{15}F_{Max}\left(z,z_p\right)+\tilde{D}_{peak}\left(z\right) \qquad \forall \quad z \tag{22}$$

$$\sum_{i=1}^{4}\sum_{k=1}^{n_i} PG\left(t_m,z,i,k\right)+UE\left(t_m,z\right)+\sum_{z_p=1}^{15}PF\left(t_m,z_p,z\right)\times\left(1-PFLoss\left(z_p,z\right)\right)\cong$$
$$\tilde{D}\left(t_m,z\right)+\sum_{z_p=1}^{15}PF\left(t_m,z,z_p\right) \qquad \forall \quad t_m,z \tag{23}$$

$$\sum_{t_m=1}^{3}\sum_{k=1}^{n_i} PG\left(t_m,z,i,k\right)\tilde{\ge} PG\left(t_s,z,z_p\right) \qquad \forall \quad z,i;t_s=3 \tag{24}$$

$$\sum_{t_m=1}^{3} PF\left(t_m,z_p,z\right)\tilde{\ge} PF\left(t_s,z_p,z\right) \qquad \forall \quad z,z_p;t_s=3 \tag{25}$$

$$\sum_{t_m=1}^{3} UE\left(t_m,z\right)\tilde{\ge} UE\left(t_s,z\right) \qquad \forall \quad z;t_s=3 \tag{26}$$

$$PG\left(t_m,z,i,k\right),UE\left(t_m,z\right),F_{Max}\left(z,z_p\right),PF\left(t_m,z,z_p\right),UM\left(z\right)\ge 0 \qquad \forall t_m,z,z_p,i,k \tag{27}$$

stages are considered as the solution procedure for the proposed FHPP as follows:

- Converting the FAPP model into its equivalent auxiliary crisp model
- Converting the FDPP into its equivalent auxiliary crisp model
- Applying an interactive fuzzy programming solution algorithm to obtain the final preferred solution.

Formulating the FAPP as an Auxiliary Crisp Model

In order to solve the FAPP model, it should be transformed to an auxiliary crisp model. Here we present efficient strategies to convert the fuzzy objective function and soft constraints into equivalent crisp equations.

Treating the Objective Functions of FAPP

Since all the coefficients in the objective functions are crisp, it is sufficient that the multi objective FAPP model be converted into an equivalent single-objective FAPP model. In linear programming, in order to convert the Multi Objective Linear Programming (MOLP) model into an equivalent single-objective LP model, it requires an aspiration level for each objective function and defines a new objective function based on the minimizing or maximizing objective functions. Then primary objective functions along with free variables and aspiration levels should be defined as additional constraints in model (Hillier & Liberman, 1980).

First objective (Z1) is minimizing the cost of electricity generation by different power plants. Aspiration level for Z1 is stated as follows:

A = total load on 20 future years × minimum production cost

In other words, all production methods are assumed with minimum production cost. Then a non-negative variable (d1) are considered in the first objective function as the following:

$$Z1 - d1 = A \tag{28}$$

Second objective (Z2) is maximizing the total preference weights of power plants that are calculated by AHP. Aspiration level for Z1 is considered as follows:

B = total load on 20 future years × maximum preference weight

In other words, it is assumed that total load has been produced with a method which has the highest preference. Then a non-negative variable (d2) are considered in the second objective function as the following:

$$Z2 + d2 = B \tag{29}$$

According to the relation of 28, to minimize Z1, d1 should be minimized. Also according to the relation of 29, to maximize Z2, d2 should be minimized. Therefore we should define Z = d1 + d2 as objective function of FAPP problem and also consider Equations 28 and 29 as constraint in FAPP problem. The new single-objective function defined for FAPP problem is as the following:

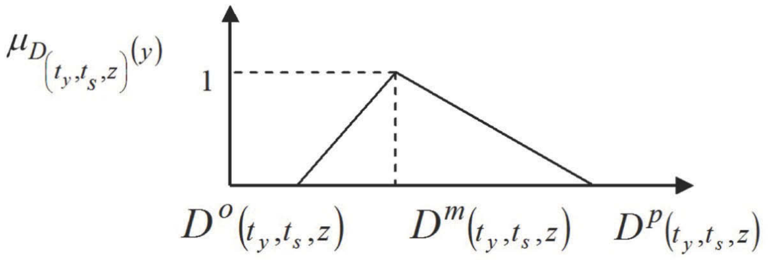
$$\text{Min } Z = d1 + d2 \tag{30}$$

Therefore problem is transformed into a FAPP problem with the single-objective function.

Treating the Soft Constraints

Due to incompleteness and/or unavailability of required data over the long-term decision horizon, the environmental data and operational parameters are typically uncertain and imprecise (fuzzy) in

Figure 5. The triangular possibility distribution of fuzzy parameter $\tilde{D}_{(t_y,t_s,z)}$



nature. Therefore, Forecasted demand in period tm of zone z and peak demand in zone z are assumed to be fuzzy numbers characterized by triangular possibility distribution. These triangular possibility distributions which are determined by using both objective and subjective data are the most common tool for modeling the ambiguous parameters due to their computational efficiency and simplicity in data acquisition (Wang & Liang, 2005; Torabi & Hassini, 2008; Torabi & Hassini, 2008b). Generally, a possibility distribution can be stated as the degree of occurrence of an event with imprecise data. Figure 5 represents the triangular possibility distribution of imprecise parameter which can be symbolized as

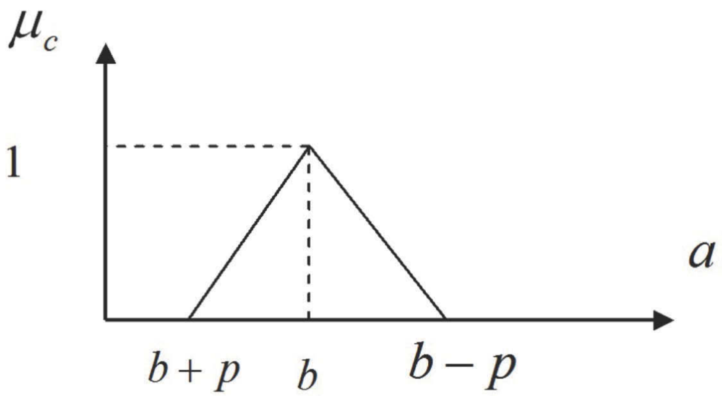
$$\tilde{D}\left(t_y, t_s, z\right) = \left(D^p{}_{(t_y,t_s,z)}, D^m{}_{(t_y,t_s,z)}, D^o{}_{(t_y,t_s,z)}\right)$$

where $D^p{}_{(t_y,t_s,z)}$, $D^m{}_{(t_y,t_s,z)}$ and $D^o{}_{(t_y,t_s,z)}$ are the most pessimistic value, the most possible value and the most optimistic value of $\tilde{D}_{(t_y,t_s,z)}$ which are estimated by the decision maker. The other fuzzy data can be modeled in the same manner in which:

$$\tilde{D}_{peak(z,t_y)} = \left(D^p{}_{peak(z,t_y)}, D^m{}_{peak(z,t_y)}, D^o{}_{peak(z,t_y)}\right)$$

To resolve the vagueness of Constraints 14-16 which permit these constraints to be satisfied as much as possible, they can be modeled by the

Figure 6. A preference-based membership function of soft equation $a \cong b$



preference-based membership functions. For example, a typical membership function of soft equation $a \cong b$ with tolerance p has been depicted in Figure 6.

Regarding the Constraints 31-34 (see Box 19) we should now compare the fuzzy right-hand sides with the crisp left-hand sides. An efficient approach to deal with such fuzzy constraints is to

Box 19. Equations 31-34

$$\sum_{i=1}^{4} PG\left(t_y,t_s,z,i\right) + PGN\left(t_y,t_s,z,i\right) + UE\left(t_y,t_s,z\right) + \sum_{z_P=1}^{15} PF\left(t_y,t_s,z_p,z\right)\times\left(1-PFLoss\left(z_p,z\right)\right) +$$
$$\sum_{z_P=1}^{15} PFN\left(t_y,t_s,z_p,z\right)\times\left(1-PFNLoss\left(z_p,z\right)\right) - \sum_{z_p=1}^{15} PF\left(t_y,t_s,z,z_p\right) - \sum_{z_p=1}^{15} PFN\left(t_y,t_s,z,z_p\right) =$$
$$A_{(ty,ts,z)}\left(x\right) \leq \tilde{D}\left(t_y,t_s,z\right) + p^1_{(ty,ts,z)} \quad \forall \quad t_y,t_s,z \tag{31}$$

And

$$\sum_{i=1}^{4} PG\left(t_y,t_s,z,i\right) + PGN\left(t_y,t_s,z,i\right) + UE\left(t_y,t_s,z\right) + \sum_{z_P=1}^{15} PF\left(t_y,t_s,z_p,z\right)\times\left(1-PFLoss\left(z_p,z\right)\right) +$$
$$\sum_{z_P=1}^{15} PFN\left(t_y,t_s,z_p,z\right)\times\left(1-PFNLoss\left(z_p,z\right)\right) - \sum_{z_p=1}^{15} PF\left(t_y,t_s,z,z_p\right) - \sum_{z_p=1}^{15} PFN\left(t_y,t_s,z,z_p\right) =$$
$$A_{(ty,ts,z)}\left(x\right) \geq \tilde{D}\left(t_y,t_s,z\right) + p^1_{(ty,ts,z)} \quad \forall \quad t_y,t_s,z \tag{32}$$

The inequality relation of Equations 14 and 16 can be constructed in the same way:

$$\sum_{i=1}^{4} \frac{\left\{PG_{init}\left(z,i\right)\times\left(1-Decay\right)^{ty} + \sum_{tyb=1}^{ty} PG\exp step\left(z,i\right)\times PG\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times\left(1-PGLoss\left(z,i\right)\right)}{1+RESPP\left(z,i\right)}$$
$$+\sum_{i=1}^{4}\frac{\left\{\sum_{tyb=1}^{ty} PGN\exp step\left(z,i\right)\times PGN\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times\left(1-PGNLoss\left(z,i\right)\right)}{1+RESPP\left(z,i\right)} +$$
$$\sum_{z_p=1}^{15}\left\{F_{Max}\left(t_y,z_p,z\right)\times\left(1-PFLoss\left(z_p,z\right)\right)\right\} + UM\left(z,t_y\right) - \sum_{z_p=1}^{15} F_{Max}\left(t_y,z,z_p\right) = B_{(ty,z)}\left(x\right) \geq \tilde{D}_{peak}\left(z,t_y\right) - p^2_{(ty,z)} \quad \forall t_y,z \tag{33}$$

$$\left\{PG_{init}\left(z,i\right)\times\left(1-Decay\right)^{ty} + \sum_{tyb=1}^{ty} PG\exp step\left(z,i\right)\times PG\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times$$
$$\left(PGLoss\left(z,i\right)\right) + \left\{\sum_{tyb=1}^{ty} PGN\exp step\left(z,i\right)\times PGN\exp\left(t_{yb},z,i\right)\times\left(1-Decay\right)^{(ty-tyb)}\right\}\times\left(PGNLoss\left(z,i\right)\right)$$
$$= C_{(ty,z,i)} \geq AF\left(z,t_y\right)\times\tilde{D}_{peak}\left(z,t_y\right) - p^3_{(ty,z,i)} \qquad \forall t_y,z,i$$

where the $p^1_{\left(t_y,t_s,z\right)}$, $p^2_{\left(t_y,z\right)}$ and $p^3_{(ty,z,i)}$ denote the associated allowable tolerances. (34)

Box 20. Equations 35-38

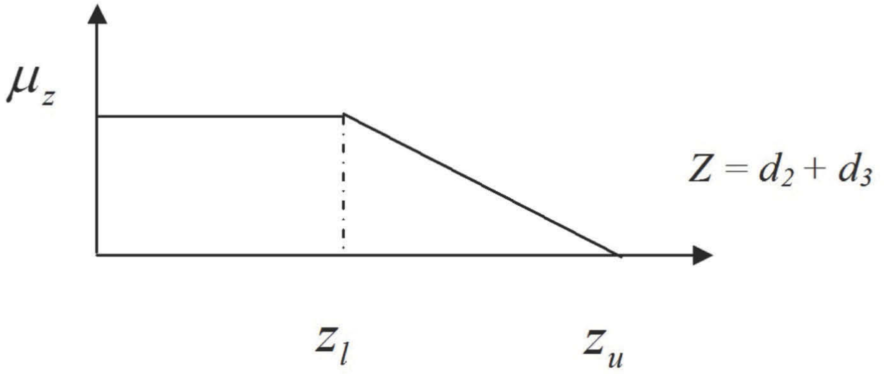
$$A_{(t_y,t_s,z)}(x) \leq w_1 D^p{}_{(t_y,t_s,z),\beta} + w_2 D^m{}_{(t_y,t_s,z),\beta} + w_3 D^o{}_{(t_y,t_s,z),\beta} + p^1_{(t_y,t_s,z)}\,; \quad \forall \quad t_y, t_s, z \tag{35}$$

$$A_{(t_y,t_s,z)}(x) \geq w_1 D^p{}_{(t_y,t_s,z),\beta} + w_2 D^m{}_{(t_y,t_s,z),\beta} + w_3 D^o{}_{(t_y,t_s,z),\beta} - p^1_{(t_y,t_s,z)}\,; \quad \forall \quad t_y, t_s, z \tag{36}$$

$$B_{(t_y,z)}(x) \geq w_1 D^p{}_{peak,\beta}(z,t_y) + w_2 D^m{}_{peak,\beta}(z,t_y) + w_3 D^o{}_{peak,\beta}(z,t_y) - p^2_{(t_y,z)}\,; \quad \forall \quad t_y, Z \tag{37}$$

$$C_{(t_y,z,i)}(x) \geq AF(z,t_y) \times \left\{ w_1 D^p{}_{peak,\beta}(z,t_y) + w_2 D^m{}_{peak,\beta}(z,t_y) + w_3 D^o{}_{peak,\beta}(z,t_y) \right\} - p^3_{(ty,z,i)}\,; \quad \forall \quad t_y, Z \tag{38}$$

Figure 7. Membership function for minimizing objective function Z = d1 + d2



convert them into their equivalent crisp ones by obtaining crisp representative numbers for the corresponding fuzzy right-hand sides. To do so, we apply the well-known weighted average method (Wang & Liang, 2005; Liang, 2006; Torabi & Hassini, 2008b). This approach seems to be the simplest and the most reliable defuzzification method in converting the fuzzy constraints into their crisp ones. In this regard, we also need to determine a minimal acceptable possibility level, β which denotes the minimum acceptable possibility level of occurrence for the corresponding imprecise/fuzzy data. Then the equivalent auxiliary crisp constraints can be represented as shown in Box 20, where $w_1 + w_2 + w_3 = 1$, and w1, w2 and w3 represent the weights of the most pessimistic, the most possible and optimistic value of the related fuzzy demands, respectively. In practice, the suitable values for these weights as well as β are usually determined subjectively by the experience and knowledge of the decision maker. Based on the concept of the most likely values proposed by Lai and Hwang (1992) and considering several relevant works (Wang & Liang, 2005; Liang, 2006; Torabi & Hassini, 2008b), we set these parameters (w2=4/6, w1=w3=1/6 and β *=0. 5*) in our numerical experiments.

Formulating the FDPP as an Auxiliary Crisp Model

Recalling the FDPP model, regarding the objective Functions 18 along with the Constraints 22 up to 26, we can apply the same approaches as used in the FAPP model.

Applying an Interactive Solution Algorithm

In the previous section, we described how the original FAPP and FDPP models could be replaced with an equivalent crisp single objective LP model, respectively. Generally, to solve the LP models, there are different techniques in the literature among them; the fuzzy programming approaches are being increasingly applied due to their ability in determining the satisfaction degree of each objective function explicitly. Thus, the decision makers can take their final decision by choosing a preferred efficient solution according to the satisfaction degree and preference (relative importance) value of each objective function. Here, we propose an interactive solution algorithm for implementation of the proposed FHPP as follows:

- **Step 1:** Determining appropriate triangular possibility distributions for the imprecise parameters and formulating the FAPP and FDPP models.
- **Step 2:** Transforming the FAPP model into its equivalent single objective LP crisp model.
- **Step 3:** Transforming the FDPP model into its equivalent single objective LP crisp model.
- **Step 4:** Solving the above-mentioned crisp models. To solve the single objective APP model, the Werner fuzzy programming method is used as follows:
    - Suppose that ZU is the high bound of objective function which has been gained of the model (APP) shown in Box 21, where v and F(v) indicate a feasible solution vector involving all of the variables in the original problem and feasible region involving crisp constraints (8-13 and 17) of the FAPP model.
    - Suppose that ZL is the low bound of objective function which has been gained of the model (APP) in Box 22.
    - Determine the membership function for the objective function and constraints of APP.

      Membership function for the objective function is defined in Figure 7. Membership function to minimize objective function Z = d1 + d2 is displayed in Box 23.

      Membership functions for the constraints (35-38) are defined in Box 24.
    - Having membership functions for fuzzy constraints and objective function, the APP problem can be transformed into a crisp optimization system as shown in Box 25.

      To solve the single objective Disaggregate Production Planning (DPP) model the Werner fuzzy programming method is used similar to the above manner.
- **Step 5:** To solve the above-mentioned crisp models for APP and DPP, the required parameters including the minimal acceptable level of satisfaction of soft constraints, α, the minimal acceptable possibility degree of imprecise data, β and also the tolerances of soft constraints, should be given by the decision maker. Moreover, if the decision maker is satisfied with the current efficient compromise solution, we should stop. Otherwise, we provide another efficient solution by changing the value of some controllable parameters say α and β.

Box 21. Equations 39-46

$$Min \;\; Z_U = d_1 + d_2 \tag{39}$$

s.t.

$$\sum_{t_{yb}=1}^{20} \frac{C_{PG}\left(t_{yb}\right) + C_{PGN}\left(t_{yb}\right) + C_U\left(t_{yb}\right)}{\left(1+disc\right)^{\left(t_{yb}-1\right)}} + \sum_{t_{yb}=1}^{20}\sum_{tc_y=t_{yb}}^{20} \frac{Ccap_{PG}\left(t_{yb}\right) + Ccap_{PGN}\left(t_{yb}\right) + Ccap_{PFN}\left(t_{yb}\right)}{\left(1+disc\right)^{\left(tc_y-1\right)}} - d_1 = A \tag{40}$$

$$\sum_{t_y=1}^{20}\sum_{t_s=1}^{4}\sum_{z=1}^{15}\sum_{i=1}^{4} W_{zi} \times PG\left(t_y, t_s, z, i\right) + d_2 = B \tag{41}$$

$$A_{\left(t_y,t_s,z\right)}\left(x\right) \le w_1 D^p{}_{\left(t_y,t_s,z\right),\beta} + w_2 D^m{}_{\left(t_y,t_s,z\right),\beta} + w_3 D^o{}_{\left(t_y,t_s,z\right),\beta} \;\; ; \quad \forall \quad t_y, t_s, z \tag{42}$$

$$A_{\left(t_y,t_s,z\right)}\left(x\right) \ge w_1 D^p{}_{\left(t_y,t_s,z\right),\beta} + w_2 D^m{}_{\left(t_y,t_s,z\right),\beta} + w_3 D^o{}_{\left(t_y,t_s,z\right),\beta} \;\; ; \quad \forall \quad t_y, t_s, z \tag{43}$$

$$B_{\left(t_y,z\right)}\left(x\right) \ge w_1 D^p{}_{peak,\beta}\left(z,t_y\right) + w_2 D^m{}_{peak,\beta}\left(z,t_y\right) + w_3 D^o{}_{peak,\beta}\left(z,t_y\right) \; ; \quad \forall \quad t_y, Z \tag{44}$$

$$C_{\left(t_y,z,i\right)}\left(x\right) \ge AF\left(z,t_y\right) \times \left\{ w_1 D^p{}_{peak,\beta}\left(z,t_y\right) + w_2 D^m{}_{peak,\beta}\left(z,t_y\right) + w_3 D^o{}_{peak,\beta}\left(z,t_y\right) \right\} ; \forall \quad t_y, Z \tag{45}$$

$$v \in F(v) \tag{46}$$

IMPLEMENTATION OF FHPP MODEL FOR ELECTRICITY GENERATION PLANNING IN IRAN

The proposed model has been implemented in Iran by using Iranian Electricity Industry Statistics, data of energy balance of Iran and Tavanir Co. using Lingo version 8 software. The output of the model is presented in Figure 8 and 2. Figure 8 shows the production amount of aggregate methods of electricity generation i in zone z and in season ts = 3 of year ty=1 (PG(ty, ts,z,i)) which is an output of FAPP model for autumn season of first year and data of this table is used as inputs for FDPP model.

Figure 9 shows the outputs of FDPP model which present the amount of power plants production only for each month in autumn season of first year. The results indicate a very close relation between the real load trend and our model outputs. In the real planning which is made in Iran's Electricity Network, there is no relationship between long-term planning and mid-term planning, no suitable balance in Electricity zones, and high rate of electricity blackout and loss. However, taking this approach, all these shortcomings are removed and electricity production is made with the least rate of electricity blackout and loss. The electricity demand is also satisfied with the best combination of power plants.

Box 22. Equations 47-54

$$Min \;\; Z_L = d_1 + d_2 \tag{47}$$

S.t.

$$\sum_{t_{yb}=1}^{20} \frac{C_{PG}\left(t_{yb}\right) + C_{PGN}\left(t_{yb}\right) + C_U\left(t_{yb}\right)}{\left(1 + disc\right)^{\left(t_{yb}-1\right)}} + \sum_{t_{yb}=1}^{20} \sum_{tc_y = t_{yb}}^{20} \frac{Ccap_{PG}\left(t_{yb}\right) + Ccap_{PGN}\left(t_{yb}\right) + Ccap_{PFN}\left(t_{yb}\right)}{\left(1 + disc\right)^{\left(tc_y - 1\right)}} - d_1 = A \tag{48}$$

$$\sum_{t_y=1}^{20} \sum_{t_s=1}^{4} \sum_{z=1}^{15} \sum_{i=1}^{4} W_{zi} \times PG\left(t_y, t_s, z, i\right) + d_2 = B \tag{49}$$

$$A_{\left(t_y,t_s,z\right)}\left(x\right) \leq w_1 D^p{}_{\left(t_y,t_s,z\right),\beta} + w_2 D^m{}_{\left(t_y,t_s,z\right),\beta} + w_3 D^o{}_{\left(t_y,t_s,z\right),\beta} + p^1_{\left(t_y,t_s,z\right)} ; \quad \forall \quad t_y, t_s, z \tag{50}$$

$$A_{\left(t_y,t_s,z\right)}\left(x\right) \geq w_1 D^p{}_{\left(t_y,t_s,z\right),\beta} + w_2 D^m{}_{\left(t_y,t_s,z\right),\beta} + w_3 D^o{}_{\left(t_y,t_s,z\right),\beta} - p^1_{\left(t_y,t_s,z\right)} ; \quad \forall \quad t_y, t_s, z \tag{51}$$

$$B_{\left(t_y,z\right)}\left(x\right) \geq w_1 D^p{}_{peak,\beta}\left(z, t_y\right) + w_2 D^m{}_{peak,\beta}\left(z, t_y\right) + w_3 D^o{}_{peak,\beta}\left(z, t_y\right) - p^2_{\left(t_y,z\right)} ; \quad \forall \quad t_y, Z \tag{52}$$

$$C_{\left(t_y,z,i\right)}\left(x\right) \geq AF\left(z, t_y\right) \times \left\{ w_1 D^p{}_{peak,\beta}\left(z, t_y\right) + w_2 D^m{}_{peak,\beta}\left(z, t_y\right) + w_3 D^o{}_{peak,\beta}\left(z, t_y\right) \right\} - p^3_{\left(ty,z,i\right)} ; \quad \forall \quad t_y, Z \tag{53}$$

$$v \in F(v) \tag{54}$$

Box 23. Equation 55

$$\mu_Z(d_1 + d_2) = \begin{cases} 1 & if \quad d_1 + d_2 < Z_L \\ \dfrac{Z_U - (d_1 + d_2)}{Z_U - Z_L} & if \quad Z_L \leq d_1 + d_2 \leq Z_U \\ 0 & if \quad d_1 + d_2 > Z_U \end{cases} \tag{55}$$

The advantages of the addressed new approach (FHPP) are as follows:

1. Attention to the hierarchical structure aspects of power systems production planning.
2. The proposed model decreases complexity of problem using disaggregation of the problem at different levels.
3. The proposed model is a proper updating feedback system to increase reliability and developing performance of the power system production planning.

Box 24. Constraints and Equations 56-59

If: $w_1 D^p{}_{(t_y,t_s,z),\beta} + w_2 D^m{}_{(t_y,t_s,z),\beta} + w_3 D^o{}_{(t_y,t_s,z),\beta} = M$

If: $w_1 D^p{}_{peak,\beta}\left(z,t_y\right) + w_2 D^m{}_{peak,\beta}\left(z,t_y\right) + w_3 D^o{}_{peak,\beta}\left(z,t_y\right) = N$

$$\mu^1{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}\left(x\right)\right) = \begin{cases} 1 & if \quad A_{(t_y,t_s,z)}\left(x\right) < M \\ \dfrac{M + p^1_{(t_y,t_s,z)} - A_{(t_y,t_s,z)}\left(x\right)}{p^1_{(t_y,t_s,z)}} & if \quad M \le A_{(t_y,t_s,z)}\left(x\right) \le M + p^1_{(t_y,t_s,z)} \\ 0 & if \quad A_{(t_y,t_s,z)}\left(x\right) > M + p^1_{(t_y,t_s,z)} \end{cases} \tag{56}$$

$$\mu^2{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}\left(x\right)\right) = \begin{cases} 1 & if \quad A_{(t_y,t_s,z)}\left(x\right) > M \\ \dfrac{A_{(t_y,t_s,z)}\left(x\right) - M - p^1_{(t_y,t_s,z)}}{p^1_{(t_y,t_s,z)}} & if \quad M - p^1_{(t_y,t_s,z)} \le A_{(t_y,t_s,z)}\left(x\right) \le M \\ 0 & if \quad A_{(t_y,t_s,z)}\left(x\right) < M - p^1_{(t_y,t_s,z)} \end{cases} \tag{57}$$

$$\mu_{Dpeak(z,t_y)}\left(B_{(t_y,z)}\left(x\right)\right) = \begin{cases} 1 & if \quad B_{(t_y,z)}\left(x\right) > N \\ \dfrac{B_{(t_y,z)}\left(x\right) - N - p^2_{(t_y,z)}}{p^2_{(t_y,z)}} & if \quad N - p^2_{(t_y,z)} \le B_{(t_y,z)}\left(x\right) \le N \\ 0 & if \quad B_{(t_y,z)}\left(x\right) < N - p^2_{(t_y,z)} \end{cases} \tag{58}$$

$$\mu_{Dpeak(z,t_y)}\left(C_{(t_y,z,i)}\left(x\right)\right) = \begin{cases} 1 & if \quad C_{(t_y,z,i)}\left(x\right) > N \\ \dfrac{C_{(t_y,z,i)}\left(x\right) - N - p^3_{(t_y,z,i)}}{p^3_{(t_y,z,i)}} & if \quad N - p^3_{(t_y,z,i)} \le C_{(t_y,z,i)}\left(x\right) \le N \\ 0 & if \quad C_{(t_y,z,i)}\left(x\right) < N - p^3_{(t_y,z,i)} \end{cases} \tag{59}$$

4. By applying the proposed approach, power system production planning problem will be solved in less time and with less computer memory.
5. FHPP is very consistent with changes, due to its high flexibility.
6. Weakness of using imprecise data is solved appropriately by fuzzy theory and increased reliability of model's solutions.
7. Accurate planning is done and blackout problems will be nearly solved.
8. By using AHP technique, those technologies would be chosen for electricity generations which are unpolluted and efficient, besides their economical views for electricity industry.

Box 25. Equations 60-70

$$\lambda = Min \quad \begin{Bmatrix} \mu_Z(d_1 + d_2), \mu^1{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}(x)\right), \mu^2{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}(x)\right), \\ \mu_{Dpeak(z,t_y)}\left(B_{(t_y,z)}(x)\right), \mu_{Dpeak(z,t_y)}\left(C_{(t_y,z,i)}(x)\right) \end{Bmatrix}$$

$$\text{Max } \lambda \tag{60}$$

$$\text{s.t.} \tag{61}$$

$$\lambda \leq \mu_Z(d_1 + d_2) \tag{62}$$

$$\lambda \leq \mu^1{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}(x)\right) \quad \forall t_y, t_s, z \tag{63}$$

$$\lambda \leq \mu^2{}_{D(t_y,t_s,z)}\left(A_{(t_y,t_s,z)}(x)\right) \quad \forall t_y, t_s, z \tag{64}$$

$$\lambda \leq \mu_{Dpeak(z,t_y)}\left(B_{(t_y,z)}(x)\right) \quad \forall t_y, z \tag{65}$$

$$\lambda \leq \mu_{Dpeak(z,t_y)}\left(C_{(t_y,z,i)}(x)\right) \quad \forall t_y, z, i \tag{66}$$

$$\sum_{t_{yb}=1}^{20} \frac{C_{PG}(t_{yb}) + C_{PGN}(t_{yb}) + C_U(t_{yb})}{(1+disc)^{(t_{yb}-1)}} + \sum_{t_{yb}=1}^{20} \sum_{tc_y=t_{yb}}^{20} \frac{Ccap_{PG}(t_{yb}) + Ccap_{PGN}(t_{yb}) + Ccap_{PFN}(t_{yb})}{(1+disc)^{(tc_y-1)}} - d_1 = A \tag{67}$$

$$\sum_{t_y=1}^{20} \sum_{t_s=1}^{4} \sum_{z=1}^{15} \sum_{i=1}^{4} W_{zi} \times PG(t_y, t_s, z, i) + d_2 = B \tag{68}$$

$$v \in F(v) \tag{69}$$

$$0 \leq \lambda \leq 1 \tag{70}$$

Figure 8. Amount of electricity generated with each aggregate method of electricity generation for autumn season of first year

zone z	Production amount of aggregate methods of electricity generation i in zone z and in autumn season t_s = 3of first year t_y=1: $PG(t_y, t_s, z, i)$MW			
	Steam (i=1)	Gas (i=2)	Combine Cycle (i=3)	Hydro (i=4)
1	1251.2	222.656	342.314	40.877
2	2240.2	87.0744	0.0	94.5156
3	2116.0	59.64	0.0	9.42165
4	1769.436	3865.765	2681.574	268.4921
5	662.4	1307.607	1359.456	0.0
6	1738.8	490.6384	0.0	5976.018
7	0.0	0.0	0.0	0.0
8	235.52	273.0518	0.0	0.0
9	588.8	632.184	0.0	0.0
10	0.0	1323.213	1014.594	18.69375
11	55.2	1264.368	0.0	0.0
12	220.8	119.28	132.888	87.2375
13	1619.2	0.0	427.28	0.0
14	1177.6	1033.76	0.0	0.0
15	0.0	215.698	399.644	0.0

Figure 9. Amount of power plant production in each month of autumn season of the first year

k		power plants production in each month of autumn PG(t_m, z, i, k)MW		
	steam power plants (i=1) in zone=1	October (t_m=1)	November (t_m=2)	December (t_m=3)
1		143.28	516.612	0
2		0	601.3	0
	Gas power plants (i=2) in zone=1			
1		61.24	0	0
2		1.132	55.2	0
3		97.3	0	0
	Combine cycle power plants (i=3) in zone=1			
1		0	314.08	0
2		0	0	0
	Hydro power plants (i=4) in zone=1			
1		23.01	24.28	0
2		3.106	3.106	0
3		11.987	11.987	0
...		....	.....	.....
	steam power plants (i=1) in zone=15			
1		0	0	0
	Gas power plants (i=2) in zone=15			
1		95.706	0	0
2		0	0	117.15
	Combine cycle power plants (i=3) in zone=15			
1		412.496	412.496	412.496
	Hydro power plants (i=4) in zone=15			
1		0	0	0

CONCLUSION

In this paper FHPP has been applied as a new approach for PPGP. The proposed approach converts complex electricity generation planning problem to small sub-problems which could be easily solved and need less computer memory. This approach is relatively more effective than traditional approaches which are used in Iranian power plant planning system. Besides, the feedback system increases the flexibility of the system and dynamically allows the model to be well-suited with changes. Unexpected consumer behavior makes uncertainty for demand prediction thus the outputs of demand models are not accurate. This is a very important issue for electricity generation planning. Fuzzy theory can solve this weakness appropriately and increase reliability of model's solutions. Therefore accurate planning could be done and any shortage in electricity demand satisfaction could nearly be solved. In this research also with the combination of the AHP method and linear programming model, environmental pollution, efficiency, proportion in total capacity and power plant activity in year criteria are considered in addition to the previously considered cost based models.

REFERENCES

Al-Kalaani, Y. (2008). *Power generation scheduling algorithm using dynamic programming: Nonlinear analysis*. Elsevier Ltd. doi:10.1016/j.na. 11.082

Alonso, F., Turner, K., Walter, B., Wrang, B., Clavel, P., & Sprenger, W. (1992). Present practices on load forecasting and load management: A survey. *Electra*, *145*, 69.

Bitran, G. R., & Hax, A. C. (1981). Disaggregation and resource allocation using convex knapsack problem with bounded variable. *Management Science*, *21*(40).

Bloom, J. A., & Gallant, L. (1994). Modeling dispatch constraints in production cost simulations based on the equivalent load method. *IEEE Transactions on Power Systems*, *9*(2), 598–611. doi:10.1109/59.317684

Carrion, M., & Arroyo, J. M. (2006). A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem. *IEEE Transactions on Power Systems*, *21*, 1371–1378. doi:10.1109/TPWRS.2006.876672

Cheng, C. P., Liu, C. W., & Liu, C. C. (2000). Unit commitment by Lagrangian relaxation and genetic algorithms. *IEEE Transactions on Power Systems*, *15*, 707–714. doi:10.1109/59.867163

Cohen, A. I., & Yoshimura, M. (1983). A branch-and-bound algorithm for unit commitment. *IEEE Transactions on Power Apparatus and Systems*, *102*, 444–451. doi:10.1109/TPAS.1983.317714

Dantzig, G. B., & Wolfe, P. (1960). Decomposition principle for linear programs. *Operations Research*, *8*, 101–110. doi:10.1287/opre.8.1.101

Dotzauer, E. (2001). *Energy system operation by Lagrangian relaxation.* Doctoral thesis, Linköping University, Department of Mathematics, Sweden.

Eriksen, P. B. (2001). Economic and environmental dispatch of power/CHP production systems. *Electric Power Systems Research*, *57*, 33–39. doi:10.1016/S0378-7796(00)00116-4

Ford, L. R., & Fulkerson, D. R. (1958). A suggested computation for maximal multicommodity network flows. *Management Science*, *5*, 97–101. doi:10.1287/mnsc.5.1.97

Fung, R. Y. K., Tang, J., & Wang, D. (2003). Multiproduct aggregate production planning with fuzzy demands and fuzzy capacities. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *33*(3), 302–313. doi:10.1109/TSMCA.2003.817032

Gill, P. E., Murray, W., & Wright, M. H. (1981). *Practical optimization*. London, UK: Academic Press.

Golovin, J. J. (1975). *Hierarchical integration of planning and control technique report.* Operation research center M.I.T. No. 116.

Gomes, B. A., & Saraiva, J. T. (2009). Demand and generation cost uncertainty modelling in power system optimization studies. *Electric Power Systems Research*, *79*(6). doi:10.1016/j.epsr.2008.12.010

Goransson, L., & Johnsson, F. (2009). Dispatch modeling of a regional power generation system Integrating wind power. *Renewable Energy*, *34*, 1040–1049. doi:10.1016/j.renene.2008.08.002

Hakonen, H. (1996). *Unit commitment optimization of backpressure power plants in cogeneration planning* (In Finnish). Master thesis, Systems Analysis Laboratory, Helsinki University of Technology.

Hax, A. C., & Meal, H. C. (1975). Hierarchical integration of production planning scheduling. In Giesler, M. A. (Ed.), *Studies in management sciences, logistic* (*Vol. 1*, pp. 53–69). North Holland.

Hillier, C. F., & Liberman, G. J. (1980). *Introduction to operation research* (3rd ed.).

Hobbs, W. J., Hermon, G., Warner, S., & Sheble, G. B. (1988). An enhanced dynamic programming approach for unit commitment. *IEEE Transactions on Power Systems*, *3*, 1201–1205. doi:10.1109/59.14582

Hsu, H. M., & Wang, W. P. (2001). Possibilistic programming in production planning of assemble-to-order environments. *Fuzzy Sets and Systems*, *119*, 59–70. doi:10.1016/S0165-0114(99)00086-X

Illerhaus, S. W., & Verstege, J. F. (1999). *Optimal operation of industrial CHP-based power systems in liberalized energy markets*. In IEEE Power Tech'99 Conference, Budapest, Hungary, August 29–September 2.

Jalilzadeh, S., Shayeghi, H., & Hadadian, H. (2009). Integrating generation and transmission networks reliability for unit commitment solution. *Energy Conversion and Management*, *50*, 777–785. doi:10.1016/j.enconman.2008.09.027

Kazarlis, S. A., Bakirtzis, A. G., & Petridis, V. (1996). A genetic algorithm solution to the unit commitment problem. *IEEE Transactions on Power Systems*, *11*, 83–92. doi:10.1109/59.485989

Kumar, S., & Naresh, R. (2009). Nonconvex economic load dispatch uses an efficient real-coded genetic algorithm. *Applied Soft Computing*, *9*, 321–329. doi:10.1016/j.asoc.2008.04.009

Lai, Y. J., & Hwang, C. L. (1992). A new approach to some possibilistic linear programming problems. *Fuzzy Sets and Systems*, *49*, 121–133. doi:10.1016/0165-0114(92)90318-X

Liang, T. F. (2006). Integrating production-transportation planning decision with fuzzy multiple goals in supply chains. *International Journal of Production Research*, *46*(6), 1477–1494. doi:10.1080/00207540600597211

Medina, J., Quintana, V. H., & Conejo, A. J. (1999). A clipped-off interior point technique for medium-term hydro-thermal coordination. *IEEE Transactions on Power Systems*, *14*, 266–273. doi:10.1109/59.744542

Muckstadt, J. A., & Koenig, S. A. (1977). An application of Lagrangian relaxation to scheduling in power-generation systems. *Operations Research*, *25*, 387–403. doi:10.1287/opre.25.3.387

Mula, J., Poler, R., Garcia-Sabater, J. P., & Lario, F. C. (2006). Models for production planning under uncertainty: A review. *International Journal of Production Economics*, *103*, 271–285. doi:10.1016/j.ijpe.2005.09.001

Nabona, N., Gil, C., & Albrecht, J. (2001). Long-term thermal power planning at VEW ENERGIE using a multi-interval Bloom and Gallant method. *IEEE Transactions on Power Systems*, *16*(1), 69–77. doi:10.1109/59.910783

Nabona, N., & Pages, A. (2002). *Long-term electric power planning in a competitive market using the Bloom and Gallant procedure and a modeling language.* Technical Report DR2002/24, Dept. Estadıstica i Inv. Operativa, Univ. Politec. de Catalunya, Barcelona. Retrieved from http://www-eio.upc.es/gnom

Nabona, N., & Pages, A. (2004). Long-term electric power planning in liberalized markets using the Bloom and Gallant formulation. In Alonso-Ayuso, A., Cerda, E., Escudero, L. F., & Sala, R. (Eds.), *Optimizacio n bajo incertidumbre* (pp. 185–211). Valencia, Spain: Tirant lo Blanch.

Ozdamar, L., Atli, A. O., & Bozyel, M. A. (1996). Hueristic family disaggregation technique for Hierarchical production planning systems. *Integration Journal of Production Research*, *34*, 2613–2628. doi:10.1080/00207549608905047

Pages, A. (2002). *Procediment de Bloom i Gallant de planificacio´ a llarg termini d'unitats te`rmiques de generacio´ ele`ctrica usant la descomposicio´ de Dantzig–Wolfe. Final-year project, Facultat de Matematiques i Estadıstica, Univ*. Barcelona: Polite`cnica de Catalunya.

Pages, A., & Nabona, N. (2002). *Long-term electric power planning using the Bloom and Gallant's linear model: A comparison of solution techniques*. Technical report DR2002/25, Dept. Estadı´stica i Inv. Operativa, Univ. Politec. de Catalunya, Barcelona.

Patra, S., & Goswami, S. K. (2009). Fuzzy and simulated annealing based dynamic programming for the unit commitment problem. *Expert Systems with Applications*, *36*, 5081–5086. doi:10.1016/j.eswa.2008.06.039

Perez-Ruiz, J., & Conejo, A. J. (2000). Multi-period probabilistic production cost model including dispatch constraints. *IEEE Transactions on Power Systems*, *15*(2), 502–507. doi:10.1109/59.867132

Rong, A., Hakonen, H., & Lahdelma, R. (2008). A variant of dynamic programming algorithm for unit commitment of combined heat and power systems. *European Journal of Operational Research*, *190*, 741–755. doi:10.1016/j.ejor.2007.06.035

Rong, A., Hakonen, H., & Lahdelma, R. (2009). A dynamic regrouping based sequential dynamic programming algorithm for unit commitment of combined heat and power systems. *Energy Conversion and Management*, *50*(4). doi:10.1016/j.enconman.2008.12.003

Rong, A., Lahdelma, R., & Grunow, M. (2009). An improved unit decommitment algorithm for combined heat and power systems. *European Journal of Operational Research*, *195*, 552–562. doi:10.1016/j.ejor.2008.02.010

Sadeghi, K. H. R., Ghaderi, S. F., Azadeh, A., & Razmi, J. (2009). Forecasting electricity consumption by clustering data in order to decrease the periodic variable's effects and by simplifying the pattern. *Energy Conversion and Management*, *50*, 829–836. doi:10.1016/j.enconman.2008.09.036

Sakawa, M., Kato, K., & Ushiro, S. (2002). Operational planning of district heating and cooling plants through genetic algorithms for mixed 0–1 linear programming. *European Journal of Operational Research*, *137*, 677–687. doi:10.1016/S0377-2217(01)00095-9

Sen, S., & Kothari, D. P. (1998). Optimal thermal generating unit commitment: A review. *Electric Power Energy Systems*, *20*, 443–451. doi:10.1016/S0142-0615(98)00013-1

Sheble, G. B., & Fahd, G. N. (1994). Unit commitment literature synopsis. *IEEE Transactions on Power Systems*, *9*, 128–135. doi:10.1109/59.317549

Snyder, W. L., Powell, H. D., & Rayburn, J. C. (1987). Dynamic programming approach to unit commitment. *IEEE Transactions on Power Systems*, *2*, 339–350. doi:10.1109/TPWRS.1987.4335130

Tang, J., Fung, R. Y. K., & Yong, K. L. (2003). Fuzzy modeling and simulation for aggregate production planning. *International Journal of Systems Science*, *34*(12/13), 661–673. doi:10.1080/00207720310001624113

Tang, J., Wang, D., & Fung, R. Y. K. (2000). Fuzzy formulation for multi-product aggregate production planning. *Production Planning and Control*, *11*, 670–676. doi:10.1080/095372800432133

Tanha, R., & Ghaderi, S. F. (2007). *Hierarchical production planning in a fuzzy environmental.* International Conference of Iranian Operations Research Society, IORC2007 Sharif Technology and Kish University of Iran.

Thorin, E., Brand, H., & Weber, C. (2005). Long-term optimization of cogeneration systems in a competitive market environment. *Applied Energy*, *81*(2), 152–169. doi:10.1016/j.apenergy.2004.04.012

Torabi, S. A., & Hassini, E. (2008). An interactive possibilistic programming approach for multiple objective supply chain master planning. *Fuzzy Sets and Systems*, *159*, 193–214. doi:10.1016/j.fss.2007.08.010

Torabi, S. A., & Hassini, E. (2008b). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19).

Ummels, B. C., Gibescue, M., Pelgrum, E., Kling, W. L., & Brand, A. J. (2007). Impact of power on thermal generation unit commitment and dispatch. *IEEE Transactions on Power Systems*, *22*, 44–51.

Virmani, S., Imhof, K., & Mukherjee, S. (1989). Implementation of a Lagrangian relaxation based unit commitment problem. *IEEE Transactions on Power Systems*, *4*, 1373–1379. doi:10.1109/59.41687

Wang, D., & Fang, S. C. (1997). A genetics-based approach for aggregate production planning in a fuzzy environment. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *27*(5), 636–645. doi:10.1109/3468.618262

Wang, R. C., & Fang, H. H. (2001). Aggregate production planning with multiple objectives in a fuzzy environment. *European Journal of Operational Research*, *133*, 521–536. doi:10.1016/S0377-2217(00)00196-X

Wang, R. C., & Liang, T. F. (2004). Application of fuzzy multiobjective linear programming to aggregate production planning. *Computers & Industrial Engineering*, *46*(1), 17–41. doi:10.1016/j.cie.2003.09.009

Wang, R. C., & Liang, T. F. (2005). Applying possibilistic linear programming to aggregate production planning. *International Journal of Production Economics*, *98*, 328–341. doi:10.1016/j.ijpe.2004.09.011

Zhuang, F., & Galiana, F. D. (1988). Towards a more rigorous and practical unit commitment by Lagrangian relaxation. *IEEE Transactions on Power Systems*, *3*, 763–773. doi:10.1109/59.192933

Chapter 8
Communication as a Key Factor in Cooperation Success and Virtual Enterprise Paradigm Support

Ing. Martin Januska
University of West Bohemia in Pilsen, Czech Republic

ABSTRACT

Commonality among business subjects and the ability to communicate with each other effectively are critical factors for the success of the project. Communication between these entities is a source of information and data, which all participants need for being able to work effectively. Therefore, the communication is strongly correlated to the performance. Nowadays, there is a significantly increasing pressure on the speed of communication, transparency, relevance, and volume of data transmitted. This need leads to design of a new communication environment.

INTRODUCTION

This chapter deals with description of problems small and medium enterprises (SME's) deals with during project cooperation or using Virtual Enterprise Paradigm. Number of important problems is addressed trough effective communication and appropriate communication environment in this chapter.

Virtual Enterprise (VE) is a temporary coalition of companies that have come together to share skills and resources to exploit the business opportunities that are unable to cope alone. Through effective collaboration and integration of resources, knowledge and skills held by individual members of virtual communities, Virtual Enterprise is capable of achieving the desired objectives with high quality and low price. It

DOI: 10.4018/978-1-4666-2098-8.ch008

maximizes resources utilization and minimizing initial investments and distribution of total risk. However, the main objective is to minimize the time at which new products and services appear on the market. Nowadays, it seems that Virtual Enterprise is one of the most promising approaches for small and medium-sized companies in the future.

The cooperation of several companies on one-off projects such as R & D means a collaboration of a large number of users across a number of totally different business entities. There is none or very minimal possibility that these different entities will unify their enterprise information systems for the short-term cooperation. In the long-term cooperation the idea of unification of corporate information systems in terms of return on investment is also very controversial. Therefore the start of cooperation is threatened by the absence of an effective way of information and data exchange.

Another important question in this concept is traceability and relevance of communication. In terms of trust it is essential that each of the entities is able to monitor and store the communication. That allows reverse analysis of communication back in time.

However, the possibility of reverse analysis is again in terms of cooperation of more SME's inadequate. It is all about quickness, quality and price. Therefore it is necessary to monitor communication and the states of processes in real time. That allows clear identification of problems and greatly eliminates wasting of time in communication. At the same time, there is evident who is responsible for the waste of time and who will bear the all potential consequences of possible unobserved deadlines. The Ability to monitor communication also applies for the customer who ordered the project. He is therefore given the ability to monitor the state of the communication providing assurance on the progress of work on his projects.

Effective communication environment for affordable price to small and medium-sized enterprises (SME's) are currently on the market only in very limited quantities. There are already existing similar sophisticated massive server-based communication environments or in a smaller scale, electronic forums. However, these solutions require a central server where all data are stored. Paradox is that the concept of communication through a central server as a data repository is very secure and still it meets with the considerable reluctance of companies to store their data on a server which is not directly under their control.

VIRTUAL ENTERPRISE

Definition of Virtual Enterprise

Typically, Virtual Enterprise is established by parent company, which then plays the main role of the coordinator and leader in the entire Virtual Enterprise. This system contains a number of shortcomings that need to be solved by any effective way. The concept of Virtual Enterprises networks seems to be suitable environment and effective tool for creating own Virtual Enterprises.

The concept of Virtual Enterprise is applicable to both small and medium-sized enterprises and large companies. Through the Virtual Enterprise Network, companies are able to take advantage of business opportunities that no company was able to use as an individual. The general concept is to merge more small and medium-sized businesses with free business relationships or to make happen the closer cooperation of a small number of large companies.

In other words, Virtual Enterprise is simply a network of processes connections which make value added in the supply chain. Connection is only to a specific time in order to achieve specific business goals. It is important to say that there is no new legal entity, and after reaching the target, virtual company ceases to exist. Supply chain of Virtual Enterprise exceeds and erode traditional boundaries between companies and presents new opportunities and challenges, both in terms of business opportunities and in terms of technological and organizational requirements. In the business sector there are emerging new business strategies aimed at exploiting opportunities and maximizing benefits from a relatively narrow window of possibilities arising from volatility and unpredictability of the global markets.

Another goal of the Virtual Enterprise is the optimal sharing of resources and risks through collaboration. This concept is primarily a reaction to changes in markets and the possibility of using the short-term business opportunities and utilization of available capacity. The main characters are the flexibility and re-configurability, which is the ability to respond quickly and flexibly to new conditions and circumstances, both predictable and unpredictable. Another very important characteristic of Virtual Enterprise is the ability to cooperate within the internal network of Virtual Enterprise and maximize added value.

Types of Virtual Enterprises

Virtual Enterprise according to H. T. Goranson is possible to divide in four standard types, from its combination the Virtual Enterprise is made up. According to draft of this book it doesn't have to be just consolidation of corporations, but partners of the network of Virtual Enterprise can be companies, also for example individual division of society, universities, groups of consumers or unions.

Type 1: Opportunity Driven

Virtual Enterprise formed as a response to business opportunity. This is in its clean form ideal and the most interesting kind of Virtual Enterprise, where certain enterprise identifies business opportunity (or will distinguish a change), which offers competitive advantage or possibility of usage. Company which identified opportunity and decided to use it became after it the mother's enterprise (initiator) rise of Virtual Enterprise. It has to identify needed partners with needed basic (core) abilities and integrate them into the Virtual Enterprise. This is ideal kind of Virtual Enterprise which breaks down after acomplishment (usage) of given opportunity.

Type 2: Capability-Driven

It means relatively permanent coalition of enterprises that mostly persist from pasts and now are searching for new business occasions. Generally they only accept new partner if he is fundamental for usage of new opportunity. An example of this type of Virtual Enterprise is big corporate bodies.

Type 3: Supplier Chain

Here we discuss supply chain which while deriving benefits from relatively conventional business relations, shows elasticity (agility) in reaction to needs of the market. As an example the usage of electronic business in conjunction with conventional business venture can be introduced.

Type 4: Bidding Consortium

This group has in interaction among its members relatively common terms. But derives benefit from agile practices in reaction of market requirements. It acts as Virtual Enterprise at representation collective abilities of consumers. For example small construction company, that is able in co-operation to supply requisite construction. (Construction works, wiring system work, water supply, heating.) Each of these activities is provided by different company, which in relation to customer acts as one and then responds accordingly to their requirements.

Creation of Virtual Enterprise

By identification of business opportunity parent company will take role of initiator of rising Virtual Enterprise. Parent company as an initiator has to choose and contact suitable firm or supplier to complete main process. Main process in this case is understood production of consumer's requisite product, or services and its delivery to customer. Customer's request is only satisfaction of his needs and requirements. What way will these needs and requirements be satisfied, or what way will main process be executed, isn't important for consumer. This is fully in hands of mother firm as an initiator and leader of Virtual Enterprise. Formation of Virtual Enterprise is indeed the most difficult throughout the life cycle of Virtual Enterprise as to the part of selection of partners and their management. Main task of initiator of Virtual Enterprise is selection of suitable partners and creation of process models of Virtual Enterprise and their exact requirements. In conjunction with models there must be created a policy of Virtual Enterprise, that inclusive procedural model, have to accept with no doubts all potential partners of VE. It is because of the reason, that latter will not happen time waste when clearing up different opinions and views of thing across VE.

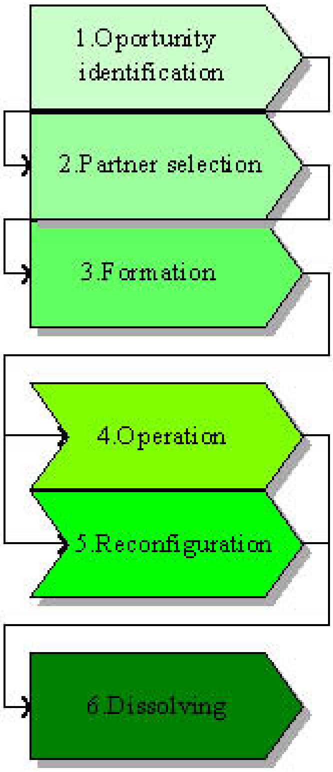
Parent company has to assure, that the VE will be able to fully satisfy customers needs. That can be reached by decomposition of main process to sub-processes and by selecting partners which will have requisite abilities and will then be able to realize these processes. These main partners may of course then subdivide processes given to them into another sub-processes and allocate (outsource) them by other company. Because of this, main process can be done in terms of those hierarchical VE networks. Here's crucial the decomposition of a big and complex problems, that companies are not able to solve separately, to smaller and easier to solve sub-processes, that are easily to catch for the company.

If the processes, which nobody is doing in the VEN, will be identified of course it will lead to addressing partners from outside the VEN. These partners will enter VE in outsourcing relation. To meet the demands of consumer subjects inside the networks of VE connect and therefore make up one new Virtual Enterprise. As soon as the order is done VE breaks down and subjects wait for another order in terms of VEN.

It is necessary to concern, that the entrepreneurial subjects do not get business orders only through VEN, but as though VEN serves here only as additional source of business opportunity, which would not be possible to achieve separately.

From Figure 1, life cycle of VE it is obvious that most crucial place at formation VE are phases 1,2 and 3 on the part of difficulty on organization. Phase 4 and 5 go are common and easy to handle. Phase 6 proceeds according to plan which has been created during formation of VE. This inactivation proceeds in agreement with plan made up in advance. It is important to say, that even after the dissolving of VE, it still responsible for its liabilities which some of the partners have to carry out. This could be for example guarantee on goods.

Figure 1. Life cycle of VE



Ad 1: Opportunity Identification

Business opportunity was identified in this step by a company which tends to become initiator of Virtual Enterprise creation. It is necessary to obtain more detail information about the business opportunity in this step. This process precedes and closely interwoven with the second step. Second step is the selection of partners and with their involvement detail exploration of the business opportunity.

Ad 2: Partner Selection

This phase is certainly the most demanding in terms of planning and management decisions requirements.

According to Liu Zhi, Mei Lai, Jiang Jie the foundation of Virtual Enterprise is initiated by a single parent company which will be in the role of coordinator and leader after the Virtual Enterprise was formed. As a leader or initiator the parent company is responsible for the selection of suitable partners. The initiator must create a model of all processes and their precise requirements. Along with the model the strategy for Virtual Enterprise must be created. Strategy together with the model must accept without question throughout the entire Virtual Enterprise by all potential partners. The reason is to avoid the time involved to clarify the different views and perspectives on the matter throughout the Virtual Enterprise. The parent company must ensure that Virtual Enterprise will be able to fully meet customer requirements which are done by decomposition of large and complex problems to the easily manageable sub-processes and selecting partners with the required skills to meet those processes. These key partners can of course continue to divide the processes to other sub-processes and allocate (outsource) them in other companies. This means that even very difficult main process can me handled in terms of Virtual Enterprise.

Ad 3: Formation

In the process of formation of Virtual Enterprise is necessary to choose suitable partners with regard in particular to minimize the cost, process time and maximize the production of added value. Suitability of partners should be considered on the basis of both price and time of their bids. Here is important to note once more that the main target of Virtual Enterprise to minimize time to market and costs. Partner in Virtual Enterprise are for example different not only by their geographic locations but they can be also different business entities with different business structure. At this stage it is necessary to synchronize information and communication systems. Synchronization of information and communication technology is crucial factor in Virtual Enterprise creation since everyone uses their own methods of work organization, information transfer and control of their own processes.

According to Hongmel Gou, Biqing Juany, Wenhuang Liu, Yu Li, Shluku Reu on the one hand, any member of the Virtual Enterprise is an independent company engaged in specific sub-processes using its own resources and trying to maintain its own independence and know how, but on the other hand synchronization and cooperation between partners engaged in the sub-processes is required.

According to H. T. Goranson parent company as an initiator of creation of Virtual Enterprise must clearly define the strategy. This strategy must be clear, well reasoned and goals of this strategy must be accepted by all members of Virtual Enterprise. Furthermore it is necessary mention and asses important attributes of Virtual Enterprise during the creation process.

- Re-use of created infrastructure of the Virtual Enterprise (possibility to use existing infrastructure for further business opportunities after dissolution of actual one).

- Extensibility of existing Virtual Enterprise (possibility to accept new partner in the Virtual Enterprise if the conditions requires it).
- Managing of individual partners in Virtual Enterprise (how the structure within the company and data share will be managed).
- A loose network of partners in Virtual Enterprise (minimizing the cost of removal of a partner in the case of amendments).

Important is to mention, that in the process of formation of VE it is essential to define precisely whole series of things namely according to H. T. Goranson.

- **Metrics:** Metrics will be applied across the whole network of VE. These metrics of course comes from conventional financial and operational metrics.
- **Capital:** It is necessary to determine in detail who bring capital into the VE not financial only, but also all sources, information including. If intellectual proprietorship is included it must be precisely defined how it will be rated and how its price will be observed in time. All dynamically transformative deposits must be appreciated this way, no just the information. At this point of forming VE new and clear financially-law structure has to originate.
- **Liabilities:** At this point it is necessary to take into account all liabilities generated, including those very improbable. Here rises another part of law structure. It is defined here, who is responsible for what and what are the guarantees of security that the can be later presented to costumer.
- **Risks and Bonuses:** At this point we have to define bonuses. It does not mean, that the risk can be expressed directly monetarily, but it must clearly define financial bonuses for members of VE taking the risk in specified height.
- **Plan of Dissolving:** VE must have already during it's formation brightly defined progress on it's dissolving. Here acts primarily about type 1 and 3 that are already from the start virtual like temporary VE. Important thing that the here must be defined is, when to dissolving will begin (inflating event, fall below threshold level gains).

Ad 4: Operation

From external environment point of view the Virtual Enterprise should appear as a single business organization. There are no more requirements for parent company as initiator in this phase but on the other hand there must be some kind of leader and coordinator of Virtual Enterprise.

Ad 5: Reconfiguration

This phase is closely associated with phase 4 Operation. It is necessary to respond flexible and adapt to new conditions when unexpected changes affect the function of Virtual Enterprise. Operation and reconfiguration phase of the Virtual Enterprise is quite common.

Ad 6: Dissolving

As has already been taken into consideration during the formation of Virtual Enterprise there comes a time when the business opportunity is fully utilized (met) or whenever the situation on the market changes so the business opportunity ceases to exist. At that time it's time for dissolution or radical change of Virtual Enterprise. This dissolving is based on dissolving plan prepared in advance in phase of forming of the Virtual Enterprise. It is essential to mention here that even after dissolution commitments of Virtual Enterprise still have to be carried by any of the partners. For example guarantee on the goods.

Obstacles to the Virtual Enterprise Paradigm

There were identified fundamental barriers to the functioning of the concept of Virtual Enterprises. These barriers are as follows.

Issue 1

First, the mutual distrust of interested business subject's. Firms or potentially all business entities entering virtual companies face considerable reluctance of other partners to share any data and information. It is important to say that the for functioning of a virtual company is trust between partners one of the key factors of success and of course on the other hand the lack of trust is the main obstacle of proper functioning. It is not just about sharing sensitive information, but also sharing risks, which are not always distributed evenly to all partners.

Issue 2

The second major area of concern is the mutual communication and exchange of data and information. The problem of reluctance to share sensitive information relates more to the previous mentioned problem. But here it must be reminded that for short-term co-operation it is impossible to unify information systems and individual metrics throughout the Virtual Enterprise. For long-term cooperation is the unification of corporate information systems in terms of relative cost effect is still debatable, and rather unrealistic. It is therefore necessary to clearly define the management of capital, obligations, risks and rewards, and define a plan of dissolution as a virtual company after completion of the contract ceases. Typical trigger event is delivery of a contract or drop in profits in the defined threshold level. It is necessary to introduce a unified communications environment and metrics so that inter-firm cooperation is possible. For this purpose it is necessary to use an external communication tool and have already built sufficient trust so that the interested commercial operators would be willing to share their data in an environment that is not directly under their control.

Issue 3

The problem of communication effectiveness is associated with the problem of speed of response to change. The main idea behind the Virtual Enterprise Paradigm is the use business opportunities from a relatively narrow window resulting from the instability of markets, where rapid response is another key factor. Interested parties must already have communication channels, so the own organization and starting a virtual company or reconfiguration of existing structures comes immediately as a response to market changes.

Issue 4

The last issue, which is mentioned, is a little awareness of the market about this concept, which is also related to and supports the first-mentioned problem, a lack of trust.

An important unifying element of all these problems is effective communication and communication environment.

Communication in the Virtual Enterprise Environment

Fast, efficient and transparent communication was identified as a basic need for a good functioning in terms of Virtual Enterprise. None of the other known parameter affects the efficiency of cooperation as much as communication does.

This conclusion is based on the author interviews with different business entities representatives and is supported by number of experts in academic and public sector in occasional debates on this topic.

Advantage and need of utilization of an appropriate communication tool can be seen on Figure 2. This figure is an indication of current state of communication in regular project. All communication is addressed across dozens of emails, telephone calls and personal meetings. This solution is inadequate in terms of the Virtual Enterprise and it is specifically because of the large number of stakeholders with different geographic location.

Daily-based communication where everything is handled by hundreds of emails, telephone calls and personal meetings is outlined there. This solution in the concept of Virtual Enterprise is inadequate. It is possible to see it in Table 1. Each of the communication modes has its advantages and disadvantages. The proposed environment has much in common with an electronic discussion forum. Advantages over the discussion forum are in better traceability, data backup and there are significantly lover hardware and software demands. The main advantage is that there is no need of any installation and thus no need for central servers and unification of company ICT.

Another important question in this concept is traceability and relevance of communication. In terms of trust it is essential that each of the entities is able to monitor and store the communication.

Figure 2. Classical communication

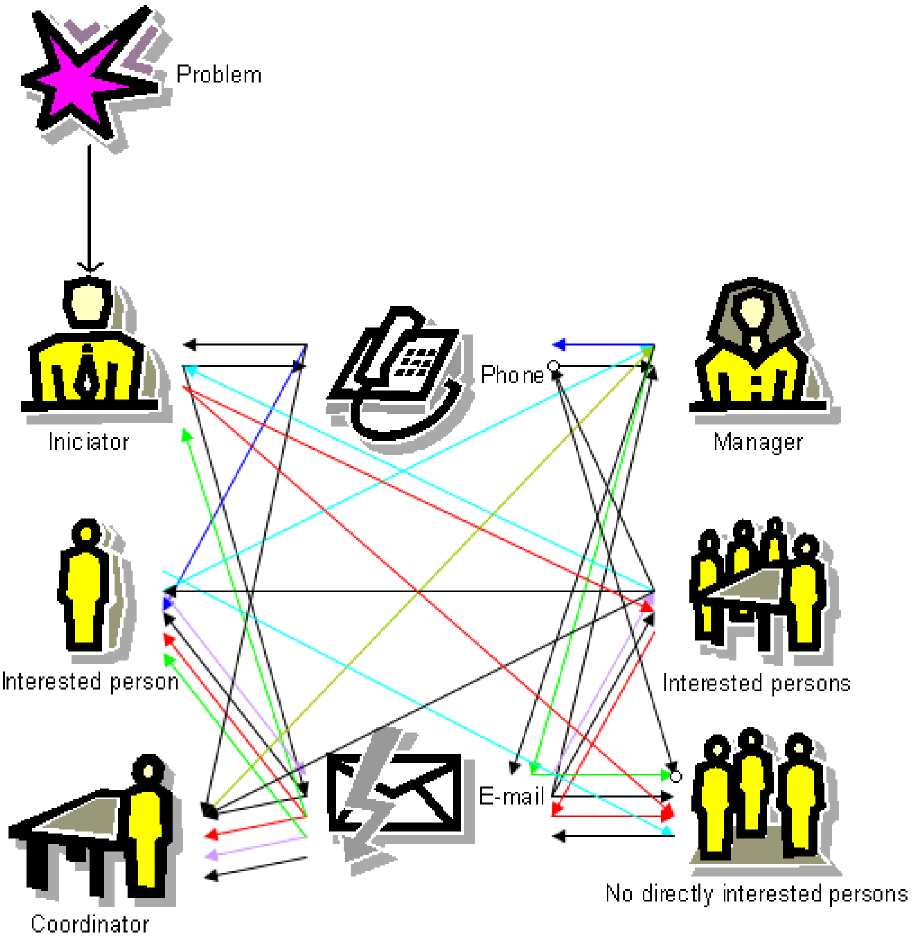


Table 1. Ways of communication

	Phone	Persona meetings	Post	Electronic discusion forum	Instant messaging	E-mail	Proposed environment
Speed of the response	+ +	+ +	− −	−	+ +	−	−
Volume of Data transmited	− −	−	−	+ +	+	+ +	+ +
Data security	+	+ +	−	+	−	+	+
Number of Participants	− −	+	− −	+ +	−	+	+ +
Substantion	− −	−	−	+	−	+	+ +
Long-term transparency	−	−	−	+ +	−	−	+ +
Traceability of old information	− −	− −	−	+ +	−	+	+ +
Demands on the user	+	+ +	+	−	+	+	+
SW HW demands	+	+ +	+	− −	−	−	−
Cost	−	−	+ +	+	+ +	+ +	−
Operating cost's	−	+	−	+ +	+ +	+ +	+ +

That allows reverse analysis of communication back in time.

However, the possibility of reverse analysis is again in terms of cooperation of more SME's inadequate. It is all about quickness, quality and price. Therefore it is necessary to monitor communication and the states of processes in real time. That allows clear identification of problems and greatly eliminates wasting of time in communication. At the same time, there is evident who is responsible for the waste of time and who will bear all potential consequences of possible disregarded deadlines. The Ability to monitor communication also applies for the customer who ordered the project. He is therefore given the ability to monitor the state of the communication providing assurance on the progress of work on his projects.

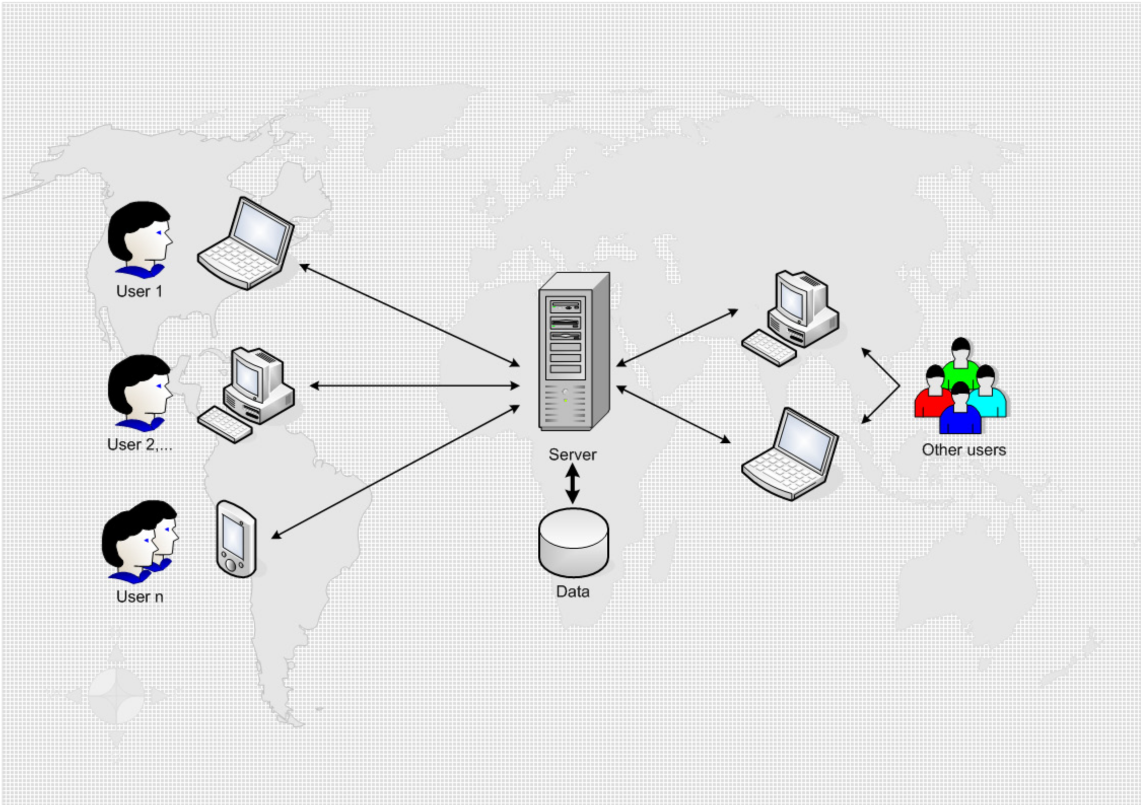
Effective communication environment, which would be affordable to small and medium-sized enterprises (SME's), is currently on the market only in very limited quantity. There are already existing similar sophisticated massive server-based communication environments or in a smaller scale, electronic forums. However, these solutions require a central server where all data are stored. Paradox is that the concept of communication through a central server as a data repository is very secure and still it meets with the considerable reluctance of companies to store their data on a server, which is not directly under their control (see Figure 3).

SOLUTIONS AND RECOMMENDATIONS

Proposed communication environment works as a workstation application on the email client basis see Figure 4. Server is used only for distribution of the software client and its actualization. All data are stored in the client's email account, which is mostly on the corporate server. So there is no need of central server and transmitting data storage outside the corporate network.

The principle of proposed environment can be seen on Figure 4. There will be no central server but on the contrary the data exchange is on the email client basis. As already mentioned at the beginning of the paper there is none or minimal possibility of unification of information communication technologies in short term inter-firm cooperation. Unification of ICT in long time cooperation is also questionable with regard to the price-performance ratio. This means that quick start of cooperation is threatened by the absence of an effective way of information and data exchange. This is the reason why the email client based solution was evaluated and chosen as the most appropriate solution. Paradox is that even when the concept of communication through a central server as a data repository is very secure, easier to implement and more effective according to authors research, business subjects are considerably reluctant to store their data on a server which is not directly under their control. Email based solution is also more appropriate from the compatibility of different internal information

Figure 3. Communication concept with central server



systems (ICT) point of view. All ICT systems are able to send emails and email is simple open data format, which is easy to process.

It is possible to imagine proposed environment as an email client based on the similar principles as Microsoft Outlook. All information are stored in email accounts of individual users and proposed environment is only a workstation application sorting received emails appropriately. There is no need for unification of ICT systems. All interested business subjects can use their own internal information system and communicate with each other via email.

1. **The Communication and Information Exchange:**
   a. Creation of clear reporting structure.
   b. Ensuring that the message will get to all interested users.
   c. Avoidance of unnecessary flooding of unrelated users by unsolicited messages.
   d. Assigning tasks to individual users.
   e. Environment allows imposing requirements on individual users.
   f. Effective feedback.
   g. Sorting out of already outdated information.
   h. Registration of new users.
   i. Message board for posting information within Virtual Enterprise.
2. **Analysis and Management of the Communication:**
   a. Users with appropriate rights can monitor state of communication and whole process.
   b. Allocation of rights to individual users.
   c. Reverse analysis of the all time related information related to messaging and tasks.
   d. From the perspective of specific message or task.
   e. From the perspective of specific user
   f. From the perspective of a specific topic or project.
3. **Data Warehouse:**
   a. Exchanged data backup.
   b. Project documentation export possibility in various data format.
   c. Well sorted knowledge base usable in similar projects.

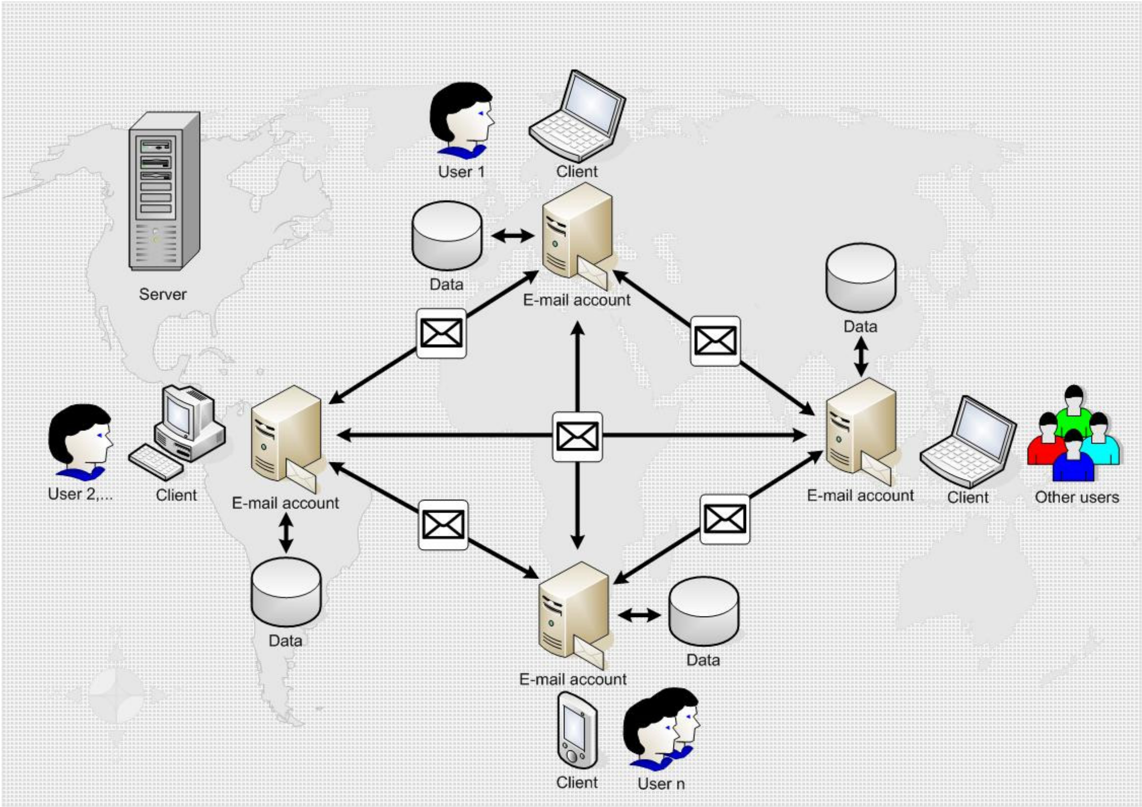
Creation of Clear Reporting Structure

The basic requirement for the communication environment is the maximum transparency of the information exchanged. This is achieved by using a suitable sorting and storing messages in lucid directory tree. It can be said that appropriate structure of the messages is the base for transparency of all communications. If one takes a classic email client, where the messages appear in a directory beneath another, when the number of messages crosses more than two pages the clarity of communication is minimal. User loses an overview of the reports, e.g. which message is from what project and it is very difficult to determine exactly from what report it is only from the subject or sender.

In the proposed environment, the report classifies the directory tree according to the content (belonging to a particular project). This directory tree can be defined by any user who establishes a new topic. Therefore the messages are then sort to the pre-made directory structure, thereby ensuring their appropriate classification. Topics (directories) and messages not directly related to the user he does not have to read and on the other hand, reports of one subject are all stored in one place. There directories in which some new message was added are colored. Different color is used for example for the directories of unread message or of user-selected themes.

The following example is showing the directory of invented tree. Communication can be divided into directories, which can contain an unlimited

Figure 4. Communication without central server



number of subdirectories and their messages containing text are the last degree. The example shows that Project 1 contained three tasks that had to be addressed and solutions had to be discussed or reported. In addressing task 1 were two problems that had to be managed. Messages are automatically stored in the allocated space. Therefore if the user does not have to deal directly with the task No. 1 he does not have to read the reports appearing in other directories. If the user deals directly with this problem, he will immediately know that a new message appeared in the email comment on this topic. Alternatively, if there is a need to invite another user to help to solve the problem 1 in task 1, this user will be given the availability to see only the communication about task 1 or for the problem 1.

Ensuring that Messages will get to all Interested Users

Cooperation in a large number of users from different business entities on the same project is another problematic point of ensuring that all reports and relevant information received to all interested users. This is problematic because not every user involved in solving the problem, knows exactly whom in the network he should contact specifically. Another problem coming into play is the human factor. E.g. failure to add the address to the copy, or ignorance of a particular address. Because of this, it often happens that the information does not reach all of the interested users.

This problem must be solved in the proposal, this problem is addressed in such a way that the user himself does not fill in the address field.

If the user wants to reply in a specific location of directory tree in the debate, the client software stores directly in itself information about what users have which rights in the directory tree, and accordingly it sends the message to their email account. To avoid congestion of user's email accounts generated by the client software, each such report shall contain the generated four digit code that are used to set filters by conventional mailbox. Therefore in the classic mailboxes folder there is created a new folder by using filters and then all the messages generated by the client are saved there. This method clearly separates the message generated and sent by the client from other communication. It cannot be assumed that all communication will be via client software. And there must be said that the client software is required to create and send emails as well as serving its own synchronization and maintaining consistency of information on processing time. These information messages are still going through the networks as emails but contain only a code string which is unreadable without the client. For this reason, the filter in a mailbox is recommended.

Environment Allows Imposing Requirements on Individual Users

Due to maximizing of the efficiency of communication in the proposed environment it can be placed on each user's predefined requirements which they have to meet, confirm or reject. Examples of requirements: accept, approve, urgent response requested etc.

Effective Feedback

Effective feedback is a problem again due to the cooperation of a large number of people on one project. It is important that the report on progress and work progress is given to all collaborators, this should prevent from waste in the form of redundant or parallel activities. Information is automatically sent as a copy to all users, so the procedures work on the project informed everyone whether they are workers or managers.

Sorting out of Already Outdated Information

For easier navigation in incoming messages and to locate that information is already out of date information should be some way sorted. In my proposal, this is done through distribution of the projects themselves respectively in two groups of subjects and current projects and archive. If the issue is finished respectively project is done than it can be moved to the archive. This is achieved by reduction of information that appears in the initial screen, current projects, and directory trees current projects are easier to navigate in them. In the case of the archive directory structure of communication it can not be easier but in this case it is not necessary. If you need to look for the information in the archive, it has clearly specified information so it can be traced. Thus, the archive of messages is not required the fastest possible but the completeness and clarity of the appropriate structure of information storage. Messages are stored to ensure completeness of information and project documentation. All data must remain compact for the needs of any reverse analysis or similar work on the project, which then can act as a knowledge base and thus significantly simplify the work.

Registration of New Users

One of the advantages of the proposed system is that it ensures that information arrives automatically to all interested users. This is not possible without prior registration by the system. It is also important to ensure that the new user will get to know about already elapsed communications regarding the issues on which he begins to work. It will make it easier for him to orientate in the problem and gives him the information about the state of existing solutions. In this case, it is necessary to forward all messages already written in the topics to this new user.

Analysis and Management of the Communication

Users with the right to have the power can monitor all the timing information related to messaging. This function is essential in order to prove the relevance and support fulfilling of project deadlines. With the ability to see for example how long it took to the user to respond to the message the manager dealing with the communication analysis is then able to identify clearly who is responsible for the late response and thus a possible delay of the project. This function can be demonstrated as one of the pre-set functions of user requirements.

Two companies are working on joint project in research and development, first company deals with design and production of the device cover and the second one deals with the electronic parts inside the device. In the example should be mentioned that the second company has a limit for development of electronic products for 30 days. It is important to say that this development is controlled by company number 1, which is responsible for the delivery of information on time and for all the approvals. Thanks to this system it is clearly visible, for example, that the company number 2 sent the requirement for approval of scheme addressing internal parts the fifteenth day. In the system is then clearly seen that the report requirement left on the fifteenth day. Employee of company number 1 responsible for approving read it on the eighteenth day, and replied after four days. Therefore, if there was a failure to finish the project on time, due to the proposed environment it is very easy to identify who and how long was working on the project. In the example mentioned above the company number 2 was waiting for an answer for seven days and they should be therefore deducted from the final date of the contract.

In the case of the proposed client software this problem is solved by using an auxiliary email which leaves right after opening the message without the user knowing about it.

Specifically, it is possible to monitor and analyze these times:

- **When the user sent or received the message.** This time is a normal part of email header.
- **When the user opened the message.** In this case the client generates and sends supportive email in background for analysis purposes only.
- **When the user responded to the message.** This time is also a standard part of the header of each message. And it is important for monitoring of how long users run their tasks on the project.

Communication analysis is proposed from three basic aspects:

- **From the perspective of specific message.** There is a possibility to select a specific message and to visualize it in the table of two columns who and when read the message. It is possible to determine specifically which user and when responded to the message.
- **From the perspective of specific user.** There is offered the opportunity to see in two tables, what message the user received, to which of them and when did he respond, or when the user created a topic.
- **From the perspective of a specific topic.** User can view a specific topic and find out when and which user contributed to this topic or read this topic.

For the time analysis of the project Gantt chart is used. Users can mark important messages and visualize them in a Gantt chart. This chart can be made both in terms of individual users and the level of business entities cooperating on the project. Messages that appear in the Gantt chart can be manually selected to keep the chart transparent.

Data in the Communication Environment

In the communication environment possibility to save and export whole communication in appropriate format is required. This can be used as complete project documentation. It also creates a knowledge base, which is possible to use in the future.

Automatically there is a great emphasis on data security. During cooperation with various companies for example in the research and development organizations have to exchange classified information which can be very valuable.

Suitable communication tool helps to link the company ICT with no need to change or unificate the ICT, but here it is important to mention the crucial point. The crucial point is the need of unification or creation of uniform metrics across the entire project!

FUTURE RESEARCH DIRECTIONS

It is essential to further optimize and develop communication environment for SME's project cooperation and universal project metrics. Communication environment usable by all SME's in Virtual Enterprise with no need of unification of ICT technologies will greatly improve the ability of SME's to cooperate.

Goal of the authors' research is to design and optimize communication environment for Virtual Enterprise paradigm support. Specific targets are to make the whole communication traceable and documented, and to support larger number of participants across number of companies in better arranged form than classical email client. These advantages are gained by adding the unique code to each message, which allows the client to sort the messages precisely. Another advantage is the possibility to track and analyze all messages and responsibility for delay back in time. Main difference in this solution is no need of central server.

It is necessary to ensure the highest possible applicability in real business and therefore sometimes user friendliness and easy control is more important than the complex user functions. Interesting advantages of this concept comparing to the existing solutions are in the easy integration into the company, no need for the central server, high data security and support of large number of users. Also there is the possibility to transparently sort and track all the messages and perform simple time analyses. This simple and affordable software client provides managers with a relatively strong communication tool with the basic functions for analyzing and managing the communication.

Goals of further research of the author are optimization and further support of Virtual Enterprise paradigm trough effective communication.

CONCLUSION

This chapter deals with general description of Virtual Enterprise Paradigm and communication environment suitable for Virtual Enterprise Paradigm support. Cooperation of small and medium enterprises is appropriate way to increase competitiveness and reach for new business opportunities.

Communication is a key factor in any interfirm cooperation. According to authors' research in the field of Virtual Enterprises, communication factor is the second most important factor right after mutual confidence. But mutual confidence can be build by effective communication.

By using the proposed communication environment and proper tool there is no need for unification and big investments in to the information and communication technologies. All information and data exchange is done by email and since email is a simple and open data format it can be integrated and processed by any ICT system.

There is a number of papers and researches on Virtual Enterprise subject because Virtual Enterprise Paradigm seems to be one of the most promising paradigms for increasing competitive advantage of small and medium enterprises nowadays. This paradigm faces number of problems during its implementation. Due to easy integration and creation of communication channels creation of successful Virtual Enterprise is easier and proposed communication environment partly solves number of problems of this concept.

REFERENCES

Bernhard, R. K., & Dissel, M. (2001). A toolset for building the virtual enterprise. *Journal of Intelligent Manufacturing*, *12*, 121–131. doi:10.1023/A:1011248409830

Chodur, M., Januska, M., Sulova, D., & Palka, P. (2009). Value chain of virtual enterprise - Possible modern management concepts and value drivers identification. *Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium,* Vienna. ISBN 1726-9679

Dowlatshahi, S., & Qing, C. (2006). The relationships among virtual enterprise, information technology, and business performance in agile manufacturing. *European Journal of Operational Research*, 174.

Goranson, H. T. (1999). *The agile virtual enterprise: Cases, metrics, tools*. Quorum Books.

Hongmel, G., Biqing, J., Wenhuang, L., Yu, L., & Shluku, R. (2003, April). Computers in industry, Vol. 50. *Operation Management of Virtual Enterprise*, *3*, 333–352.

Januska, M. (2011). *Communication as a key factor in virtual enterprise paradigm support*. In Innovation and Knowledge Management: A Global Competitive Advantage, Kuala Lumpur, Malaysia. ISBN 978-0-9821489-5-2

Januska, M., & Chodur, M. (2009). *Virtual enterprise network. Internation Spring Seminar of Electronics Technology ISSE2009*. Piscataway, NJ: IEEE.

Januska, M., & Kurkin, O. (2010). *Communication environment designed for project cooperation of small and medium enterprises.* In The 21th International DAAAM SYMPOSIUM "Intelligent Manufacturing & Automation: Theory, Practice & Education", Zadar, DAAAM International Vienna 2010, ISBN 978-3-901509-73-5

Januska, M., Kurkin, O., & Miller, A. (2010). *Communication environment for small and medium enterprises.* In The 14th International Business Information Management Association Conference, Istanbul, 2010. ISBN 978-0-9821489-3-8

Liu, Z., Lai, M., & Jiang, J. (2004). Computer supported cooperative work in design. In *Cooperation Model in Virtual Enterprises*, (pp. 72-77).

Mann, D. (2005). *Creating a lean culture*. New York, NY: ProductivityPress.

ADDITIONAL READING

Beckett, C. R. (2003). Determining the anatomy of business systems for a virtual enterprise. In *Computers in Industry, 51*, 2. ISSN 0166-3615

Mehandjiev, N., & Grefen, P. (2010). *Dynamic business process formation for instant virtual enterprises* (1st ed.). doi:10.1007/978-1-84882-691-5

Pons, D. J. (2001). *A methodology for system integrity in design.* PhD Thesis, University of Cantenbury, New Zealand.

Thompson, K. (2008). *The networked enterprise: Competing for the future through virtual enterprise networks*. ISBN 978-0-929652-45-0.

KEY TERMS AND DEFINITIONS

Communication Environment: Communication software designed for increasing efficiency of communication.

Virtual Enterprise: Loose connection of companies that aims to share skills, resources, costs and benefits to achieve one or more projects answering to the market opportunities for products and services.

Virtual Enterprise Network: Group of companies interested in creation of Virtual Enterprises.

Virtual Enterprise Paradigm: Idea and rules for creating and operating a Virtual Enterprise.

Chapter 9
The Redefined Role of Consumer as a Prosumer:
Value Co-Creation, Coopetition, and Crowdsourcing of Information Goods

Rauno Rusko
University of Lapland, Finland

ABSTRACT

The scarcity of resources and tightening competition drive small and medium enterprises to find new solutions for product development and production. In addition to other (competing) firms and strategic alliances, the firms are searching assistance for production and R&D also among other stakeholders, such as consumers and public sector. In addition to the importance of careful stakeholder analysis, this study emphasises the old ideas, introduced initially by Alvin Toffler, about the role of consumer as a producer and developer of the products, which is the role of prosumer in the contemporary business and technological environment. The updated perspectives of prosumer are directed in this study into the concepts, such as consumer-based coopetition, crowdsourcing and value co-creation. These viewpoints provide new solutions especially for the capable SMEs to plan the production and design of the products with the help of customers in spite of the small organization. Furthermore, this study shows that the contemporary applications of crowdsourcing are concentrated in the business of Information Communication Technology (ICT) and its solutions and platforms. Therefore, also open information and closed innovation strategies are in the focal point of this study. The main contribution of this study is directed in these discussions with a new introduced framework, which is based on the earlier studies of this field.

DOI: 10.4018/978-1-4666-2098-8.ch009

INTRODUCTION: THE IMPORTANCE OF STAKEHOLDERS IN BUSINESS

Usually there is, in the field of management studies, a normative intention to promote business of the company (or companies) through the research subject. For example, in economics the normative viewpoints are connected only some branches, such as researches of economic policy. This normative aim of management studies requires a control or management of the business and business environment. This might be possible via defining the entities, which have some relevance for the success of the company and their targets and for the means affecting that success. In order to develop the business and the business environment of a company, it might be useful to have stakeholder analysis or to follow the ideas of "stakeholder management." Stakeholder management or "stakeholder theory" is a relatively old tool in the management studies and practice, already Follet (1941) introduced the idea of managing the stakeholder relationships (See, also Garvare & Johansson, 2010). Actually, it is possible to consider stakeholder theory as an open challenge to the neo-classical economic theories of the firm, which are focused on the conventional input – output model of the firm (Donaldson & Preston, 1995; Scholl, 2001; Chigona et al., 2009).

There are several different definitions for stakeholders. Perhaps, the most popular definition is that stakeholders are all those who can affect, or are affected by, the achievement of organisational objectives (Freeman & Reed, 1983; Garvare & Johansson, 2010). An alternative definition for stakeholders is that they are distinguished from other affected or interested parties with following characteristics: (i) provide essential means of support required by an organisation; and (ii) could withdraw their support if their wants or expectations are not met, thus causing the organisation to fail, or inflicting unacceptable levels of damage (Galvare & Johansson, 2010). Thus, the traditional way to consider company and its relevant entities is the viewpoint of stakeholders. Stakeholder management of the business are often key for the success (see, e.g. Hillman & Keim, 2001).

The use of the term "stakeholder" as opposed to "interest groups" or "constituencies" is a deliberate contrast to "stockholders" and "shareholders" (Scholl, 2001; Chigona et al., 2009). However, partly these concepts could interpret to be parallel or at least overlapping with the concept of stakeholder. According to Garvare & Johansson (2010), interested parties "are those that have an interest in the organisational activities, output or outcome, but these parties are not capable of significantly influencing the state of the organisation or its stakeholders." In other words, interest groups or interested parties are not primary stakeholders of the business.

Garvare & Johansson (2010) introduce the following categories of actors in the context of stakeholder framework: primary stakeholders, secondary stakeholders and interested parties. Furthermore, they distinguished two categories: overt stakeholders to describe stakeholders that are known to the management of the organization and latent stakeholders to describe stakeholders that are not known to the management of the organization. Actually, from the viewpoint of the management of organization, and sustainability of business (cf. Garvare & Johansson, 2010), it is important to try to keep the most of the stakeholders in the side of the "overt" stakeholders and to practice the continuing active stakeholder analysis or other strategic analysis of the business environment.

In the management studies, there is a slight discrepancy about the actors involved in the category of primarily stakeholders. However, in nearly all of these alternative lists of primarily stakeholders consists of the following actors: owners (or stockholders), customers, investors, suppliers, employees and sometimes also government have been mentioned. For example, Galbreath (2006) divides primary stakeholders further into two branches: internal and external. In the category of internal primary the stakeholders are in the state in which the firms engage with them and have responsibilities to them: employers and shareholders belong in this category. According to Galbreath (2006), the category of "external" primary stakeholders includes constituents such as customers, communities, suppliers, government entities and the natural environment.

As a scientific research, this chapter have some restrictions. This research is based on some examples of the cases in which the customers are in the role of prosumer, or when they are participating in the process of crowdsourcing. In this sense this research is a multi-case study in which the applicability and generalizability of the results is limited. However, because the cases are in the area of ICT, the results of the study are the most applicable for the business solutions of the ICT branch and especially for the platforms of social mediums.

In this study we emphasise the importance of stakeholders and the business possibilities based on the careful stakeholder analysis. However, this study focuses only one of these stakeholders, namely customers, and shows that already this one group of stakeholder enables multidimensional possibilities to promote business, if we enlarge the traditional roles of this stakeholder in the stakeholder analysis. In this sense, from the standpoint of entrepreneurs, a customer is not "only" a customer but also a potential partner in planning and developing the products and business. Especially, in the context of information communication technology (ICT) and in products based on social mediums, customers are also in the role of producer, or prosumer, creating value of the product with the entrepreneur and other entities of the firm (c.f. Toffler, 1980). This study emphasise this perspective by considering theoretical literature of these themes in section 2 and practical business examples in section 3. Alternative business models of ICT are introduced in section 4. Finally there are concluding remarks.

LITERATURE REVIEW

This section is focused on describing, based on the literature of management research, the role of customer as a part of production and product development process. In other words, customer is considered as a prosumer in the contemporary business possibilities and environment.

The concept of "prosumer" was obviously invented by Alvin Toffler (1980) in his book "Third Wave." The same idea were introduced, without a specific concept of "prosumer", also by McLuhan & Nevitt (1972). Noteworthy is that they considered as early as 1972 the consumer's role of producer in the context of electric technology.

The concept of prosumer is possible to interpret several ways. In addition to treat consumer as a producer, it is possible to consider consumer as a "professional." This is the case especially among the more advanced hobbyists, when their capabilities in leisure and hobby are close to capabilities of professional specialists. In order to develop the features of the products according to the affections of the hobbyists, the producer need to closely cooperate with them. i.e. in the case of product development. The other possible way to interpret "prosumer" is based on the low-profit activities in which the production or activities are the most important aim both for the producer as well as the consumer. Many new kinds of interest groups, for example in the branch of "green values", are promoting sustainable development i.e. by recycling the goods (see, e.g. Strati et al., 2004) or taking care of some services typical for public sector. In these kinds of activities of "third sector" the profit maximization is insignificant or even impossible target for these activities.

However, this study emphasises the interpretation of the concept of prosumer in which business perspectives, earnings and value creation are in the focus of the consideration. Therefore, concepts such as coopetition, value co-creation and crowdsourcing are in the focal points of this study.

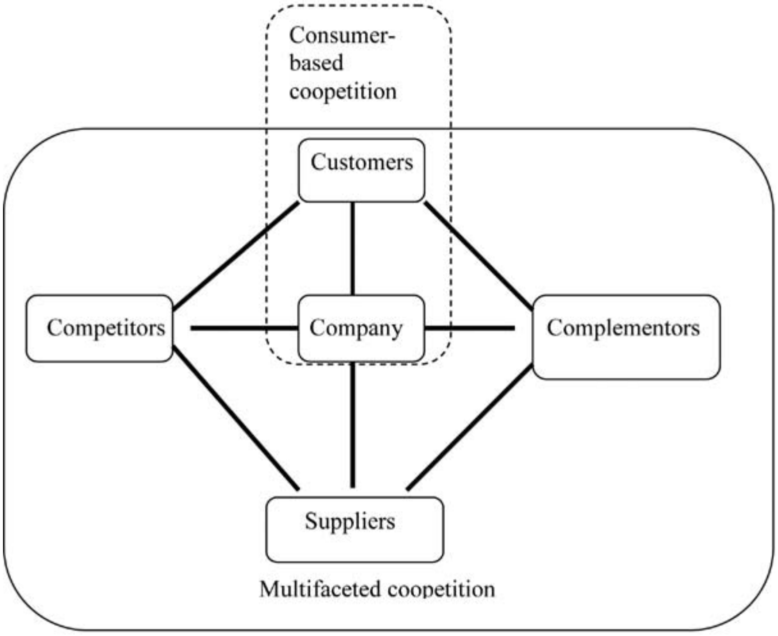
Coopetition concept is possible to divide into two categories: dyadic coopetition and multifaceted coopetition (Rusko, 2010; see, also e.g. Luo, 2004 and Brandenburger & Nalebuff, 1996). In dyadic coopetition two (or more) competing firms will cooperate with each other. In this relatively narrow perspective the other stakeholders, such as customers or public sector, of the business are not necessarily gaining from this cooperation, in other words, it is "only" win-win -situation. In more multifaceted coopetition in which e.g. consumers are involved in the framework is possible to attach win-win-win -situation (Walley, 2007). In this case, cooperation between the competing firms is not any threat for other stakeholders of the business and therefore it is following the idea of value net, which is introduced in the context of coopetition in Brandenburger & Nalebuff (1996).

This study is focused on the role of consumers as a part of production and product development process. Value net or some perspectives of coopetition is not solely based on the cooperation between competing firms, but it takes into the account also the roles of suppliers, and to some extent, consumers as the players and actors of the coopetitive game. Especially Walley (2007) has emphasised the consumer coopetition in his study. There is not solely coopetition between firms or firms and consumers, but also between consumers, e.g. in the forms of consumer associations.

It is not possible to completely disjoint solely one particular part of the network from the overall network effect of the value net. Thus, the success of the firm is dependent on the overall stakeholder management or value net. However, the focal point of this study is in the relationships between firm and customer - without forgetting the other important relationships of the business (Figure 1).

Multifaceted value-creation is an important feature of coopetition and of value net, in which also the customers or consumers are involved. In the field of management studies, there also several other theoretical and practical discussions, which emphasise value co-creation, increment

Figure 1. Multifaceted coopetition (Value Net) and consumer-based coopetition (cf. Brandenburger & Nalebuff 1996)



value or co-creation of value in the context of consumers. In this section we introduce some them.

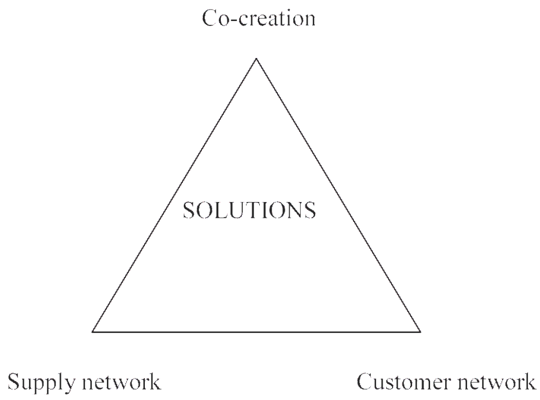
Already in the early papers, associated with the conceptual framework typical for the concept of prosumer, have been noticed the specific role of consumers (or customers) especially in the context of information technology (McLuhan & Nevitt, 1972). Furthermore, also the first papers of the *value co-creation* of customers, focused on information technology; and e.g. internet, which is important arena or medium for consumer based value co-creation (see, e.g. Kambil et al., 1999). They described, as an example, the development process of automobiles, actually in the conglomerate of Fiat, which " … wanted to test new design concepts for its Punto, it invited potential customers to visit the Fiat Web site and select from an array of features. More than 3,000 people participated. As a result, Fiat was able to capture valuable insight into the likes and dislikes of a targeted consumer group, test different design concepts at low cost and design a car far more reflective of customer preferences… What Fiat has discovered is a new way to create value… " (Kambil et al., 1999, 38). Perhaps, by chance, also another early publication, such as Prahalad and Ramaswamy (2004), which focused also on customer value co-creation, introduced examples from the vehicle sector: namely one example based on motor-bikes and Harley Davidson (because of the feature in which the bikers are riding together and customizing their motorcycles), and other example based on auto mobiles (Scion car). However, Prahalad and Ramaswamy (2004) also associated consumer value co-creation with ICT sector by considering examples from Apple and iTunes.

Prahalad and Ramaswamy continued the discussions of value co-creation, emphasising the role of experiences and networked, empowered, and active consumers and consumer communities (2004).

They claim that even the role of markets has changed: instead of traditional perspective with separate markets from the value creation process, they see market to be integrated in the value creation process. In other words, by basing the consideration with Figure 1, there is between company and consumers (customers) a market or a place in which value co-creation process takes place. In the sense of multifaceted coopetition, it is possible to consider these features as a one part of the consumer-based coopetition.

The importance of consumers in production process have been also emphasised in the discussions of *service-dominant logics*. The basic idea of service-dominant logics is based on the fact that "… value is fundamentally derived and determined in use – the integration and application of resources in a specific context – rather than in exchange – embedded in firm output and captured by price…" (Vargo et al., 2008, 145). Although the service-dominant logics is relatively independent branch of discussion in the field of management (and marketing), it has relatively close relationship with the other concepts, introduced above, such as prosumer, value co-creation or consumer coopetition (cf. Lusch & Vargo, 2006). The closeness with value creation concept is especially obvious. Furthermore, e.g. Cova & Saile (2008) emphasise the importance of solutions and networks in the context of service-dominant logic. (Figure 2)

Figure 2. Three pillars for solutions in the Service-Dominant logics. (Cova & Salle, 2008; see, also Lappalainen, 2009)



One important contemporary branch of practical and theoretical discussion, in the field of management studies, which also emphasise the role consumer as a prosumer, is crowdsourcing. This concept is a relatively new and for this reason there is not any established definition for crowdsourcing. In 1998, the American multinational pharmaceutical company Eli Lilly first time created a platform called InnoCentive, which implemented the functions, which are today known as crowdsourcing (Schenk & Guittard, 2009). Here are, however, two alternative definitions for crowdsourcing:

1. Business practice that means literally to outsource an activity to the crowd (Howe, 2006; Burger-Helmchen & Penin, 2010).
2. A form of outsourcing not directed to other companies but to the crowd by means of an open tender or open call via an Internet platform. (Schenk & Guittard, 2009).

There are some differences in the contents of these two definitions. Although both of them are initially directed to the ICT sector and Internet or social medium activities, the first definition is larger: it will not exclude the possibility that some crowdsourcing activities will take place outside of branch of ICT and Internet. In spite of the fact that the current activities are focused on these branches or mediums, it is possible that this concept is useful also in other branches or businesses - at least in the future.

Crowdsourcing is based on the relationship between consumer and enterprise. When some business activities are outsourced to the crowd, that is to the consumers, the consumer is in the role of prosumer: he or she is producing or developing the products or services partly for his/her own interests and also for the interests of other consumers at the same time. In the same way as value co-creation is possible to place in Figure 1 in the category of consumer-based coopetition, also crowdsourcing, especially in Internet has the same elements. In addition to firm and consumer, also other stakeholders or the participants of the multifaceted value net are aware of this crowdsourcing -and in some cases they have even possibility to participate and get some outcomes of this crowdsourcing process.

THE BUSINESS POSSIBILITIES FOR SMES IN THE CONTEXT OF CONSUMER COOPETITION, PROSUMING, AND CROWDSOURCING: SOME EXAMPLES

At its best, crowdsourcing enables to cut production or product development costs of the business. Crowdsourcing and especially its ICT applications require platform in which the development process will happen. Thus, in the case of crowdsourcing, there are initially relatively high establishment costs because of planning and implementation activities of this platform. If the platform is functional and enough attracting for the target groups, it will provide products, product ideas or even regular cash flows to the enterprise. In this sense, crowdsourcing is following the typical cost characteristics of information goods (See, e.g. Shapiro & Varian, 1999).

If the firm has capabilities to establish and construct this kind of platform and it has also ideas how to catch the customers to this platform, this concept provides several possibilities even to the SMEs.

1. It provides free labour force in the forms of visiting customers of these pages to develop and plan the products of the business.
2. The most sophisticated forms of outsourcing provides products - planned by customers - to the internet pages of the platform in which the (other) customers will pay for them (at once). This is possible especially in the branches of entertainment, such as music, games and

videos. One example is Audiodraft (see, e.g. Kaleva 2010 or Audiodraft, 2011).

3. In the case of totally free crowdsourcing platforms, they might provide possibilities for chargeable by-product. This is the case in the open-sourced Linux -systems: part of the product family and programs are free, but some applications are chargeable. Linux operating system was developed initially especially by Linus Thorvald and registered in May, 1994 by Michael McLagan (Linux, 2011).

Audiodraft has built a platform in which the producer of entertainment is able to get music for the games or other production. Producer will create a contest by using the platform of Audiocraft in order to get best possible music for their purposes. The musicians will participate in the contest and probably win the prize. Audiodraft will get a payment for the launching the contest. (Audiodraft, 2011). Generally, these kinds of arrangements of crowdsourcing, enables turnover even for relatively small enterprises. All you need is a well-planned platform with a good business idea, which is based on, perhaps, the seemingly natural human need to be active participant in the arrangements associated with social mediums.

Crowdsourcing is based on multidimensional or multifaceted networks. Some of the participants in the crowdsourcing platforms are also entrepreneurs or representatives of the firms. These participants; individual consumers, customers, providers, entrepreneurs, firms and representatives of the firms are not only competing with each other but also cooperating with each other. Thus, often there is associated the multifaceted value net or coopetition in these platforms of crowdsourcing. Crowdsourcing is also associated with value co-creation or service-dominant logics because of the role of customers or consumers are so important in the business models based on crowdsourcing. All of these considered concepts or business models are based on open innovation policy (see, e.g. Leimeister et al., 2009).

OTHER ALTERNATIVE BUSINESS MODELS IN THE BRANCH OF ICT

An alternative business model for ICT business is a closed innovation perspective -or system locked-in model (see, et al. Shapiro & Varian, 1999) which, for example, Microsoft is closely following. Open innovation - closed innovation dimension have been already earlier associated with coopetition discussions (See, e.g. Rusko, 2008; Figure 3).

Perhaps, the most important message of Figure 3 is that intentional coopetition is based more on

Figure 3. Open and closed innovation dichotomy and coopetition concept (Rusko, 2008)

Flows of Innovation				
Open	**A.Intentional successful cooperation**	Towards fusion or cartel between competitors?	Total spillover effect	Competition with high level of open innovation is actually unintentional coopetition
		B.Intentional coopetition		
			C.Unintentional coopetition, spillover	
	E.Unsuccessful cooperation	**F.Unsuccessful coopetition**		
Closed				**D."Pure" competition with closed innovations**
	Cooperation	**C o o p e t i t i o n**		**Competition**

cooperation than competition and, therefore, more on open innovation than closed innovation. An important question is, whether business models following the idea of crowdsourcing are more closely in position A (intentional (successful) cooperation) than B (intentional coopetition)? However, crowdsourcing often involves in the elements of competition, even the example of Audiodraft shows this fact. If not there is competition between firms, then at least competition between consumers or between customers.

If the typology, introduced in Figure 3, is functional, then the strategy e.g. followed by Microsoft is in the point D. It emphasises mostly closed innovation and competition strategy. Of course, the situation is not so black and white, because the larger firms have several business units and therefore some diversification in their business strategies in each unit.

The typology in Figure 3 is only suggestive. For example, in the case of competition there are many different alternative strategies. One of them is "hypercompetition", a strategy introduced by Richard D'Aveni (1997). In hypercompetition competitive advantage is temporal and based on, for example, the newness of market or technology and appears often with unpleasant manoeuvres of firms.

An alternative way to consider open and closed innovation systems has been introduced by Pisano and Verganti (2008). In more detail, they combine two dimensions: participation (open or closed) and governance (hierarchical or flat) in the same fourfold table (Figure 4). As a result, they get four categories: Innovation Mall with hierarchical governance and open participation, Innovation Community with flat governance and open participation, Elite Circle with hierarchical governance and closed participation and Consortium with flat governance and closed participation.

It is interesting to notice that Pisano and Verganti (2008) named some companies as an example for each category. It is also worth noticing that InnoCentive and Linux are placed in different

Figure 4. Four ways to collaborate. Pisano and Verganti (2008, 82)

Participation / **Governance**	Hierarchical	Flat
Open	**Innovation Mall** A place where a company can post a problem, anyone can propose solutions, and the company chooses the solutions it likes best (InnoCentive)	**Innovation Community** A network where anybody can propose problems, offer solutions, and decide which solutions to use (Linux open-source software community)
Closed	**Elite Circle** A select group of participants chosen by a company that also defines the problem and picks the solutions (Alessi's handpicked group of 200-plus design experts)	**Consortium** A private group of participants that jointly select problems, decide how to conduct work, and choose solutions. (IBM's partnerships with select companies to jointly develop semiconductor technologies)

categories. According to Pisano and Verganti, InnoCentive is following a typical Innovation Mall strategy and Linux is based on Innovation Community strategy. However, above we have noticed that both of these examples are typical for crowdsourcing activities.

Actually, perhaps the most important distinctive feature between the categories of hierarchical and flat is based on value creation and capturing. In other words, there are on the background different types of networks and value net. In the case of hierarchic governance the value is created via innovation process for the strictly directed needs of the company. In the case of flat governance the value is created either for the open indefinable needs of the company (Consortium) or for open needs of society or community (Innovation Community). Furthermore, the typology of Pisano and Verganti (2008) is associated also with cooperation activities. The main target for business and for different kinds of ways to organise innovations is to attach competitive advantage. Competition and success in the markets is the underlying characteristics for networking.

In other words, the classification of Pisano and Verganti (2008) consists of the following underlying features: value creation, cooperation and competition. These features are also typical for multifaceted coopetition. Therefore, it is possible to apply their perspectives in the coopetition viewpoints and discussions. This application is depicted in Figure 5.

In Figure 5 the innovation strategy of company is divided in two classes: idea process and exploitation process. Participation -character is interpreted in Figure 5 actually to be the same as the strategy of idea process. Participation is either open or closed, that is, the idea process is following either open or closed innovation strategy. Governance -feature describes the strategy in

Figure 5. The classification of Pisano and Verganti (2008) applied to the context of coopetition and crowdsourcing perspectives

Participation (the strategy in *Idea Process*)	**Governance** (The strategy in *Exploitation Process*) Hierarchical (Closed)	Flat (open)
Open	**A. Consumer-based coopetition with crowdsourcing** -Value creation for the needs of the company -Limited open innovation strategy - Open innovation strategy in the idea process and closed strategy in the exploitation process	**B. Multifaceted coopetition with open-sourced crowdsourcing** -Value creation for the needs of society or for the community -Only limited value creation via brand marketing or goodwill value for the company (e.g. Linus). -Open innovation strategy in the idea and exploitation processes
Closed	**C. Competition-based coopetition** -Closed innovation strategy both in the idea and exploitation processes	**D. Limited multifaceted coopetition strategy of the company.** -Closed innovation strategy in the idea process and open (limited) strategy in the exploitation process

exploitation process. Hierarchical strategy means in other words closed strategy in the exploitation process and flat strategy is the same as open strategy in the exploitation process.

When both the idea process and exploitation process are following the open innovation strategy, the consumers are clearly in the role of prosumer participating in the producing and consuming processes in the platform. This situation (State B) is named as the *Multifaceted coopetition with open-sourced crowdsourcing* in Figure 5. Furthermore, the State A includes also characteristics typical for crowdsourcing. In this case company decides how to utilize the results and innovations of the platform. In the State B the gains of the company which have established the platform are incidental or implicit (and therefore also value co-creation is incidental) compared to States A, C and D in which the standpoint of the platform is based on the future gains of the company (but now the gains for the customers are not so self-evident.

All in all, the different contemporary perspectives and realised business possibilities of prosumer, such as value co-creation, service-dominant logics or crowdsourcing are part of the multifaceted activities and business environment of the firm. Therefore, it seems to be possible to apply multifaceted value net framework -or multi-faceted consumer based coopetition -viewpoint to them. In addition to that, coopetition perspectives are useful also in the context of open - closed innovation discussions.

CONCLUSION

In addition to importance of careful stakeholder analysis, including consumers, this paper emphasise one potential strategy, which is promising especially from the viewpoint of SMEs, namely the consumer based business model. This business model has been considered from the several alternative perspectives: prosumer, (consumer) coopetition, value co-creation, service-dominant logics and finally crowdsourcing. Actually "prosumer" is possible to treat as a main concept, which covers these above mentioned other concepts.

Business models or strategies, which are based on consumers and their activities in Internet or in social mediums, provide business possibilities also for SMEs. The construction of successful platform for these kinds of services requires capabilities and a good business idea for the content of this platform. However, when functioning, crowdsourcing is able to provide "free" labour force to the firm. Successful crowdsourcing is possible also for SMEs because the "crowds" will replace the need to hire more planners and other workers to the firm. Thus, it provides, in its best, business models with low costs and remarkable business possibilities. Also, this study shows that the contemporary applications of crowdsourcing are concentrated in the business of Information Communication Technology (ICT) and its solutions and platforms. Therefore, also open information and closed innovation strategies are in the focal point of this study.

Furthermore, this paper makes an initiative to interpret prosumer and its connections with some resembling concepts, such as value co-creation, service dominant logics, crowdsourcing and consumer-based coopetition. This paper shows that there is still need to continue these discussions and develop further the concepts associated with prosumer. Also, this paper contributes by providing new perspectives for open - closed innovation strategies by applying (multifaceted) coopetition framework and discussions in the context of collaborative innovation discussions. It is important for practitioners of business in everyday tactical and strategic plans to be aware of the simultaneity of the multidimensional cooperation and competition characteristics.

One important area for further research is to develop the detailed framework for SMEs in order to exploit practically the possibilities of crowdsourcing in their business. These kinds of future researches might involve for example the needs of SMEs for technical and business competences and supports, and the means to fulfil these needs. Although the idea of consumer as the role of producer (prosumer) is relatively old, the research area, focused on practical applicability of this idea, in many areas of business need still further research.

REFERENCES

Audiodraft. (2011). *AudioDraft*. Retrieved January 8, 2011, from http://www.audiodraft.com/

Brandenburger, A., & Nalebuff, B. (1996). *Co-opetition*. New York, NY: Doubleday Currency.

Burger-Helmchen, T., & Julien Pénin, J. (2010). *The limits of crowdsourcing inventive activities: What do transaction cost theory and the evolutionary theories of the firm teach us?* AIMS Workshop on Open Innovation, Caen, March 26, 2010.

Chigona, W., Roode, D., Nabeel, N., & Pinnock, B. (2009). Investigating the impact of stakeholder management on the implementation of a public access project: The case of Smart Cape. *South African of Business Management*, *41*(2), 39–49.

Cova, B., & Salle, R. (2008). Marketing solutions in the accordance with the S-D logic: Co-creation value with customer network actors. *Industrial Marketing Management*, *37*, 270–277. doi:10.1016/j.indmarman.2007.07.005

D'Aveni, R. (1998). Waking up to the new era of hypercompetition. *The Washington Quarterly*, (Winter): 183–195. Retrieved from http://www.twq.com/98winter/daveni.pdf doi:10.1080/01636609809550302

Donaldson, T., & Preston, L. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, *20*(1), 65–91.

Follett, M. P. (1941). Dynamic administration. In Metcalf, H. C., & Urwick, L. (Eds.), *The collected papers of Mary Parker Follett*. New York, NY: Harper and Brothers publications.

Freeman, R. E., & Reed, D. L. (1983). Stockholders and stakeholders: A new perspective on corporate governance. *California Management Review*, *25*(3), 88–106.

Galbreath, J. (2006). Does primary stakeholder management positively affect the bottom line? Some evidence from Australia. *Management Decision*, *44*(8), 1106–1121. doi:10.1108/00251740610690649

Garvare, R., & Johansson, P. (2010). Management for sustainability – A stakeholder theory. *Total Quality Management*, *21*(7), 737–744. doi:10.1080/14783363.2010.483095

Hillman, A., & Keim, G. (2001). Shareholder value, stakeholder management, and social issues: What's the bottom line? *Strategic Management Journal*, *22*(2), 125–139. doi:10.1002/1097-0266(200101)22:2<125::AID-SMJ150>3.0.CO;2-H

Howe, J. (2006). The rise of crowdsourcing. *Wired*. Retrieved January 8, 2011, from http://www.wired.com/wired/archive/14.06/crowds.html

Kaleva. (2010, 13 November). Ääntä Avoimella Kisalla. *Kaleva*.

Kambil, A., Friesen, G. B., & Sundaram, A. (1999). Co-creation: A new source of value. *Outlook Journal*, *2*, 38–43.

Lappalainen, M. (2009). *Entrepreneurial orientation at the level of dyad relationships in supply chains and networks. Jyväskylä Studies in Business and Economics, 85*. University of Jyväskylä.

Leimeister, J., Huber, M., Bretschneider, U., & Krcmar, H. (2009). Leveraging crowdsourcing - Activation-supporting components for IT-based idea competitions. *Journal of Management Information Systems*, *26*(1). doi:10.2753/MIS0742-1222260108

Linux. (2011). *About us*. Retrieved January 3, 2011, from http://www.linux.org/about/

Luo, Y. (2004). A coopetition perspective of MNC-host government relations. *Journal of International Management*, *10*, 431–451. doi:10.1016/j.intman.2004.08.004

Lusch, R., & Vargo, S. (2006). Service-dominant logic: Reactions, reflections and refinements. *Marketing Theory*, *6*(3), 281–288. doi:10.1177/1470593106066781

McLuhan, M., & Nevitt, B. (1972). *Take today, the executive as drop out*. New York, NY: Harcourt Brace Jovanovich.

Pisano, G., & Verganti, R. (2008). What kind of collaboration is right for you? *Harvard Business Review*, (December): 78–86.

Prahalad, C. K., & Ramaswamy, V. (2004). *The future of competition*. Harvard Business School Press.

Rusko, R. (2008). Unintentional coopetition and supply chain management. In J. Kujala & P. Iskanius (Eds.), *Proceeding of the 13th International Conference on Productivity and Quality Research, ICPQR2008*, Oulu, 25–27 June, (pp. 642–653).

Rusko, R. (2010). Exploring the concept of coopetition: A typology for the strategic moves of the Finnish forest industry. *Industrial Marketing Management*, *40*, 311–320. doi:10.1016/j.indmarman.2010.10.002

Schenk, E., & Guittard, C. (2009). *Crowdsourcing: What can be outsourced to the crowd, and why?* Retrieved January 3, 2011, from http://halshs.archives-ouvertes.fr/halshs-00439256/

Scholl, H. (2001). Applying stakeholder theory to egovernment: Benefits and limits. *Proceedings of the IFIP Conference on Towards the E-Society: E-Commerce, EBusiness, E-Government,* Deventer, Netherlands.

Shapiro, C., & Varian, H. R. (1999). *Information rules: A strategic guide to the network economy*. Harvard Business School Press.

Strati, F., Schleicher-Tappeser, R., Loiselle, S., Hansen L. G., Di Paolo, A. M., Rosenbrand, A., & Ojeda, S. (2004). Sustainable district logistics: A theoretical framework for understanding a new paradigm. INNESTO Discussion paper, June 2004.

Toffler, A. (1980). *Third wave*. Bantam Books.

Vargo, S. L., Maglio, P., & Akaka, M. (2008). On value and value co-creation: A service systems and service logic perspective. *European Management Journal*, *26*(3), 145–152. doi:10.1016/j.emj.2008.04.003

Walley, K. (2007). Coopetition: An introduction to the subject and an agenda for research. *International Studies and Management & Organization*, *37*(2), 11–31. doi:10.2753/IMO0020-8825370201

KEY TERMS AND DEFINITIONS

Consumer Based Business Model: This business model covers several alternative perspectives: prosumer, (consumer) coopetition, value co-creation, service-dominant logics and finally crowdsourcing.

Consumer-Based Coopetition: One form of multifaceted coopetition consisting of the company, consumers (customers) and a market or a place in which value co-creation process takes place.

Coopetition: Simultaneous cooperation and competition between firms or other actors.

Crowdsourcing: It is based on the relationship between consumer and enterprise. When some business activities are outsourced to the crowd, that is to the consumers, the consumer is in the role of prosumer.

Open Innovation: Type of innovation which is available without restrictions.

Prosumer: Consumer as in the role of producer.

Service-Dominant Logics: Business logics which emphasizing services and the role of consumer in the production process.

Stakeholder Analysis: Tool of analysis for business environment and its interplay with company.

Chapter 10
Distributed Production Planning Models in Production Networks

Paolo Renna
University of Basilicata, Italy

ABSTRACT

Production networks can be dynamically structured and involving multiple production sites with different objectives. This organizational structure is able to match agility and efficiency to compete in the global market. In this environment is impossible for a single organization to control whole production networks; thus, a decentralized approach has been developed to manage the production networks. However, the coordinate mechanism in decentralized control is more important to obtain a high level of performance. The research proposes innovative coordination strategies for coordinate production networks by Multi Agent Architecture. A link between negotiation strategies and a production planning algorithm has been developed in order to support the coordination strategies proposed. In particular, two protocols to reach an agreement between customer and the production network have been proposed: negotiation and an expected profit approaches. Moreover, two coordination strategies have been proposed: index efficiency and ranking price approaches. Finally, the possibility of divide the orders in lots by the customer is proposed. A simulation environment based on open source code and Multi Agent Architecture has been developed to test the proposed approaches. The experiments have been conducted in different conditions of workload and mar-up; the results of the simulation provide the information necessary to select the suitable coordination and protocol mechanisms in a distributed production planning problem.

DOI: 10.4018/978-1-4666-2098-8.ch010

INTRODUCTION

The market globalization and increasing of competition forces the manufacturing companies to adopt distributed production approach. Moreover, Small and Medium Enterprises can compete to a global level if they collaborate in production networks. The distributed approach of production planning requires coordination mechanism in order to obtain a high level of performance (Wiendahl and Lutz, 2002). Advanced Planning and Scheduling (APS) tools are considered by many as the state of the art manufacturing and scheduling practices. These tools are designed to support a centralized production, therefore multi-facility of a single company. The application of APS tools become very complex and difficult in distributed production system, especially when the unit are independent (Stadtler, 2005).

Decentralized production planning approaches lead to several advantages in managing production networks: i) data management is more suitable for independent unit; ii) production planning system is robust, scalable, extensible and easier to adapt when the strategies change; iii) the production planning problem is distributed and therefore more easier to solve; iv) production planning systems of the units are more easier to integrate.

However, distributed production planning approaches have some drawbacks: i) the performance of distributed approaches are lower than the centralized approaches; ii) the performance of the coordination approaches are difficult to foresee; iii) a third independent part is necessary to manage the network in order to avoid opportunistic behavior.

This research concerns the production planning problem in a production network characterized by independent unit, therefore without sharing of information among the plants involved. Small and Medium Enterprises can gain competitive advantages to participate in this kind of network.

Multi Agent Systems (MAS) is the appropriate framework for developing distributed applications, and this is particularly true in Distributed Production Planning problems (Swaminathan et al., 1996; Parunak andVanderbok, 1998). A MAS is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver (http://www.cs.cmu.edu/~softagents/). A MAS needs of proper coordination mechanism in order to guarantee goals achievement.

The main objectives of this research are:

- The development of the Multi Agent Architecture framework in static and dynamic views able to support the distributed production problem.
- Two coordination mechanisms have been proposed: the first mechanism is performed by an efficiency index computed on the proposal characteristics submitted by the plants. The second is based only on the evaluation of the price submitted by the plants.
- Two protocols to reach an agreement between the customer and the network have been proposed: a negotiation approach and an approach performed in a single step defined “expected profit”.
- The proposal computed by the plants is obtained by a link with the local production planning algorithm that provides a set of production planning alternatives.
- A simulation environment is developed in order to test the proposed approaches and evaluate the performance.

The chapter is structured as follows: section 2 reviews the literature in the multi-plant production planning context; section 3 describes the framework of the Multi Agent architecture; section 4 introduces the production planning model of the plants; in section 5 the two strategies of the plants is presented, while the coordination strategies are described in section. Section 7 explains the simulation environment developed and in section

8 the simulation results are discussed. Finally conclusions and further researches in this area are drawn in section 9.

LITERATURE REVIEW

A multi facility production planning problem can be formulated as follows: given an external demand for items over a time horizon and a set of facilities able to produce those items, it needs to find a production planning over multiple facilities that maximizes customer and company satisfaction. This problem is subject to two categories of constraints:

- Customer constraints; the volume, due date and price requested.
- Facility constraints; capacity, costs of resources and information sharing.

Many authors discussed the problem of coordination multi facility production problem. Ertogral and Wu (2000) have proposed an auction based mechanism to address multi facility production planning coordination. The paper focused on structural mappings between mathematical decomposition and iterative auction mechanisms wherein agents compete based on their local utilities, announced conflict pricing, and production targets. Experimental results show that the proposed auction mechanism provides impressive improvement over the traditional monolithic method without significant degradation to the solution quality. The numerical test wasn't a very dynamic environment and the performance measures were limited. Moreover, the problem concerned a supply chain environment.

Timpe and Kallrath (2000) posed with a multi-sites, multi-products production environment and their model considers production, distribution and marketing issues dealing substantially with a lot sizing problem in a distributed scenario. However, their model maximizes the contribution margin or the satisfied demand in a priori known demand scenario, and such a case is quite difficult to happen in a real production planning scenario.

Dhaenens-Flipo and Finke (2001) also considered production and distribution issues of a multi-facilities, multi-plant and multi-period industrial problem supposing as known the demand over the planning period.

Lo Nigro et al. (2003) proposed to model and design coordination problems within production network by using the Multiple Agent Technology. In particular, the paper proposes new strategies for coordinating production-planning activities within production networks. Such models have been developed and tested by using a proper simulation environment developed by using open source code and architecture. The results of the research can be located at two levels: (a) concerning the specific coordination problem addressed, the research provides some insights to make decisions about the choice of coordination approaches to be used in distributed production planning problems; (b) at more strategic level, the paper shows how Agent Technology and discrete event simulation can be used to build up efficient coordination structures for production networks.

Moon and Seo (2005) proposed a research that deals with the advanced planning problem for minimizing makespan with workload balancing considering capacity constraints, precedence relations, and alternative resources with different operation times in a multi-plant chain. The problem is formulated as a multi-objective mixed integer programming (mo-MIP) model which determines the operations sequences with resource selection and schedules. Therefore, the approach proposed is a centralized approach.

Lin and Chen (2007) proposed a monolithic model of the multi-stage and multi-site production planning problem. The contribution of this planning model is to combine two different time scales, i.e., monthly and daily time buckets. Then, the approach is centralized, the relevance is the case study application of the approach proposed.

Tsiakisa and Papageorgiou (2008) investigated the optimal configuration of a production and distribution network subject to operational and financial constraints. A mixed integer linear programming (MILP) model is proposed to describe the optimization problem. A case study for the coatings business unit of a global specialty chemicals manufacturer is used to demonstrate the applicability of the approach in a number of scenarios.

Kanyalkar, A. P. and Adil (2005) considered production planning of multi-site production facilities with substitutable capacities serving multiple selling locations where the supplying plant is dynamically determined. A linear programming model is developed to produce the time and capacity aggregated plan and the detailed plan simultaneously. The model developed here shows potential in coordinating the production and distribution planning of a company with multi-location parallel manufacturing facilities in one or several countries, in several selling locations and in using the make-to-stock product staging strategies.

Alvarez (2007) discussed some specific characteristics of the planning and scheduling problem in the extended enterprise including an analysis of a case study, and reviews the available state-of-the-art research studies in this field. Most studies suggest that integrated approaches can have a significant impact on the system performance, in terms of lower production costs, and less inventory levels.

Agent-based and auction based systems can be considered as some of the most promising techniques for implementing collaborative planning and scheduling systems in the supply chain, although they have not been able to provide a good enough global optimal solution that is well accepted in industry. Other important challenges are the definition of the interactions and development of negotiation protocols between the different echelons of the manufacturing network at the planning and scheduling level. In an extended manufacturing network it is more difficult to manage all the interactions that are necessary to ensure that disruptions and related changes in one plant are taken into account by other plants avoiding unnecessary waits and inventory. This issue has not been sufficiently addressed.

Yuan-Jye and Feng-Yi (2009) presented a multi-plant tolerance allocation model. A mathematical programming model was presented to distribute the components to the suitable plants to achieve an objective of minimizing the multi-plant manufacturing cost. The multi-plant manufacturing cost is composed of machining tolerance cost, quality loss cost, setup cost, material handling cost, assembly operation cost, manual operation cost, and transportation cost. Then, an example product is tested and discussed.

Lima et al. (2006) proposed an Agent-based Production Planning and Control system that can be dynamically adaptable to local and distributed utilization of production resources and materials. The multi-agent system is based on three main agents: Client, Resource, and Manager. These agents negotiate the final product, and the correspondent components, requested by the client. An order for each product (component) triggers a process of dynamic design of a production system to fulfill that particular order. This system exists until the end of the order. The research proposed a formalization of the architecture.

Argoneto et al. (2008) proposed a Multi Agent Architecture for coordination mechanism in reconfigurable enterprises. In particular game theory approaches have been developed at high and medium level production planning. A simulation environment was developed in order to test the proposed approaches benchmarked with negotiation and centralized approaches. The simulation results show how the game theory approaches lead to results comparable with the negotiation and centralized approaches.

Monteiro et al. (2007) proposed an approach of coordination of decisions in a multi-site. A virtual enterprise node (VEN) is defined as an individual actor of the network. A VEN is either a planner agent that allows a dynamic planning based on local constraints (production cost, load, capacity, etc.) or a negotiator agent that is in charge of the cooperation with the partners. In addition to the VEN agents, two virtual agents complete the architecture. At a higher level of the VEN, the tier negotiator agents are in charge of relaxing the constraints at tier level. At the uppermost level, the supply chain mediator agent has to find a global resolution via cost based on constraint relaxation.

Chen and Wang (2009) proposed a decision algorithm on higher-level work orders dispatching problems under a holistic manufacturing configuration of multiple facilities. The multi-facility work order dispatching problems have been formulated as a stochastic non autonomous Lotka–Volterra difference game. A closed loop control scheme with discrete event dynamical system is proposed based on the setup of evolutionary game.

Chung et al. (2009) studied a multi-factory production scheduling problem, which was structured in a series model. The model is subject to capacity constraints, precedence relationship, and alternative machines with different processing time. The objective function is to minimize the makespan, which consists of the processing time, the transportation time between resources either within the same factory or across two different factories, and the machine set-up time among operations.

Torabi and Hassani (2009) proposed a multi-objective, multi-site production planning model integrating procurement and distribution plans in a multi-echelon supply chain network with multiple suppliers, multiple manufacturing plants and multiple distribution centres. Due to the imprecise/fuzzy nature of the objectives' aspiration levels and some critical data, an interactive fuzzy goal programming formulation is first developed.

Göttlich et al. (2010) developed a model which allows for the study and optimization of arbitrarily complex supply networks, including order policies and money flows. They proposed a mathematical description that captures the dynamic behavior of the system by a coupled system of ordinary differential delay equations. The underlying optimization problem is solved using discretization techniques yielding a mixed-integer programming problem.

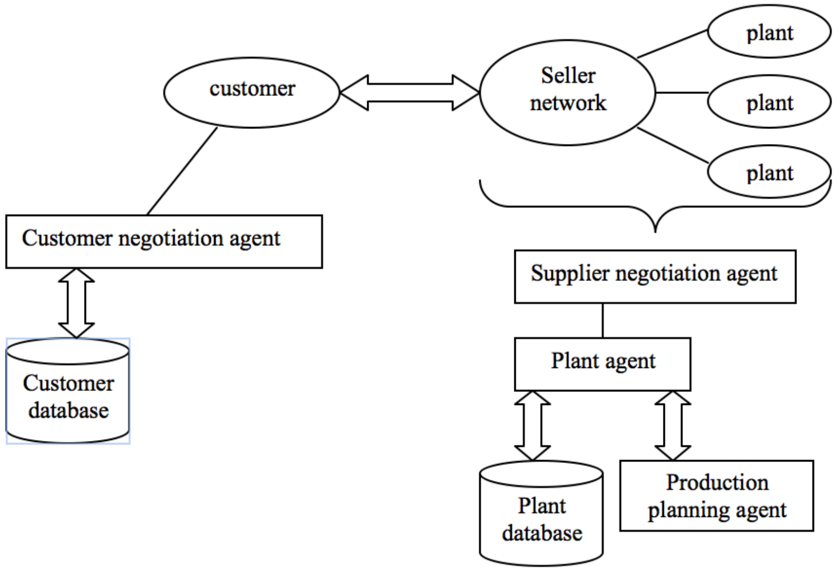
As showed, many authors have addressed the multi facility production-planning problem as a distributed problem and in some researches by using Multi Agent approach. However, few researches concern the development of a negotiation approach linked to production planning algorithm implemented by a Multi agent Architecture. The main trust of this research can be summarized as follows:

- The design of Multi Agent Architecture by workflow methodologies like IDEF and UML activity diagrams in order to highlight the static and dynamic point of views.
- The production planning algorithm of each local plant is a decision support to negotiation between the network and the customer.
- The research proposes two coordination approaches among the plants and two protocols to reach the agreement between customer and network. These approaches are implemented in an environment of independent units.
- The development of the simulation environment based on MAS architecture allows to test the proposed methodologies in a very dynamic environment where the demand is not known a priori.

THE REFERENCE ENVIRONMENT

The production network consists of an independent plant operating according to a Make To Order production strategy. In this scenario, the production planning problem cannot be solved in a single step since the demand over the planning horizon is not known a priori; that is orders

Figure 1. Agent based architecture



enter the plants network and are subsequently broadcasted through it.

In particular, let us consider a N plants; each plant j with $j=1,\ldots N$ makes decisions about its local production planning by fixing when and how much to produce.

In order to simplify the Architecture, let us suppose one customer and O orders; the customer is allowed to input its order o with its related characteristics that are the required volume, price and due date. Figure 1 describes the Agent based Architecture of the proposed research.

The framework of Figure 1 consists of a customer that submits an order to a seller network. The seller network is composed by a set of plants in which the order can be allocated.

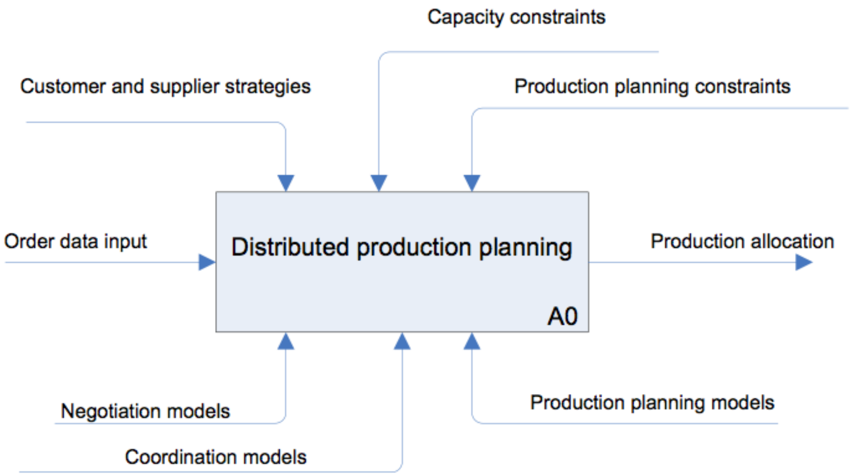
The customer consists of:

- The customer negotiation agent (CNA), that puts the order characterized by technological and commercial information and it evaluates the counter-proposal of the seller network.
- The customer database registers all the information concerning the negotiation with the seller network (both negotiation that reach an agreement and not).

The seller network consists of:

- The supplier negotiation agent (SNA), who is in charge with order processing, counter-proposal formulation and performs the co-ordination process among the plants of the network.
- The plant agent (PA) receives information on the order and transmits these information to the Production Planning Agent. The PA determines the volume and due date of its production and transmits these information to the SNA.
- The production planning agent receives information on the order characteristics and it performs a local production planning algorithm in order to provide several production alternatives to the PA.

Figure 2. IDEF0 context diagram



- The plant database registers all the information concerning the order allocation to the plant.

Figure 2 reports the diagram IDEF0 of the context in which operates the agent based architecture described above.

The global input of the system is given by the order data input; the customer transmits to the seller network the order data (volume, price and due date).

The production allocation is the final output of the system; if the negotiation between customer and seller network reaches an agreement the order is allocated to the plants.

The system is subject to the following constraints:

- **Customer and Negotiation Strategies:** They define the parameters to evaluate and formulate the proposals.
- **Capacity Constraints:** They represent the maximum capacity of the seller network (that depends by the plants);
- **Production Planning Constraints:** They are the parameters used to provided the production alternatives information.

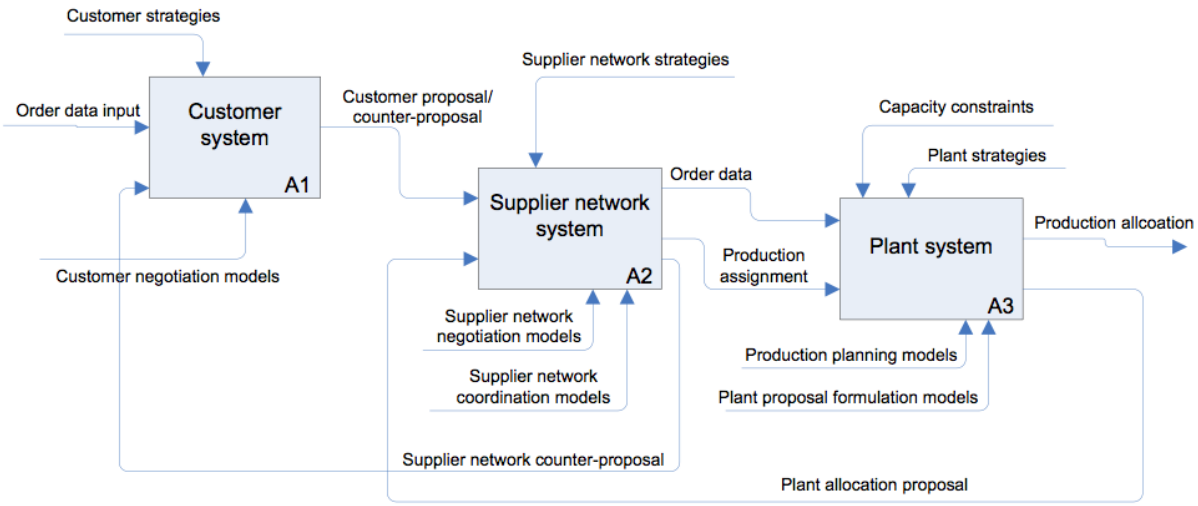
The system operates through the following mechanisms:

- **Negotiation Models:** They are the negotiation protocols and schemes;
- **Coordination Models:** They are the methodologies used to coordinate and allocate the production among the plants;
- **Production Planning Models:** They compute the production planning alternatives for the plants.

Figure 3 reports the structure of the three parts involved: customer system, supplier network system and plant system.

The inputs of the customer system are the following: the order data input (global input of the entire system) and the counter-proposal computed by the supplier network. The outputs of the customer system are the order proposal transmitted to the supplier network and, alternatively, the evaluation of the counter-proposal submitted by the supplier network. The evaluation of the supplier network counter-proposal is performed by the customer negotiation models and subject to the customer strategy parameters.

Figure 3. IDEF0 overall system



The output of the customer system constitutes on of the input of the supplier network system; the other input is the plant allocation proposal of the customer order.

The supplier network system transmits the order data to the plant system. Moreover, the supplier network system uses the coordination models to allocate the production among the plants ("production assignment"). The last output is the counter-proposal obtained by the negotiation models and subjected to the negotiation parameters.

The order data and the production assignment are the inputs of the plant system. The plant system computes an allocation proposal using local production planning models and proposal formulation models subjected to the capacity and strategies constraints. The outputs are: the allocation proposal transmitted to the supplier network system and the final production allocation if the agreement is reached between customer and supplier network system.

Figure 4 shows the UML activity diagram of the distributed production planning process. As the reader can notice, three swim lines are visible in Figure 4, one for each of the actors involved: CAN, SNA and PA.

The process starts with the order data input activity in which the customer define the characteristics of the order o, represented by the array $(i, V_i, dd_i, p_i)_0$, being i, the selected product typology, V_i the required quantity, dd_i the requested due date and p_i the price.

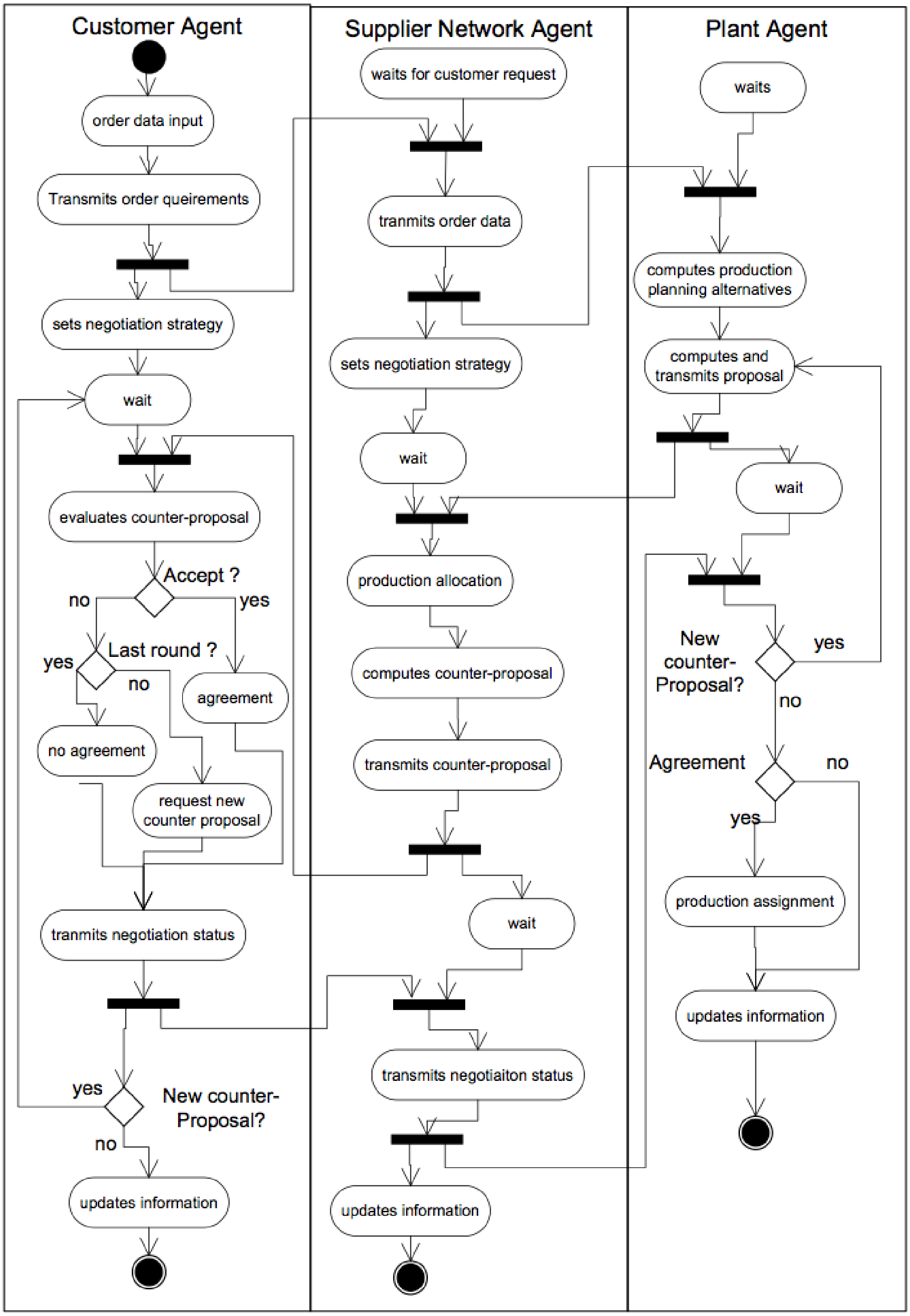
Then, the following actions are carried out by the CNA:

Transmits order requirement: The CNA transmits the order characteristics $(i, V_i, dd_i, p_i)_0$ to the SNA.

Sets negotiation strategy: The CNA selects the negotiation strategy by the parameters that characterized the evaluation of the SNA counter-proposal. In this chapter, the strategy is performed by a utility function as showed in Equation 1:

$$Thu(r) = Thu_{\max} \cdot \left(1 - \frac{r-1}{r_{\max}-1}\right)^2 +$$
$$F \cdot \left(\frac{r-1}{r_{\max}-1}\right) \cdot \left(1 - \frac{r-1}{r_{\max}-1}\right) + \quad (1)$$
$$Thu_{\min} \cdot \left(\frac{r-1}{r_{\max}-1}\right)^2$$

Figure 4. UML activity diagram



being:

- r is the round of negotiation.
- $Thu_{\max}$ is the maximum value of the utility.
- $Thu_{\min}$ is the minimum value of the utility.
- F is the slope factor of the function.

Therefore, the CNA sets the parameters: $Thu_{\max}$ and F.

Wait: The CNA waits for the SNA counter-proposal submission.

Evaluates SNA counter-proposal: The CNA evaluates the counter proposal of the SNA (V_{j*},dd_{j*},p_{j*}) by the following equations:

$$U = U_v + U_{dd} + U_p \tag{2}$$

U is the total satisfaction of the customer, where U_v, U_{dd}, U_p are computed as:

$$U_v = \max\left(\left(\frac{V_{j*} - V_{\min}}{V_i\text{-}V_{\min},}\right);0\right), \tag{3}$$

U_v is the customer utility related to the volume proposed by the SNA, where V_{min} is the minimum value of volume accepted by the customer.

$$U_{dd} = Max\left(Min\left(\frac{dd_{j*} - dd_{\min}}{dd_i - dd_{\min}};\frac{dd_{\max} - dd_{j*}}{dd_{\max} - dd_i}\right);0\right) \tag{4}$$

U_{dd} is the customer utility related to the due date proposed by the SNA, where dd_{min} is the maximum earlier due date and *ddmax* ids the maximum delay accepted by the customer.

$$U_p = Min\left(\left(\frac{p_i}{p_{j*}}\right);1\right) \text{ if } p_{j*}<p_{max}\text{, otherwise}$$
$$U_p = 0 \tag{5}$$

U_p is the customer utility related to the price proposed by the SNA, where p_{max} is the maximum value of price accepted by the customer.

The computation of U as sum of Equations 3,4 and 5 means that the attributes requested by the customer have the same importance.

In case $U \geq Thu(r)$ at generic round r, the CNA accepts the counter-proposal and, consequently, the agreement with SNA is signed. On the contrary, if $U < Thu(r)$ and $r<r_{max}$ the CNA asks for a new counter-proposal. Last case, if $r > r_{max}$, the CNA rejects the proposal and quits the negotiation.

Transmits negotiation status: The CNA transmits to the SNA the evaluation of the counter-proposal (accept/new counter-proposal/quit).

Updates information: At the end of the negotiation process, the CNA updates the information on the success or unsuccessful of the negotiation.

The following actions are performed by the SNA:

- **Transmits order data:** The SNA transmits the order characteristics to all plants of the network.
- **Sets negotiation strategy:** The SNA sets the parameters to define the strategy negotiation. In this chapter the negotiation strategy is performed in the coordination strategy activity.
- **Wait:** The SNA waits for the proposal of the plants.
- **Production allocation:** The SNA collects all proposals by the plants involved in the network. Then, the SNA performs a coordination strategy to allocate the production at each plant. The coordination strategies proposed are deeply described in section 6.
- **Computes counter-proposal:** The SNA, after the production allocation to the plants, computes the counter-proposal to submit to the CNA. The SNA computes the counter proposal by the following equations:
    - $$V = \sum_{i*} V_{i*} \tag{6}$$

- The volume is the sum of the volume assigned by the SNA to the plants involved i^*.
- $$DD = \max_{i^*}\left\{DD_{i^*}\right\} \quad (7)$$
- Due date is the due date of the plant later.
- $$\Pr_{tot} = \sum_{i^*} \Pr_{i^*} * V_{i^*} \quad (8)$$
- The price of the entire volume is the sum of unit price for the volume of the plants involved.

- **Wait:** The SNA waits for the evaluation by the CNA of the counter-proposal submitted.
- **Transmits negotiation status:** The SNA transmits the negotiation status (accept/new- counter proposal/quit) to the plants involved in the network.
- **Updates information:** At the end of the negotiation process, the SNA updates the information on the success or unsuccessful of the negotiation.

The following actions are performed by the PA:

- **Computes production planning alternatives:** The PA receives the order data by the SNA and perform its local production planning algorithm (described in section 4).
- **Computes and transmits proposal:** The PA performs a strategy (described in section 5) in order to select the proposal, afterwards, the proposal is transmitted to the SNA.
- **Wait:** The PA waits for the negotiation status derived from the negotiation process between the CNA and SNA.
- **Production assignment:** If the agreement is reached between SNA and CNA, the PA approves the production assigned by the SNA.
- **Updates information:** At the end of the negotiation process, the PA updates the information on the success or unsuccessful of the negotiation.

PRODUCTION PLANNING MODEL

The *PA* computes the production planning alternatives by a production planning model. The production planning model is based on a modified Wagner-Within model (Wagner and Whitin, 1958).

Each plant is characterized by the following data:

- h_j: Number of manpower hours needed for a unit of product in the plant j.
- w_j: Unit cost per hour of regular manpower in the plant j.
- s_j: Unit cost per hour of overtime manpower in the plant j.
- m_j: Unit direct production cost (energy + raw part) in the plant j.
- i_j: Unit inventory cost in the plant j.
- $MAXW_j$: Hours of direct and regular manpower available in the unit time period in the plant j.
- $MAXS_j$: Hours of direct and overtime manpower available in the unit time period in the plant j.
- D^o :The quantity requested by the customer for the order o.
- $t = 1,\ldots,T$: Generic planning period, where T is the planning horizon.

  The above data are considered for each period t and they have the same value over the planning horizon.
- $X^o(t)$: Volume of product assigned to period t for the order o.
- $W^o(t)$: Hours of direct and regular manpower assigned to period t for the order o.
- $S^o(t)$: Hours of direct and overtime manpower assigned to period t for the order o.
- $INV^o(t)$: Volume of product in inventory at the end of period t for the order o..

- $t_a^{\,o}$: Time of arrival of order o.
- dd_{i*}: Due date for the production planning algorithm.

The objective function of the production planning model is the maximization of the profit:

$$\max\left\{p_{j*}V_j^{\,o} - C_j^{\,o}\right\} \tag{9}$$

where,

$$V_j^{\,o} = \sum_{t=t_a^{\,o}}^{dd_{i*}} X^o(t) \tag{10}$$

$$C_j^o = \sum_{t=t_a^o}^{dd_{i*}} \left[i_j \cdot INV_j^o(t) + w_j \cdot W_j^o(t) + s_j \cdot S_j^o(t)\right] + m_j \cdot V_j^o\left(t\right) \tag{11}$$

The Equation 10 is the total volume that the plant proposes.

The Equation 11 is the total costs for manufacture the volume V_j^o.

The production planning model is subjected to the following constraints:

$$X_j^o(t) = \frac{W_j^o(t) + S_j^o(t)}{h_j} \tag{12}$$

$$0 \le W_j^o\left(t\right) \le MAXW_j\left(t\right) \tag{13}$$

$$0 \le S_j^o\left(t\right) \le MAXS_j\left(t\right) \tag{14}$$

$$V_j^{\,o} \le D^o \tag{15}$$

$$INV_j^{\,o}(t) = X_j^{\,o}(t) + INV_j^{\,o}(t-1), \forall t \in [t_a^{\,o}, dd_{i*} - 1] \tag{16}$$

$$INV_j^{\,o}(t_a^{\,o} - 1) = 0$$

$$INV_j^{\,o}(t) \ge 0, \forall t \in [t_a^{\,o}, dd_{i*}] \tag{17}$$

Constraint 12 forces the total amount of hours of direct manpower (regular and overtime) to be equal to the amount of hours need for the amount of product assigned for each period t.

Constraints 13 and 14 force the amount of hours (regular and overtime) to be respectively lower than the maximum hours available and positive. Constraint 15 assures that the total volume proposed by the plant is minor of the volume requested by the customer. Constraint 16 calculates the amount of volume storied for each period t. The constraints is computed for $t \in [t_a^{\,o}, dd_{i*} - 1]$, because at period dd_{i*} the order will send to the customer. Constraint 17 assures that the stock-out is not allowed.

The plant uses the above production planning models to computes a set of production alternatives.

The algorithm performed by the plant is the following:

- **Initializes algorithm parameter:**
  - $dd_j^{\,L}$ is the lower bound of the due date for the computation of the production alternatives.
  - $dd_j^{\,H}$ is the upper bound of the due date for the computation of the production alternatives.
  - $p_j^{\,L}$ is the lower bound of the price for the computation of the production alternatives.
  - $p_j^{\,H}$ is the upper bound of the price for the computation of the production alternatives.
  - These ranges ($dd_j^{\,L}$ - $dd_j^{\,H}$) and ($p_j^{\,L}$ - $p_j^{\,H}$) in this chapter are the following:
    - *(dd_i-4,dd_i+4),* therefore the algorithm explores the alternatives to delivery the order before four periods and late four periods.

- $(p_i, p_i{*}1.4)$, the minimum price is the price requested by the customer while the maximum value is increased of 40%.

- **Set initial N.O. constraints:**
  - $p_{i*} = p_j^{\ H}$
  - $dd_{i*} = dd_j^L$
  - Then, the PA solves the production planning model to obtain the volume and profit level associated to p_{i*} and dd_{i*}t(it builds the production alternative array)
- **Reduces N.O. price:** The PA reduces the price p_{i*}' (previously calculated) according to Equation 18:
  - $p_{i*} = p_{i*}' - \alpha \cdot (p^H_{\ j} - p^L_{\ j}),\ \alpha \in (0,1)$ (18)
- **Increases N.O. due date:** The PA increases the due date $dd_i{*}'$ (previously calculated) as showed in Equation 19:
  - $dd_{i*} = dd_{i*}' - \alpha \cdot (dd^{end}_{\ \ i*} - dd^{int}_{\ \ i*}),\ \alpha \in (0,1)$. (19)

The outputs of the above algorithm are two matrixes: one concerns the possible profit that the plant can reach, the other the volume offered. Each combination leads to a possible counter-proposal of the plant; at k-th alternatives an array of production planning alternatives PrA_k is associated, that is $PrA_j = (Pr_k, V_k, dd_k, p_k)\ \forall\ k$. Pr_k is the profit of the production alternatives.

The two matrixes can be represented as shown in Table 1.

The PA needs to perform a strategy to use the knowledge derived by the two matrixes and computes a proposal.

PLANT STRATEGY

The plants are in competition with each other to acquire the orders or part of its submitted by the customer. Therefore, the strategy that the plant chooses leads to define the volume assigned to it (the profit that can gain). The strategy of the plant has to be integrated in the methodology to reach the agreement between customer and network. The strategies proposed in this chapter are two: negotiation and no negotiation approaches.

Negotiation Approach

The negotiation approach works through the following activities:

Once the plant receives the customer order array $(i, V_i, dd_i, p_i)_0$, it computes the production planning alternatives by the algorithm described in section 4. At first round the plant computes the counter-proposal by the production planning alternatives that maximize the profit. In particular, the PA builds the set $K_0 = \{1,2,..k,\ldots,n*\}$ of alternatives such as:

$$\mathrm{Pr}_k = \mathrm{Pr}_{\max} = \max_{j=1,\ldots,n} \left\{ \mathrm{Pr}_j \right\} \quad \forall k \in K_0 \qquad (20)$$

and it searches within K_0 for the alternative $j*$ such as:

$$j*|\min_{j\in K_0} \left(\frac{\left|dd_j - dd_i\right| + \left|p_j - p_i\right| + \left|V_j - V_i\right|}{3} \right) \qquad (21)$$

Table 1.

	p_1	p_2	….	p_m			p_1	p_2	….	p_m
dd_1	V_1	V_2	…	V_m		dd_1	Pr_1	Pr_2	…	Pr_m
dd_2	…	…	…	…		dd_2	…	…	…	…
…	..	…	..	…		…	..	…	..	…
dd_l	…			$V_{l*m=k}$		dd_l	…			$Pr_{l*m=k}$

On the other hand, if $r > 1$, the PA applies a profit reduction strategy that depends on the negotiation round, that is it computes the new acceptable profit at the round r as in Equation 22:

$$\mathrm{Pr}_r = \mathrm{Pr}_{\max} - \frac{PR_{\max} - PR_{\min}}{r\max} \cdot r \tag{22}$$

Afterwards PA builds the set of production alternatives $K_r = \{1,2,..k,\ldots,m*\}$ such that:

$$\mathrm{Pr}_k \geq \mathrm{Pr}_r \quad \forall k \in K_r \tag{23}$$

and it finds the alternative $j*$ that minimizes the Relation 21 with $j \in K_r$. The array $(dd_{j*}, p_{j*}, V_{j*})$, both in cases $r = 1$ and $r > 1$, represents the plant proposal.

No Negotiation Strategy

A negotiation approach is characterized by the following drawbacks that affect the performance of the procurement process:

- The customer's and supplier's strategies have to be defined, the generative function typology for each role (creative or reactive counteroffer).
- The maximum number of rounds. The performance of the agreement depends of the round of the negotiation.
- The information exchange; for example one agent simple refuses or indicates the issues to be ameliorated.
- The negotiation ending criteria; if the negotiation ends with the maximum number of round or, in case of disagreement a centralized approach is implemented.

The proposed approach is computed by only one step and no strategies have to be designed over the time of negotiation. Therefore, the main advantages are the following:

- The reduction of time to reach an agreement.
- The reduction of information exchange.
- The "intelligence" of the agents can be limited.

The proposed approach performs a single step in which the suppliers compute their proposal by the same information of the negotiation approach. The suppliers compute the proposal combining the profit and the difference from the order characteristics in order to obtain an expected profit.

The supplier computes the counter-proposal by the following algorithm:

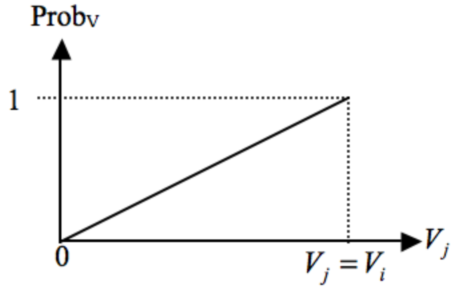
The first step is to evaluate an expected profit value of the supplier. The expected profit is computed among the production alternatives PrA_j. The plant for each $PrAj$ computes the probability to get the order by Equation 24:

$$prob_j = \frac{1}{3}\left(\left[1 - \left(\frac{\left|dd_j - dd_i\right|}{dd_{\max} - dd_i}\right)\right] + \frac{1}{p_{\max} - p_i}\left[\begin{array}{l} Min\left(\frac{p_i}{p_j}, 1\right) - \\ \frac{p_i}{p_{\max}} \end{array}\right] + \frac{V_j}{V_i} \right) \tag{24}$$

The Equation 24 is a normalized average, therefore the value is between 0 and 1. If the output is 1 it means that the production planning alternative perfectly matches the customer's request and, therefore, the probability to obtain the order is very high (presumably the 100%). Otherwise, the more the value of the equation decreases, minor is the chance to obtain an agreement.

In particular the Equation 24 is composed by three components reported in Figures 5,6 and 7. The probability regarding the volume ($Prob_v$) is reported in Figure 5; the probability is one if the supplier offer the volume requested by the cus-

Figure 5. Volume probability



tomer and decrease proportionally to the decrement of the volume.

The probability regarding the due date ($Prob_{dd}$) is reported in Figure 6; the probability is one if the supplier offer the due date requested by the customer and decrease proportionally to the increment of the delay until the value zero when the due date is the maximum value possible (dd_{max}).

The probability regarding the price ($Prob_p$) is reported in Figure 7; the probability is one if the supplier offer the price requested by the customer and decrease proportionally to the increment of the price until the value zero when the price is the maximum value possible (p_{max}). The component reported in Equation 24 is the equation line of Figure 7.

The second step is the evaluation of a expected profit for each production alternatives, computed by Equation 25:

$$Ex\,\mathrm{Pr}_j = \mathrm{Pr}_j \cdot prob_j \tag{25}$$

Equation 25 estimates the profit that the supplier can gain by a *PrAj* as a compromise between the profit and the correlate "distance."

Finally, the plant computes the counter proposal among the PA_j by Equation 26:

$$j^* | \max\left(Ex\,\mathrm{Pr}_j\right) \tag{26}$$

The Equation 26 evaluates the best compromise between the profit of the supplier and the probability to reach an agreement.

COORDINATION POLICY

The SNA collects the proposals of the plants and it have to formulate a counter-proposal for the CNA.

It can be located two cases:

- The total volume proposed by the plants of the network is minor of the volume requested by the customer; in this case, no coordination strategy is necessary, because the total volume proposed by the plants can be proposed to the SNA.
- The total volume proposed by the plants of the network is major of the volume requested by the customer. In this case, the SNA needs to perform a strategy to assign the volume to each plant.

Figure 6. Due date probability

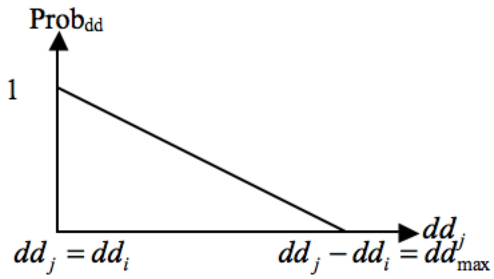
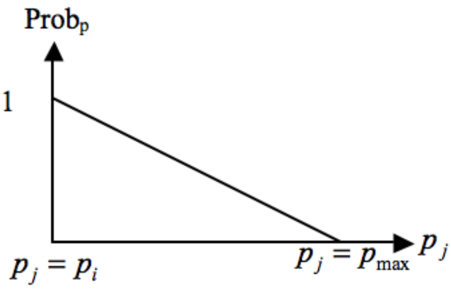


Figure 7. Price probability



Efficiency Index Approach

The coordination activity proceeds by the following steps:

The SNA computes a ranking of the plants by the following Equation 27 (an efficiency index of the plant proposal):

$$dis\tan ce_j = \frac{\max\limits_j \Pr_j - \Pr_j}{\max\limits_j \Pr_j - \min\limits_j \Pr_j} + \frac{V_j - \min\limits_j \Pr_j}{\max\limits_j V_j - \min\limits_j V_j} + \frac{\max\limits_j DD_j - DD_j}{\max\limits_j DD_j - \min\limits_j DD_j} \tag{27}$$

At this point the SNA agent makes decision about the volume sharing among the plants of the network. The order is split among the plants with the higher index until the ordered volume is achieved. Generally, the last plant of the ranking list involved in the order sharing gets a volume lower than the volume proposed. Therefore, this plant runs again the production planning algorithm, but in this case the following constraints are added:

$$V_j^o = \sum_{t=t_a^o}^{dd_{j*}} X^o(t) = V_{j*} \tag{28}$$

$$dd_{j*} \le dd_j \tag{29}$$

$$\Pr_{j*} \le \Pr_j \tag{30}$$

The Equation 28 forces the plant to provide the volume assigned by the SNA. The constraints 29 and 30 force the plant to maintain the same level of quality of the plant's proposal.

This volume is lower than the volume proposed by the plants, therefore it is feasible by the plant.

Moreover, the objective function is the following:

$$MIN \left\{ \begin{matrix} \sum_{t=t_a^o}^{dd_{i*}} \left[i_j \cdot INV_j^o(t) + w_j \cdot W_j^o(t) + s_j \cdot S_j^o(t) \right] + \\ m_j \cdot V_j^o\left(t\right) \end{matrix} \right\} \tag{31}$$

The objective function 31 minimizes the costs of the production planning.

The main features of the efficiency index approach are the following:

- The approach leads to reduce the number of the plants involved; the volume is shared among the better plants.
- The plants less competitive are more penalized. These plants can gain volume only if the capacity of the better plants is insufficient to satisfy the customer.
- The approach takes into account all the characteristics of the customer order.

Ranking Price Approach

In order to evaluate the real advantages of the efficiency index approach, it is proposed a simpler approach based on the price that characterizes the proposal of the plants.

The efficiency approach is modified substituting the Equation 27 with the Equation 27b:

$$dis\tan ce_j = \frac{\max\limits_j \Pr_j - \Pr_j}{\max\limits_j \Pr_j - \min\limits_j \Pr_j} \tag{27b}$$

The volume is shared among the plants as the above procedure.

The objective is to highlight if a ranking based on an elaborated index leads to a real advantages.

Lot Approach

This is a strategy that the customer can choose in order to increase the performance level and allows the participation of more plants to the order production.

Some plants can be less competitive for two causes:

- The production costs are higher than the other plants.
- The capacity of these plants is very low to compete with other plants.

In order to involve these plants in the supply of the customer orders, a lot approach has been proposed. The objective is to share the volume among all the plants of the network.

The approach proposed regards a network of independent plants, in this environment the information sharing is difficult to achieve. The coordination strategy proposed tries to involve in the order production the plants that are less competitive for the limited capacity.

The CNA divides the order in several lots; then the variables that the CNA have to define are: the number of lots and the quantity of the lots.

The simpler strategy is to divide the order in lots of equal volume and *n* number as the number of the plants of the network. Therefore, the CNA transmits to the SNA *n* orders as showed in Equation 32:

$$D_L{}^o = \frac{D^o}{N} \tag{32}$$

being *N* the number of plants.

Therefore the customer order is divided in *N* orders with the same characteristics (except the volume that is $D_L{}^o$). In this chapter for each order *o* it is obtained four orders $(i, D_L{}^o, dd_i, p_i)_0$.

The lots are assigned to the plants as a single order by the procedures described in the above paragraphs.

The main features of the ranking approach are the following:

- The approach leads to increase the number of the plants involved; the volume is shared among the several plants.
- The plants less competitive (limited capacity) can be more competitive and therefore gain some lots.
- The plants less competitive for the production costs don't gain advantages by this approach.

SIMULATION ENVIRONMENT

The Multi Agent Architecture has been implemented and tested through a simulation environment developed by using the Java Development Kit (JDK) package.

The modeling formalism adopted is a collection of independent agents interacting via discrete event's mechanism.

The network consists of four agent types: the plant agent, the supplier network agent, the customer negotiation agent and the order generation agent. Those agents have the following tasks:

- The plant agent supervises local plant data and algorithms.
- The customer negotiation agent manages the agent protocol (the contract net protocol in this case) and decides to whom the order should be allocated.
- The supplier network agent is in charge, together with order agents, with plant agent coordination and agent protocol management.
- Finally, the order generation agent generates the list of random orders and it is also in charge with the determination of the

number of simulation runs to be executed in order to obtain the desired interval of confidence.

It has been developed a test environment of the distributed production planning context. It consists of a simulation environment that can be used to test the functionality of the proposed approaches and to understand advantages of added value services in a network of plants.

The simulation environment described above is utilized to test the proposed approach in a network of four plants. The aim of this study is to understand the performance of the coordination strategies proposed.

In order to highlight the issues of the proposed approaches, the network is composed by plants with the same characteristics. Table 2 reports the plants' data.

Table 3 reports the four experimental classes performed; there are considered two levels of network utilization that depend on the volume required by the customer and two levels of price of the orders.

The experimental classes of Table 3 are simulated for: negotiation and no negotiation; efficiency index and ranking price; lot approach. Therefore, the total simulation experiments are 32 considering each combination. The customer inputs nine orders as showed in Table 4.

The volume of the orders is obtained by the computation of the network capacity multiplied the utilization showed in Table 3.

Table 2. Plants' data

h (hours)	2
m (unit costs)	5
w (unit costs)	10
s (unit costs)	15
i (unit costs)	2
MAXW (hours)	8
MAXS (hours)	16

Table 3. Experimental classes

Experiment No.	Network utilization	Mark-up
1	50%	50%
2	80%	50%
3	80%	80%
4	50%	80%

Table 4. Orders data

Ord. No	1	2	3	4	5	6	7	8	9
Input time	1	11	21	31	41	51	61	71	81
Due date	10	20	30	40	50	60	70	80	90

The price is obtained by the computation of an average unitary cost:

$$average\, unit \cos t = m + \frac{s+w}{2} \cdot h + i \qquad (33)$$

The Equation 33 computes the average unit cost considering the average between the ordinary and overtime hour cost. Then, the price is computed by the mark-up showed in Table 3.

The performance measures are the following:

- **Un-satisfaction index of the volume requested by the customer:** It is the percentage of the volume that the network doesn't satisfy.
- **Un-satisfaction index of the price:** It is the percentage increment of the price requested by the customer.
- **Un-satisfaction index of due date:** It is the percentage increment of the due date requested by the customer. The percentage is computed regarding the order horizon (the periods between the time of input and due date requested for the order.
- **Total profit:** It is the global profit reached by the network of plants.

- Utilization of ordinary hours.
- Utilization of over-time hours.
- Inventory costs.
- **Split:** It is the average number of plants that participate to manufacture an order. In case of lot approach, this index regards the single lot.
- **Profit unbalanced index:** It is the index of unbalanced profit among the plants computed by the following equations (being N the number of plants):

$$average\ profit = \frac{\sum_{k=1}^{N} profit_k}{N} \tag{34}$$

Equation 34 is the average profit reached by each plant if the profit is distributed uniformly.

$$unbalanced\ index = \frac{\sum_{k=1}^{N} \left| profit_k - average\ profit \right|}{average\ profit} \tag{35}$$

If the profit is distributed among plants equally, the Equation 35 is equal to 0, otherwise the Equation 35 is greater than 0. This performance is an important index that describes how the profit is shared among the plants. In fact, if the profit is unbalanced that means, some plants gain low profit from the network.

SIMULATION RESULTS

Table 5 and 6 report the simulation results of the performance indexes over all the experimental classes. In particular, Table 5 reports the performance of customer (satisfaction indexes) and suppliers (profit), while Table 6 reports the performance of the network. The simulation results reported are the following:

- **Customer:** The two cases are reported: input of the order and the order divided in lots.
- **Coordination:** How the plants are coordinated by the SNA: efficiency index and ranking on price.
- **Plant's Strategy:** How the generic plant computes the counter-proposal: negotiation and expected profit approaches.

From the analysis of the results the following issues can be drawn:

- The coordination strategy based on efficiency index of the plant leads to reduce the volume un-satisfaction in all conditions. If the customer divides the order in lots the volume un-satisfaction is reduced to zero with coordination strategy based on efficiency index. The coordination strategy based on ranking price leads to the worst

Table 5. Performance indexes (Customer and suppliers)

Customer	Coordination	Plant's strategy	Volume %	Price %	Due date %	Total profit
Order input	Efficiency index	Negotiation	1.39	8.08	34.44	34,406
Order input	Efficiency index	Expected profit	0.43	9.69	24.17	46,636
Order input	Ranking price	Negotiation	2.12	4.91	30.50	36,154
Order input	Ranking price	Expected profit	0.61	11.34	26.11	48,565
Lots input	Efficiency index	Negotiation	0.00	2.53	0	26,135
Lots input	Efficiency index	Expected profit	0.00	6.88	15.00	54,875
Lots input	Ranking price	Negotiation	3.25	3.22	5.49	25,713
Lots input	Ranking price	Expected profit	5.46	9.63	10.97	50,072

Table 6. Performance indexes (network)

Customer	Coordination	Plant's strategy	Profit Unbalance	Ut ord	Ut over	Inv cost	Split
Order input	Efficiency index	Negotiation	0.53	4,096	1,424	15,526	2.83
Order input	Efficiency index	Expected profit	0.63	4,098	1,488	15,494	2.81
Order input	Ranking price	Negotiation	0.47	3,982	1,502	14,033	3.20
Order input	Ranking price	Expected profit	1.70	4,030	1,544	14,283	3.22
Lots input	Efficiency index	Negotiation	0.00	4,871	771	15,125	1
Lots input	Efficiency index	Expected profit	0	4,871	771	12,870	1
Lots input	Ranking price	Negotiation	0.28	4,576	809	11,512	1.19
Lots input	Ranking price	Expected profit	1.30	4,302	1,083	11,851	1.37

performance in case of lots. Therefore, the lots approach is more affected by the particular coordination strategy performed.

- The minimum value of un-satisfaction price index is obtained in case of order divided in lot, efficiency index coordination strategy and negotiation approach. Generally, the expected profit leads to increase the un-satisfaction price for the customer.
- The possibility to divide the order in lots leads to reduce the un-satisfaction index of due date. The minimum value is obtained for the lot, efficiency index coordination strategy and negotiation.
- The expected profit approach leads to increase the profit of the plants. The coordination strategy based on ranking price increases the profit when the order is not divided in lots, while in other cases leads to decrease the profit.
- The possibility to divide the order in lots leads to distribute the profit uniformly among the plants.
- Generally, the coordination strategy based on ranking price leads to increase the utilization of overtime hours and reduces the hours in ordinary.
- The lot approach allows to reduce the inventory costs of the products by the distribution to more plants.
- The strategy coordination based on ranking price leads to increase the average number of plants involved in an order. In case of lot approach, the performance index regards each single lot, however the ranking price increase the number of plants involved.

The main performance for each experimental class are reported in appendix. These results allow to obtain a complete mapping of the performance measures regarding the workload and mark-up conditions. These data can be used as a knowledge base in order to select the best approach evaluating the environmental conditions.

CONCLUSION

This chapter deals with distributed production planning problem in network of independent plants. In particular, the research proposes two protocols to reach the agreement between the customer and the network: negotiation and expected profit performed in a single step. Then, two coordination strategies have been proposed: one based on an efficiency index of the plants, the other one on the ranking price proposed by the plants. Finally, the above approaches are tested when the customer decides to divide the order in several lots.

A Multi Agent Architecture has been designed and developed in order to support to the infrastructure of the problem discussed. The Architecture designed is implemented by a simulation environment in open source as JAVA package. The experimental plan was conducted on two parameters: volume and mark-up.

The research suggests how, through simulation, to evaluate the behavior of the several conditions and highlight the advantages of each approach.

The conclusions of this research can be summarized as follow:

- The protocol to reach an agreement between customer and network and the coordination strategy are more important to define, because the performance of each actor involved (plants and customers) depend radically by these approaches.
- The expected profit approach proposed in this chapter leads to performance comparable with the negotiation approach for the customer performance, while the plants profit increases significantly. Moreover, the expected profit is performed in a single step, therefore it is an approach more simply than the negotiation (no negotiation rounds and strategies have to be set).
- The coordination strategy based on efficiency index is the better compromise between customer and network performance. The ranking price leads increment the profit of the plants, but a significantly reduction of the customer performance (especially price and number of plants involved in an order).
- The choice of the customer to divide the orders in a number of lots leads to increase the performance of the customer and to distribute the profit uniformly among the plants. From the point of view of the plants the behavior is different in negotiation and expected profit. In case of expected profit the division of the orders leads to increase the profit, while, in case of negotiation the profit of the plants is reduced.

Further researches will investigate the following aspects in depth:

- The proposed approaches will be investigated in complete environmental conditions. The overlap among the orders is a factor to be investigated; the dynamicity of the orders inputted by the customer in terms of price, volume and due date. Therefore, the analysis of the proposed approaches in a stable and more dynamically environment in order to evaluate the robustness.
- A proper local knowledge (for each agent) and an inferential engine (fuzzy logic) that will enable the agents to select the best strategy. The customer agent can be define the number of lots in which divide the order. The supplier network agent can select the best coordination strategy, and the plant agent can select its strategy for the proposal formulation.
- Furthermore, opportune approaches can be developed to enable the plants to constitute a coalition using a Game Theory approach. The coalitional mechanism will be based on cooperative Game Theory and the simulation environment will be properly developed to investigate the added value given by this innovative approach.

REFERENCES

Alvarez, E. (2007). Multi-plant production scheduling in SMEs. *Robotics and Computer-integrated Manufacturing*, *23*, 608–613. doi:10.1016/j.rcim.2007.02.006

Argoneto, P., Perrone, G., Renna, P., Lo Nigro, G., Bruccoleri, M., & Noto La Diega, S. (2008). *Production planning in production networks models for medium and short-term planning*. Springer.

Chen, Y. J., & Wang, W.-L. (2009). Orders dispatching game for a multi-facility manufacturing system. *Expert Systems with Applications*, *36*(2), 1885–1892. doi:10.1016/j.eswa.2007.12.040

Chiung, M., & Seo, Y. (2005). Advanced planning for minimizing makespan with load balancing in multiplant chain. *International Journal of Production Research*, *43*(20), 4381–4396. doi:10.1080/00207540500142449

Chung, S. H., Lau, H. C. W., Choy, K. L., Ho, G. T. S., & Tse, Y. K. (2009). Application of genetic approach for advanced planning in multi-factory. *International Journal of Production Economics*, *127*(2). doi:doi:10.1016/j.ijpe.2009.08.019

Dhaenens-Flipo, C., & Finke, G. (2001). An integrated model for industrial production-distribution problem. *IIE Transactions*, *33*, 705–715. doi:10.1080/07408170108936867

Ertogral, K., & Wu, S. D. (2000). Auction-theoretic coordination of production planning in the supply chain. *IEE Transactions*, *32*, 931–940. doi:10.1080/07408170008967451

Göttlich, S., Herty, M., & Ringhofer, C. (2010). Optimization of order policies in supply networks. *European Journal of Operational Research*, *202*, 456–465. doi:10.1016/j.ejor.2009.05.028

Intelligent Software Agents. (n.d.). *Website*. Retrieved August 13, 2009, from http://www.cs.cmu.edu/~softagents/

Kanyalkar, A. P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 4431–4454. doi:10.1080/00207540500142332

Lima, R. M., Sousa, R. M., & Martins, P. J. (2006). Distributed production planning and control agent-based system. *International Journal of Production Research*, *44*(18), 3693–3709. doi:10.1080/00207540600788992

Lin, J. T., & Chen, Y.-Y. (2007). A multi-site supply network planning problem considering variable time buckets– A TFT-LCD industry case. *International Journal of Advanced Manufacturing Technology*, *33*, 1031–1044. doi:10.1007/s00170-006-0537-z

Lo Nigro, G., Noto La Diega, S., Perrone, G., & Renna, P. (2003). Coordination policies to support decision making in distributed production planning. *Robotics and Computer-integrated Manufacturing*, *19*, 521–531. doi:10.1016/S0736-5845(03)00062-0

Monteiro, T., Roy, D., & Anciaux, D. (2007). Multi-site coordination using a multi-agent system. *Computers in Industry*, *58*, 367–377. doi:10.1016/j.compind.2006.07.005

Parunak, V., & Vanderbok, R. (1998). *Modeling the extended supply network*. Presented at ISA-Tech'98, Houston, TX, 1998, Stadtler, H. (2005). Supply chain management and advanced planning—Basics, overview and challenges. *European Journal of Operational Research*, *163*, 575–588.

Swaminathan, J. M., Smith, S. F., & Sadeh, N. M. (1996). A multi-agent frame work for supply chain dynamics. *Proceedings of NSF Research Planning Workshop on AI & Manufacturing,* Albuquerque, NM, 1996.

Timpe, C. H., & Kallrath, J. (2000). Optimal planning in large multi-site production networks. *European Journal of Operational Research*, *126*, 422–435. doi:10.1016/S0377-2217(99)00301-X

Torabi, S. A., & Hassani, E. (2009). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19), 5475–5499. doi:10.1080/00207540801905460

Tseng, Y.-J., & Huang, F.-Y. (2009). A multi-plant tolerance allocation model for products manufactured in a multi-plant collaborative manufacturing environment. *International Journal of Production Research*, *47*(3), 733–749. doi:10.1080/00207540701528792

Tsiakis, P., & Papageorgiou, L. G. (2008). Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics*, *111*, 468–483. doi:10.1016/j.ijpe.2007.02.035

Wagner, H. M., & Whitin, T. M. (1958). The dynamic version of the economic lot size. *Management Science Magazine* (US), October 1958.

Wiendahl, H.-P., & Lutz, S. (2002). Production networks. *Annals of CIRP*, *51*(2), 5–22. doi:10.1016/S0007-8506(07)61701-6

ADDITIONAL READING

Bhatnagar, R., Chandra, P., & Goyal, S. K. (1993). Models for multiplant coordination. *European Journal of Operational Research*, *67*, 141–160. doi:10.1016/0377-2217(93)90058-U

Brandolese, A., Brun, A., & Portioli-Staudacher, A. (2000). A multi-agent approach for the capacity allocation problem. *International Journal of Production Economics*, *66*, 269–285. doi:10.1016/S0925-5273(00)00004-9

Cakravastia, A., & Nakamura, N. (2002). Model for negotiating the price and due date for a single order with multiple suppliers in a make to order environment. *International Journal of Production Research*, *40*(14), 3425–3440. doi:10.1080/00207540210147007

Cantaessa, M., Fichera, S., Grieco, A., La Commare, U., Perrone, G., & Tolio, T. (2002). Process and production planning in manufacturing enterprise networks. *Proceeding of the 1st CIRP Seminar on Digital Enterprise Technology,* Durham (UK), (pp. 187-190).

Goetschalckx, M. (2002). Strategic network planning. In Stadtler, H., & Kilger, C. (Eds.), *Supply chain management and advanced planning—Concepts, models software and case studies* (pp. 105–121).

Kanyalkar, P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 4431–4454. doi:10.1080/00207540500142332

Perrone, G., Renna, P., Cantamessa, M., Gualano, M., Bruccoleri, M., & Lo Nigro, G. (2003). An agent based architecture for production planning and negotiation in catalogue based e-marketplace. *Proceeding of 36th CIRP – International Seminar on Manufacturing Systems*, 03-05 June 2003, Saarbruecken, Germany.

APPENDIX

Table 7. Volume un-satisfaction

Class no.	Negotiation	Expected profit	Ranking price negotiation	Ranking price expected profit	Lot negotiation	Lot expected profit	Lot ranking Price negotiation	Lot ranking Price Expected profit
1	0	0	0	0	0	0	0	0
2	2.78	1.39	2.78	1.39	0	0	4.48	0
3	2.78	0.35	4.47	1.04	0	0	0	0
4	0	0	2.22	0	0	0	0	23.75

Table 8. Delay un-satisfaction

Class no.	Negotiation	Expected profit	Ranking price negotiation	Ranking price expected profit	Lot negotiation	Lot expected profit	Lot ranking Price negotiation	Lot ranking Price Expected profit
1	33.33	17.78	31.11	25.56	0	30	0	24.72
2	33.33	25.56	33.33	25.56	0	0	21.94	0.00
3	35.56	26.67	35.56	26.67	0	0	0	0.00
4	35.56	26.67	35.56	26.67	0	30	0	19.17

Table 9. Price un-satisfaction

Class no.	Negotiation	Expected profit	Ranking price negotiation	Ranking price expected profit	Lot negotiation	Lot expected profit	Lot ranking Price negotiation	Lot ranking Price Expected profit
1	8.65	9.10	14.25	15.38	3.00	7.50	3.00	15.66
2	10.40	11.15	10.53	11.15	5.25	7.50	8.02	7.50
3	5.23	7.07	8.61	11.46	1.25	6.25	1.25	6.25
4	8.04	11.44	4.84	7.38	0.62	6.25	0.63	9.12

Table 10. Total profit

Class no.	Negotiation	Expected profit	Ranking price negotiation	Ranking price expected profit	Lot negotiation	Lot expected profit	Lot ranking Price negotiation	Lot ranking Price Expected profit
1	20,577	25,504	22,021	28,640	16,940	35,604	16,940	33,396
2	36,935	44,699	37,475	44,699	30,912	45,842	29,224	45,842
3	48,710	71,305	52,561	74469.6	32,903	80,678	32,903	80,678
4	31,406	45,036	32,561	46452.8	23,784	57,376	23,784	40,412

Table 11. Split

Class no.	Class no.	Negotiation	Expected profit	Ranking price negotiation	Ranking price expected profit	Lot negotiation	Lot expected profit	Lot ranking Price negotiation
1	2.22	2.11	2.11	2.89	2.89	1	1	1.86
2	4	4	4	4	4	1	1.74	1
3	3.11	3.11	3.11	3.89	3.89	1	1	1
4	2	2	2	2.11	2.11	1	1	1.62

Chapter 11
Design of Robust Supply Chains:
An Integrated Hierarchical Planning Approach

El-Houssaine Aghezzaf
Ghent University, Belgium

Carles Sitompul
Ghent University, Belgium

ABSTRACT

In a supply chain operating under uncertainty, a possible approach to reduce the complexity and scope of the planning process is to organize all involved critical planning decisions in a hierarchical structure. This chapter attempts to explore new ways of integrating production and scheduling plans in a complex supply chain taking into account effects of some specific uncertainty types. In particular, uncertainty types inherent to the demand and to the process or equipment are considered. To deal with demand uncertainty at the strategic level, the safety stock placement problem in supply chains with limited production capacities is investigated. Results of this analysis and its consequences at the design level are reported and discussed. At the tactical level, each stage in the supply chain generates its own aggregate plans in order to balance supply and demand. To deal with uncertainty at this level, some robust deterministic planning models are discussed. These models make use only of the readily available data, such as averages and standard deviations, related to the uncertain planning parameters. At the operational level, the issue of disaggregating the generated robust tactical plans into detailed plans is investigated. A model taking into account the progressive deterioration of the production equipment is discussed. The results of some simulations are also reported and discussed.

DOI: 10.4018/978-1-4666-2098-8.ch011

INTRODUCTION

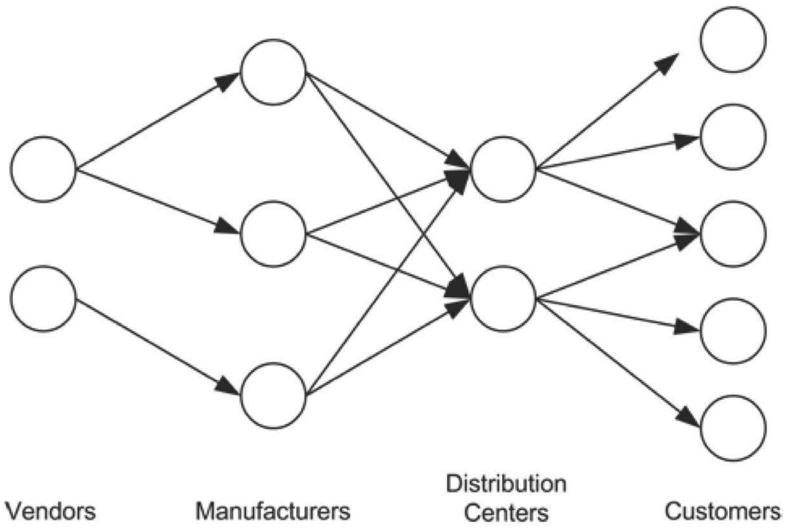
A supply chain consists of vendors, manufacturers, distribution centers and customers that are connected by flow of materials, money and information as shown in Figure 1. A manufacturer transforms either raw materials into semi-finished products or semi-finished products into finished products. A distribution center is responsible for receiving, sorting, picking and dispatching products into inventories without physically transforming the products. Supply chain management consists of all activities necessary to plan, control and monitor the movement of materials as they flow from their source to the end customer. The aim of a supply chain is naturally to satisfy customer demands in the right level of quantity, quality, and on the right time. We refer the reader to the book “Modeling the supply chain” by Shapiro (2001) for a thorough introduction to modeling in supply chains.

Hierarchical Planning

As mentioned before, supply chain management consists of activities such as planning, procuring, producing, transporting, and selling. A procurement plan decides on what to buy, when to buy, from whom to buy, and so on. A production plan determines when to produce, how much to produce, and so forth. A distribution or transportation plan consists of decisions on what and where to transport, which transportation mode to use (truck, train, et cetera). It is worth noting that all other supply chain activities are driven by the first activity, that is: demand and supply planning, also known as supply chain planning.

Based on the significance and extent of the involved planning decisions, the complete planning process in a supply chain can be categorized hierarchically (see Shapiro, 2001). At the highest level, decisions are typically made for strategic matters for a planning horizon of one to five years and revised periodically (each two years). Strategic decisions have significant impact on the long-term success of the supply chain as they involve a substantial amount of investments and are future oriented with multifunctional consequences. This last fact makes these decisions rather difficult to revise if something goes wrong. Typical strategic decisions involve the design of the logistics network, including facility locations,

Figure 1. A typical supply chain network



production technologies and plant capacities. Once the strategic context is established, the tactical decisions involve the development of material flow management policies, including production levels at all plants, assembly policies, inventory levels, and lot sizes. Finally, the operational level deals with the daily (weekly) activities. The decisions at this level are concerned with the scheduling of operations, including transportation, to assure in-time delivery of final products to customers.

Figure 2 shows the hierarchical process of decision-making in a supply chain and the limitation of our discussion area (in grey). At the highest level, strategic decisions typically deal with the design of a supply chain. Problems such as supplier selection (Vidal and Goetschalckx, 2000; Wang and Shu, 2007; Wu and Olson, 2008), network design (Kallraat, 2005; Chen et al., 2007; You and Grosmann, 2008; Francas and Minner, 2009), capacity planning (Malcolm and Zenios, 1994; Laguna, 1998; Aghezzaf, 2005; Lusa, et al., 2008) and safety stock placement (Graves and Willems, 2000; Lesnaia et al., 2004; Sitompul, et al., 2008; Shu and Karimi, 2009) are typically dealt with at the strategic level. At this level, we tackle demand uncertainty using safety stock and formulate therefore a safety stock placement problem in a capacitated supply chain.

At the aggregate level, tactical decisions are typically meant to bridge the strategic and operational plans. The following issues are usually dealt with at the tactical level: aggregate planning (Leung and Wu, 2004; Sitompul and Aghezzaf, 2008), lot sizing (Raa and Aghezzaf, 2005; Guan et al., 2006; Van den broecke et al., 2008), preventive maintenance planning (Weinstein and Chung, 1999; Aghezzaf, et al., 2007; Aghezzaf and Najid, 2008) and transportation mode selection (Miller, et al., 2005; Cochran and Ramanujam, 2006; Srinivasan and Bhargavi, 2007). At this level, we tackle both demand uncertainty and equipment uncertainty by defining and using some capacity cushion levels and a preventive maintenance planning respectively. We formulate some aggregate production-planning models attempting to balance production and demand while taking into account these two types uncertainty.

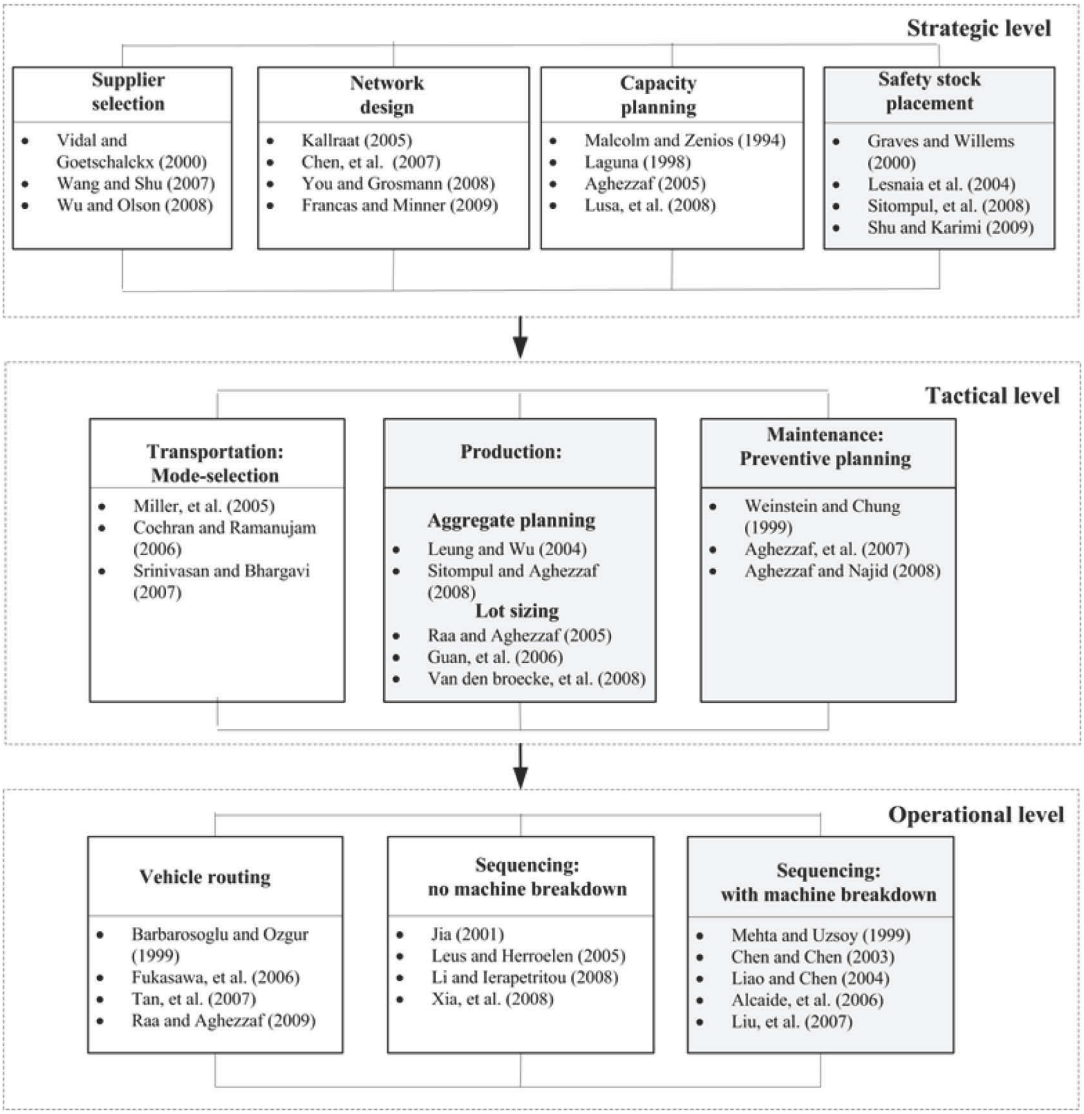
Production scheduling and sequencing (Jia, 2001; Leus and Herroelen, 2005; Li and Ierapetritou, 2008; Xia, et al., 2008; Mehta and Uzsoy, 1999; Chen and Chen, 2003; Liao and Chen, 2004; Alcaide, et al., 2006; Liu, et al., 2007) problems are typically tackled at the operational level. At this operational level, we will tackle equipment uncertainty using a scenario based optimization approach in the translation of the tactical plan into a feasible operational plan.

Uncertainty and Robustness

In a dynamic and uncertain environment, to be able to effectively carry out the necessary planning activities in a supply chain, managers need as much information as possible on the so-called planning parameters. The critical planning parameters in a supply chain are customer demands, machine capacities, supplier lead-times, etc. These parameters are naturally dynamic and change over time. The planning activities become even more complex when these parameters are not only dynamic but also subject to uncertainty. Geary et al. (2002), have classified the uncertainty affecting a supply chain in there are four categories: demand, process, supply and control uncertainty. Demand uncertainty is characterized as the difference between anticipated and actual orders of customers. Process uncertainty affects the system's internal ability to meet production targets. Supply uncertainty results from poorly performing suppliers, not meeting the requirements. Control uncertainty is associated with information flow and transformation of orders into production targets.

If improperly tackled, these types of uncertainty may have severe consequences on the performance of the supply chain. In particular, this may lead to deterioration in service levels and to increased avoidable costs. When demand is higher than anticipated, for example, the system

Figure 2. A hierarchical planning process



may experience the so-called stock out, when no more stock is available to satisfy the demand. This unmet demand may turn out to be lost sales resulting in a missed profit opportunities. On the other hand when demand is low, the system may experience extra stock bringing about extra inventory or holding costs. Also, if a machine breaks down, the planned production levels cannot be fully met. This means that the available inventory may not be sufficient to satisfy the realized demand even if this latter is correctly anticipated. If a supplier delivers its materials too late, the system may also not be able to satisfy the demand. If materials or semi finished product's quality does not meet the requirements, extra expense may result from reworking or scrapping the non-conforming materials.

The term robustness for a system is often associated with the system's ability to operate appropriately under adverse and severe conditions. In the context of production planning, different authors provided different definitions for a robust plan. However, all these definitions are centered around the idea that the generated "optimal" production plan (or solution) remains feasible even when the worst scenario occurs. Measures of robustness were also defined and discussed. As a measure of robustness, Rosenblatt and Lee (1987) used the number of times that a solution (plan) lies within a pre-specified percentage of optimal solution, for different sets of scenarios. In Mulvey et al. (1995) and Van Landeghem and Van Maele (2002), robustness is measured by the variability of the key performance measures. Aghezzaf et al. (2010) and Sitompul and Aghezzaf (2008) defined a robust plan as a plan that remains feasible, while maintaining a targeted service level, under the most probable scenarios. Optimization frameworks attempting to produce robust solutions to optimization problems were also proposed (Mulvey et al., 1995; Ben-Tal and Nemirovski, 1998). Throughout the years, the robust optimization framework proposed in (Mulvey et al., 1995) has been applied to a vast variety of problems, such as capacity expansion problems (Laguna, 1998), logistic problems (Yu and Li, 2000), fleet planning problems (List et al., 2003), and aggregate production planning problems (Leung and Wu, 2004; Aghezzaf, et al., 2010).

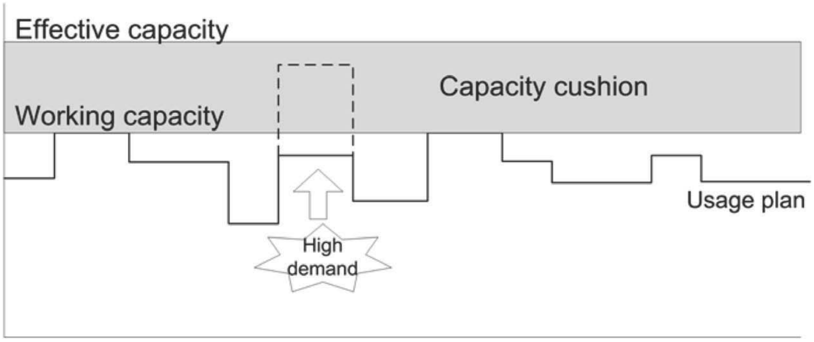
The remainder of the chapter is organized as follows: the "background" section defines the objectives of this chapter and provides a general description of the issues that are addressed. Section "safety stock placement problem" discusses the safety stock placement approach at the strategic level to tackle demand uncertainty. Section "tactical production planning with uncertain demand" discusses and develops some robust tactical planning models which integrate the variability of the demand. Section tactical production planning with uncertain process output" extends the tactical planning models to include the uncertainty stemming from the production tools. Section "a robust integrated hierarchical planning approach" provides an integrated model which attempts to coordinate the strategic and tactical planning pieces in an integrated hierarchical manner. Each section provides some numerical examples and results to show strengths and weaknesses of the proposed approaches and models. A section discussing future research directions and a general conclusion wrap up the chapter.

BACKGROUND

Among the possible approaches to contain supply chain poor performance resulting from uncertainty, one can mention introduction of safety stocks, capacity cushions and preventive maintenance policies. Often, right after a replenishment or at the beginning of the planning horizon, the level of inventory is sufficient to satisfy the anticipated demand. As time goes by, the inventory decreases while it is used to satisfy the realized customer demand. If this demand is low during the replenishment lead-time, the available inventory will be sufficient to cover it completely. However, if it is high, the available inventory will be dropping very fast. If the inventory runs out before a stock is replenished over again, the supply chain will be experiencing a stock out, hence unmet orders. A common approach to resolve this issue consists in anticipating an extra amount of stock meant to cover the excess demand. This extra stock amount is the so-called safety stock used typically to hedge against demand uncertainty.

Alternatively, a capacity management approach can be taken to resolve some of the issues resulting from demand uncertainty. If the usage plan uses effective capacity to meet the anticipated demand, then the resulting usage plan will be too sensitive to even small increases in demand and will very often be infeasible. Recall that effective capacity is the actual maximum demand a system can meet. One can thus extend the concept of capacity cushion to this context and define some working capacity, which is smaller than the effective capacity. The working capacity is obtained by

Figure 3. Capacity cushion



subtracting the capacity cushion from the effective capacity. If the usage plan uses this working capacity to meet the anticipated demand and if the realize demand is higher than anticipated, an extra amount of capacity can still be used to meet some of this demand excess. Figure 3 illustrates this issue.

If a machine breaks down, the available effective capacity will experience a decrease. Consequently, it may happen that the available production level and inventory cannot meet the realized demand. One possible way to reduce the impact of equipment failure is obviously to elaborate and implement an effective preventive maintenance policy. We hereby assume that if we perform a preventive maintenance at the beginning of a production period, the chance of a machine breaking down will decrease significantly. Also, one can logically e convinced that the available effective capacity cannot be fully used during maintenance. Therefore, production should carefully be plan while taking into account the chance that a machine or a whole process may break down.

Chapter's Objectives

Quantifying and managing the effect of demand and/or process uncertainty on the various operations in a supply chain is a very complex issue. The various research papers which have talked this topic studied the effect of uncertainty at specific planning or operations levels. The main objective of this chapter is not only to propose planning approaches taking uncertainty into account at specific levels in a supply chain but also to link all these specific plans amongst them so as to achieve a best possible performance throughout the supply chain. Effect of uncertainty is therefore addressed at the tree different planning levels, and also at the two transition levels i.e. between strategic level and tactical level and between tactical level and operational level. Also, various authors, such as Gupta and Maranas (2003), Cheng et al. (2004), Dolgui et al. (2005), and You and Grosmann (2008), have formulated joint optimization models of different operations in the supply chains often taking demand uncertainty into account. Although these models attempt to achieve some kind of "global" optimality, such formulations bring about more complexity in terms of computational tractability. To go around this complexity, probably at some aggregation-disaggregation price, we opted for a decomposition of such complex problems into simpler and more manageable models while maintaining the targeted performance level.

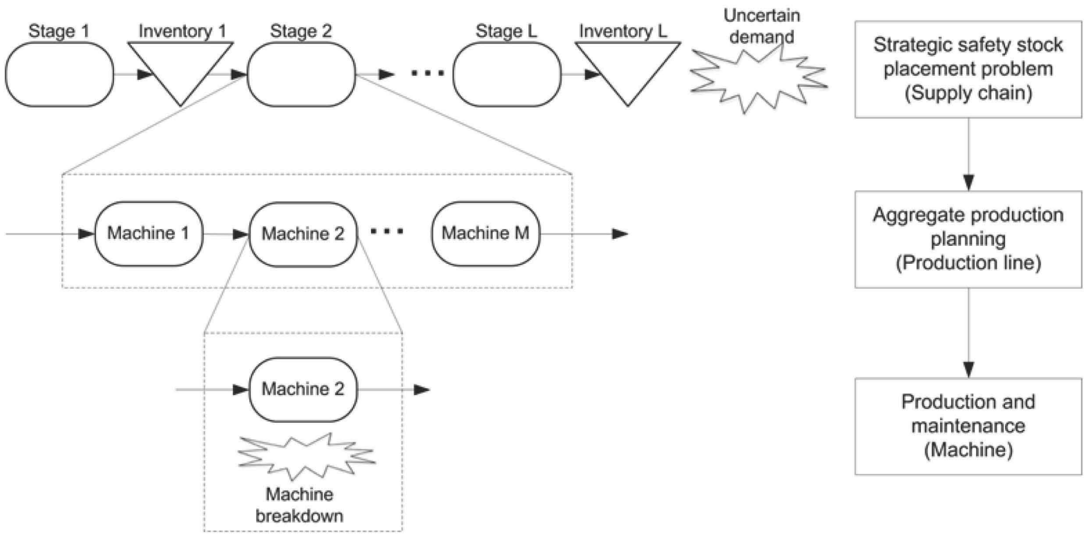
In this chapter we explore some approaches to integrate the various plans in a supply chain taking into account demand and equipment uncertainty. In an attempt to address the effect of uncertainty, we adopt a hierarchical planning approach in order to reduce the planning complexity in a supply chain through a set of policies dealing with demand and capacity uncertainties. We use the hierarchical approach to decompose a complex problem into simpler problems at the strategic, tactical and operational level. We will explicitly take into account this hierarchical approach during the formulation process of each planning level.

General Problem Description

In this chapter, we consider only supply chains which take a serial structure, where stage 1 supplies stage 2, stage 2 supplies stage 3 and so on, while stage L is facing an uncertain demand. We also assume that each stage has also a serial structure of production, where machine 1 supplies machine 2 and so on. Finally, we assume that each individual machine is subject to progressive deteriorating over time and may eventually break down. We call this type of uncertainty equipment or machine uncertainty. Figure 4 shows the problem description for each planning level. This linear structure is the simplest topology a supply chain may assume. Some of our results may be extended to more complex structures. However, there are some additional complications inherent to the structure itself making this extension less obvious.

As stated earlier, we will use a hierarchical approach for the supply chain's planning. As shown in Figure 4, each level can be associated with one planning level in a supply chain. To better clarify the hierarchical process in decision-making, we select –for each level- a problem that addresses the appropriate issue of uncertainty. At the highest level, strategic decisions typically deal with issue related to supply chain design. At this level, we tackle demand uncertainty using safety stock and formulate a safety stock placement problem in a capacitated supply chain. At the aggregate level, a tactical decision is made to bridge the strategic and operational plans. At this level, we tackle both demand uncertainty and machine uncertainty using some capacity cushion levels and integrated preventive maintenance planning. We formulate an aggregate production-planning problem to balance production supply and demand. At the operational level, we tackle machine uncertainty using a scenario based optimization approach to translate a tactical plan into an operational plan.

Figure 4. Problem situation



STRATEGIC SAFETY STOCK PLACEMENT PROBLEM

At the strategic level, Graves and Willems (2000) model the safety stock placement problem in an uncapacitated supply chain assuming that demand is uncertain. We extend the model to a capacitated supply chain and assume that the demand follows a normal distribution with average μ and a standard deviation σ. The problem is to simultaneously determine the optimal location and the size of safety stock in the supply chain such that the flow of material remains smooth. We use a two steps approach to solve the problem in the capacitated case. The first step consists in simulating the effect of capacity for a single stage supply chain (see also Mapes, 1992). The result, namely the correction factor of safety stock, is generalized to a multi-stage serial supply chain. The resulting problem is then solved using a shortest path based algorithm.

Single Stage Model

In an uncapacitated stage, a typical formula for safety stock is given by $ss = z_\alpha \sigma$, where z_α is the value of the cumulative standard normal distribution for an α probability of stock out (e.g. z_α = 2.33 for a α=1% stock out probability). For a capacitated stage, we use the following parameter which we used to characterize the stage: $\rho = \dfrac{\kappa - \mu}{\sigma}$, where κ is the production capacity. As expected, if we use the safety stock for an uncapacitated stage to deal with uncertain demand in a capacitated stage, the service level will most probably be plummeting. To achieve a stock out probability of $\alpha = 0.01$, we increment the quantity of safety stock for each capacity level. Figure 5 shows the safety stock required to achieve a 1% stock out probability for each level of ρ (hence capacity). Clearly more safety stock is needed for large variations of demand.

If we define a ratio θ comparing the amount of safety stock for the capacitated case to the amount of safety stock for the uncapacitated case, then this ratio can be seen as a correction factor of safety stock needed for a capacitated stage to achieve the same stock out probability as for the uncapacitated one. We make a non-linear regression analysis, which shows that:

$$\theta = 1 + 5.25 e^{-5.25(\rho - 0.075)}.$$

The coefficient of determination for such this regression is 0.997 (indicating that the regression model is suitable to predict the required safety stock levels for other values of ρ).

Multi-Stage Model

Let S_l be the outbound service time (in periods) of stage l in the supply chain, that is the time guaranteed by stage l to its successive stage in the chain. Let SI_l be the inbound service time (in periods) for stage l, that is the time required by stage l to get its raw material. Assume that the production time of stage l to produce an amount of x is one period, and then the effective production lead-time equals $SI_l + 1$. The net replenishment time for stage l can then be defined as:

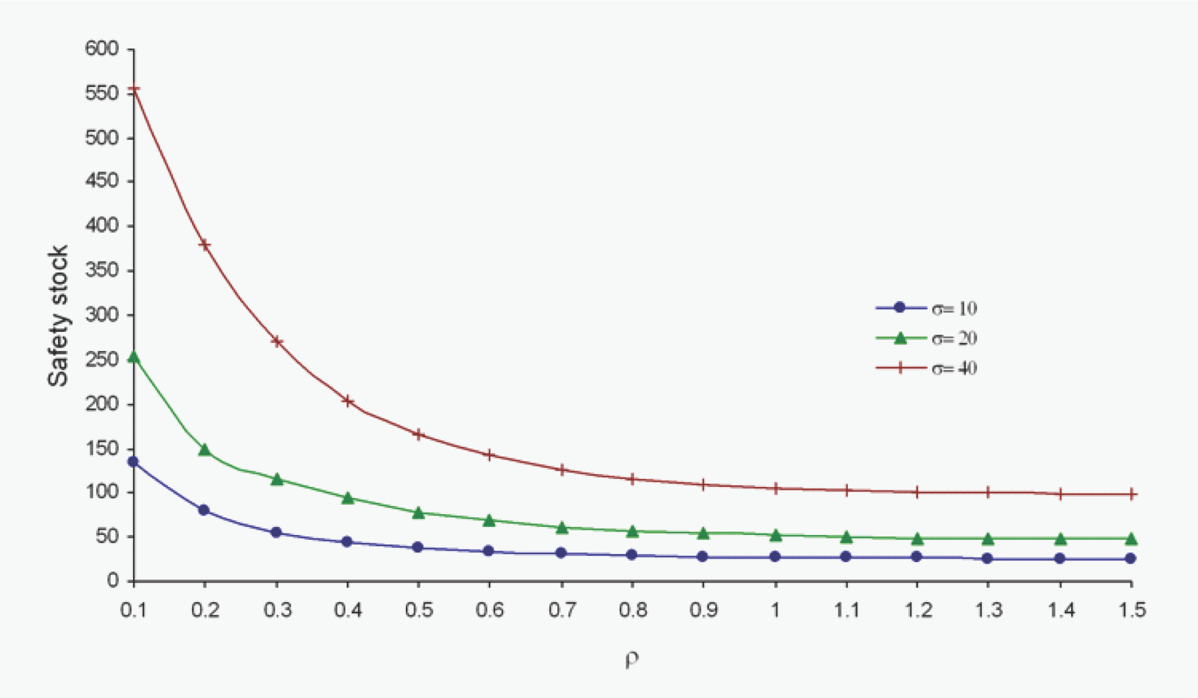
$$\tau_l = SI_l + 1 - S_l.$$

Given that during net replenishment time, the standard deviation of demand is $\sigma\sqrt{\tau_l}$ and the excess capacity is equal to $\tau_l\left(\kappa_l - \mu\right)$. The system's parameter for stage l can be written as:

$$\rho_l = \frac{\tau_l\left(\kappa_l - \mu\right)}{\sigma\sqrt{\tau_l}} = \frac{\left(\kappa_l - \mu\right)\sqrt{1 + SI_l - S_l}}{\sigma}$$

The correction factor for stage l is then given by the following:

Figure 5. Safety stock for a capacitated stage



$$\theta_l = 1 + 5.25e^{-5.25(\rho_l - 0.075)}.$$

If the net replenishment time for stage l is strictly positive then the base stock policy is to bring the stock up to the base stock level. The base stock level is set to satisfy demand during this net replenishment time, of course while taking into account the correction factor, hence:

$$B_l = \mu\left(1 + SI_l - S_l\right) + \theta_l z_\alpha \sigma \sqrt{1 + SI_l - S_l},$$

where the safety stock is given by:

$$SS_l = \theta_l z_\alpha \sigma \sqrt{1 + SI_l - S_l}.$$

If the net replenishment time for stage l is zero or negative then it is better to delay orders such that production realization coincides with demand delivery. In an uncapacitated stage, the safety stock is not needed because production is not limited by capacity. In a capacitated stage, we still need a safety stock such that the capacity plus this safety stock will be able to meet the maximum demand for one period, i.e.

$$SS_l + \kappa_l = \mu + z_\alpha \sigma,$$

$$SS_l = z_\alpha \sigma - \left(\kappa_l - \mu\right).$$

Note that a correction factor is needed for one period of production, that is: $\rho_l = \dfrac{\kappa_l - \mu}{\sigma}$, hence replacing $\kappa_l - \mu$ with $\rho_l \sigma$ gives the safety stock for a non-positive net replenishment time as follows:

$$SS_l = \theta_l \sigma \left(\max\left(0, z_\alpha - \rho_l\right)\right),$$

where θ_l is the correction factor for stage l given the correction factor for one period. This equation

Table 1. Computational time

	W= 4		*W=6*	
N	**Scenario-based**	**Robust deterministic**	**Scenario-based**	**Robust Deterministic**
1	1'	0.25"	3'	0.25"
2	na*	0.25"	na	50"
100	na	5'	na	5'

*na= not available

also shows that if the excess capacity of a stage in one period is greater than $z_\alpha\sigma$ then it is not necessary to put safety stock in that stage.

The resulting problem for safety stock placement in a capacitated problem is therefore naturally a non-linear optimization model. Because of the assumption of a serial supply chain, we can model the problem as a shortest path problem. Let $S_l = v$ means that the outbound service time for stage l is equal to v period and $SI_l = u$ means that the inbound service time for stage l is equal to u period. In a serial supply chain, the inbound service time for stage l is equal to the outbound service time for stage $l-1$, $\left(SI_l = S_{l-1}\right)$. The holding cost associated with putting safety stock for this combination is given in Box 1.

For a 3-stage supply chain (as shown in Figure 6), assume that the inbound service time for stage 1 is given by $S_0 = 0$ meaning that it has an abundant source of raw material and suppose that the last stage in this supply chain has to immediately fulfill customer demands, that is $S_3 = 0$. Let M_s be the maximum service time allowable for stage $l = 1, 2$. The problem is to find a path from the origin node to the destination node, which gives the minimum total cost (see Figure 6).

TACTICAL PRODUCTION PLANNING WITH UNCERTAIN DEMAND

Tactical production planning is concerned with balancing production and demand. It attempts to determine the optimal amount of capacity to be assigned to the production of each product family. The issue of demand uncertainty in production planning has been addressed mainly using stochastic programming (Dempster et al., 1983; Bitran and Tirupati, 1993; Kira et al., 1997). Leung and Wu (2004) formulated the tactical production planning under demand uncertainty using the framework of Mulvey, et al. (1995). Recently, Guan et al. (2006) made use of a branch and cut

Box 1. Holding cost

$$\cos t_l\left(u,v\right) = \begin{cases} h_l\left(1 + 5.25e^{-5.25\left(\frac{(\kappa_l-\mu)\sqrt{1+u-v}}{\sigma}-0.075\right)}\right) z_\alpha \sigma\sqrt{1+u-v}, & 1+u-v > 0, \\ h_l\left(1 + 5.25e^{-5.25\left(\frac{(\kappa_l-\mu)\sqrt{1+u-v}}{\sigma}-0.075\right)}\right)\sigma\left(\max\left(0, z_\alpha - \dfrac{\kappa_l-\mu}{\sigma}\right)\right), & 1+u-v \le 0, \end{cases}$$

where h_l is the holding cost per unit product in one period.

algorithm to solve stochastic lot-sizing problems under demand uncertainty.

Deterministic Production Planning

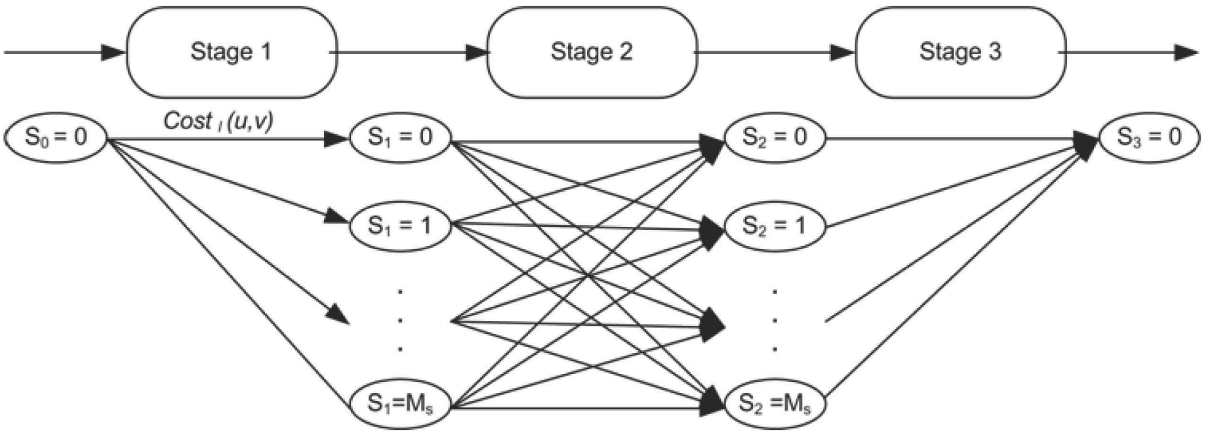
Let P be the set of product families to be produced during a W-periods planning horizon H. Each period w is divided into T sub-periods. Each product family $k \in P$ has a set of finished products denoted by N_k where each finished product j has a periodic demand $d_{jk}(w)$. The following parameters are also used for the production-planning model:

- a_{jkm}: Unit of time needed to produce one unit product j of family k in machine m (in hour),
- $c_{jk}(w)$: Variable production cost for one unit product j of family k in period w (in €/unit/period),
- $h_{jk}(w)$: Holding cost of one unit product j of family k in period w (in €/unit/period),
- $f_{km}(t,w)$: Fixed cost of family k in machine m in sub-period t of period w (in €),
- $\theta_m(t,w)$: Variable cost of overtime in machine m in sub-period t of period w (in €/hour),
- $\kappa_m^{rg}(t,w)$: Regular capacity of machine m in sub-period t of period w (in hour),
- $\kappa_m^{ov}(t,w)$: Overtime capacity machine m in sub-period t of period w (in hour),
- and decision variables as follows:
    - $Q_{km}(t,w)$: Capacity reserved for production of family k in machine m during sub-period t of period w (in hour),
    - $O_m(t,w)$: Additional overtime capacity required in machine m during sub-period t of period w (in hour),
    - $y_{km}(t,w)$: 1 if production of family k in machine m takes place in sub-period t of period w, and 0 otherwise,
    - $x_{jkm}(t,w)$: Unit finished product j of family k produced in machine m in sub-period t of period w.

The deterministic tactical production planning can then be formulated as shown in Box 2.

Equation 1 states the objective function of minimizing the total cost, consisting of produc-

Figure 6. A shortest path problem



tion, holding and capacity related costs. Equations 2 and 3 state capacity constraints for regular and overtime capacity respectively, and express that a capacity reserved for production must not exceed the capacity limitations. Equation 4 states that if a production takes place in sub-period *t* of period *w* then a fixed cost is realized in that sub-period. Equation 5 states that a production of finished product in a certain sub-period must not exceed the capacity reserved. Equation 6 states that the movement of inventory from one machine to the following machine will take place in each sub-period. Equation 7 states the usual inventory balance constraints from one period to the next period.

The proposed model can be distinguished from existing models in the literature based on two unique characteristics. First, the model links fixed cost to the amount of capacity reserved for a given product family in a given production stage. Second, the model also explicitly takes into account the temporary aspect in a multi-stage system, which monitors the movement of production from one stage to the next in order to assure feasibility at the detailed level.

Scenario-Based Production Planning

Now, consider that demand parameters $d_{jk}\left(w\right)$ are uncertain but following a stationary normal distribution with average $\mu_{jk}\left(w\right)$ and standard deviation $\sigma_{jk}\left(w\right)$. According to Mulvey, et al. (1995), stochastic parameters can be represented by a finite number of scenarios. Therefore, the resulting models are often referred to as scenario-

Box 2. Equations 1-7

Minimize

$$\sum_{k\in P}\sum_{j\in N_k}\left(c_{jk}\left(w\right)\sum_{t=1}^{T}x_{jkM}\left(t,w\right)+h_{jk}\left(w\right)i_{jk}\left(w\right)\right)+\sum_{t=!}^{T}\sum_{l=1}^{L}\left(\sum_{k\in P}f_{km}\left(t,w\right)y_{km}\left(t,w\right)+\theta_{m}\left(t,w\right)O_{m}\left(t,w\right)\right) \quad (1)$$

Subject to:

$$\sum_{k\in P}Q_{km}\left(t,w\right)-O_{m}\left(t,w\right)\leq\kappa_{m}^{rg}\left(t,w\right),\forall t,w,m, \quad (2)$$

$$O_{m}\left(t,w\right)\leq\kappa_{m}^{ov}\left(t,w\right),\forall t,w,m, \quad (3)$$

$$Q_{km}\left(t,w\right)-\left(\kappa_{m}^{rg}\left(t,w\right)+\kappa_{m}^{ov}\left(t,w\right)\right)y_{km}\left(t,w\right)\leq 0,\forall k,t,w,m, \quad (4)$$

$$\sum_{j\in N_k}a_{jkm}x_{jkm}\left(t,w\right)-Q_{km}\left(t,w\right)\leq 0,\forall k,t,w,m, \quad (5)$$

$$\sum_{v=1}^{w-1}\sum_{\tau=1}^{T}\left(x_{jk,m-1}\left(\tau,v\right)-x_{jkm}\left(\tau,v\right)\right)+\sum_{\tau=1}^{t-1}x_{jk,m-1}\left(\tau,w\right)-\sum_{\tau=1}^{t}x_{jkm}\left(\tau,w\right)\geq 0,\forall j,k,t,w,m, \quad (6)$$

$$\sum_{t=1}^{T}x_{jkM}\left(t,w\right)+i_{jk}\left(w-1\right)-i_{jk}\left(w\right)=d_{jk}\left(w\right),\forall j,k,w, \quad (7)$$

$$Q_{km}\left(t,w\right),O_{m}\left(t,w\right),x_{jkm}\left(t,w\right),i_{jk}\left(w\right)\geq 0,y_{km}\left(t,w\right)\in\left\{0,1\right\}.$$

based optimization models. Assume that $\Omega = \{1, 2, \ldots, S\}$ is a set of possible scenarios representing uncertain demand, where $d_{jk}^{s}(w)$ denote the demand level under scenario s with probability of occurrence p^{s}. Then, the scenario based production planning can be formulated as shown in Box 3.

The cost function ξ_s^* is the optimal value obtained by solving the deterministic model $d_{jk}^{s}(w)$ realized under scenario $s \in \Omega$. The cost function ξ_s is the optimal cost resulting from the occurrence of scenario $s \in \Omega$ given the robust values of variables $Q_{km}(t,w)$ and $O_m(t,w)$, that is:

$$\xi_s = \sum_{w=1}^{W} \left(C_{prod}^{s}(w) + C_{cap}(w) \right)$$

where

$$C_{prod}^{s}(w) = \sum_{k \in P} \sum_{j \in N_k} \begin{pmatrix} c_{jk}(w) \sum_{t=1}^{T} x_{jkM}^{s}(t,w) + \\ h_{jk}(w)\, i_{jk}^{s}(w) + \\ p_{jk}(w)\, r_{jk}^{s}(w) \end{pmatrix},$$

$$C_{cap}(w) = \sum_{t=1}^{T} \sum_{m=1}^{M} \begin{pmatrix} \sum_{k \in P} f_{km}(t,w)\, y_{km}(t,w) + \\ \theta_m(t,w)\, O_m(t,w) \end{pmatrix}.$$

Equation 8 states the objective function, minimizing the maximum difference between optimal ξ_s^* for scenario s if solved deterministically and the robust value of ξ_s for given decision

Box 3. Equations 8-14

Minimize

$$\eta \max_{s \in \Omega} \left(\xi_s - \xi_s^* \right) + \lambda \sum_{s \in \Omega} p_s \xi_s \tag{8}$$

Subject to:

$$\sum_{k \in P} Q_{km}(t,w) - O_m(t,w) \le \kappa_m^{rg}(t,w), \forall t, w, m, \tag{9}$$

$$O_m(t,w) \le \kappa_m^{ov}(t,w), \forall t, w, m, \tag{10}$$

$$Q_{km}(t,w) - \left(\kappa_m^{rg}(t,w) + \kappa_m^{ov}(t,w) \right) y_{km}(t,w) \le 0, \forall k, t, w, m, \tag{11}$$

$$\sum_{j \in N_k} a_{jkm} x_{jkm}^{s}(t,w) - Q_{km}(t,w) \le 0, \forall k, t, w, m, s, \tag{12}$$

$$\sum_{v=1}^{w-1} \sum_{\tau=1}^{T} \left(x_{jk,m-1}^{s}(\tau,v) - x_{jkm}^{s}(\tau,v) \right) + \sum_{\tau=1}^{t-1} x_{jk,m-1}^{s}(\tau,w) - \sum_{\tau=1}^{t} x_{jkm}^{s}(\tau,w) \ge 0, \forall j, k, t, w, m, s, \tag{13}$$

$$\sum_{t=1}^{T} x_{jkM}^{s}(t,w) + i_{jk}^{s}(w-1) - i_{jk}^{s}(w) + r_{jk}^{s}(w) = d_{jk}^{s}(w), \forall j, k, w, s, \tag{14}$$

$$Q_{km}(t,w), O_m(t,w), x_{jkm}^{s}(t,w), i_{jk}^{s}(w), r_{jk}^{s}(w) \ge 0, y_{km}(t,w) \in \{0,1\}$$

variables $Q_{km}\left(t,w\right)$ and $O_{m}\left(t,w\right)$ and also minimizing the average value of the costs. Note that the decision maker can freely set the tradeoff parameters between these two objectives. Equations 9, 10 and 11 are basically the same as Equation 2, 3 and 4 in the deterministic model. Equation 12 states that a production under the realization of scenario s should not exceed the capacity reserved. Therefore, the robust plan will call for a reserved capacity, which is not dependent on the scenario realization. Equation 13 states the inventory movement constraints for each scenario realization. Equation 14 states the usual inventory balance constraints. In this formulation, however, the inventory level depends on the realization of demand. We also take into account the level of unmet demand $r_{jk}^{s}\left(w\right)$ if inventory cannot satisfy demand, which is then penalized by market price $p_{jk}^{s}\left(w\right)$.

Robust Deterministic Production Planning

There are some criticism and drawbacks associated with the scenario-based optimization model. Kaut and Wallace (2007) argue that there is no single scenario generator that fits all models even if these models were subject to the same phenomenon. The model often requires a huge computational time and space, related to the number of scenarios needed to represent the uncertainty of the parameters.

We propose a robust deterministic model, which exploits some readily available information regarding the uncertain demand. Recall that although demand is uncertain, it follows a normal distribution with parameter average $\mu_{jk}\left(w\right)$ and standard deviation $\sigma_{jk}\left(w\right)$. Assume that our production plan calls for a production in period v to cover demand from period $v, v+1, \ldots, w$, then inventory at the beginning of period u plus production must exceed the maximum reasonable demand during period v until w, D_{jk}^{vw}. The maximum demand D_{jk}^{vw} for a certain service level $100\left(1-\alpha\right)\%$ can then be given as follows:

$$D_{jk}^{vw} = \sum_{u=v}^{w} \mu_{jk}\left(u\right) + z_{\alpha}\sqrt{\sum_{u=v}^{w} \sigma_{jk}\left(u\right)^{2}}$$

The robust deterministic model can then be formulated as shown in Box 4.

Equations 15-20 are basically the same as Equations 1-6 in the deterministic model. In Equation 21, we use the average demand to formulate the inventory balance constraints. Equation 22 states that if production takes place in period *v* to cover demand from *v* to *w* then initial inventory plus production must exceed the maximum demand during period *v* to *w*. Equation 23 states the decomposition of the planning horizon into subsets of planning horizon, where production only takes place in period v. Equation 24 ensures that production can take place in period *v* only if decision variable z_{jk}^{vw} takes value 1.

TACTICAL PRODUCTION PLANNING WITH UNCERTAIN PROCESS OUTPUT

We also consider a production planning case when the process is imperfect because machines progressively deteriorate over time. If a machine breaks down, the output level reduces which is related to the time needed to repair the machine. We assume that the failure of a machine *m* follows a Weibull distribution with shape parameter α_{m} and scale parameter β_{m}. Again, we propose a robust deterministic model taking advantage the available information about this machine uncertainty.

There are two types of maintenance actions, namely preventive maintenance and corrective maintenance. We believe that both actions should be placed accordingly in the hierarchical structure.

Box 4. Equations 16-24

Minimize

$$\sum_{k\in P}\sum_{j\in N_k}\left(c_{jk}(w)\sum_{t=1}^{T}x_{jkM}(t,w)+h_{jk}(w)\,i_{jk}(w)\right)+\sum_{t=!}^{T}\sum_{m=1}^{M}\left(\sum_{k\in P}f_{km}(t,w)\,y_{km}(t,w)+\theta_m(t,w)\,O_m(t,w)\right) \quad (15)$$

Subject to:

$$\sum_{k\in P}Q_{km}(t,w)-O_m(t,w)\le \kappa_m^{rg}(t,w),\forall t,w,m, \quad (16)$$

$$O_m(t,w)\le \kappa_m^{ov}(t,w),\forall t,w,m, \quad (17)$$

$$Q_{km}(t,w)-\left(\kappa_m^{rg}(t,w)+\kappa_m^{ov}(t,w)\right)y_{km}(t,w)\le 0,\forall k,t,w,m, \quad (18)$$

$$\sum_{j\in N_k}a_{jkm}x_{jkm}(t,w)-Q_{km}(t,w)\le 0,\forall k,t,w,m, \quad (19)$$

$$\sum_{v=1}^{w-1}\sum_{\tau=1}^{T}\left(x_{jk,m-1}(\tau,v)-x_{jkm}(\tau,v)\right)+\sum_{\tau=1}^{t-1}x_{jk,m-1}(\tau,w)-\sum_{\tau=1}^{t}x_{jkm}(\tau,w)\ge 0,\forall j,k,t,w,m, \quad (20)$$

$$\sum_{t=1}^{T}x_{jkM}(t,w)+i_{jk}(w-1)-i_{jk}(w)=\mu_{jk}(w),\forall j,k,w, \quad (21)$$

$$\sum_{t=1}^{T}x_{jkM}(t,v)+i_{jk}(v-1)-D_{jk}^{vw}z_{jk}^{vw}\ge 0,\forall j,k,v,w;v\le w, \quad (22)$$

$$\sum_{u=1}^{w}\sum_{v=w}^{W}z_{jk}^{uv}=1,\forall j,k,w, \quad (23)$$

$$\sum_{t=1}^{T}a_{jkM}x_{jkM}(t,v)-\left(\sum_{t=1}^{T}\left(\kappa_m^{rg}(t,v)+\kappa_m^{ov}(t,v)\right)\right)\sum_{w=v}^{W}z_{jk}^{uw}\le 0,\forall j,k,v, \quad (24)$$

$$Q_{km}(t,w),O_m(t,w),x_{jkm}(t,w),i_{jk}(w)\ge 0,z_{jk}^{vw}y_{km}(t,w)\in\{0,1\}.$$

A maintenance activity is very important and at times requires a lot of resources. We propose that preventive maintenance should be integrated at the tactical level while uncertainty due to machine breakdowns is addressed at the operational level. In doing so, we do not need to frequently respond to machine breakdowns at the operational level.

Tactical Production and Preventive Maintenance Planning

Assume that the last preventive maintenance action took place in period v, then the expected maintenance duration in period w, $v\le w$ is given by:

$$t_m^{mt}\left(v,w\right)=\begin{cases} t_m^{pr}+t_m^{cr}\int_0^T r_m\left(t\right)dt, v=w, \\ t_m^{cr}\int_0^T r_m\left(t+\left(w-v\right)T\right)dt, v<w, \end{cases}$$

where t_m^{pr} and t_m^{cr} denote the duration of preventive and corrective maintenance respectively, and $r_m\left(t\right)$ denotes the failure rate of machine m. Consequently, the expected maintenance cost in period w given that the last preventive maintenance took place in period v is given by:

$$c_m^{mt}\left(v,w\right)=\begin{cases} c_m^{pr}+c_m^{cr}\int_0^T r_m\left(t\right)dt, v=w, \\ c_m^{cr}\int_0^T r_m\left(t+\left(w-v\right)T\right)dt, v<w, \end{cases}$$

where c_m^{pr} and c_m^{cr} denote the cost of preventive and corrective maintenance respectively. Let $Z_{mt}\left(v,w\right)$ be the decision variable, which takes value 1 if preventive maintenance takes place in period v to cover all maintenance until period w, then the tactical production preventive maintenance planning can be formulated as shown in Box 5.

Equation 25 states the objective function minimizing the total of production, holding, and maintenance related costs. Equations 26 and 27 state the inventory balance constraint in machine M (i.e. the last machine in the production line and other machines respectively. Equation 28 states that a fixed cost is realized if production takes place in a period. Equation 29 states the capacity constraint where production in a period is limited by capacity minus the average duration of maintenance during that period. Equation 30

Box 5. Equations 25-30

Minimize

$$\sum_{k\in P}\sum_{m=1}^{M}\sum_{w\in H}\left(c_{km}^{p}\left(w\right)X_{km}\left(w\right)+h_{km}\left(w\right)I_{km}\left(w\right)+f_{km}\left(w\right)y_{km}\left(w\right)\right)+\sum_{m=1}^{M}\sum_{w\in H}\sum_{v\in H,v\leq w}c_m^{mt}\left(v,w\right)Z_{mt}\left(v,w\right), \quad (25)$$

Subject to:

$$I_{kM}\left(w-1\right)+X_{kM}\left(w\right)-D_k\left(w\right)=I_{kM}\left(w\right),\forall k,w, \quad (26)$$

$$I_{km}\left(w-1\right)+X_{km}\left(w\right)-X_{k,m+1}\left(w\right)=I_{km}\left(w\right),\forall k,w,m=1,..,M-1, \quad (27)$$

$$X_{km}\left(w\right)\leq \kappa_m y_{km}\left(w\right),\forall k,m,w, \quad (28)$$

$$\sum_{k\in P}a_{km}X_{km}\left(w\right)\leq \kappa_m-\sum_{v\in H,v\leq w}t_m^{mt}\left(v,w\right)Z_{mt}\left(v,w\right),\forall m,w, \quad (29)$$

$$\sum_{v\in H,v\leq w}Z_{mt}\left(v,w\right)=1,\forall w, \quad (30)$$

$$X_{km}\left(w\right),I_{km}\left(w\right),y_{km}\left(w\right)\geq 0, Z_{mt}\left(v,w\right)\in\left\{0,1\right\},$$

where $D_k\left(w\right)=\sum_{j\in N_k}d_{jk}\left(w\right)$ denote the demand of product family k in period w.

makes sure that there exists one preventive maintenance action that covers each period in the planning horizon. Again, the resulted formulation is in fact deterministic which results in a reasonable computational time.

Operational Planning and Corrective Maintenance

At the operational level, we want to allocate the capacity reserved at the tactical level for the production of finished products. In a rolling horizon approach, only the first period of the tactical plan is implemented. At this operational level, we encounter problems due to the fact that machine may break down, leading to a capacity reduction.

We extend the runout formula of Bitran et al. (1981) for the case with machine breakdowns. The objective of the model is to distribute each family's production into finished products such that the runouts of families coincide with the runouts of their corresponding finished products. A coincidence runout means a saving in setup costs. The runout time of a family k in machine m is defined as follows:

$$Rt_{km} = \frac{X_{km} + \sum_{j \in N_k} i_{jkm}\left(0\right)}{\sum_{j \in N_k} d_{jk}^{e}},$$

where $d_{jk}^{e} = \max\left(0, d_{jk} - i_{jkM}\left(0\right)\right)$ denotes the effective demand in period 1.

According to Barlow and Hunter (1960), the number of failures occurring after t periods is considered as a Poisson process:

$$P\left(N\left(t\right) = n\right) = \frac{R\left(t\right)^{n} e^{-R(t)}}{n!},$$

where $R\left(t\right) = \int_0^t r_m\left(u\right) du.$ The disaggregation process of family into finished products subject to machine breakdowns can then be formulated as show in Box 6.

Equation 31 states the objective function of minimizing the absolute deviation between the runouts of families and finished products augmenting by the penalty of not meeting planned production. Equation 32 states that a family production must be distributed over the planned production of finished production. Equation 33 states that production of finished product when *n* breakdowns occur must not exceed the available capacity due to preventive and corrective maintenance. Equation 34 states the formula for runout finished products given the occurrence of *n* breakdowns. Equation 35 states that the production with *n* breakdowns must not exceed the production with *n-1* breakdowns. Equation 36 states the unmet planned production, which is the difference between the planned production and the production subject to *n* breakdowns.

A ROBUST INTEGRATED HIERARCHICAL PLANNING APPROACH

We propose two steps of integration in this hierarchical approach. The first step is to integrate the strategic and tactical level and the second step is to integrate the tactical and operational level.

Strategic Level Planning

At the strategic level, the result of the safety stock placement problem is guaranteed service times (hence net replenishment time, τ) which is then used to calculate all realized demand during net replenishment time, D_{jkl}^{vw} where safety stock is given by SS_{jkl}^{vw}, for all consecutive periods $\left(u, v\right) \in H, u \leq v.$ The realized demand during net replenishment time and the safety stock are given as follows:

Box 6. Equations 31-36

Minimize

$$\sum_{m=1}^{M}\sum_{k\in P}\sum_{n\in S_m}\left(\sum_{j\in N_k} P\left(N\left(1\right)=n\right)\left|Rt_{km}-rt_{jkm}\left(n\right)\right|\right)+\omega\sum_{m=1}^{M}\sum_{k\in P}\sum_{j\in N_k}\sum_{n\in S_m} P\left(N\left(1\right)=n\right)x_{jkm}^{u}\left(n\right), \quad (31)$$

Subject to:

$$\sum_{j\in N_k} x_{jkm}=X_{km}, \forall k,m, \quad (32)$$

$$\sum_{k\in P}\sum_{j\in N_k} x_{jkm}^{f}\left(n\right)\le \kappa_m - t_m^{pr}Z_{mt}-t_m^{cr}n, \quad (33)$$

$$rt_{jkm}\left(n\right)=\frac{x_{jkm}^{f}\left(n\right)+i_{jkm}\left(0\right)}{d_{jk}^{e}}, \forall j,k,m,n, \quad (34)$$

$$x_{jkm}^{f}\left(n\right)\le x_{jkm}^{f}\left(n-1\right), \forall j,k,m,n=1,..,N_m^{\max} \quad (35)$$

$$x_{jkm}^{u}\left(n\right)\ge x_{jkm}-x_{jkm}^{f}\left(n\right), \forall j,k,m,n, \quad (36)$$

$$x_{jkm}, x_{jkm}^{f}\left(n\right), rt_{jkm}\left(n\right), x_{jkm}^{u}\left(n\right)\ge 0$$

$$D_{jkl}^{vw}=\sum_{u=v}^{w}\mu_{jk}\left(u\right)+SS_{jkl}^{vw},$$

$$SS_{jkl}^{vw}=\begin{cases}\theta_{jkl}^{vw}z_\alpha\sigma_{jk}^{vw}\sqrt{\tau}, & \tau_l>0\\ \theta_{jkl}^{vw}\sigma_{jk}^{vw}\left(\max\left(0,z_\alpha-\rho_{jkl}^{vw}\right)\right), & \tau_l\le 0\end{cases}$$

where θ_{jkl}^{vw} denotes the correction factor for finished product j of family k for consecutive periods $\left(u,v\right)\in H, u\le v$.

Tactical Level Planning

At the tactical plan, we formulate both the tactical production and preventive maintenance planning simultaneously. Combining both formulations from the earlier sections, we can model the tactical planning model as shown in Box 7.

Equation 37 states the objective function to minimize the total of production costs, capacity related and maintenance related costs. Equations 42 and 43 suggest that maintenance durations are proportionally allocated to regular and overtime capacity, i.e. we assume that machine breakdowns are uniformly distributed during a period. Other equations have been discussed in previous sections.

At this tactical level, we obtain both a production plan and a preventive maintenance plan. Those plans are then used at the operational level to disaggregate capacity reserved to finished products subject to machine breakdown.

Operational Level Planning

Since we are dealing with multi sub-periods in a period then the number of breakdowns in one period can be described as a scenario tree for each

Box 7. Equations 37-49

Minimize

$$\sum_{w\in H}\left(C_{prod}\left(w\right)+C_{cap}\left(w\right)+C_{mt}\left(w\right)\right) \tag{37}$$

Subject to:

$$\bar{\kappa}_m\left(t,w\right)=\kappa_m\left(t,w\right)-\sum_{v\in H,v\leq w} t_m^{mt}\left(t,v,w\right)Z_{mt}\left(v,w\right),\forall m,t,w, \tag{38}$$

$$\sum_{k\in P} Q_{km}\left(t,w\right)\leq\bar{\kappa}_m\left(t,w\right),\forall m,t,w, \tag{39}$$

$$Q_{km}\left(t,w\right)-\kappa_m\left(t,w\right)y_{km}\left(t,w\right)\leq 0,\forall k,m,t,w, \tag{40}$$

$$\sum_{j\in N_k} a_{jkm}x_{jkm}\left(t,w\right)\leq Q_{km}\left(t,w\right),\forall k,m,t,w, \tag{41}$$

$$\sum_{k\in P} Q_{km}\left(t,w\right)-O_m\left(t,w\right)\leq\frac{\kappa_m^{rg}\left(t,w\right)}{\kappa_m\left(t,w\right)}\bar{\kappa}_m\left(t,w\right),\forall m,t,w, \tag{42}$$

$$O_m\left(t,w\right)\leq\frac{\kappa_m^{ov}\left(t,w\right)}{\kappa_m\left(t,w\right)}\bar{\kappa}_m\left(t,w\right),\forall m,t,w, \tag{43}$$

$$\sum_{v=1}^{w-1}\sum_{\tau=1}^{T}\left(x_{jk,m-1}\left(\tau,v\right)-x_{jkm}\left(\tau,v\right)\right)+\sum_{\tau=1}^{t-1}x_{jk,m-1}\left(\tau,w\right)-\sum_{\tau=1}^{t}x_{jkm}\left(\tau,w\right)\geq 0,\forall j,k,t,w,m, \tag{44}$$

$$\sum_{t=1}^{T}x_{jkM}\left(t,w\right)+i_{jk}\left(w-1\right)-i_{jk}\left(w\right)=\mu_{jk}\left(w\right),\forall j,k,w, \tag{45}$$

$$\sum_{t=1}^{T}x_{jkM}\left(t,v\right)+i_{jk}\left(v-1\right)-D_{jk}^{vw}z_{jk}^{vw}\geq 0,\forall j,k,v,w;v\leq w, \tag{46}$$

$$\sum_{u=1}^{w}\sum_{v=w}^{W}z_{jk}^{uv}=1,\forall j,k,w, \tag{47}$$

$$\sum_{u=1}^{w}\sum_{v=w}^{W}Z_{mt}\left(u,v\right)=1,\forall w, \tag{48}$$

$$\sum_{t=1}^{T}a_{jkM}x_{jkm}\left(t,v\right)-\left(\sum_{t=1}^{T}\kappa_m\left(t,w\right)\right)\sum_{u=w}^{W}z_{jk}^{wu}\leq 0,\forall j,k,w, \tag{49}$$

$$Q_{km}\left(t,w\right),x_{jkm}\left(t,w\right),i_{jk}\left(w\right)\geq 0,z_{jk}^{vw},Z_{mt}\left(v,w\right),y_{km}\left(t,w\right)\in\left\{0,1\right\}$$

continued on following page

Box 7. Continued

where

$$C_{prod}(w) = \sum_{k\in P}\sum_{j\in N_k}\left(c_{jk}(w)\sum_{t=1}^{T} x_{jkM}(t,w) + h_{jk}(w)\, i_{jk}(w)\right),$$

$$C_{cap}(w) = \sum_{t=1}^{T}\sum_{m=1}^{M}\left(\sum_{k\in P} f_{km}(t,w)\, y_{km}(t,w) + \theta_m(t,w)\, O_m(t,w)\right),$$

$$C_{mt}(w) = \sum_{v\in H, v\le w}\sum_{t=1}^{T}\sum_{m=1}^{M} c_m^{mt}(t,v,w)\, Z_{mt}(v,w)$$

sub-period (see Figure 7). A scenario s is then defined as a single path of machine breakdowns from $t=1$ to $t=T$, with probability $\pi(s)$.

The operational planning problem can then be formulated as shown in Box 8.

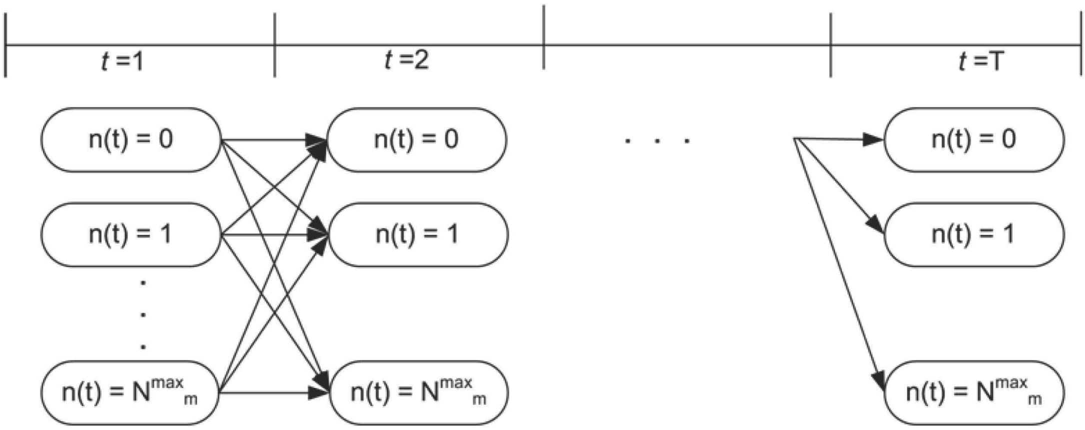
Equation 50 states the objective function of minimizing the absolute deviation of families and finished products runouts augmented by the penalty of not meeting planned production. Equations 51-54 have been discussed earlier, that is for each sub-period in period 1. Equation 55Equations states the runout formula for each finished products for a single path because effective demand is calculated for each period (instead of sub-periods).

Solutions and Recommendations

We have tested all models using AMPL/CPLEX on a 3GHz CPU and 1 GB RAM Processor using hypothetical data. The hypothetical data were inspired by real life problems. At the strategic level, we have a 3-stage serial supply chain satisfying customer demand. At the tactical level, we have a 2-machine production line to produce a product family for 6-periods planning horizon. In the remainder of this section, finding from these computational tests, are discussed.

In a capacitated supply chain, it is shown that the quantity of safety stock needs to be adjusted by some correction factors. This adjustment is needed to ensure a certain service level such that the safety stock is able to cover the variation of

Figure 7. A scenario tree of machine breakdowns



Box 8. Equations 50-55

Minimize

$$x^{f}_{jkm}\left(n,t\right) \le x^{f}_{jkm}\left(n-1,t\right), \forall j,k,m,t,n \in S_{m}\left(t\right), \tag{50}$$

Subject to:

$$\sum_{k\in P}\sum_{j\in N_k} a_{jkm}x^{f}_{jkm}\left(n,t\right) \le \kappa_{m} - t^{pr}_{m}Z_{mt} - t^{cr}_{m}n, \forall m,t,n \in S_{m}\left(t\right), \tag{51}$$

$$\sum_{j\in N_k} a_{jkm}x^{f}_{jkm}\left(n,t\right) \le Q_{km}\left(t\right), \forall k,m,t,n \in S_{m}\left(t\right), \tag{52}$$

$$x^{f}_{jkm}\left(n,t\right) \le x^{f}_{jkm}\left(n-1,t\right), \forall j,k,m,t,n \in S_{m}\left(t\right), \tag{53}$$

$$x^{u}_{jkm}\left(n,t\right) \ge x_{jkm}\left(t\right) - x^{f}_{jkm}\left(n,t\right), \forall j,k,m,t,n \in S_{m}\left(t\right), \tag{54}$$

$$rt_{jkm}\left(s\right) = \frac{i_{jkm}\left(0\right) + x^{s}_{jkm}}{d^{e}_{jk}}, \forall j,k,m,s \in \Omega_{m}, \tag{55}$$

$$x^{s}_{jkm}, rt_{jkm}\left(s\right), x^{s}_{jkm}\left(n,t\right), x^{u}_{jkm}\left(n,t\right) \ge 0$$

demand during net replenishment time. Even if net replenishment time is zero or negative, a safety stock is still required particularly for a very limited capacity. In a serial supply chain, the decision to put some safety stock in one stage depends on the net replenishment time of its upstream stage. In general, these decisions are dependent on the interaction among capacity, the standard deviation of demand, and holding costs. It is worth noting that the safety stock placement model in a capacitated supply chain determines both the location and the size of safety stocks simultaneously.

For the tactical production planning, we tested both the scenario-based optimization model and the robust deterministic model. In terms of average cost, the proposed robust deterministic model produces a solution, which is 4% higher than that of the scenario-based model. In terms of standard deviation of cost, the proposed model produces a solution that is 10% lower than that of the scenario-based model. The small variation of cost is due to the objective function, which uses a min-max model. In general, we can say that the robust deterministic model emphasizes more on the variation of the costs. Nevertheless, this emphasis can be traded off for a better value of average cost by changing the parameter z_{α}, which is used to calculate the demand during net replenishment time. Although the scenario-based model trades off average and variation of costs, its computational complexity hinders the process of trading off within reasonable time.

We also conduct the computational time comparison between the scenario-based model and the robust deterministic model. Table 1 shows the results for the computational time, where N denotes the number of finished products and W denotes the length of planning horizons.

It is shown that scenario-based model is very difficult to solve even for a modest instance of data. For each finished product, we assume that uncertain demand can be realized in three different scenarios. Hence for a 6 periods of planning horizon, we need 3^6=729different scenarios to solve the scenario-based model. It can be seen that even for the smallest two finished products problem, the computational time becomes intractable.

For the integration of production and maintenance planning, we evaluate two approaches of preventive maintenance: general and cyclical policies. A cyclical policy states that the time between two consecutive preventive maintenance actions is the same and constant over the whole planning horizon. In a general policy, maintenance periods do not necessarily fall at equally distant epochs. In terms of cost, the general model gives better solutions than the cyclical model. Both models perform equally well in term of service levels, they produce solutions, which give a 97.6% service levels. The effect of tight capacity, long duration of maintenance and small machine parameters (α, β) similarly tightens capacities, which shows that a stable capacity level gives a better service level.

Based on these findings, we can securely conclude that addressing the issue of uncertainty in supply chains using a hierarchical decision making process has many advantages at all levels. At the strategic level, the determination of guaranteed service times from one stage to another may be employed to determine the optimal location and size of safety stocks. At this strategic level, the safety stock placement model could be used to determine guaranteed service times and the quantity of safety stock for all stages in a supply chain. This model requires capacity information from all stages in the supply chain. This means that all stages (partners) in the supply chain must disseminate their capacity information to other partners in the chain. The findings also suggest that when the capacity of a stage is limited, then the stage should place a safety stock even though its net replenishment time is non-positive. It is also worth noting that safety stock placed in a stage allows the stage to independently generate its own tactical plan.

At the tactical level, we the robust deterministic model could be implemented to solve both production and maintenance planning. This robust deterministic model requires only a reasonable amount of computational time. The findings also suggest that a robust deterministic model performs almost as well as the scenario-based model in terms of average cost and the variability of the costs. At this tactical level, we have formulated the movement of finished product inventory from one period to the next in addition to product movement from one machine to the next. In doing so, the machines in the production line are decoupled, which allows production planners to independently generate operational plans for each machine.

At the operational level, the objective function of the model should be able to minimize the absolute deviation of runouts, while attempting to produce a number of finished products as close as possible to the planned production. We have used the scenario-based model at this level because machine failures follow some Poisson distributions.

Mula, et al. (2006) pointed out that there is a need to further investigate new approaches to modeling uncertainty in supply chains, particularly because of the complexity inherent in a supply chain. This work seeks to explore new ideas in order to resolve this difficult issue in a complex supply chain. It has been shown that hierarchical planning is an effective and efficient way to reduce the complexity of a supply chain. The safety stock placement model at the strategic level allows each stage in the chain to act independently to generate its own tactical plan. The inventory movement constraints at the tactical plan decouple the machines from the production line. Moreover, the formulation of runout times is capable of synchronizing the production of finished products across the whole production line, even though each machine is scheduled independently.

It is worth pointing out that the hierarchical planning should be seen as a continuous process of decision making. Strategic decisions are transformed into tactical decisions and tactical decisions are then translated to operational decisions without intermittent. Conversely, information and feedback are transmitted from the lower level to support decision-making at the upper level.

FUTURE RESEARCH DIRECTIONS

The simulation that evaluated the effect of capacity constraints on a single-stage supply chain has been conducted only for a targeted 1% stock out probability. It is therefore necessary to conduct more simulations for other values of the stock out probability. It is also worth investigating a more general structure of supply chain instead of a serial structure. In this general case, the possibilities of dynamic programming (Graves and Willems, 2000) should be further explored, taking into account the capacity limitations. An immediate area of future research should be directed toward the inclusion of transportation and distribution problems. That way, we can completely analyze and evaluate a supply chain including both production and transportation problems.

At the tactical level, capacity cushion levels and preventive maintenance actions are employed simultaneously. However, their formulations are still independent from one to another. We believe that there should be a common strategy that can be employed to deal with both demand and machine uncertainties. Webster (2008) refers to this strategy as a system slack, which is used to deal with uncertainties in the system. Such a research will eventually advance the modeling of other types of uncertainty, such as supply lead times, and quality uncertainty. The concept of service level can then be expanded from only meeting the quantity of demand to the quality level. Problems related to quality management should also be tackled hierarchically. For example, product design problems should be dealt with at the strategic level while sampling strategies for statistical process control should be discussed at the tactical level.

In this work, a scenario-based optimization model is used to disaggregate families into their corresponding finished products. Hence, there is still a need to address the issue of computational complexity at this level. It is worthwhile to develop a better and efficient algorithm particularly because the planning horizon at this tactical level is very short.

The hierarchical planning approach suggests that besides the hierarchy involved in decision-making, there is also a hierarchy of products. During the integration process of strategic and tactical level planning, we are confronted with the problem of allocating capacity for each product family. We have assumed that the capacity of a stage is proportionally allocated to all product families based on the demand. The same proportional assumption has also been made for the allocation of capacity to all finished products. It is however necessary to investigate further on a more efficient and effective way on allocating capacity to product families and finished products.

One of the most important activities in managing supply chains is controlling activities. In an uncertain environment, the resulting plan should be kept to monitor and measure the performance of the plans for future actions. There exists a great need to manage information and feedback in a supply chain. These issues of information control remain unanswered in this work area, and deserved to be investigated further.

CONCLUSION

In this chapter, an integrated hierarchical planning approach for robust design and planning of a supply chain is presented and discussed. This hierarchical planning approach is adopted because most supply chains make their decisions based on the natural hierarchy existing within their managerial systems. There are typically three levels of planning in a supply chain: strategic, tactical and operational levels. It is therefore necessary to translate plans from the strategic level into the tactical level, and from the tactical level into the operational level while maintaining a prescribed service level. This work attempts to explore and develop new approaches integrating the various plans in supply chains in order to resolve the complex issue of uncertainty inherent in these supply chains.

Three models are formulated -one for each level- addressing problems that most commonly occur in a supply chain. At the strategic level, the safety stock placement problem is formulated for a capacitated supply chain. The effect of capacity limitation is the increase of the quantity of required safety stock by a certain correction factor. Even when the net replenishment time is non-positive, a capacitated stage must place safety stocks in order to maintain the prescribed service level. At the tactical level, the aggregate production planning is formulated to address two types of uncertainty: demand uncertainty and capacity uncertainty. Some capacity cushion levels are used to deal with demand uncertainty and a preventive maintenance planning is used to deal with capacity uncertainty. We propose a general preventive maintenance policy where maintenance periods do not necessarily fall at equally distant epochs. At the operational level, a product family is disaggregated into finished products taking into account machine breakdowns. The operational level planning aims at producing the planned production decided at the tactical level as accurately as possible, in addition to synchronizing production across the production line. In summary, we attempt to solve one of the most important problems in a supply chain, namely meeting uncertain demand using machinery which is subject to failures.

Considering the results from each planning level, an integrated hierarchical approach is proposed in this research. Two phases of integration are considered: 1) the integration of strategic and tactical level planning and 2) the integration between tactical and operational level planning. This collection of models can serve as a basis for further elaborated models to solve more complex problems in a supply chain. It is worth noting that the complexity in a supply chain is partly reduced by the use of safety stock at the strategic level, the formulation of inventory movement constraints at the tactical level and the formulation of runout deviations at the operational level. At the strategic level, the guaranteed service time of a stage (along with the safety stock) decouples it from other stages in the supply chain, which allows it to generate its own tactical plan. At the tactical level, the inventory movement constraints also decouple a machine from others in the production line. Finally, the formulation of runout deviations synchronizes the production of finished products across the production line even though the planning is executed independently for each machine. At the tactical level, partitions of planning horizon for both demand realization and preventive maintenance actions are used. Such partitions bring about a deterministic formulation while maintaining the prescribed service level. The computational complexity of such a robust deterministic formulation stays within a reasonable amount of time and space.

REFERENCES

Aghezzaf, E.-H. (2005). Capacity planning and warehouse location in supply chains with uncertain demands. *The Journal of the Operational Research Society*, *56*(4), 453–462. doi:10.1057/palgrave.jors.2601834

Aghezzaf, E.-H., Jamali, M. A., & Ait-Kadi, D. (2007). An integrated production and preventive maintenance planning model. *European Journal of Operational Research*, *181*(2), 679–685. doi:10.1016/j.ejor.2006.06.032

Aghezzaf, E.-H., & Najid, N. (2008). Integrated production planning and preventive maintenance in deteriorating production systems. *Information Sciences*, *178*, 679–685. doi:10.1016/j.ins.2008.05.007

Aghezzaf, E.-H., Sitompul, C., & Najid, N. (2010). Models for robust tactical planning in multi stage production systems with uncertain demands. *Computers & Operations Research*, *37*(5), 880–889. doi:10.1016/j.cor.2009.03.012

Alcaide, D., Rodriguez-Gonzales, A., & Sicilia, J. (2006). A heuristic approach to minimize expected makespan in open shops subject to stochastic processing times and failures. *International Journal of Flexible Manufacturing Systems*, *17*, 201–226. doi:10.1007/s10696-006-8819-1

Barlow, R. E., & Hunter, L. C. (1960). Optimum preventive maintenance policies. *Operations Research*, *8*, 90–100. doi:10.1287/opre.8.1.90

Ben-Tal, A., & Nemirovski, A. (1998). Robust convex optimization. *Mathematics of Operations Research*, *23*, 769–805. doi:10.1287/moor.23.4.769

Bitran, G. R., Haas, E. A., & Hax, A. C. (1981). Hierarchical production planning: A single stage system. *Operations Research*, *29*(4), 717–743. doi:10.1287/opre.29.4.717

Bitran, G. R., & Tirupati, D. (1993). Hierarchical production planning. In Graves, S. C., Rinnooy Kan, A. H. G., & Zipkin, P. (Eds.), *Handbooks on operations research and management science* (*Vol. 4*, pp. 523–568). Amsterdam, The Netherlands: North-Holland.

Chen, C.-L., Yuan, T.-W., & Lee, W.-C. (2007). Multi-criteria fuzzy optimization for locating warehouses and distribution centers in a supply chain network. *Journal of the Chinese Institute of Chemical Engineers*, *38*, 393–407. doi:10.1016/j.jcice.2007.08.001

Chen, J., & Chen, F. F. (2003). Adaptive scheduling in random flexible manufacturing systems subject to machine breakdowns. *International Journal of Production Research*, *41*(9), 1927–1951. doi:10.1080/0020754031000119016

Cheng, L., Subrahmanian, E., & Westerberg, A. W. (2004). Multi-objective decisions on capacity planning and production-inventory control under uncertainty. *Industrial & Engineering Chemistry Research*, *43*(9), 2192–2208. doi:10.1021/ie0303404

Cochran, J. K., & Ramanujam, B. (2006). Carrier-mode logistics optimization of inbound supply chains for electronics manufacturing. *International Journal of Production Economics*, *103*, 826–840. doi:10.1016/j.ijpe.2006.01.005

Dempster, M. A. H., L., F. M., Jansen, L., Lageweg, B. J., Lenstra, J. K., & Rinnooy Kan, A. H. G. (1983). Analysis of heuristics for stochastic programming: Results for hierarchical scheduling problems. *Mathematics of Operations Research*, *8*, 525–537. doi:10.1287/moor.8.4.525

Dolgui, A., & Prodhon, C. (2007). Supply planning under uncertainties in MRP environments: A state of the art. *Annual Reviews in Control*, *31*, 269–279. doi:10.1016/j.arcontrol.2007.02.007

Francas, D., & Minner, S. (2009). Manufacturing network configuration in supply chains with product recovery. *Omega*, *37*, 757–769. doi:10.1016/j.omega.2008.07.007

Geary, S., Childerhouse, P., & Towill, D. (2002). Uncertainty and the seamless supply chain. *Supply Chain Management Review*, *6*(4), 52–60.

Graves, S. C., & Willems, S. P. (2000). Optimizing strategic safety stock placement in supply chains. *Manufacturing and Service Operations Management*, *2*(1), 68–83. doi:10.1287/msom.2.1.68.23267

Guan, Y., Ahmed, S., Nemhauser, G. L., & Miller, A. J. (2006). A branch and cut algorithm for the stochastic uncapacitated lot-sizing problem. *Mathematical Programming*, *105*(1), 55–84. doi:10.1007/s10107-005-0572-9

Gupta, A., & Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & Chemical Engineering*, *27*, 1219–1227. doi:10.1016/S0098-1354(03)00048-6

Jia, C. (2001). Stochastic single machine scheduling with an exponentially distributed due date. *Operations Research Letters*, *28*, 199–203. doi:10.1016/S0167-6377(01)00065-7

Kallrath, J. (2005). Solving planning and design problems in the process industry using mixed integer and global optimization. *Annals of Operations Research*, *140*, 339–373. doi:10.1007/s10479-005-3976-2

Kaut, M., & Wallace, S. W. (2007). Evaluation of scenario-generation methods for stochastic programming. *Pacific Journal of Optimization*, *3*(2), 257–271.

Kira, D., Kusy, M., & Rakita, I. (1997). A stochastic linear programming approach to hierarchical production planning. *The Journal of the Operational Research Society*, *48*, 207–211.

Laguna, M. (1998). Applying robust optimization to capacity expansion for one location in telecommunications with demand uncertainty. *Management Science*, *44*(11), 101–110. doi:10.1287/mnsc.44.11.S101

Lesnaia, E., Vasilescu, I., & Graves, S. C. (2004). *The complexity of safety stock placement in general-network supply chains: Innovation in Manufacturing Systems and Technology (IMST)*. Massachusetts Institute of Technology.

Leung, S. C. H., & Wu, Y. (2004). A robust optimization model for stochastic aggregate planning. *Production Planning and Control*, *15*(5), 502–514. doi:10.1080/09537280410001724287

Leus, R., & Herroelen, W. (2005). The complexity of machine scheduling for stability with a single disrupted job. *Operations Research Letters*, *33*, 151–156. doi:10.1016/j.orl.2004.04.008

Li, Z., & Ierapetritou, M. (2008). Process scheduling under uncertainty: review and challenges. *Computers & Chemical Engineering*, *32*, 715–727. doi:10.1016/j.compchemeng.2007.03.001

Liao, C. J., & Chen, W. J. (2004). Scheduling under machine breakdown in a continuous process industry. *Computers & Operations Research*, *31*, 415–428. doi:10.1016/S0305-0548(02)00224-1

List, G. F., Wood, B., Nozick, L. K., Turnquist, M. A., Jones, D. A., & Kjeldgaard, E. A. (2003). Robust optimization for fleet planning under uncertainty. *Transportation Research Part E, Logistics and Transportation Review*, *39*, 209–227. doi:10.1016/S1366-5545(02)00026-1

Liu, L., Gu, H.-Y., & Xi, Y.-G. (2007). Robust and stable scheduling of a single machine with random machine breakdowns. *International Journal of Advanced Manufacturing Technology*, *31*, 645–654. doi:10.1007/s00170-005-0237-0

Lusa, A., Corominas, A., & Munoz, N. (2008). A multistage scenario optimisation procedure to plan annualised working hours under demand uncertainty. *International Journal of Production Economics*, *113*, 957–968. doi:10.1016/j.ijpe.2007.11.009

Malcom, S. A., & Zenios, S. A. (1994). Robust optimization of power systems capacity expansion under uncertainty. *The Journal of the Operational Research Society*, *45*, 1040–1049.

Mapes, J. (1992). The effect of capacity limitations on safety stock. *International Journal of Operations & Production Management*, *13*, 26–33. doi:10.1108/01443579310045536

Mehta, S. V., & Uzsoy, R. (1999). Predictable scheduling of a single machine subject to breakdowns. *International Journal of Computer Integrated Manufacturing*, *12*(1), 15–38. doi:10.1080/095119299130443

Miller, E. J., Roorda, M. J., & Carrasco, J. A. (2005). A tour-based model of travel mode choice. *Transportation*, *32*, 399–422. doi:10.1007/s11116-004-7962-3

Mulvey, J. M., Vanderbei, R. J., & Zenios, S. A. (1995). Robust optimization of large scale systems. *Operations Research*, *43*(2), 264–281. doi:10.1287/opre.43.2.264

Raa, B., & Aghezzaf, E.-H. (2005). A robust dynamic planning strategy for lot-sizing problem with stochastic demands. *Journal of Intelligent Manufacturing*, *16*(2), 207–247. doi:10.1007/s10845-004-5889-3

Rosenblatt, M. J., & Lee, H. L. (1987). A robustness approach to facilities design. *International Journal of Production Research*, *25*(4), 479–486. doi:10.1080/00207548708919855

Shapiro, J. F. (2001). *Modeling the supply chain*. Pacific Grove, CA: Duxbury.

Sitompul, C., & Aghezzaf, E.-H. (2008). *Robust production planning: An alternative to scenario based optimization model.* Paper presented at the Modelling, Computation and Optimization in Information Systems and Management Sciences, Metz, France.

Sitompul, C., Aghezzaf, E.-H., Van Landeghem, H., & Dullaert, W. (2008). Safety stock placement problems in capacitated supply chains. *International Journal of Production Research*, *46*, 4709–4727. doi:10.1080/00207540701278406

Srinivasan, K. K., & Bhargavi, P. (2007). Longer-term changes in mode choice decisions in Chennai: A comparison between cross-sectional and dynamic models. *Transportation*, *34*, 355–374. doi:10.1007/s11116-007-9116-x

Van den broecke, F., Aghezzaf, E.-H., & Van Landeghem, H. (2008). Cyclical volume planning and fair share mix decisions, delivery a more robust service level. *Production Planning and Control, 19*(7), 668-676.

Van Landeghem, H., & Vanmaele, H. (2002). Robust planning: A new paradigm for demand chain planning. *Journal of Operations Management*, *20*, 769–783. doi:10.1016/S0272-6963(02)00039-6

Vidal, C. J., & Goetschalckx, M. (2000). Modeling the effect of uncertainties on global logistic systems. *Journal of Business Logistics*, *21*(1), 95–120.

Wang, J., & Shu, Y.-F. (2007). A probabilistic decision model for new product supply chain design. *European Journal of Operational Research*, *177*, 1044–1061. doi:10.1016/j.ejor.2005.12.032

Webster, S. (2008). *Principles and tools for supply chain management* (13th ed.). Boston, MA: McGraw-Hill/Irwin.

Weinstein, L., & Chung, C. H. (1999). Integrating maintenance and production decisions in a hierarchical production planning environment. *Computers & Operations Research*, *26*, 1059–1074. doi:10.1016/S0305-0548(99)00022-2

Wu, D., & Olson, D. L. (2008). Supply chain risk, simulation, and vendor selection. *International Journal of Production Economics*, *114*, 646–655. doi:10.1016/j.ijpe.2008.02.013

Xia, Y., Chen, B., & Yue, J. (2008). Job sequencing and due date assignment in a single machine shop with uncertain processing times. *European Journal of Operational Research*, *184*, 63–75. doi:10.1016/j.ejor.2006.10.058

You, F., & Grosmann, I. E. (2008). Mixed-integer nonlinear programming models and algorithms for large-scale supply chain design with stochastic inventory management. *Industrial & Engineering Chemistry Research*, *47*, 7802–7817. doi:10.1021/ie800257x

Yu, C.-S., & Li, H.-L. (2000). A robust optimization model for stochastic logistic problems. *International Journal of Production Economics*, *64*, 385–397. doi:10.1016/S0925-5273(99)00074-2

ADDITIONAL READING

Ahmed, S., J., K. A., & Parija, G. (2003). A multi-stage stochastic integer programming approach for capacity expansion under uncertainty. *Journal of Global Optimization*, *26*(1), 3–24. doi:10.1023/A:1023062915106

Anily, S., & Federgruen, A. (1991). Capacitated two-stage multi-item production/inventory model with joint setup costs. *Operations Research*, *39*, 443–455. doi:10.1287/opre.39.3.443

Ben-Daya, M. (2002). The economic production lot-sizing problem with imperfect production processes and imperfect maintenance. *International Journal of Production Economics*, *76*, 257–264. doi:10.1016/S0925-5273(01)00168-2

Bookbinder, J. H., & Tan, J.-Y. (1988). Strategies for the probabilistic lot-sizing problem with service level constraints. *Management Science*, *34*(9), 1096–1108. doi:10.1287/mnsc.34.9.1096

Chakraborty, T., Giri, B. C., & Chaudhuri, K. S. (2008). Production lot sizing with process deterioration and machine breakdown. *European Journal of Operational Research*, *185*, 606–618. doi:10.1016/j.ejor.2007.01.011

Clark, A. J., & Scarf, H. (1960). Optimal policies for a multi-echelon inventory problem. *Management Science*, *6*, 475–490. doi:10.1287/mnsc.6.4.475

Crespo Marguez, A., Gupta, J. N. D., & Sanchez Heguedas, A. (2003). Maintenance policies for a production system with constrained production rate and buffer capacity. *International Journal of Production Research*, *41*(9), 1909–1926. doi:10.1080/0020754031000123877

Dauzere-Peres, S., & Lasserre, J. B. (2002). On the importance of sequencing decisions in production planning and scheduling. *International Transactions in Operational Research*, *9*, 779–793. doi:10.1111/1475-3995.00388

Federgruen, A., & Zipkin, P. (1986). An inventory model with limited production capacity and uncertain demand I: The average costs criterion. *Mathematics of Operations Research*, *11*, 193–207. doi:10.1287/moor.11.2.193

Gfrerer, H., & Zapfel, G. (1995). Hierarchical model for production planning in the case of uncertain demand. *European Journal of Operational Research*, *86*(1), 142–161. doi:10.1016/0377-2217(95)00066-Y

Groenevelt, H., Pintelon, L., & Seidmann, A. (1992). Production batching with machine breakdowns and safety stocks. *Operations Research*, *40*(5), 959–971. doi:10.1287/opre.40.5.959

Gupta, A., & Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & Chemical Engineering*, *27*, 1219–1227. doi:10.1016/S0098-1354(03)00048-6

Hax, A. C., & Meal, H. C. (1975). Hierarchical integration of production planning and scheduling. In Geisler, M. A. (Ed.), *Studies in Management Sciences* (*Vol. 1*, pp. 53–69). New York, NY: Elsevier. doi:10.1007/978-3-642-27922-5_19

Inderfurth, K., & Minner, S. (1998). Safety stock in multi-stage inventory systems under different service measures. *European Journal of Operational Research*, *106*, 57–73. doi:10.1016/S0377-2217(98)00210-0

Karmarkar, U. S. (1987). Lot sizes, lead times and in-process inventories. *Management Science*, *33*(3), 409–418. doi:10.1287/mnsc.33.3.409

Kouvelis, P., & Yu, G. (1997). *Robust discrete optimization and its applications*. Boston, MA: Kluwer Academic Publisher.

Lagodimos, A. G., & Anderson, E. J. (1993). Optimal positioning of safety stock in MRP. *International Journal of Production Research*, *31*, 1799–1813. doi:10.1080/00207549308956823

Lasserre, J. B., & Merce, C. (1990). Robust hierarchical production planning under uncertainty. *Annals of Operations Research*, *26*, 73–87. doi:10.1007/BF02248585

Lee, C.-Y. (2004). Machine scheduling with availability constraint. In Leung, J. Y.-T. (Ed.), *Handbook of scheduling: Algorithm, models, and performance analysis*. Boca Raton, FL: CRC Press.

McKay, K. N., Safayeni, F. R., & Buzzacott, J. A. (1995). A review of hierarchical production planning and its applicability for modern manufacturing. *Production Planning and Control*, *6*(5), 384–394. doi:10.1080/09537289508930295

Sahinidis, N. V. (2004). Optimization under uncertainty: State-of-the art and opportunities. *Computers & Chemical Engineering*, *28*, 971–983. doi:10.1016/j.compchemeng.2003.09.017

Schmidt, G. (2000). Scheduling with limited machine availability. *European Journal of Operational Research*, *121*, 1–15. doi:10.1016/S0377-2217(98)00367-1

Silva Filho, O. S. (1999). An aggregate production planning model with demand uncertainty. *Production Planning and Control*, *10*(8), 745–756. doi:10.1080/095372899232579

Simpson, K. F. (1958). In-process inventory. *Operations Research*, *6*, 863–873. doi:10.1287/opre.6.6.863

Tarim, S. A., & Kingsman, B. G. (2004). The stochastic dynamic production/inventory lot-sizing problem with service level constraints. *International Journal of Production Economics*, *88*(1), 105–119. doi:10.1016/S0925-5273(03)00182-8

Tayur, S., Ganeshan, R., & Magazine, M. (Eds.). (1999). *Quantitative models for supply chain management*. Norwell, MA: Kluwer Academic. doi:10.1007/978-1-4615-4949-9

KEY TERMS AND DEFINITIONS

Capacity Cushion: An amount of capacity, which is reserved to avoid unmet demand or stock out due to demand or process uncertainty.

Hierarchical: A concept that acknowledges the hierarchy in decision making in a system.

Preventive Maintenance: A maintenance activity, which is planned before hand to preventively avoid a huge amount of inflated capacity due to machine breakdowns.

Robustness: A characteristic of a system that is able to strongly protect itself from changes or uncertainty.

Safety Stock: An extra stock put into inventory to achieve a certain service level.

Service Level: A performance measure, which shows the ability of a system to satisfy its customers demand.

Supply Chain: A group of vendors, manufacturer, distribution centers and customers, which are connected by flows of goods, information and money.

Uncertainty: The stochastic nature of planning parameters due to lack of information or the inability to predict the outcome of a future.

Section 3
Network Applications

Chapter 12
Measures of Risk on Variability with Application in Stochastic Activity Networks

Yousry H. Abdelkader
Alexandria University, Egypt

ABSTRACT

The author proposes a simple measure of variability of some of the more commonly used distribution functions in the class of New-Better-than-Used in Expectation (NBUE). The measure result in a ranking of the distributions, and the methodology used is applicable to other distributions in NBUE class beside the one treated here. An application to stochastic activity networks is given to illustrate the idea and the applicability of the proposed measure.

INTRODUCTION

An important issue that looms high in the management of real life project is that of risk under conditions of uncertainty. "Risk" is may be used as a synonymous with "Variability", which is best estimated by the variance of the completion time of 'milestone events', including the project completion time, or the project cost, or the resources consumed in its execution or might be R&D see, e.g., (Elamaghraby, 2005; Wang and Hwang, 2007; Durbach and Stewart, 2009). On the other hands, Liu and Liu (2002) defined the expected value and variance for measuring the portfolio return and the risk, respectively. Therefore, one of the most basic measure of risk is the standard deviation or variance. However, other measures of risk may be considered as well see, e.g., (Yitzhaki, 1982; Shailt and Yitzhaki, 1989; Konno and Yamazaki, 1991; Kijima and Ohnishi, 1993; Duffie and Pan, 1997; Levy, 1998; Ringuest et al., 2000; Leshno & Levy, 2002; Tang, 2006; Neiger et al., 2009). Graves and Ringuest (2009) discussed the well known six decision making methods: 1. Mean-Variance, 2. Mean-Semivariance, 3. Mean-Critical Probability, 4. Stochastic

DOI: 10.4018/978-1-4666-2098-8.ch012

Dominance, 5. Almost Stochastic Dominance, and 6. Mean-Gini. They showed the strength and limitations of each technique, and the relationships between the various methodologies. On the other hand, one would prefer a portfolio return with larger degree of asymmetry when the mean and variance are same. A concept of skewness is introduced by Li et al. (2010) to measure the asymmetry of fuzzy portfolio return. The squared coefficient of variation $[CV]^2 (= \frac{variance}{(mean)^2})$ is used to characterize the variability of a distribution see, e.g., (Nuyens & Wierman, 2008). Distributions with $CV^2 > 1$ are said to have high variability and distributions with $CV^2 < 1$ are said to have low variability.

Most of the above literature discussed and compared measures of risk in portfolio decision making. In this paper, we propose a measure that assists in comparing variances, hence variability. This measure of risk is used to rank many proposed distribution functions and applying it in project management. Besides, it can be applied in portfolio decision making when different distributions are used. The concept of skewness as well as the squared coefficient of variation are also considered. An application to stochastic activity networks (SANs) is given to illustrate the effectiveness of the proposed measure.

Many probability distributions are discussed in literature as representative of a project activity times. To the best of our knowledge, all suggested distributions fall in the class of 'New Better than Used in Expectation (NBUE)' distributions. For the sake of self-containment we state the distributions that are most frequently discussed in treatises on stochastic activity networks, their mean (denoted by $E(.)$ or μ), variance (denoted by $Var(.)$ or σ^2) and skewness (denoted by $\gamma_1 = \frac{\mu_3}{\sigma^3}$, where μ_3 is the third central moment and σ is the standard deviation).

- The Generalized Beta distribution with probability density function

$$f(x) = \frac{1}{(b-a)^{k_1+k_2-1} B(k_1, k_2)} (x-a)^{k_1-1} (b-x)^{k_2-1},$$

$$a \le x \le b, \tag{1}$$

where $B(k_1, k_2)$ is the complete Beta function. $B(k_1, k_2) = \Gamma(k_1)\Gamma(k_2)/\Gamma(k_1 + k_2)$,and $\Gamma(k) = (k-1)!$ if k is a positive integer, and $\Gamma(k) = \int_0^\infty t^{k-1} e^{-t} dt$ if $k \ge 0$. The mean, the variance and skewness are given by

$$E(X) = a + (b-a)\frac{k_1}{k_1 + k_2},$$
$$Var(X) = (b-a)^2 \frac{k_1 k_2}{(k_1+k_2)^2 (k_1+k_2+1)},$$
$$\gamma_1 = \frac{2(k_2 - k_1)\sqrt{(1 + k_1 + k_2)}}{\sqrt{(k_1 k_2)}(2 + k_1 + k_2)}. \tag{2}$$

The beta distribution with $k_1 = 2$ and $k_2 = 3$ is discussed by Golenko (1989).

- The Beta-PERT distribution, so designated because it was the distribution initially proposed by Malcolm et al. (1959) in their seminal paper on PERT (Program Evaluation and Review Technique). The proposed mean and variance of activity time distribution are given by

$$E(X) = \frac{a + 4m + b}{6}$$
$$and \tag{3}$$
$$Var(X) = (\frac{b-a}{6})^2,$$

where a, m, and b are; respectively, the 'optimistic', 'most likely' and 'pessimistic' times of the activity. Equation 3 holds when $k_1 = k_2 = 4$, or $k_1 = 3 + \sqrt{2}$ and $k_2 = 3 - \sqrt{2}$, or $k_1 = 3 - \sqrt{2}$ and $k_2 = 3 + \sqrt{2}$ in 2 above. The latter two special cases satisfy $k_1 + k_2 = 6$, see (Elmaghraby, 1977, p236). The skewness will be $0, \frac{-1}{\sqrt{2}}$ and $\frac{1}{\sqrt{2}}$ in the above three cases respectively.

- The Uniform distribution, defined on the range $x \in [a, b]$ is discussed by Kleindorfer (1971), with probability density function

$$f(x) = \frac{1}{b-a}, \qquad a \le x \le b,$$

with mean, variance and skewness are given by

$$E(X) = \frac{a+b}{2},$$
$$Var(X) = \frac{(b-a)^2}{12} \quad and \tag{4}$$
$$\gamma_1 = 0.$$

- The Triangular distribution discussed by Williams (1992) and Johson (1997), with probability density function

$$f(x) = \begin{cases} \frac{2(x-a)}{(m-a)(b-a)}, & a \le x \le m \\ \frac{2(b-x)}{(b-a)(b-m)}, & m < x \le b \end{cases}$$

where the range of the random variable (r.v.) is defined on the interval $[a, b]$, $m \in [a, b]$ and m stands for the mode. The mean, variance and skewness are given by

$$E(X) = \frac{a+m+b}{3},$$
$$Var(X) = \frac{1}{18}(a^2 + b^2 + m^2 - ab - am - bm)$$
$$and$$
$$\gamma_1 = \frac{\sqrt{2}(a+b-2m)(2a-b-m)(a-2b+m)}{5(a^2+b^2+m^2-ab-am-bm)} \tag{5}$$

- The exponential distribution with parameter λ is discussed by many authors (Kambrowski, 1985 and Kulkarni & Adlakha, 1986) with probability density function

$$f(x) = \lambda e^{-\lambda x}, \qquad x \ge 0, \quad \lambda > 0,$$

with mean, variance and skewness are given by

$$E(X) = \frac{1}{\lambda},$$
$$Var(X) = \frac{1}{\lambda^2} \quad and \tag{6}$$
$$\gamma_1 = 2.$$

- The Erlang distribution, discussed by Bendell et al. (1995) and their work is generalized by Abdelkader (2003) with probability density function

$$f(x) = \frac{\lambda^k}{\Gamma(k)} e^{-\lambda x} x^{k-1}, \qquad x \ge 0, \qquad k > 0. \tag{7}$$

The mean, variance and skewness are given by

$$E(X) = \frac{k}{\lambda},$$
$$Var(X) = \frac{k}{\lambda^2} \quad and \tag{8}$$
$$\gamma_1 = \frac{2}{\sqrt{k}}.$$

The remainder of this paper is organized as follows. The main definitions and preliminaries are given in Section 2. Section 3 presents a measures of variability to rank the suggested distribution functions. Besides two other measures which can be used in some special applications. Section 4 is devoted to introduce an application to stochastic activity networks. Finally, concluding remarks are drawn in Section 5.

DEFINITIONS AND PRELIMINARIES

We begin by introducing some required definitions. The following definitions and proposition are due to Ross (1983).

Definition 1: A nonnegative r.v. X with finite mean μ and probability distribution function F is said to be NBUE (New Better than Used in Expectation) if, for all $x > 0$

$$\int_x^\infty \frac{\overline{F}(y)}{\overline{F}(x)}\,dy \le \mu,$$

where $\overline{F}(x) = 1 - F(x) > 0$.

A random variable is said to be NBUE if its distribution function has that property

Definition 2: If X and Y are non-negative r.v.'s such that $E(X) = E(Y)$, then the r.v. X is said to be more variable than Y, written $X \ge_v Y$, if and only if $E[h(X)] \ge E[h(Y)]$ for all increasing and convex functions h.

Definition 3: If the r.v.'s X and Y have the distributions F and G, respectively, then X is stochastically larger than Y, written $X \ge_{st} Y$, if

$$\overline{F}(a) \ge \overline{G}(a), \text{ for all } a$$

where $\overline{G}(x) = 1 - G(x)$.

Proposition 1: If $F(x)$ is an NBUE distribution having mean μ, then

$$F \le_v \exp(\mu),$$

where $\exp(\mu)$ is the exponential distribution with mean μ.

The above proposition states that the exponential distribution has maximal variability in the class of NBUE distributions.

The following Theorem is introduced by Li (2002).

Theorem 1: Suppose X is NBUE with finite mean μ, then for all $k = 1, 2, \ldots$

$$\begin{aligned}&(i)\ E(X^k) \le k\mu\ E(X^{k-1}),\\ &(ii)\ E(X^k) \le k!\,\mu^k.\end{aligned} \tag{9}$$

MAIN RESULTS

In this section we introduce the proposed measure in Proposition 2 and its properties are summarized in corollaries 1 and 2. The variability relationships among the proposed distribution are introduced in Theorems 2 and 3. Two alternative measures of variability are also discussed.

Proposition: For any NBUE probability distribution function $F(x)$ with $E(X) = \mu$ and $Var(X) = \sigma^2$, then

$$\Delta(F) \triangleq \mu^2 - \sigma^2 \ge 0 \tag{10}$$

where $\triangleq$ stands for the definition of $\Delta(F)$.

Proof: Set $k = 2$ in part (ii) of Theorem 1, to get

$$E(X^2) \le 2\mu^2 \tag{11}$$

which is equivalent to

$$\nabla(F) = \mu^2 - (E(X^2) - \mu^2) \ge 0. \tag{12}$$

This completes the proof.

Corollary 1: A nonnegative r.v. X has a maximal variability in the class of NBUE if $\nabla(F) = 0$.

This result follows from the fact that the exponential distribution has its $\mu^2 = \sigma^2$. It also immediately follows that for all other distributions in the class NBUE $\nabla(F) > 0$.

Corollary 2: The most variability occurs when the value of $\nabla(F) = 0$, and for all the class of NBUE the value of $\nabla(F) > 0$.

The following Theorems summarize the variability relationships among the following distributions: the exponential, Erlang, Uniform, Triangular, Beta and Beta(PERT). We denote the random variables corresponding to the above distributions respectively by $X_{\exp}, X_E, X_U, X_T, X_{Beta}$ and X_{PERT}.

Theorem 2: If all the distributions stated above are symmetric about their means, then

$$Var(X_U) \geq Var(X_T) \geq Var(X_{Beta(3,3)}) \geq Var(X_{PERT}). \tag{13}$$

Proof: Under the assumption that all distributions are symmetric about their mean implies the four distributions have the same mean. This, in turn, implies that for the Triangular and PERT the mode $m = (a+b)/2$, and that for the Beta we must have $k_1 = k_2 = 3$ or 4. It is sufficient to show, by Corollaries 1 and 2, that the variances of the corresponding r.v.'s bear the same inequalities to each other. It is easy to demonstrate that since all means $= (a+b)/2$, by substitution in (2)-(5),

$$\begin{aligned} Var(X_U) &= \frac{(a-b)^2}{12}, \\ Var(X_T) &= \frac{(a-b)^2}{24}, \\ Var(X_{Beta(3,3)}) &= \frac{(a-b)^2}{28}, \\ Var(X_{Beta(4,4)}) = Var(X_{PERT}) &= \frac{(a-b)^2}{36}, \end{aligned} \tag{14}$$

and the ranking of (13) is validated.

For other values of k_1 and k_2, we discuss the following two cases:

For $k_1 = k_2 = 2$ or 1, the inequality (13) changes to

$$Var(X_U) \geq Var(X_{Beta}) \geq Var(X_T) \geq Var(X_{PERT}).$$

For $k_1 = k_2 = 5$, the inequality (13) changes to

$$Var(X_U) \geq Var(X_T) \geq Var(X_{PERT}) \geq Var(X_{Beta}),$$

and hence the proof.

Remark 1: According to the notation of Proposition 2, we can rewrite the statement of Theorem 2 as

$$\Delta(F_U) \geq \Delta(F_T) \geq \Delta(F_{Beta}) \geq \Delta(F_{PERT}),$$

where

$$\begin{aligned} \Delta(F_U) &= \mu^2 - Var(X_U), \\ \Delta(F_T) &= \mu^2 - Var(X_T), \\ \Delta(F_{Beta}) &= \mu^2 - Var(X_{Beta}), \end{aligned}$$

and

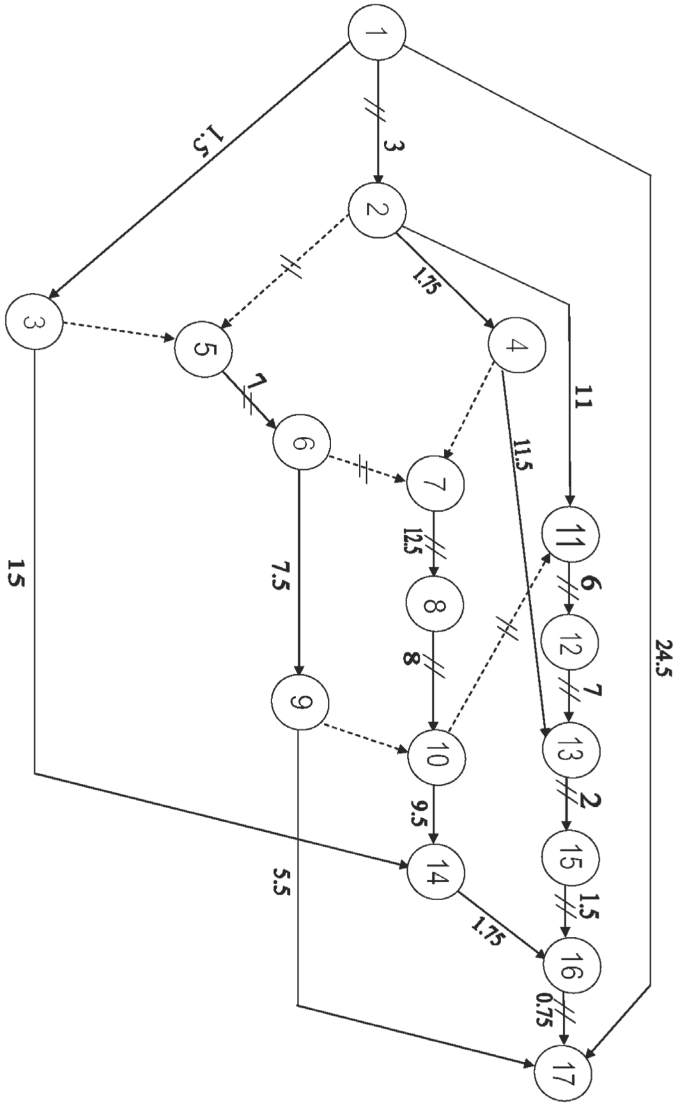
$$\Delta(F_{PERT}) = \mu^2 - Var(X_{PERT}).$$

The following Theorem will be discussed, under the same assumption of Theorem 2, for the Erlang distribution when $k = 2, 3, 4$ and 5. We exclude $k = 1$, since the Erlang distribution in this case is reduced to the exponential distribution.

Theorem3: If $E(X_U) = E(X_E) = E(X_T) = \mu$,

$$Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq Var(X_T). \tag{15}$$

Figure 1. The mean of each activity is indicated on each arc and the critical path is shown in the network



Proof: According to the Proposition 1 and Corollary 1 the exponential distribution has a maximal variability in the class of NBUE distributions; hence the inequality $' \leq '$ is true for any other distributions. This establishes the left-most inequality. Let

$$\begin{aligned} &\Delta(F_U) = \mu^2 - Var(U), \\ &\Delta(F_E) = \mu^2 - Var(E) \quad and \\ &\Delta(F_T) = \mu^2 - Var(X_T), \end{aligned} \tag{16}$$

be the measures of variability of the Uniform, Erlang and Triangular distributions; respectively. As indicated in the proof of Theorem 2, equality of the means implies that the mode m of the Triangular distribution is exactly mid-way between a and b, i.e., $m = (a+b)/2$. To prove the theorem it is required to show that

$$\Delta(F_E) \leq \Delta(F_U) \leq \Delta(F_T), \tag{17}$$

where

$$\Delta(F_U) = \frac{(a+b)^2}{4} - \frac{(b-a)^2}{12}, \tag{18}$$

$$\Delta(F_E) = \frac{k^2}{\lambda^2} - \frac{1}{k}\frac{k^2}{\lambda^2} = \frac{(a+b)^2}{4} - \frac{(a+b)^2}{4k}, \tag{19}$$

$$\Delta(F_T) = \frac{(a+b)^2}{4} - \frac{(b-a)^2}{24}. \tag{20}$$

It is easy to see that the inequality (17) is hold when $k = 2$ and 3.

For $k = 4$, the inequality (17) is true when

$$\begin{aligned} &ab \geq \frac{(b-a)^2}{12} \quad or \\ &ab \geq Var(X_U) \quad and \\ &a, b > 0 \end{aligned} \tag{21}$$

For $k = 5$, the inequality (17) is true when

$$\begin{aligned} &ab \geq 2\frac{(b-a)^2}{12} \quad or \\ &ab \geq 2Var(X_U) \quad and \\ &a, b > 0 \end{aligned} \tag{22}$$

The proof is completed.

Corollary 3: The above two Theorems showed that

For $k_1 = k_2 = 2$

$$\begin{aligned} &Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq \\ &Var(X_{Beta(2,2)}) \geq Var(X_T) \geq Var(X_{PERT}). \end{aligned}$$

For $k_1 = k_2 = 3$

$$\begin{aligned} &Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq \\ &Var(X_T) \geq Var(X_{Beta(3,3)}) \geq Var(X_{PERT}). \end{aligned} \tag{23}$$

For $k_1 = k_2 = 5$

$$\begin{aligned} &Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq \\ &Var(X_T) \geq Var(X_{PERT}) \geq Var(X_{Beta(5,5)}). \end{aligned}$$

Remark 2: Haha (2008) showed that the uniform distribution has more variability and the above Theorems showed that the variability of the uniform distribution is less than the exponential and Erlang distributions.

ALTERNATIVE MEASURES OF VARIABILITY

Besides the measures mentioned in Graves and Ringuest (2009), another two measures are also proposed for comparing between distributions.

The First Measure

The following Lemma and the consequence Proposition are due to Ross (1983).

Lemma 1: Let F and G be continuous distribution functions. If X has distribution F, then the r.v. $G^{-1}(F(X))$ has distribution G.

Proposition 3: Let F and G are distributions such that $\bar{F}(a) \geq \bar{G}(a)$, then there exist r.v.'s X and Y having distributions F and G respectively such that

$$P(X \leq Y) = 1.$$

This means that, if $X \geq_{st} Y$, then there exist r.v.'s X_1 and Y_1 having the same distributions of X and Y such that X_1 is at least as larger as Y_1 with probability one.

The Second Measure

This measure is due to Mood et al. (1974) page 74, which characterizes the distribution by the variance.

Suppose that $f_1(x)$ and $f_2(x)$ are two probability density functions with the same mean μ such that

$$\int_{\mu-c}^{\mu+c} (f_1(x) - f_2(x))dx \geq 0, \tag{24}$$

for every value of c, then

$$\sigma_1^2 < \sigma_2^2,$$

which means that, the variance σ_1^2 in the first density is smaller than the variance σ_2^2 in the second density. The converse of inequality (24) is not true. That is, if $\sigma_1^2 < \sigma_2^2$, we cannot conclude that the corresponding densities satisfy the inequality (24) for all values of c.

APPLICATION IN SANs

This section introduces an application to stochastic activity networks by applying Theorems 2 and 3. The following worked example demonstrates the comparison between the variances of the proposed distribution which are discussed in the paper.

Example: The network in Figure1 is taken from Elmaghraby (1977 p 314). The activity times and tasks description of ship-boiler repair are shown in Table 1. The three durations attached to each activity are the optimistic "a", most likely "m", and pessimistic "b" estimates, obtained by asking the experts. We modified the most likely time to be $(=\frac{a+b}{2})$ to agree with the equality of the means for all distributions. The mean project completion time for all distributions is equal to 47.75. Table 2 shows the squared coefficient of variation (SCV) of each critical activity. The SCV for the exponential distribution is equal to 1 and the SCV for Erlang distribution when k=2,3,4and 5 are 0.5, 0.333, .025and .02, respectively. Table 3 summarizes the variances, skewness and the sum squared coefficient of variation (SSCV) obtained from the proposed distributions. The SSCV for the exponential distribution is equal to 9 and for the Erlang distribution when k=2,3,4and 5are equal to 4.5,3,2.25 and 2, respectively.

Remark 3: In Table 2, we note that the SCV for the activities 15 and 18 are greater than the SCV of Erlang distribution when $k = 4$ and 5. The reason for that is both activities violate the Equations 21 and 22, that is, $a > 0$.

Remark 4: From Table 3 we note that

$$\begin{aligned} &Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq \\ &Var(X_T) \geq Var(X_{Beta(3,3)}) \geq Var(X_{PERT}), \end{aligned} \tag{25}$$

$$\begin{aligned} &Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq \\ &Var(X_{Beta(2,2)}) \geq Var(X_T) \geq Var(X_{PERT}), \end{aligned} \tag{26}$$

Table 1. Activity times and description

Activity	Describtion	Predecessor	Duration
1	Initial Hydrostatic Test	-	1,3,5
2	Remove air registers	-	0,1.5,3
3	Repair under boiler	-	14,24.5,35
4	Remove drum internals	1	0.5,1.75,3
5	Rag for chemical cleaning	1	5,11,17
6	Clean and repair air register assemblies	2	10,15,20
7	Repair drum internals	4	5,11.5,18
8	Remove refractory material	1, 2	4,7,10
9	Repair inner air casing	8	1,7.5,14
10	Exploratory block	4,8	7,12.5,18
11	Retube and poll	10	4,8,12
12	Repair outer air casing	9	1,5.5,10
13	Rebrick	9,11	5,9.5,14
14	Chemically clean	5,11	4,6,8
15	Preliminary hydrostatic test	14	0,7,14
16	Install drum internals	7, 15	1,2,3
17	Install air registers	6,13	0.5,1.75,3
18	Final hydrostatic tests	16	0,1.5,3
19	Install plastic refractory	17, 18	0.5,0.75,1

Table 2. The squared coefficient of variation of the critical activities for the proposed distributions

CA	U	B(2,2)	T	B(3,3)	B(4,4)	B(5,5)
1	0.148	0.088	0.074	0.063	0.049	0.040
8	0.061	0.036	0.030	0.026	0.020	0.016
10	0.064	0.038	0.032	0.027	0.021	0.017
11	0.083	0.050	0.041	0.035	0.027	0.022
14	0.037	0.022	0.018	0.015	0.012	0.010
15	0.333	0.200	0.166	0.142	0.111	0.090
16	0.083	0.050	0.041	0.035	0.027	0.022
18	0.333	0.200	0.166	0.142	0.111	0.090
19	0.037	0.022	0.018	0.015	0.012	0.010

where, CA denotes to the Critical Activity, U denotes to the Uniform distribution, T denotes to the Triangular distribution and B(.,.) denotes to the Beta distribution for different values.

$$Var(X_{\exp}) \geq Var(X_E) \geq Var(X_U) \geq Var(X_T) \geq Var(X_{PERT}) \geq Var(X_{Beta(5,5)}). \tag{27}$$

Remark 5: The coefficient of skewness which is shown in Table 3 ranking the exponential and Erlang distributions for different values of *k*. The zero skewness for the other distributions came from the symmetry assumption of those distributions.

In making decisions about which project to include in a real industrial cases, one should evaluate the risk. Many R&D and IT projects fail in either the marketing stage or the implementation stage. The results of this paper including the above example provide an authoritative source to engineers or managers who need to choose the appropriate distribution for evaluating risk in their decision making. In all distributions discussed in this paper we compute the variance, the skewness and the squared coefficient of variation. Based on these measures the engineers or managers would select an appropriate portfolio.

Table 3. The variance, skewness, and SSCV of proposed distributions

Distribution	Variance	Skewness	SSCV
Exponential	370.0625	2	9
Erlang(k=2)	185.03	1.414	4.5
Erlang(k=3)	123.35	1.155	3
Erlang(k=4)	92.515	1	2.25
Erlang(k=5)	74.013	0.8944	1.8
Uniform=Beta(1,1)	38.519	0	1.179
Beta(2, 2)	23.113	0	0.706
Triangular	19.262	0	0.586
Beta(3,3)	16.508	0	0.5
PERT=Beta(4,4)	12.839	0	0.393
Beta(5,5)	10.505	0	0.317

CONCLUSION

In this paper, a simple measure is used to rank the distribution functions. The proposed distributions which are discussed are: the exponential, Erlang, Uniform, Triangular, Beta and Beta(PERT) distribution with different values of k_1 and k_2. All suggested distributions fall in the class of NBUE distributions and considered to be symmetric about their mean. The ranking of the distributions are discussed in Theorems 2 and 3. Corollary 3 summarizes the final results. Two alternative measures are stated for comparing the variability between the distributions. The second measure may be used when the graphical representation is considered. The condition, $\sigma_1^2 < \sigma_2^2$, in the third measure is only evident that $f_1(x)$ has more area near the mean than $f_2(x)$, at least for certain intervals about the mean. Finally, an application to stochastic activity networks is introduced. The example network which is shown in the application verified the results of Theorems 1 and 2. On the other hand, in portfolio selection theory (see, e.g. Markowitz, 1952 1959) we can consider the portfolio return as a constant for all proposed distributions and the risk is varying. The issue that may require further investigation is the development of a measure do not restrict the assumption that the distributions are symmetric about the mean. Also, more distributions may be included for future research.

ACKNOWLEDGMENT

The author would like to thank Prof. Salah E. Elmaghraby from North Carolina State University, USA for his remarks that improved the paper.

REFERENCES

Abdelkader, Y. H. (2003). Erlang distributed activity times in stochastic activity networks. *Kybernetika*, *39*(3), 347–358.

Bendell, A., Solomon, D., & Carter, J. M. (1995). Evaluating project completion times when activity times are Erlang distribution. *The Journal of the Operational Research Society*, *46*, 867–882.

Duffie, D., & Pan, J. (1997). An overview of value at risk. *Journal of Derivatives*, *4*(3), 7–49. doi:10.3905/jod.1997.407971

Durbach, I. N., & Stewart, T. J. (2009). Using the expected values to simplify decision making under uncertainty. *Omega*, *37*, 312–330. doi:10.1016/j.omega.2007.02.001

Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. New York, NY: Wiley.

Elmaghraby, S. E. (2005). On the fallacy of averages in project risk management. *European Journal of Operational Research*, *165*, 307–313. doi:10.1016/j.ejor.2004.04.003

Golenko (Ginzburg), D. I. (1989). A new approach to the activity-time distribution in PERT. *The Journal of the Operational Research Society*, *40*, 389–393.

Graves, S. B., & Ringuest, J. L. (2009). Probabilistic dominance criteria for comparing uncertain alternatives: A tutorial. *Omega*, *37*, 346–357. doi:10.1016/j.omega.2007.03.001

Hahn, E. D. (2008). Mixture densities for project management activity times: A robust approach to PERT. *European Journal of Operational Research*, *188*, 450–459. doi:10.1016/j.ejor.2007.04.032

Johnson, D. (1997). The triangular distribution as a proxy for beta distribution in risk analysis. *The Statistician*, *46*(3), 387–398. doi:10.1111/1467-9884.00091

Kamburowski, J. (1985). An upper bound on the expected completion time of PERT networks. *European Journal of Operational Research*, *21*, 206–212. doi:10.1016/0377-2217(85)90032-3

Kijima, M., & Ohnishi, M. (1993). Mean-risk analysis of risk aversion and wealth effects on optimal portfolios with multiple investment opportunities. *Annals of Operations Research*, *45*, 147–163. doi:10.1007/BF02282046

Kleindorfer, G. B. (1971). Bounding distributions for a stochastic acyclic network. *Operations Research*, *19*(7), 1586–1601. doi:10.1287/opre.19.7.1586

Konno, H., & Yamazaki, H. (1991). A mean-absolute deviation portfolio optimization model and its application to Tokyo stock market. *Management Science*, *37*, 519–531. doi:10.1287/mnsc.37.5.519

Kulkarni, V. G., & Adlakha, V. G. (1986). Markov and Markov regenerative PERT networks. *Operations Research*, *34*(5), 769–781. doi:10.1287/opre.34.5.769

Leshno, M., & Levy, H. (2002). Preferred by 'all' and preferred by 'most' decision makers: Almost stochastic dominance. *Management Science*, *48*(8), 1074–1085. doi:10.1287/mnsc.48.8.1074.169

Levy, H. (1998). *Stochastic dominance: Investment decision making under uncertainty*. Boston, MA: Kluwer.

Li, X. (2002). A new interpretation of NBUE property of life distribution with some applications. *Chinese Journal of Applied Probability and Statistics*, *16*(1), 67–72.

Li, X., Qin, Z., & Kar, S. (2010). Mean-variance-skewness model for portfolio selection with fuzzy returns. *European Journal of Operational Research*, *202*, 239–247. doi:10.1016/j.ejor.2009.05.003

Liu, B., & Liu, Y. K. (2002). Expected value of fuzzy variable and fuzzy expected value models. *IEEE Transactions on Fuzzy Systems*, *10*(4), 445–450. doi:10.1109/TFUZZ.2002.800692

Malcolm, D. G., Roseeboom, J. H., Clark, C. E., & Fazar, W. (1959). Application of technique for research and development program evaluation. *Operations Research*, *7*, 646–669. doi:10.1287/opre.7.5.646

Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, *7*, 77–91.

Markowitz, H. (1959). *Portfolio selection: Efficient diversification of investments*. New York, NY: Wiley.

Mood, A. M., Graybill, F. A., & Boes, D. C. (1974). *Introduction to the theory of statistics*. London, UK: McGraw-Hill.

Neiger, D., Rotaru, K., & Churilvo, L. (2009). Supply chain risk identification with value-focused process engineering. *Journal of Operations Management*, *27*, 154–168. doi:10.1016/j.jom.2007.11.003

Nuyens, M., & Wierman, A. (2008). The foreground-background queue: A survey. *Performance Evaluation*, *65*, 286–307. doi:10.1016/j.peva.2007.06.028

Ringuest, J. L., Graves, S. B., & Case, R. H. (2000). Conditional stochastic dominance in R&D portfolio selection. *IEEE Transactions on Engineering Management*, *74*(4), 478–484. doi:10.1109/17.895342

Ross, S. M. (1983). *Stochastic process*. New York, NY: John Wiley & Sons.

Shalit, H., & Yitzhaki, S. (1989). Evaluating the mean Gini approach to portfolio selection. *The International Journal of Finance*, *1*(2), 15–31.

Tang, C. S. (2006). Perspective in supply chain risk management. *International Journal of Production Economics*, *103*(2), 451–488. doi:10.1016/j.ijpe.2005.12.006

Wang, J., & Hwang, W. L. (2007). A fuzzy set approach for R&D portfolio selection using real options valuation model. *Omega*, *35*(3), 247–257. doi:10.1016/j.omega.2005.06.002

Williams, T. W. (1992). Practical use of distributions in network analysis. *The Journal of the Operational Research Society*, *43*, 265–270.

Yitzhaki, S. (1982). Stochastic dominance and Gini's mean difference. *The American Economic Review*, *72*(1), 178–185.

Chapter 13
A Conceptual "Cybernetic" Methodology for Organizing and Managing the E-Learning Process through [D-] CIVEs:
The Case of "Second Life"

Pellas Nikolaos
University of the Aegean, Greece

ABSTRACT

This chapter presents a conceptual-pedagogical "cybernetic" methodology for cyber entities' (avatars') spatial awareness, in an innovative way by using Second Life (SL). According to this section, it's crucial to answer the major question of how teachers can permit effective actions through the organizational complexity of virtual and technical interactions that SL governs, making it more practical for Higher Education. Additionally, the chapter's objective emphasizes the creation of an organizational-educational (multi-) method, which is essential for effective planning and conducting in distance learning programs. Furthermore, the construction effort is based on Anthony Stafford Beer's "Viable System Model" (VSM) principal characteristics, in which the chapter contends the pedagogical analysis of teaching and didactic process that should be supported by any "open," "viable," and "sustainable" virtual learning environment. The systematic description and classification of groups' interaction scripts aim is to help facilitating and enhancing teams' knowledge management by providing reusable patterns that leverage the ample possibilities.

DOI: 10.4018/978-1-4666-2098-8.ch013

INTRODUCTION

Modern virtual worlds combine elements of social networking and 3D computer games. We must also remember that from the mid 1990's, gaming consoles like Nintendo, Sega and Sony, have a small connection to the Internet. As a result of this "gaming revolution" from the recent generation of consoles (see Play station 2, Microsoft Xbox) were followed the un-structured way that allows users to have more freedom of options and movements, as was the *Grand Theft Auto*, games as well as typed as "god game" (Au, 2001), such as "*The Sims online"*. Later of course came forefront, the MMORPGs (Massively multiplayer online role-playing games), such as World of Warcraft (WoW) and Everquest, in which users have specific tasks to be completed in order to take over world leaders and gain their avatars and not really the same, superhuman skills and abilities.

According to Schroeder (2008), these types of virtual worlds consider as "persistence", which continue to exist and to operate even after the departure of the user, in which people feel that they are there with others and can to interact with them. The element of continuity is explicitly mentioned in the mode structure (tools and system requirements) and second the existence of cyber entities (online & offline users) of cyberspace. Even when someone decides to leave, the virtual environment will continue to exist, yet overwhelming the guest's/user's computer shut down, the temporal flow of things, and data changes do not stop. When the user gets back, he can see the changes in both the active site and changes to other people. The presence of the users that are not needed for the development and operation of the virtual space, but each user's personal contribution is extremely important for the perpetuation. We should not forget that a virtual world includes, among two others, an ever-changing economy and growing community, which in essence, is something that can be described as a *"cyber-ecosystem "*. There are developed and enhanced to the greatest extent as possible as they can humans' interactions at a distance through virtual representatives, communication between themselves and the public environment of action. Most new users ("newbies"), felt the need to create virtual communities through which they will meet each other, they will exchange views and even implement joint programs. The 3D-graphic anthropomorphic figure of a user enables to actively control the dynamic interaction of users via keyboard and mouse. The difference from those who support the 1st personally dimension of virtual reality, is listed in online social spaces with spatial and temporal continuity, regardless of the party that it is and whether or not the user was there. The form of social interaction is now a continuation of social networks and blogs in cyberspace which is really differentiated and distinguishes them from MMORPGs. Their "philosophy" is to reach users a specific goal and to strengthen gradually and successfully passed the difficult situations, which they are found on the road to glory and this is really their absolute pleasure.

A simple virtual environment (VE), is a computer system that produces a three dimensional virtual environment for users, in which interacts and receives real-time feedback. If multiple users are connected and interact with one another, then the above definition is extended to a multi-user or shared VE. A collaborative system of the virtual world (CVE: Collaborative Virtual Environment), aiming at a cooperative target, can produce a well-designed virtual reality (VR) world, with additional educational tasks, such as synchronous and asynchronous communication, experience and deepening the "collective" presence of distributed users. Within this context, the developments of virtual environments, which we are presented, unveil the [D-] CIVEs ([Distributed-] Collaborative Immersive Virtual Environments). A [D-] CIVE is a whole virtual world or separated virtual worlds, supported by an educational function. Users are represented by avatars that populate a CVE and can be provided with additional behaviors such as gestures, interactions, movements and sounds. Each [D-] CIVE must be complying with a set of requirements to be widely used. Users are offered a high-level of presence through their representation of an image of their choice, which simulates some basic realistic effects, such as gestures and movements, which give them a shared sense of space, presence and time. Users are also able to navigate in a shared three-dimensional space, in order to approach the content provided, to examine their knowledge, to interact with each other, to practice their skills and obtain information provided. Furthermore, users are informed of the presence of others (avatars), arrival and departure.

The outline intention of this research elaborates the structural components of [D-] CIVEs, which are similar with Second's Life (SL) qualitative-structural characteristics. There are many reasons for choosing SL in Education, but we differentiate two of them:

1. Firstly, because previous studies have shown and demonstrated that this immersive spatial "world" was very useful for constructing more effective applications in Higher education.
2. Secondly, because it enhances sharing and integration of knowledge. Instead, we really agree and further believe that the use of SL can upgrade current knowledge management even more substantial and in situations go beyond visualizing data or reviewing spatial models in visual activities, like architecture and design.

According to this case, our paper presents the initiative benefits and affords from SL's enrichment characteristics and focus on constructing a "teaching-organizational" method, which is essential for planning and conducting effective distance learning courses. This gain will be supported through to a "cybernetic model," which can be adapted successfully by any "open" and "sustainable" education system. Particularly helpful for the present study, is the value-added of this framework, which can give a common basis for able reach to the potential educational value of other virtual worlds, with emphasis on integrating innovative teaching methods.

SECOND LIFE

Second Life (SL), is a 3D virtual world website, available to the public since 2003. The company is responsible for its creation, based in San Francisco led by Phillip Roselade, employ more than 300 labors from around the world. It is a "persistence" 3D virtual world with flexible construction tools and programming objects, with the easy to use programming language LSL (Linden Scripting Language), 3D voice chat, images, supporting for multiple languages, switching weather conditions day or night, depending on the personal desire of each resident (residents). Thus have the opportunity to register for free to experiment or create imagined to have a minimal cost. There are few, and those who see that although the SL looks like The Sims online, and track that was what brought the people acquainted with the operation of avatars, and some of the functions are almost identical (e.g. text, speech).

With the help of a web browser, which is simulated a 3D visual word in front of users' PCs they can create personal cyber entities, which are able to navigate, walk, teleport and communicate with others via voice or text. Access to essential services, of course, are the constructions of objects by using "prims" (or "primitives") that component of 3D complex structures or purchase a virtual land, requiring the payment of a minimum amount.

REVIEW OF THE LITERATURE

A crucial idiosyncratic reason for the success of Second Life (SL), was the emergence of Web 2.0 and the consequent movement of "social networking" (Brown & Green, 2009). Creating blogs by users, gives a new impetus to the spread of *"virtual reality three-dimensional network,"* in environments, like SL, favoring the formation of educational and non-community (Gajenda et al., 2010; Thomas & Brown, 2008).

From 2006 onwards, Second Life, gradually began to be used for educational purposes (Liu, 2006) and the use of technical features and functions it offers, now could be included in the category of [D-] CIVEs (Caetano et al., 2009; Braun et al., 2009; Mumme et al., 2008; Mansour & Mostafa, 2008). Indeed in recent years has been rebuilt and used as a "hybrid" learning environment, universities, colleges, libraries and international non-governmental organizations (Baker et al., 2009; Jennings & Collins, 2008), even under the assistance of the same Second Life's construction company, the Linden Lab (Kay & FitzGerald, 2008).

According to Jarmon et al. (2009), there is a growing demand for empirical research studies related to learning design and teaching practices in three-dimensional virtual worlds. This section presents contemporary research conducted in collaborative learning through the platform Second Life. Based on this research, we will describe how the characteristics of the Second Life support collaborative learning and present suggestions in any way could the platform be strengthened further to support meaningful learning. A multitude of platforms studied to determine the best design proficiency for online learning, through the validation of characteristics, philosophy and policies in relation to some basic design principles for virtual collaborative learning environments. Based on the evaluation results of previous studies; as a conclusive result we truly understand that SL as an educational platform can increase the educational value of learning and the potential benefits might be increased. The choice of this platform is justified by the majority of literature (Bignell & Parson, 2010; Ma et al., 2010; Dunn, 2010; Walker & Rockinson-Szapkiw, 2009; Wankel & Kingsley, 2009; Brown et al., 2008; Hobbs et al., 2006; Childress & Braswell, 2006). For example, Jarmon et al. (2009), report that literature to date suggests that when educational activities in Second Life is well designed and integrated into the core course content, the use of Second Life can help experiential learning based on the work (project-based) and interdisciplinary communication. Furthermore, Second Life is the most popular virtual world Web-based, compared to the number of subscribers and exchange of money.

There are over 15.000.000 subscribers' users in the virtual world of Second Life, and over one million active users. Statistics from December 18, 2008, show that 1.500.000 people had entered in the previous period sixty days (Beard et al., 2009). Success, on the large number of users, these environments (Second Life, Active Worlds, World of Warcraft etc.) is not difficult to explain: the freedom that it gives to users to express themselves, to experiment, to format the appearance and to develop a kind of social life in the artificial environment is quite desirable elements (Herman et al., 2006). Specifically for Second Life, has been found by Vosinakis et al. (2011) that contributes to learning problems (Problem-based learning) as a pedagogical approach in multiple ways: supporting roles of teacher and pupil, supportive relationships encourage students, property operations and facilitate the evaluation activities.

Additionally, the SL is basically being adopted largely for academic, social and business purposes. More specifically, many educational institutions have begun to explore the possibilities of Second Life as an educational platform and other types of organizations already using it to support learning distance (Zaid et al., 2011; Macedo & Marcado, 2010; Wang & Hsu, 2009; Gazzard, 2009; De Lucia et al., 2009). Almost all references to educational activities in virtual environments multiple users (Multi-User Virtual Environments - MUVE) concerning Second Life. Major teaching and learning potential of the platform recognized by many educational institutions internationally and there is a variety of tasks (projects) which explore the educational possibilities (Salt et al., 2008). Areas of interest include astronomy, medicine, music, literature, biology, history, ecology, tourism and forensic sciences.

In previous research that was published by Boellstorf (2008), participants of focus groups, indicate that the study of a course aided by various support features of Second Life. The gap through the virtual and the physical world, and its effect on the ideas of personhood and relationships between avatars, is the one of the most interesting aspects of Boellstorf's analysis. For many residents, having a separate embodiment in cyberspace is liberating. The first step forward from this was the evidence of trans-gender people experimenting with a new lifestyle, before making final decisions for their real life. Affordances of the most commonly reported by students was that three-dimensional virtual environment of Second Life maintained its applications real world (transport) of the theories and strategies studied in a matter of course. Moreover, the investigation concluded that learning is enhanced by several of the affordances of Second Life in combined with an educational design that builds on the work (project-based). Other results reveal that the virtual environment supports the success of modern communication and social interaction (De Lucia et al., 2009). Also, the instructors reported that students were motivated and noticed that participants were less familiar with the use of environment seeking information from others or attending to understand that they should go or what to do.

Regarding the educational perspective of Second Life, the main responses were taking roles (role playing), the artistic expression and education activities based on simulations or scenarios. However, several international publications and several negative note characteristics of the platform Second Life. According to De Lucia et al. (2009) investigations', Second Life rated very low in terms of utility, ease of use and team's behavior in relation to the online email, video conferencing and MSN. The best score related to the entertainment team that it was perceived (Salt et al., 2008). More specifically it refers to a sharp learning curve and difficulty navigating in virtual conditions by users not familiar with three-dimensional computer games. It should be noted, however, that these problems are also reported by Monahan et al. (2008), in the evaluation of a different three-dimensional virtual environment. Other researchers remain "skeptical" about their educational horizons Second Life (Mason & Rennie, 2008). The main reasons are that:

1. Second Life, includes several adults' activities and educational areas.
2. It is difficult to guarantee that no one in avatar handles is the user.
3. Some educators believe that the virtual classroom cannot replace face-to-face learning, and as a result students take place in a real room.
4. Requires a relatively high level technical infrastructure for broadband access, network speed, graphic display capabilities and processing speed in individual machinery.
5. It does not have a smooth interface with other online products.

In conclusion, Second Life could be considered as one of the most functional platforms for distance learning through PCs and Web-based technologies for supporting [D] CSCL ([Distributed-] Computer Supported Collaborative Learning) scripts (Alvarez, 2006; Cross et al., 2007) and because users take advantage of the interactive multimedia features in an efficient and practical way (Anderson-Inman, et al., 2008; 2007).

But what it causes us particular impression and takes seriously the present work, is the fact that until now has never been known to any education community, a specific research that can include the modern demands of the organizational infrastructure and management of learners' interactions and the effective use of the proposed tools of the environment in which they operate. Of the approximately, from up to 60 "live" virtual worlds that we know, we chose SL for our research, on creating an organizational-teaching framework for, with a VSM's cybernetic approach. It is important to be observed, as well as we have seen from the relevant literature that we presented above, it would be the most interested world for users.

AN INNOVATIVE EDUCATIONAL [D-] CIVE: INITIATIVE BENEFITS AND AFFORDANCES

The virtual environment SL can configure and control unexpected situations that may be occurring in the real world. This helps students develop their ability to solve problems of high level, especially problems that are not well structured. They perform authentic tasks as real workers, to explore new places, meet people of different cultures, and use various tools to gather information and solve problems (Kemp & Haycock, 2008; Steed & Tromp, 1998). The common areas, which find application technologies of collaborative virtual learning environments, are:

- Creating online communities for the training of trainers.
- Giving a mean of multiple communication channels in distance education (synchronous or asynchronous).
- Learning through experimentation.
- Training adult learners' scripts.
- Involvement in scientific projects.
- Understand the story through the "dip" and "emotional" involvement.
- Promoting social and moral development.
- Providing an environment for planning and cooperation.
- Creating an exploratory research study of mathematical concepts.
- Engaging in scientific research and the quest for information.

Based on the above information, we identify the following research questions and the main evidences that:

- **Second Life is an auxiliary "medium" for collaborative applications***:* This seeks to explore the views of students on the effectiveness of this original technology and pedagogical approach, and their future expectations from it. Furthermore, it raises the interest of the pumping perception of students about the advantages, disadvantages and future improvements of each platform.
- **Cyber entities' representation can efficiency being evolved in cooperating groups:** The effectiveness of cooperative learning techniques must first of all be heavily based on face-to-face interaction. Therefore, to compensate for this, special attention has paid to strengthening the concept of team and users through the realization and affords transport on the avatars. These were evaluated in relation to cooperation, communication and learning.
- **The organizational structure of the educational framework can produce to learners many affordances that can be used to enhance the perception of the learning space:** The virtual representation of face to face interaction is enough to justify the use of virtual worlds. It is necessary to strengthen the traditional teaching to justify the extra time and cost that is required. Naturally, this question addresses to the tools and transportation that can be

used to improve this visual approach, and increase competitiveness that are compared with traditional techniques and remote collaborative learning.

The upgrading quality of "immersing experience" presented by the three-dimensional virtual world to a PC screen and the absolute connection of these can gives a new dimension in terms of key learning areas such as: (a) "Empirical," which includes reflection experience, knowledge and individual skills for problem-solving activities; (b) "Constructive," which illustrates from a student to conquer the processing of primary data sources and knowledge and finally (c) "Social," which develops a dialectical relationship between users, for shaping common framework for activity and learning, which will eventually lead to collective responsibility and co-construction of knowledge.

Our teaching strategy requires a "cybernetic model" which is related to a structured learning environment (Jackson, 2000; Beer, 1981). Primarily, this should be supported in managing the complexity of interactions among participants, which determines the role of everyone individual user and although which communication channels are available for use. This distinction very clearly indicates also on how effective the organizational interactions can be managing crucial circumstances in the environment (Britain & Liber, 1999; Liber, 1998). The construction of our model follows Stafford Beer "Viable System Model" (VSM) (Beer, 1972), which is a speculative model of the organizational structure of any "viable" or "autonomous" system. This participation would be structured *in such a way* as to allow separate *meetings* of *users* to take place in an "adaptable" changing environment, which has capable requirements that right owners want. VSM is a system that is alleged cybernetics description for applying to each body system and can provide autonomy (Beer, 1979).

Similarly, a key issue that must be explored by users who involved in the teaching-process vector (teacher and students) is the managing of "action groups" that is used for delivering courses. So at this point, if the purpose of education is to provide a more effective teaching method, compared with the traditional, reinforcing the provided quality of education, than advance called alone to examine or remove the methods, techniques and tools that will help him to accomplish his work rationally. Companions in this effort are adult learners who are directly involved to find the final pedagogical-added value of this virtual environment. Therefore, we can consider as an appropriate organizational structure teaching in a virtual world, providing an easier management of complex interactions and communication channels between members, keeping intact the specificity and behavior which, presumably that it was the same as the real.

SECOND LIFE'S NOVEL STRUCTURAL REQUIREMENTS FOR AN INNOVATIVE DEVELOPMENT PATH OF E-LEARNING

A distributed-collaborative immersive virtual learning environment is a standardized, computer-based environment that supports the delivery of web-based learning and facilitates the contemporary interaction between students and teachers while also providing asynchronous learning resources for use by individual students. [D-]CIVEs (like SL) are designed to facilitate communication between the teachings of those who participate in an educational process, whether for distance learning for education in the classroom or a combination of both. In planning to follow, was a mainstay in the table (Table 1) based on the characteristics of a virtual environment as defined by Dillenbourg (2002) and formed the basis for reflection on how to enrich the platform Second Life.

Table 1. Structural components of Second Life

Structural components of Second Life	Using for…
Information space designed with a clear orientation in different disciplines	(a) Intelligent storage and use information even after the completion of a multi-authoring tools. (b) Easy construction and sharing information files through other sources.
Virtual "place" or "space" of interactive communication (Conceptual framing)	Variety of "sustainable" interactions: (a) respect to time, means (b) sharing objects (indirect contact) (c) the number of participants (d) kind of interaction (e) sense of "coexistence" with other users (conversion into a social space)
Representing a variety of information environments	(a) A variety of tools for use, not only text (note-cards) but also chat text or IM. (b) Ability to create new information and acts on it. (c) Using 3D in an alternative and attractive way, enabling navigation or tele-transportation in a virtual space. (d) The main objective is the appropriate use of information and determines the structural relationship that develops in space. (e) Awareness of the space that students at any time want to be declared.
Meaningful student involvement in shaping the educational area	(a) Questionnaires or problem solving simulations. (b) Activities for the sharing of objects. (c) Students create information and spread their nets. (d) Teachers mete references.
Students' input inside and outside in the class	Support different forms of informal and formal e learning that combined with traditional education (types of blended learning).
Heterogeneous integration of innovative technological achievements	(a) Support administrative functions (e.g. records, statement of courses). (b) Provide all the functions provided by the natural world. (c) Include a variety of functions e.g. professor's hardware so as students' can e.g. Send e-mail with questions at the forum (where the system intelligently can accompany them with a history of movements, actions on this). (d) The main axis of self-learning and teaching from the teacher where necessary. (e) Creating personal spaces (rooms) and configuration option.
Support different pedagogical approaches	(a) Flexible teaching methods based on the principles of cooperativeness, adaptability, knowledge of building constructive and Problem-based Learning. (b) Uniform distribution of the course objectives in accordance with the classification of Bloom (1956). (c) Technical support different collaborative learning (Jigsaw, Brain flowing).
Supports natural characteristics of real world environment	Software tools should be: (a) Using virtual classroom objects (e.g. BBS for brainstorming and manuals for "newbies") (b) Learning materials: a) books (note cards) (c) Discussions in pupil groups through the different channels of communication (Chat, Call, IM)
Ergonomic design of a virtual space accessible from different categories of users	(a) Planners should take into account that the virtual space will be used by users with different skill levels in communication technologies and information. (b) Second Life is easily accessible because it provides guidelines that guide the user during the first contact with the environment (Help Island).
Spatial flexibility for exploration	(a) Spatial parameters such as size, architecture, infrastructure and physical environment affect the way students shape their social contacts. (b) Promote the educational value in virtual environments should meet the expectations of the teacher and students' spatial and temporal flexibility, exploiting the inherent social stimuli they receive in their spatial organization. (c) Provide a unique and flexible environment for educators who are interested in implementing distance learning scenarios and explore the application of new media.

continued on following page

Table 1. Continued

Structural components of Second Life	Using for…
Developing a variety of teaching models	(a) Developing a variety of teaching models for Distance Learning, this will provide recommendations on appropriate teaching-camera models (e.g. [Social-] constructivist model for collaboration between teammates). (b) Approaches and ways of using available ICT order to provide high quality professional development teachers in Education.
Providing tools that help reduce user's "extrinsic cognitive load"	A standard option of user's "interface" is available to support both in the form of graphical representation and the variety of multimedia tools for fine organization and coordination of learning activities.
Design and development of multilingual Knowledge Base	Design and development of multilingual "Knowledge Base" in Education, which will produce a variety of educational materials and tools to support teaching roles and whose development is an ongoing process that will allow feedback and registration of educational content; created from end users.

KEY FACTORS INFLUENCING THE CHOICE OF SECOND LIFE FOR RESEARCH

As it discussed in detail above, the VR applies that are featuring in multi-user virtual environments, can provide the ability to create innovative educational worlds to explore and interact with intuitive and natural way. The choice of this platform (Second Life) was based on specific grounds, which appear to be able to meet the requirements of an educational process:

1. In addition to various educational communities created from time to time in SL, since 2006 operated a discussion forum (SLED list - SL Educators List) with more than 6.500 educators who share their experiences with colleagues from around the world.
2. SL is not considered as an on-line gaming platform like WoW (World of Warcraft), Lineage 2, etc., as there is no beginning or end, or rules and levels of power rating of the user, nor any purpose of integration. The initial starting of creation, would serve the needs of communication and collaboration between distributed users, who will co-exist in an "open" virtual global society overrun by avatars. Virtual representatives introduce an important social dimension to the experience of cooperation, and promote a more "anthropomorphic" interaction and enhance the feeling of participation, which is very important to support cooperation. In Second Life, the "anthropomorphic" virtual representatives, assist in a more natural and effortless interaction of participants.
3. In contrast to the 3D virtual platform Fortrerra's System Inc. (http://www.forterrainc.com/), anyone can enter in SL, freely. There is a possibility for those wishing to buy virtual clothes and goods they need, putting real money (transaction via Paypal). For teachers it is also possible through various addresses (inside and outside SL), to obtain the appropriate tools for learning (e.g., slide viewers, e-books, tutorials).
4. As an "open" society, SL provides a favorable environment for meetings with people from different parts of the world. This factor can sometimes cause some difficulties and is an aspect that could cause concern for teachers. On the other hand, the "potential" advantages (interactive multimedia, such as prims, textures), can enhance the active involvement of learners in the learning material, giving them a much wider range of learning opportunities.

5. Includes many updates that users have significantly upgraded the platform with technical details, which could be considered "educational" fit for use. Simplifying the interface also allows a greater degree of interaction with other platforms (e.g. Moodle), and information and navigation programs (flash player, web-browser, etc.).
6. The ability to design courses in e-learning platform Moodle, combined with the virtual environment of SL, creates an application "open" code (open source project), called "Sloodle" (Simulation-Linked Object Oriented Dynamic Learning Environment: Second Life + Moodle). The Sloodle (http://www.sloodle.org) aims to develop and share useful tools (see Figure 1), supporting education in virtual worlds, making teaching easier (Kemp et al., 2009).
7. Finally, it is necessary to see that the SL cannot be a "bad" application (killer application) for educational use. There is no doubt that familiarity with the environment and the "challenges" (educational, technological and organizational), can provide a solid foundation on which to can support such educational programs as long as there is an adequate framework for their implementation.

STATEMENT OF THE PROBLEM

According to all that we said for Web-based technologies and their evolution, Web 2.0, which includes virtual worlds, it is undoubtedly a breakthrough in information technology and application innovation in modern Education. As a novelty attracts more young people, particularly adults, who tend to strongly embrace innovative and radical ideas, precisely because it contrasts with the traditional and the establishment, as a main part of Education. This is the main evidence, because of their desire on the part of a renewal, not only in the mainstream of everyday life but also for Education. This leads to the idea of using virtual environments, which are being accepted with positive emotions and excitement to both research fields and scopes. In many universities, both the public and private sector is often either partial or total lack of memory processes, procedures, rules and guidelines which have been developed and used in sufficient depth in years beyond. As a consequence of this lack of an innovative management authority occur sometimes malfunctions with the corresponding effects are listed below:

1. Insufficient knowledge of the staff to handle issues of responsibility. This problem is usually covered by the official through cooperation with one or more colleagues looking for giving a satisfactory answer. Of course, such a process causes a decrease in overall performance, time delays, increased costs and poor quality services.
2. Complete dependence of system operation from concrete experience and well trained staff, which "carries" the knowledge and memory organization. Thus, the effects of temporary or permanent withdrawal from the body (leave, retirement) may be painful for the organization.

This paper aims at presenting a "cybernetic" methodological framework for the creation of a knowledge management authority that can be used by universities and organizations in the public key, and the private sector. This framework utilizes tools of scientific areas of management with emphasis on knowledge management. More specifically, the second chapter presents the general characteristics of knowledge management and how it affects the current operation of organizations. The third chapter describes in detail the proposed methodological framework. The paper ends with conclusions and recommendations for future research.

This new approach should be taken into account in advance of the design and development of educational virtual learning space, as the designers of such an effort, must understand the best way for learners' needs but also for the factors that affect it. Then we should try to shape the design of a space, with the main criterion that courses are offered and utilize users' experience, while focusing on what they can really do to help. To better understand this relationship, it needs to define some elements considered important by users (students and teachers) who are undoubtedly the "natural" shape interaction with the virtual space, and these are: (a) the overall atmosphere of the class (emotion, motivation to learn, presentation and link to the original objectives of the course, (b) the possibility of alternative ways of reaching one or more disciplines, aiming to optimize the performance of students, (c) the use and treatment of primary learning context-action and investigate their own without inhibitions and "must", but with proper guidance and feedback, (d) the interaction between students and teacher at that time, within the virtual environment. Particular attention is needed in the design of interactions, so not to focus on the students' attention, as a greater extent than they have contact with the environment, because in this situation we cannot concentrate on detecting and structuring the "knowledge field".

It is recommended for users (teachers and students) to use the interface, in which they feel comfortable on their screens to be learning the material easier. As a result of this extraordinary experience, they read and serve immediate needs for knowledge, which will ultimately lead to the same effect or even feedback that is required to repeat the same effort again.

HIERARCHY OF PURPOSES

Many organizations or universities, in both public and private sectors, have offered either partial or total lack of memory processes, procedures, rules and guidelines, which have been developed and used in sufficient depth in years past. This paper aims at presenting a methodology in which a "cybernetic" approach explains a theoretical framework that could guide the creation of an organizational framework for teaching, which is essential for the proper management of knowledge. This method utilizes tools of scientific areas of management with emphasis on knowledge management and includes a series of milestones, which in general are: (a) a record of the procedures which require the use of information that exist within the organization, (b) identification of knowledge's bodies (human resources, information systems, paper files, etc.) that are used in each of the above procedures, (c) identification of knowledge that can and should be utilized properly towards the creation of a *"knowledge management field"* and (d) development and creation of a system (organization - IT) to support a potentially useful decision support tool that will be adapted to the needs and demands of a learning community.

According to previous thoughts, we can say that the outline scope of this work is to present in detail the qualitative and functional features of Second Life that focused on: (a) providing the opportunity for improvement of service quality and a variety of teaching and learning methods, when this is not be distinguished from the "traditional," (b) reducing the administrative burden of organizing and distributing knowledge resources assumed by teachers, and to help support the memory / cognitive background of each student, allowing them to manage first hand time and their tasks more creatively and second to show more willingness and understanding of their subject knowledge and finally (c) contributing through 3D virtual imaging to explore scientific concepts, principles and rules that govern the real world, by using three-dimensional simulations and integration models in learning environments for better imaging effects, so that students can better understand their *"cognitive level"*.

In this paper, we present a conceptual-pedagogical "cybernetic" methodology for avatars' spatial awareness and to suggest an innovative way of using Second Life (SL) in the educational process. In this study we investigated the importance of using three-dimensional virtual people (named as "avatars" or digital alter-ego) in the learning process. Our basic concern was to prevent in great detail the mode of virtual users (teachers and students) and their contribution to the SL's interface. Because of the imposing visual presence of plausible behavioral and educational strategies, we understand that avatars are a great promise for the motivation and effectiveness of education. One of the most interesting features offered by these developments is the ability to create rich, three-dimensional environments with "student-centered" approach may consist in life-like animated with these anthropomorphic idols.

The main purpose of this study is to investigate the potential application of scientific documentation in a VSM virtual system for better managing and organizing the scope of knowledge and communication between users. Additionally, our main objective emphasized the creation of an organizational-educational method, which is essential for an effective planning and conducting of distance learning programs. For this reason we constructed a "cybernetic model" and we tried to bind pedagogical principles and teaching activities that should be supported by any "open" and "viable" virtual learning environment. The construction effort is based on Anthony Stafford Beer's "Viable System Model" (VSM) principal characteristics, in which we attend the pedagogical analysis of teaching and learning process.

THE CONTRIBUTION OF THIS RESEARCH

With this chapter we want to present an implementation plan with the theoretical basis of the VSM, to create an organizational teaching methodology which will be managing the multiple representations among users. The contribution of this chapter, first, in a theoretical-scientific level, stating: (a) through conducting an extensive literature review on the SL, (b) the theoretical adjustment of the main pedagogical principles and teaching activities for the architecture of a virtual learning environment in SL, with the assistance of the "cybernetic model" and (c) the educational value-added of Second Life's "system," as "sustainable" facility which will provide an alternative e-learning process, while contributing to important conclusions about how evolution and recognition of innovative teaching methods.

Alternatively, the originality of a practical-level teaching is that: (a) Creates the necessary conditions to organize and conduct a more effective learning, (b) Illustrates the plurality of hypermedia applications are mediated through a combination or use of tools and can bring positive developments in the teaching process, and using them: (i) students and teachers no longer need to have advanced computer skills (e.g. handling programming languages), facilitating the handling of many learning programs, without much personal time and effort (ii) made an attempt to identify the major SL's novel structural characteristics for an innovative development of learning, (iii) shows an obvious enhancement of educational opportunities and research through the global virtual world of Second Life.

VIABLE SYSTEM MODEL: THEORY AND INITIAL GROUNDWORK

These organizational models are becoming increasingly necessary due to the growth and increasing complexity of organisms, and given the complex and constantly changing external environment. Concerning the operators and the Systemic Model Organization Sustainability, the factors that shape the operational environment, inter alia, are the following: (a) continuous variation of performance requirements (e.g. regarding the enduring goals of recycling materials), (b) search for alternatives technological, financial, institutional and organizational options, (c) potential for alternative systems and e-learning, (d) use of alternative materials, learning, and (e) longitudinal changes in qualitative and quantitative characteristics of a system. Therefore, for each system that is emerging more than ever, there is a need for: (i) adapting changes in the external environment, and (b) maintenance of the internal organizational coherence.

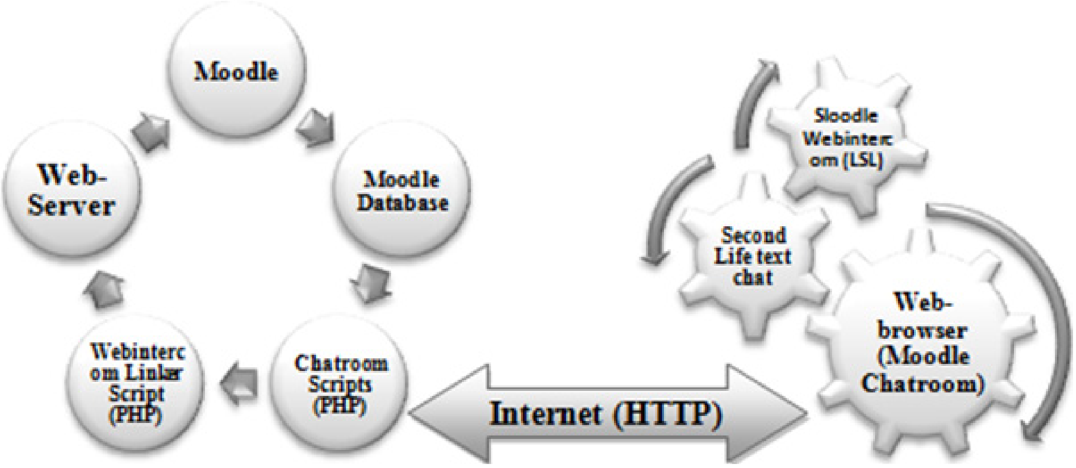
The empirical models of the body, mainly used today by the managers, can be effective up to a limit. Beyond that appear several weaknesses (Hoverstadt & Bowling, 2002): (a) based on the perception of each manager and therefore cannot be used as communication tools, (b) based on experience, often fail to deal with entirely new problems, (c) being personally tend to enhance their personal capabilities to support rather than their weaknesses, (d) address to the complexity of large organizations, and (e) limit the ability and desire for radical change.

The traditional hierarchical model (as the chart) is limited to modeling the flow of power/commands inside the body and does not model most vital elements, such as the objectives of the organization and procedures for achieving them, the formal and informal structures, communication channels and information transfer and decision processes.

The Viable System Model (VSM) offers an alternative modeling agency, which can be used as a diagnostic tool for existing organizations and as a design tool for new organisms (Jackson 2000). It was developed by Stafford Beer (Beer 1972; 1979) and is based in the field of cybernetic organizational structure, which focuses on effective management of organizations. The VSM differs from other organizational models and highlights those conditions that can create and maintain a viable organization. Defined as a viable *"a system that is capable of maintaining a separate existence"* (Beer, 1985, p. 57). The model focuses on the interactions of the organism with the external environment and the effectiveness of internal communication channels and information.

The development of the VSM was based on two fundamental concepts of "cybernetics": the *law of necessary variables* and that of the iterative system (recursive system). The *law of necessary variety* was developed by Ashby (1957) which stresses that: *"Only variety can absorb variety"* (p. 36). *Variety* is the measure of complexity is expressed as the number of possible states of a system. The *law of necessary variety* implies that in order for the system A can control the system B; you must have the same or a greater variety of system B. At whatever level you see a system is autonomous and governed by the same general authorities. *Autonomy* is defined as *"freedom of an integrated subsystem to act on his own initiative, but only within a framework for action set by the target of the overall system"* (Beer, 1985, p. 56). Based on these observations on living systems by Beer (1979) developed the theorem iterative system: *"In a recursive organizational structure any viable system contains one and contained in a sustainable system"* (p.32). It is precisely this repetition is what absorbs the complexity of the external environment and generates the complexity of the organization itself (Espejo & Gill, 2003). Based on those developed above, but other principles, theorems, laws and organizational cybernetic offices, the Beer (1979) concluded that in order for an organization to be viable, so that it can cope with complexity and change the exterior of environment, you need 5 basic functions (which are the 5 systems VSM, see Figure 1): *Mode* (System 1, S1), *Co-ordination* (Scheme 2, S2), *Control* (System 3, S3), *Intelligence* (System 4, S4) and *Policy* (System 5, S5). These functions are the two necessary mechanisms sustainability is cohesion, which includes the operation, coordination and control, and the adoption which includes the Intelligence and Policy.

Figure 1. The anatomy of Sloodle; [Adjustment from: Callaghan et al., 2009, p. 8]



The VSM is facing an organization through three key elements:

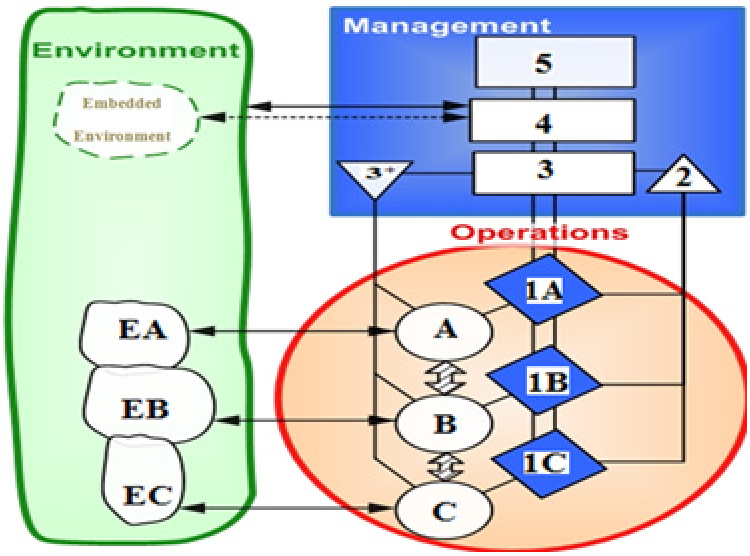
1. **Application:** It consists of the operation (S1) (see the red elliptical shape in Figure 1). The proportional in biological systems is the muscles and organs and is composed of all those elements necessary to perform the primary activities of the organization.
2. **Meta-System:** Consists of the functions of Coordination (S2), Control (S3), intelligence (S4) and Policy (S5) (see the blue diamond shape in Figure 2). A matching in biological systems is the brain and nervous system. The goal of the Meta-system is in operation to provide those services that will keep the data as an integrated and harmonious whole and is responsible for the adaptation of the organism in the environment.
3. **The Environment:** Consists of all elements of the external world that are in close association and interaction with the reference system, which can be an agency, an agency of the Department, etc. (See Figure amoebina green in Figure 2).

A system is sustainable when these three elements are in constant balance. The term balance is meant to smooth out differences between the complexity (see Figure 3) (Walker 2001):

- Operation and Meta-system i.e., The difference VO - VM (internal balance).
- Reporting System (Meta-system and Operation) and its environment, i.e. the difference VE - {VO + VM} (external balance). The mechanism of cohesion is responsible for achieving internal balance and the mechanism of Adjustment is responsible for achieving external balance. The following are the five that make up these two mechanisms.

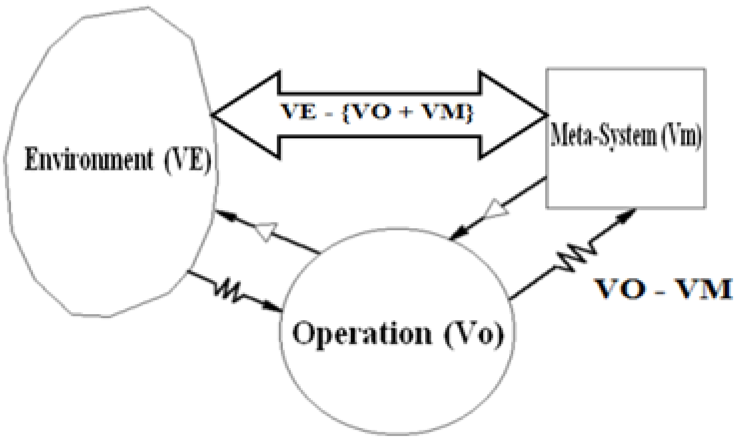
The full development of the theoretical background of the VSM can be found in the work of Beer (1972, 1979, 1985), and more information can be found in Espejo & Harnden (1989), Jackson (2000), and Walker (2001). Numerous applications of the VSM can be found in the literature (Walker, 2001; Espejo et al. 1999; Vidgen 1998; Brocklesby & Cummings 1996). On this occasion we used these previous works and finally we made our initial groundwork which includes:

Figure 2. The elaborated VSM, module level; [Adjustment from: http://www.closetheloop.gr/el/content/viable-system-model]



Operation (S1): The function is the core of the iterative model and consists the "Functional Modules" (F/M) (denoted by A, B and C in Figure 2), which perform the primary activities of the project's organization i.e. the production of goods and / or the provision of services. According to this concept of once every F/M should be a viable system. Therefore, the Administration (the Meta-system) should provide the necessary autonomy units in order to deal directly and flexibly to changes in the environment within which they operate and achieve their goals without the constant intervention of the Post-system of the body. Since the F/M systems are viable, will consist of the respective functions and the corresponding Meta-systems (local administrations) (1A, 1B and 1C in Figure 2).

Figure 3. The agency of VSM and the various complexities; [Adjustment from: Hilder (1995), p. 19]



Tuning (S2): The concept of Coordination in the VSM is the reciprocal arrangement between the support functions (i.e., Coordination) and autonomous F/M, so the organization can operate smoothly and is stabilized in emergency cases. Usually, in such cases the units tend to solve the problem with their own information and for their own interests, often affecting negatively the functioning and performance of other units, but the overall organization. Given this situation, the purpose of S2 is to provide appropriate information and mechanisms to solve the problem based on the total rather than local interest. Typical Coordination mechanisms include (Hoverstadt & Bowling, 2002): common standards, protocols, schedules and programs running. Information systems (IT systems) can help reduce direct human intervention.

Control (S3): The S3 is the "inward and this" function Meta-system (Beer, 1985). The main purpose of S3 is to achieve synergy between F/M. This is being achieved by optimizing the allocation of resources between F/M, the monitoring of their performance (through clearly defined "Performance Indicators" (PI), which must be reported, apart from financial and other performance parameters S1, as, productivity, employee morale, accidents, breakdowns, etc., but the recording must be in "near real time" and intervention in the work of F/M in case of threats to the sustainability of the broader system (Intervention by established rules). Administrative / managerial these procedures are the responsibility of integrating the S3 F/M to a set, connecting the subsystems with the wider system (e.g. the body) to which they belong. Procedures should be participatory and communicated, i.e. should be based on negotiation between the F/M and S3. This arbitrary targeting of service resource allocation can lead to unrealistic demands and expectations from S1 rules-based Intervention (Walker, 2001), who in turn, rely on the PI. The design at a higher level (strategic planning) must take into account the possibilities and limitations of the internal environment of the organization. The information is transferred from S3 to S4, in the form of "*algedonics"* (dashed line between S3 and S4 in Figure 3). Another system which is connected directly to the S3 is S3*: channel monitoring and inspection. Its aim is twofold: (a) supports the complete documentation of the managers' view of what happens in A / m, and (b) it gives F/ M confident that senior management understands the real issues they face. The design and implementation of S3 * are governed by certain rules: (i) must be more sporadic rather than regular (Beer, 1985; Hoverstadt & Bowling 2002; Espejo & Gill 2003), (b) must be known to all concerned, so as not to be understood as an undercover monitoring mechanism by the Administration, (c) should reach a depth, (d) must only link two successive iteration levels and (e) to bypass the local administrations of F/M.

Intelligence (S4): S4 is the "outward and into the future" (Beer, 1985) Post-operation of the system. The S4 is a two-way channel of communication and information between the organization and its external environment (threats, constraints, opportunities and demand), and its main role is to collect and process information from the external environment. If they require direct application communicates to S3 (business planning), while they appear to carry the long-term effects in S5, which takes the final strategic decisions (Jackson, 2000). Also, the S4 carries the instructions from S5 systems located at lower levels (namely, S3 and through the S1), and information from the S1 and S3 to S5, which are required to obtain the final strategy decisions. Because there is constant danger of overloading the S5 with non-significant information, the S4 must filter the information that promotes upward. This is accomplished by gathering information (in the form of algedonics, see Figure 5) from the S3, which converts to a form useful for the S5, acting as "algedonode" (the line between S4 and S5, in Figure 2). So, based on information gathered from internal and external environment of the organization, the S4 is the area within which strategic planning is carried out (Hayward, 2004). Ordinary activities of S4 are: the future plans, forecasts, operational research, development, public relations, etc.

Policy (S5): The S5 is responsible for shaping the policy of the organization. Its main role is to provide clear direction, values and goals for the organization. It is also responsible for taking the final strategic decisions. Successful strategic planning requires continuous communication between the elements of S3, S4 of the elements and between S3 and S4. This ensures the consideration of all internal or external capabilities and limitations of the organization. At this point, communication must be overseen by the Policy (the continuous communication between the S3 and S4 is shown with two red lines, while the supervision of this communication from the S5 - and not oversight of - is presented with two green lines in Figure 5). Failure of adequate building these communication channels leads to one of the archetypes of strategic problems, such as (Hoverstadt & Bowling, 2002):

- Focus on controlling which leads to stagnation (stasis).
- Emphasis on intelligence leads to non-achievable and non-realistic plans.
- Focus on one element of S3 and S4 (often financial) means making decisions that ignore important issues and offer solutions that are optimal with regard to the sustainability of the organization. This point is the "interface" between the two notions of viability (viability - sustainability) for the organization.

Knowledge Management through "Cybernetics"

Knowledge management is a relatively new area for scientific study administrative practices for the systematic and collective creation, dissemination and use of knowledge institutions and enterprises to radically improve the efficiency organizational structure to improve business competitiveness and develop innovative abilities (Coombs et al., 1998). It is the process in which organizations create "value" based on the knowledge of their assets. Thus, knowledge management can be an advantage for those organizations that have the potential to grow, to protect and to disseminate to their members. It is also important to note that knowledge management should not be confused with the technology and information systems as these are basic hand tools, but are not themselves knowledge management mechanisms. Already from the time of the industrial revolution has been understood that the real capital of an organization composed primarily of knowledge and organization and that knowledge is the most effective engine for growth (Steer, 1977; Rizzo et al, 1970). The issue of knowledge management comes into focus even more strongly in recent years a number of reasons summarized below (Watt, 1999; Ruggles, 1998; Earl & Scott, 1999; Warr, 1979): (a) creating wealth from knowledge is increasing, (b) the rapid changes in globalised markets, competition and rapid technological developments make the necessary continuous learning, (c) it appears now clear that innovation is the key to competitiveness and innovation is directly linked to the creation and exploitation of knowledge, (d) the need to transfer knowledge outside the boundaries of organizations grows constantly, (e) recent technological developments offer new opportunities for communication, (f) the mobility of the bodies is now more than ever to the extent that many students to see their career as a dynamic range of positions in various organizations.

The main features of knowledge management are identified as follows:

- Produces new knowledge.
- Creates access to valuable knowledge from outside sources.
- Uses accessible knowledge in decision making.
- Integrates knowledge into processes, products and / or services.
- Knowledge is being hired in documents, databases and software.
- Facilitate the development of knowledge through culture and incentives.
- Carries existing knowledge into other parts of the body.
- Measures the value of the benefits of knowledge and / or impact of knowledge management.

The benefits of knowledge management that can be provided individualized for students, communities of practice and the organization itself is this view of three levels helps to emphasize why knowledge management is important today. So now it’s more crucial to identify the benefits of this action and knowing better the reason of its importance.

The knowledge management at the individual level:

1. Helps people do their job and save time by improving decision making and problem solving.
2. Creates a sense of social ties within the organization.
3. Helps people stay informed.
4. Offers challenges and opportunities for contribution.

The knowledge management practices at the community level:

1. Develops professional skills.
2. Promotes peer mentoring.
3. Facilitates more effective networking and collaboration.
4. Develops a unique code in a common language of professional conduct in which members can follow.

The knowledge management at the organization level:

1. Helps strategy.
2. Solves problems quickly.
3. Casts best practices.
4. Improves the knowledge embodied in products and services.
5. Crosses the ideas and increases the opportunities for innovation.
6. Allows organizations to above-average competition.
7. Builds organizational memory and success factors.

For the successful management of corporate knowledge that will make the most beneficial results for the company and its people must be identified some critical factors. These factors have cumulatively and not individually to a daily goal and scope of responsible control of knowledge management.

1. The primary factor is the commitment of management to support effective project management knowledge.
2. The involvement of all employees to share knowledge, reuse of data (if applicable) and innovation in order to give benefits to the enterprise.
3. Need time and effort to make the maximum extent the intangible resources of the company to add value, which is able to define and measure.
4. The continuous upgrading of the necessary tools and technology that will facilitate the distribution of knowledge is also a critical success factor.
5. Finally, systematic alignment of knowledge management with corporate culture and

the system of remuneration of workers. As already mentioned, the reward for the dissemination of knowledge is a critical success factor of project management knowledge. This reward may not be limited to monetary value, but also at identification and definition of honorary title.

At this stage it is necessary to establish that formal teaching establishment of distributed users on Web-based technologies, requires participation and an organization of the student population and also "cybernetic" management. This kind of "management", looks first for activation of "wholeness" of members (psychosomatic entity each student) and also better dimension communication (sensory-motor alarm, cognitive and verbal abilities / skills of each student), through discussions with the teacher and the other (Landon, 1999). Therefore, integration issues, such as the trading of knowledge resources, coordination, monitoring (by the teacher), individualized activity, self-organization of "nomads" of knowledge and their adaptation to the virtual environment, will be selected by training activities and hence valuation provided the educational value of each collaborative environment, which may be used for teaching.

In addition to various methodological approaches (Mason & Rennie, 2008), we can say that "cybernetic model," as a methodology for the evaluation of [D-] CIVEs, may be raising some questions. Some of them result from the successful integration of this method in Second Life, i.e. a form of teaching that includes the acting subject (teacher and learners). Such a methodical process can "produce" the acquiring educational values of a more complete form, in which users are asked to identify the tools provided by the virtual platform and allow dialogue, communication, interaction and action learning between users by principal purpose of knowledge acquisition (Crawley, 1999). Also, the multiplication of cognitive research has fundamentally been changed the "default" view on using PCs, bringing forth the idea of *"cybernetic approach of open environments"* and the question that arises is: *"how can we construct a learning environment that takes into account student's unpredictable operation?"* (Bertrand, 1995, p. 103-104). The teaching strategy that is proposed with the "cybernetic model," as we have said above is related to the organizational structure of a learning environment in accordance with VSM principles that prescribed (Forrester, 1994). This should primarily be based on managing the interactions among to participants ("Law of the necessary diversity": *Ashby's law requisite variety*), as each team determines available channels of communication and interacts with the organizational structure and the available knowledge resources that are required for managing ("Managing Diversity": *Variety of Management*) (Ashby, 1956).

In our case, the "system's model," i.e. the virtual interface (data frame), is directly related to the actual user's environment (physical context). Hence the expressed relationship gives the ability for dynamically change of behavior in the "adaptable" operating environment through the interactions of sub-systems (human and technical resources) in different levels of feedback. A key issue that must be explored is the proper management of "action groups" that are generated during the delivery of courses. The most appropriate organizational structure of teaching in a virtual world is to provide an easier management of interactions and communication channels between team members at the same levels as with their physical presence. With these data we believe that VSM can provide a support base for exploring a "training" framework, which would adjust SL's environment. This contribution can be used pedagogically, and contributes the organizational management of the educational framework for action-based activities and interactions with the system, especially when the number of students is large (up to 30) (Liber, 1994).

A Methodological Exploration Plan for E-Learning Management with the VSM

The use of collaborative virtual environments could enhance the quality of education and achieving a more effective teaching in comparison with the traditional. This development is particularly important when the learning environment can support different pedagogical approaches to issues concerning: (a) the flawed methods of teaching (especially in teamwork), (b) learning with collaborative techniques (jigsaw, brainflowing etc.) and (c) multimedia resources (video, audio, text) to be used by students (with teachers association) to acquire knowledge. To be able to understand how this can be achieved through a didactic approach, it requires the adoption of an appropriate "teaching" model. For virtual environment integration in education should be conducted several studies on pedagogical processes both to investigate the proper method of teaching, and the way out, to create a conceptual design framework combining theories of learning and pedagogical practices and forms the basis for application in such environments.

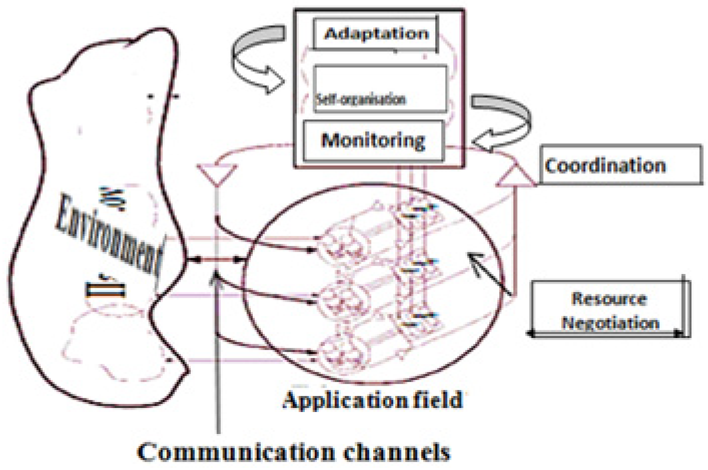
A model that could be used as a basis for establishing the framework for evaluation of pedagogical view is the "cybernetic model" (Britain & Liber, 2004; Liber, 1999). According to Britain & Liber (2004), an evaluation method of a virtual learning environment based on "cybernetic model", reflected through the key features that "Viable System Model" (VSM) governs. This "model" contains the control and management of operational and organizational structures of systems, as suggested by the British theoretical Anthony Stafford Beer (1926-2002), who first got to the effective organization and cybernetic management of the systems (Beer, 1959). The main features of VSM, permits effective action against the organizational complexity of natural and technical interactions that govern each system making it practicable. The axes of VSM's structure, can interpret an "educational" approach which determines specific key characteristics of our model and corresponding effectiveness of "cybernetic administration" development of teaching and learning components. Practically, this "systemic" approach can provide the basis for practical implementation of the "cybernetic model", but with the essentials that VSM offers (Dickover, 1994). Still is important to mention that VSM, which be used in this study, describes the mechanisms that must have held by any complex system as to remain "viable" (Achterbergh, et al., 2003). It is crucial to characterize a system as "sustainable", when it can maintain its original identity and simultaneously performing the purpose for which it was created in the dynamically changing environment in which it operates.

Additionally, it's pretty remarkable the concept of "sustainability" that is being achieved through two fundamental characteristics (Barrett 2011; Pfeifer & Bongard 2007; Kaplan & Herring, 1998): a) *autonomy*, which refers to the degree of freedom in decision making and b) *adaptation,* which refers the ability of the system to assume new "ingredients" and release them. The key feature of the VSM is the modeling of a system, as a recurrent form of the same system (feedback), while the same is a subsystem of a larger (see Figure 4).

Therefore, issues of integration of the VSM in virtual worlds should be involved (Britain & Liber, 1999, p. 20-21): (a) the negotiation of knowledge resources, (b) coordination, (c) monitoring (by the teacher), (d) the individual activities (or autonomous learning), (e) self-organizing "nomads" of knowledge and (f) the adjustment to the "action framework" will be the key selection criteria for education in the environment of Second Life. Although we decide to analyze these components to understand better their assistance for constructing our methodology (see below):

Resource bargaining channel: Firstly an e-learning program management unit (usually at the

Figure 4. The viable system model - key operational communication channels; [Adjustment from: Espejo et al., 1999, p. 662]



department level) needs to negotiate the available resources to the modules it is constructed from. Typically this is done at the start of a program; but it is being varied depending on the progress and needs of courses as they unfold.

Coordination: Modules are designed to operate completely independently of each student, having first defined which other modules are prerequisites or co-requisites. However it may be that opportunities are lost for inter-module activities.

Monitoring: Monitoring is the regular observation and recording of activities taking place in a project or program. This is a routine procedure for collecting information on all aspects of the project and an easy way to check on how project activities are progressing. It is a systematic and deliberate observation which provides feedback prompt on the progress of a project program. The report allows the information gathered to use in making decisions for improving project performance.

Personalization (or Self-organization): In many institutions teachers talk continuously about their teaching, and learn from each other's experience as it takes place – they can help each other by teaching sessions, or through peer-observation, or by sharing resources with virtual tools to support this sort of self-organization between courses or modules.

Adaptation and balancing the needs of the present and the future: Any distance learning program must be constantly examining its set of modules, and considering whether and when new modules may be needed, based on changes in the knowledge domain, the needs of society, and the new resource capabilities (e.g. funding sources). In this situation, technology can and does play a large part in this, but usually not integrated with the VLE, where the needs for adaptation are expressed.

With the main focus on this idea believe that building such a model could be better showcased the features of the SL, as well as contributing to a new dynamic dimension to managing interactions depending both on virtual worlds and learners. The above reason led us to identify an active effort to determine the development and presentation of a methodological framework that could be used as a basis for establishing a framework for evaluation of a pedagogical-organizational-technological point of view (Kolas & Stampe, 2004; Heiner et al., 2001), in this case would achieve with "Viable System Model" assistance.

GETTING THE PROJECT STARTED

The interaction that 3D VR offered, in general involves the coordination of knowledge, the psycho-motor and effective domain of students who crystallize the relationship between "student-project". The data are instrumented in teaching completeness and efficiencies of learning are interactions, customization, the realism and the "open" learning environment. Investigations in the learning field are placed on the acquisition of knowledge within a system of interactions among individuals, social and material context. The acquisition of knowledge does not depend on the stimuli or the individual mental processes, but by a set of factors consistent with human and environmental interaction (Steinkuehler & Williams, 2006; Koleva, et al., 2000). Indeed, the development that has brought human cognitive performance, leading to improve teaching plans and educational applications. Thus, we conclude that the use of such environments could support the "modern" Learning Theories in which participants can create, edit and manipulate almost any form of digital information. Objects, processes and "residents" (avatars) of the virtual world are "elements" of an active and ready to manipulate their project. Actually, teamwork and creative learning that offered in virtual worlds, allowing teachers and students using computer technology in a productive collaborative state.

Taking into account the mention that occurs as a core of creating an institution-teaching framework, it should primarily be in the research field that involves: (a) the use of potentially SLs' functional characteristics (channels of communication between users, text editing tools, etc.) and (b) Processing the e-learning "system", namely form: (i) strengthening the quality improvement of courses by using innovative methods, concept aiding the development course of instruction, when this involved a large number of students and (ii) understanding the organizational and operational structure of e-courses, with a parallel and efficient "action-group" management. We also know that from the outset designed, primarily Second Life targeted for users over 18 years old.

Therefore, it is natural for Higher Education to meet students and teachers need of that grade. Furthermore, the educational use of SL, "invite" trainee's users and teachers to cooperate in a coherent "open-access" world, with virtual objects, multiple options and approaches with a more constructive attitude. The use of computational interactive tools and applications that SL offers, contributes students to build individual or social knowledge in situations that are functional and purposeful, while developing and meta-cognitive consciousness. The designing, development and implementation of educational scenarios and activities using the virtual environment, based on a framework of general pedagogical principles that are the result of concepts developed in recent years in the field of cognitive and social-cultural theories of learning, based on: the instructional activities to design learning scenarios and active construction of knowledge (Soloway, 1990), the development of a rich conceptual network (Genovese, 2003), which takes advantage of students prior knowledge, experience and intuitions (diSessa, 1995), the developing of a new strong relationship between student-teacher (Hoyles, 1999), and the creation of communities of practice (Vergnaud, 1987).

Overview of the Pedagogical Framework

The pedagogical framework that this work presents, resulted from the analysis of the literature (Yang & Wan, 2004; Yahya & Goh, 2002; Stephen et al., 2002; Davenport et al., 1998; Nonaka et al., 2000; 1995), and partly to the considerable experience of writers in implementing the evolution of relevant systems' initial groundwork to universities and organizations both the public and private sector. The proposed framework includes a series of milestones, which in general is the following (Ndlela & du Toit, 2001): (a) analysis of the organization, (b) analysis of the external environment, (c) set an appropriate strategy for managing knowledge, (d) creation of a plan for implementing knowledge management programs, (e) Implementation and evaluation of knowledge management strategies.

The key question that arises from the content of each stage is described below as follows:

1. **Analysis & overview of the organizational structures of the system:**
    a. Consensus of users to address a problem.
    b. Use operating system tools to solve the problem and implementation of a knowledge management program.
2. **Analysis of the external environment for action-based learning:**
    a. Perception of the role of environmental action for users.
    b. A perception of the benefits of proper management of knowledge and its impact on learning.
3. **Set appropriate strategy for knowledge management:**
    a. The vision and goals of the organization.
    b. Strategies that will contribute to achieving the objectives.
    c. Knowledge management contributes to achieving strategic objectives.
4. **Create a plan for implementing knowledge management programs:**
    a. Easy or difficult it is manageable to create an organizational plan teaching-research.
    b. How the organization and action groups conquering this goal.
5. **Application of knowledge management strategies:**
    a. Strategic applications can bring students closer to knowledge.
6. **Evaluation:**
    a. The result of evaluation helps in feedback prompt.
    b. Future involvement of teammates in the system used.

Taxonomy of Structural Teaching Requirements in Second Life

The claims and the description of the teaching approach with the assistance of VSM, co-shaped and renovated through to a theoretical framework, assessed the added functionality offered by the SL, along with those proposed by Pereira et al. (2000) & Ozkan et al. (2009).

General Requirements

1. **Selection, organization and implementation of teaching activities:**
    a. Clear identification of learning objectives / teaching methodology to be followed.
    b. Functional organization of the information presented.
    c. Verification prior knowledge of students and providing feedback.
    d. Use learning strategies (edit topic, implementation, and generalization of new knowledge, feedback, recap, review, etc.)
2. **Contact - interaction in the learning community:**
    a. Type of communication (one-way, interactive "labyrinthine").
    b. Nonverbal communication (movements, facial expressions, nod, speakers and audience attitudes toward the camera, etc.).
    c. Participating students (grade dedication, note-taking, communication with teachers and students' home and remote classrooms, etc.).
3. **Types and characteristics of visual material:** Content information and customers' "higher" cognitive processes.

4. **Characteristics of Students:** Relationship / interest in teaching the subject.
5. **The presence of teachers:** The spectrum styles like creating a pleasant climate, encouraging personal expression and enhance the participation of students, etc.
6. **The role of the Coordinator of Remote class:** Support, encourage and coordinal students of classes for remote participation and communication with the teacher)

Special Requirements

The criteria/questions to assess the technological environment of educational purposes includes the extent of the prejudice to the attention of students, the desire for participation and the degree of their involvement in the teaching / learning process of the following parameters:

1. **The quality of the transmitted image:**
   a. The fidelity of the projected image (purity, depth, natural colors, etc.
   b. Transmission of movements of the participants (interrupted - frame to frame, continuous - physical movement).
2. **The quality of transmitting audio:** The fidelity of the transmitted audio.
3. **The presence of parasites, hum or noise due to the network:**
   a. Interruptions or delays in the transmission of sound.
   b. The existence of noise transmitted by the microphones in remote classrooms.
4. **The layout in teaching:** Organization and layout of the room (size and shape of the room, conference room, the order of display space, an area teacher, the audience space, space control, etc.)
5. **The network / IT infrastructure:**
   a. Ease of use any communication and technological tools that are available to teacher and students.
   b. Ability to use a variety of supervisory / media literacy.

A "Cybernetic" (Multi-) Method for Organizing and Managing Educational Activities in Second Life

Any formal establishment of a teaching process for distributed users ([D] -CIVE case), requires the participation and the "cybernetic" management plan of the student population. Learning management should be looking forward first to the activation of all current members (including the psycho-physical entity of students) and also the best communication aspect (sensory-motor, cognitive and verbal abilities / skills of each student), through conversations with the teacher and other members. With this highly important meaning, we want to illustrate how the VSM could be adapted as an organizational-educational framework and as a result we suggest some processes that Second Life can perform, which will use as a pedagogical framework for evaluating functionality. Meanwhile, this search will build on the adaptation that VSM offers, which consists the requirements and pedagogical principles governing on each "open" virtual learning environment. Through this process sought the evaluation of the collaborative virtual environment, which is a tedious task and should take account of contemporary Learning Theories, but also the variety of educational issues such as interactivity, adaptability, interaction and collaborative learning (Redfern & Naughton, 2002). For this attempt we try to build a framework evaluation for SLs' pedagogical value that takes into account:

1. The organizational context of Beer's teaching-based model (VSM: Viable System Model), includes the "cybernetic management" of an e-learning system between users and "medium" (Second Life).
2. The "supportive" environment which governs activities and educational principles,

including data from the theoretical framework, in accordance with earlier studies, which were based on assessment of SL as an alternative "tool" for e-learning courses.

3. The structure pedagogical processes, the mental, emotional and trials maximal voluntary of human behavior. In this case the "planned action" is important to realize that these procedures are important and both necessary for the successful integration of technological tools in the curricula of schools of all levels and particularly in our case for Higher Education (Smith, 2009).
4. The descriptions of possible knowledge management practices: As we known for all above "Knowledge management" is a new management practice relating to the systematic and collective creation, dissemination and use of new knowledge, to radically improve organizational efficiency, improve learning competitiveness and innovation. It is the process through which firms create value from their intellectual and based on learning resources (Hasan, 1999; Baecker, 1997; Axelrod, 1984).
5. The methodological framework for organizing the "knowledge field," in which study, enhancement and promotion of proactive change management practices and skills upgrading of human resources in companies selected industries. The project aims to provide an overview and assessment of prevailing management practices and human resource development and training. Emphasis will be given the link between strategic learning goals and skill levels of students (gap assessment) by developing proactive system management skills of workers with the definition of integrated adaptation measures develop and transfer "knowledge field" that also includes:
   a. Study strategy for developing practical operational flexibility and organizational innovation. The main goal of the project is to highlight the competitive advantages that attach to teamwork adopting flexible forms of organization and the implications these have on human resources management. Particular emphasis will be on quality and flexibility especially in the student-rotation and the development of multi-skilling of students' teamwork, which reduced hierarchical levels, focusing on core-activities and the development of subcontracting and networking universities.
   b. Designing a strategic study of the environment's benefits to develop practices and upgrade the quality of the interface. The project aims are promoting to universities, the systematic management of safety and education issues, to ensure suitable conditions for the effective application of the principles of distance education. In this way seeks to improve labor productivity and upgrade the quality of working environment, contributing more broadly to the development of human resources of the country.

There is no doubt that all these methods are remarkable, but in any e-learning platform, especially in virtual enterprises, which are studying here, we need more than a single systemic methodology. Within the present paper, we propose a new (multi-) method, which essentially combines these systemic methodologies, based on the idea of Beer's method. In order to achieve the best results for our problem, we develop a strategic knowledge management model for distance courses through virtual environments. Finally, we choose the VSM to represent the complex phases of the previous steps and identify the strategic flow of knowledge between members of the virtual enterprise. Through this process, we will try and assess the provided pedagogical value of SL. Thus, the core

Table 2. Methodological framework and students' reactions

Methodological framework to investigate the pedagogical value-added of Second Life (Professor-User)	Students' thoughts as a "pedagogical" system (Student-User)
A. Negotiation Includes all processes that concern the negotiation of knowledge resources among students and teacher. With this dialogue development, students may understand the value of using SL and as a result activating them "totally". **Use of tools:** Voice call, IM, chat text, note cards **Methodological framework for organizing the knowledge field** *Analysis & overview of the organizational structures of the system (Second Life):* This stage includes: A. Recording of a process that requires the use of existing information within the organization (information found in files, details of handling such issues in the past). B. Identification of knowledge's bodies (human resources, information systems, paper files, etc.) used in each of these processes. C. Identification of knowledge elements that can usefully be exploited by users for better understanding. **Structure pedagogical processes** *The computer as a tool of thought and perception (cognitive tool):* Considering that knowledge is built by using tools and symbols that are available to each community, we can see that also computers and technology in general, should not be treated as instruments that are used for simple transmission of knowledge but as cognitive tools. These are being involved in the learning process and help in the way of thinking, social-construction of knowledge and negotiation of meaning can be combined with the positions that we presented above.	**1. Reception Information** (A) *Collect teacher's information:* Translating the negotiations will lead to the activation of the student population. This can be achieved by sending messages (notes) or voice calls, describing students the outline scope in the virtual environment (a detailed description) (Hansen & Erdley, 2009). (B) *Completion:* Teacher should activate "totally" students' sensory-perceptual, motor and cognitive skills, which will manifest through behaviors, reactions and interactions between "action groups". A prerequisite for achieving the goal set by the teacher, is to use tools of SL, such as voice dialing and record, knowing that the thoughts of students include a dual effect derived: i) internal factors (i.e. involvement of empirical data students who know from past teachings concerning the course) and ii) external factors (learning through symbolic representations or information that would identify in Second Life). (C) *Identification:* At this stage they must determine the significance of the elements of action, highlighting the importance (from "signified" becomes "signifier"). So down through the dialectical road, the "action plans". **Descriptions of possible knowledge management practices** *Formal training:* Students attend to organize courses where they receive support materials for training in a particular subject. The material usually presented by experts in this matter. Usually in these cases the representation and presentation of learning material is via PC or video projector via the virtual environment of SL. Formal education may include the initial assessment of the quality of the presentation by estimating the percentage of knowledge understood by learners, and likely to encourage attendance by the participants of a program.
B. Coordination Includes processes of coordination, teamwork, learning activities and sharing ideas ("brainstorming") through to all available tools that SL provides. **Methodological framework for organizing the knowledge field** *Analysis of the external environment for action-based learning:* This analysis aims to reading opportunities, strategic priorities and external threats. The analysis of the action of competition is crucial for developing a successful knowledge management project. The plan should create a strategic advantage over the competition, which means expanding and enhancing the benefits of the body and neutralize the advantages of competition. **Structure pedagogical processes** *Restructuring the curriculum in order to utilize technology as efficiently as possible:* It is a structured curriculum which often precludes the use of technologies. Several academics and researchers argue that we should delete the existing curriculum and restructured, taking into account the characteristics and capabilities of the technology. Modern educational models support an interdisciplinary approach to teaching which is based on principles of social interaction and co-construction of knowledge.	**2. Understanding Information** (a) *Metaphor:* On the side of the teacher expects students to understand the importance of ongoing research, making it more constructive and clear the "samples" of knowledge (e.g. multimedia presentation material). Should be carefully guided his students, showing how to find information through the search engine (search) of the SL, either by sending messages to members, so that the instructions be made known to the whole team. (b) *Analysis:* Each student can go and see a specific task. You first need to decide with it what it believes may be useful in research and then it will be evaluated (from the rest of the team and the teacher) and self-assessed. (c) *Classification of items:* Below is the collection of data in each group and the gradual hierarchical clustering. **Descriptions of possible knowledge management practices** *Virtual "talk rooms":* These "rooms" are for chat discussions gathering where executives of the university are expected to visit for about 20 minutes as a normal part of everyday work. In these places there are regular meetings and discussions that are organized. The expectation that the executives will go to these halls and discuss their current work with everyone and these discussions will allow the spontaneous exchange of knowledge and ultimately create value for a business.

continued on following page

of the *Methodological Framework* includes the procedure shown in Table 2.

CONCLUSION

The so-called technological learning theories were influenced by the systemic theory and "cybernetics" which are facing a major problem, this possible loss of control of the educational process from the tutor. At the end of this process, the teacher is facing a major problem which is the erosion of power that is being involved in educational practice. Also, an extraordinary important problem that arises from this reasoning focuses on: "*how teacher can ultimately control the process of learning?"* In this phase, the teacher's problem will be moved to that of *"controlling technology",*

Table 2. Continued

Methodological framework to investigate the pedagogical value-added of Second Life (Professor-User)	Students' thoughts as a "pedagogical" system (Student-User)
C. Monitoring One of the most important pedagogical parameters is monitoring students' progress (as a teacher) and as a result receiving the appropriate feedback to self-assess. Teachers' role in this section will be facilitating and prescriptive (as a mediator). **Methodological framework for organizing the knowledge field** *Defining an appropriate strategy for knowledge management:* The general management knowledge is necessary but not sufficient condition to obtain strategic advantage. If the same knowledge management features found in many competitors, then none of them has the strategic advantage. In this case there is simply competitive equality, which means that the Department simply does not disadvantage compared to competitors. So it is necessary to explore and cultivate the characteristics of the organization through a knowledge management program. Every company has a business goal and a story that determines the current status. **Structure pedagogical processes** *Recognition of the idea that learning is situated:* The fact that learning is dependent on the environment in which it is built affects the design of learning environments. For this reason, the knowledge must be built within framework environments where students will be invited to use it. Educational websites, virtual reality environments and educational computer simulation can provide opportunities for students to build knowledge in a variety of different authentic settings.	**3. Information processing** *Outdoor critical evaluation:* Students complete the process of collecting and evaluating material ("external / group"). The evaluation is based on the models and criteria accepted by the learner, i.e. the principles, axioms, declarations, laws and empirical data. (b) *Construction:* The concept of creativity, relying mostly on the imagination, logic and spontaneity can be the link between free construction of "virtual" artifacts and ideas and views of users. (c) *Internal* critical appraisal*:* Here is an attempt to express all elements with the parameters (functional, aesthetic, and cognitive) that can be connected to the final distribution and binding material. **Descriptions of possible knowledge management practices** *Communities of practice:* The interest groups which arise naturally are students who are experts on common issues, dealing with a common process, or who are interested to solve similar types of problems spontaneously come together to exchange ideas. The interest groups are an opportunity to discuss problems, new events and ongoing issues.
D. Personalization **(or Independent Learning)** The system should enable permitting students to seek either databases or other sources, i.e. Learning by doing (J. Dewey). **Methodological framework for organizing the knowledge field** *Create a plan to implement knowledge management program:* If an educational company wants to achieve the strategic objectives should be operated with specific plans and drawings. The plan for implementing knowledge management program should include specific approaches (like projects and actions), timelines, involved employees and resources required. The application or otherwise of this plan can send a clear message to management on how complete was the approach and how much commitment is involved in the management of business knowledge. This stage leads to the development of a system (organization - IT) to support the creation of a knowledge management framework, which will provide a powerful tool to support timely decisions to be tailored to the needs of a university community. **Structure pedagogical processes** *Participation of teachers in the process of organization, implementation and evaluation of innovation:* House (1979) argued that the studies for innovations in education have shown that the success of an innovation is essential to engage all teachers in the planning, implementation and evaluation of innovation. Past experiences have shown that the introduction of innovations has failed dramatically when teachers had the opportunity to participate actively in all stages of innovation (Means, 1994).	**4. Preparation of action** (a) *Classification* of data: completing the phase of "treatment" will try to translate their ideas into "action plans" (organized bodies of knowledge), which demonstrates the "total" active individual's effort and the interaction and communication with others (Embodied Research Group, 2007). (b) Composition: The composition of elements is a key element in achieving the desired objectives, and are performed all these acts that demonstrate the ongoing work of each group. (c) *Planning:* The concept of "programming" identifies with the concept of action. The action starts, but always requires the redesign option, if the course proved wrong (debugging option). **Descriptions of possible knowledge management practices** *Knowledge repositories and resources:* Knowledge repositories are structured collections of documents which are often being written by students from other universities. Their purpose is to control the knowledge and experience of the author in a particular subject. The instruments of knowledge reservoirs are often categorized in separate databases based on the part of each area addressed in SL, whether they relate to a specific project or on any other topic alphabetically and assigned to easily search their students.

continued on following page

which largely explains the return to traditional teaching techniques of communication, i.e. those that the teacher can check in the classroom. The systemic view of knowledge can give us a more comprehensive and humane vision in education and this was appearing under the influence of analytical methods that has turned it into a *"super-analytical"* method of learning processes and management disciplines.

From our paper's results, we agree with the need to import, develop and recognize an 'alternative' and 'flexible' educational way that can enhance the final value of e-learning. The use of Second Life for delivery of distance learning courses and long-term use of the Higher Education should be based on the principle that defines distance learning as a continuous process, which tries to meet the needs of dynamically evolving

Table 2. Continued

Methodological framework to investigate the pedagogical value-added of Second Life (Professor-User)	Students’ thoughts as a “pedagogical” system (Student-User)
E. Self-organization The “architecture” structure of the virtual environment, should allow students to organize activities and interact with the system in the simulate world. This could be achieved through specific tools for organizing and managing various information channels. **Methodological framework for organizing the knowledge field** *Investing in the infrastructure of schools and educational organizations:* It is given a huge importance of symbols and tools for building knowledge. Therefore it’s necessary to invest money for the infrastructure of schools and the continued support of programs in technology in education. For each class period is being organized by: a) a plan for teaching phases, b) using more than one “medium” to attract students’ attention, c) a detailed course of teaching activities (with questions, evolution and ultimate conclusions as to skillfully students led to speculation and to find the desired knowledge) d) evaluation sheet. **Structure pedagogical processes** *Using web-based technologies to create and support learning communities:* The idea of community is based on two core values: The idea that social interaction and collective responsibility creates a better environment; a framework for achieving certain goals and the other in that the close link support for a number of conditions good life. This suggests that learning within a community is a social process and as such relates to the creation of linkages between learning and what is important for those who learn as well, and among students themselves.	**5. Implementation of the action** (a) Formatting ideas*:* Called the transition from the planning phase prior to action. Basically we are in a phase of inactivity, when ideas must be “transformed” in appropriate words for expressing briefly appropriate action and to implement (“out of the imaginary”). (b) *Engine* Integration: Students should be able to present the material to individual learning, highlighting the information collected through audio-visual applications, such as a video or presentations via Power Point, revealing in this way, their active participation in the activity. (*c*) *Preparation:* The mobilization of students can be seen from the “Get Information” is reflected in the final implementation of the “action plans”. If this phase achieved successfully this endeavor, the future reuse in similar circumstances, taken for granted. **Descriptions of possible knowledge management practices** *Collaboration and Organizational Development Activity:* It describes the collective behavior of structural elements as a result of interaction between them. Self-organization is basically a process of development, where environmental impact is minimal, i.e., where the development of new, complex structures takes place mainly in and the system itself. As it is mentioned in the section on evolutionary theory, self-organization can be understood by using the same variation and natural selection and other, environmentally driven processes of evolution.

continued on following page

education system, and the personal-potential needs of the learners themselves, reducing the space-time constraints.

The final conclusions that result from the convergence of these data is that Second Life could be an innovative proposal to the campus, offering yet another aspect of what we call today “sustainable” education and includes: (a) the responds to a mass scale with the needs of learners to complete and continuous enrichment of knowledge, (b) the “moral” of lifelong learning, which will be based on participatory practices and the concept of ‘social practice’ learning through similar goals, values and principles that will govern the users, (c) the development of “critical-reflective” thought and the emergence of an innovative dynamic relationship (or dimension) between teachers and learners in relation to the identification and discovery of “sustainable” sources of learning, reflecting the real needs and interests, (e) develops and evaluates alternative ways for collective action, opening its doors to a more ‘sustainable’ educational and professional future.

The idea of using the Second Life by various training organizations and academic institutions abroad (mainly from America and United Kingdom), revealed a number of advantages over “traditional” distance learning. The contribution of this paper initially in theoretical-scientific level, stating: (i) through conducting educational research done at times in this virtual environment, (b) the theoretical adjustment of the main pedagogical principles and practice of teaching management operations according to create an application context with the help of the “cybernetic model” and (iii) the educational value-added of the “virtual system” (Second Life) as “sustainable” facility which will provide an alternative e-learning facility, while contributing to important conclusions about how evolution and recognition of innovative teaching methods can be achieved. Through the examination of the knowledge that is

Table 2. Continued

Methodological framework to investigate the pedagogical value-added of Second Life (Professor-User)	Students' thoughts as a "pedagogical" system (Student-User)
F. Adaption The "adaptive quantity" of the system, depending on teacher's requirements and learners' needs keys selection criteria for creating distance learning programs. The components of "adaptation" that constitute the educational context of the activity (activity-centered approach), is a measure of guidance, and the creation of a learning community consists as well as an important reason for choosing SL's environment. **Methodological framework for organizing the knowledge field** *Application of knowledge management strategies:* The application of strategic knowledge management is being achieved when the required procedures can be integrated into existing business processes. The successful implementation of strategies ultimately determines what changes should be made and motivates capable staff accordingly so that the same desire and to support these changes. It is important that workers feel that they can experiment, albeit obviously not at the expense of the company-and not afraid to share their mistakes and one comes through learning from mistakes. If these are not known then it is likely to be repeated. Finally, in achieving a good knowledge management program is to maintain the following: • Close to the program's process, they must link knowledge management with visual objectives, creating a vision of knowledge within the overall vision of the company. • Create a position of knowledge manager. • Create a climate for transmitting knowledge. • Encourage continuous learning. • Capable technology infrastructure to support the program, according to their specific business needs. • Setting clear and systematic knowledge management processes. **Evaluation** The evaluation of the strategies is to compare performance with objective criteria and targets set by measuring the body's ability to achieve its objectives. Of course, the evaluation should be a feedback in defining strategies. Some key practical points for implementing knowledge management program in a university area: • Take into account the overall picture and the vision of the company without drastic changes often fail. Small and frequent changes based on a transition plan to the desired state best help to progress the organization. • The cooperation of the responsible management knowledge with the parts to be gradual and small projects at first. The implementation of small projects creates momentum and helps the body to accept the knowledge management. • The knowledge management requires a change in business culture. This requires time and investment in knowledge management is slow to "return" the initial investment. We need an appropriate vision and significant reserves of patience and perseverance. **Structure pedagogical processes** *Continuous evaluation, review and improvement of technological innovations:* The multifaceted evaluation is necessary to ensure the success and quality of results from the successful introduction of technologies in schools. There are two main types of evaluation: continuous (formative) and final (summative). The constant is mainly aimed at collecting data to improve a program. The final goal is mainly to measure the extent to which the program achieves its objectives and whether to continue or terminate.	**6. Save Information** If the system can store the students' creations will be reserved for the subsequent guidance of a learning course teaching (formal or informal). If this attempt is successful, then the virtual environment of Second Life will be reused for learning (feedback). In this way learning is understood not as a function of the same virtual world, but as "transformations" that occur through the dynamic relations between objects, are facts and social structures. **Descriptions of possible knowledge management practices** *Knowledge fairs (reports):* Knowledge "Reports" are like internal evaluation reports of the collective effort that was made by students for the pursuit of knowledge in virtual environment. In a relaxed atmosphere for the students in "kiosks" where "expose" the successful results and share best practices. These reports help the spontaneous knowledge exchange among teammates who would not have the opportunity to come into contact in their daily work. The reports bring the "knowledge-action" groups closer together, without specifying who should talk to whom, giving workers the opportunity to wander, to form "wells" and talk.

received by adult learners, it is desirable to work to demonstrate the importance of personal crisis, the effectiveness of the program who attended the teaching environment and the "digital action".

DISCUSSION AND FUTURE WORK

After this adaptation of the VSM in virtual environments, and its use of distance learning, the discussion that is open, should consider the ephemeral use of this "model" in real life. At first, we propose in this chapter, an investigation that could examine the development of a systemic model of knowledge management in the light of an integrated strategy for virtual enterprises in the field of consulting. The objective of the research will aim to develop specific proposals for consultants to the strategic management knowledge to gain competitive advantage and web development, virtual partnership agreements in order to preserve operational flexibility and innovation. Using the methods that were provided by our systemic approach, it will emphasize on a more creating and maintaining knowledge of internal and external business environment, rather than direct intervention of the operating characteristics of modern management of enterprise information resources. The presentation of this approach will be for knowledge management as a process rather than object to the use of systemic methodologies such as VSM (Viable Systems Model) to the synthesis of a primary multi-methodology for knowledge management.

A second, equally, important that could provide solutions, and design a prototype regional water service based on the Viable System Model (VSM). Since then, that so far in other European countries, steps have been taken to track the chemical monitoring; there has been talk of the organic. This research could suggest alternative ways to achieve the monitoring of Biological Quality Elements (BQE). Under the proposal, it can extend to the design of a European network of regional laboratories, which will take place measurements of biological quality elements and some additional chemical characteristics of water bodies, water districts, to determine their ecological quality and further management. These workshops will provide the data sources for assessing water quality and management. The design part of the Regional Monitoring Laboratory Biological Data Quality, includes the bid law in the state apparatus, the organization (from an administrative standpoint, modeled VSM), the division of labor, which will be made to the responsible sectors (the implies based on sound criteria, selection of personnel), the system design and a real study to determine the total cost of project implementation. The whole design depicts a frame of the environmental policy, since it contributes to sustainable development. This case's aim is to achieve good ecological status of all water bodies. Prerequisite-measure for achieving the goal is to design a network monitoring unit of the biological water quality.

On the other hand, future research in virtual worlds necessarily needs to answer the question under "*what are conditions of the proposal that are feasible for using virtual worlds for the professional development of modern learners?*" Other research questions that can be explored issues that are related to the investigation of the facts, in which adult learners are involved in three-dimensional collaborative virtual environments, whereas it is perhaps the most important indicator of successful learning programs. In addition, this can be explored from an overall collective assessment of the SL's value of through the conduct of a cumulative assessment. In this way we could estimate the final result of learning from them (users), based on the final test of knowledge that is learned. The key evaluation criteria relevant to assessing the computing environment as an educational tool, their attitudes toward technology environment after the engagement (for a qualifying period) and attitudes towards the lessons of the program of their school.

REFERENCES

Achterbergh, J., Beeres, R., & Vriens, D. (2003). Does the balanced score-card support organizational viability. *Kybernetes: The International Journal of systems & Cybernetics, 32*(9/10), 1387-1404.

Alvarez, M. (2006). *Second Life and school: The use of virtual world worlds in high education.* Trinity University, San Antonio, TX. Retrieved 29 March, 2011, from http://www.trinity.edu/adelwich/worlds/articles/trinity.manny.alvarez.pdf

Anderson-Inman, L., Richter, J., & Frisbee, M. (2007). Critical engagement of teachers in the Salamander Project. *Second Life Education Workshop 2007, Part of the Second Life Community Conversation* (pp. 19-26). Chicago, IL: Hilton.

Ashby, W. R. (1957). *An introduction to cybernetics, 2nd Impression*. London, UK: Chapman & Hall Ltd.

Au, W. J. (2001). Playing God. *Lingua Franca: The Review of Academic Life*, *11*(7), 12–13.

Axelrod, R. (1984). *The evolution of co-operation*. New York, NY: Basic Books.

Baecker, D. (1997). Reintroducing communication to cybernetics. *Systemica*, *11*, 11–28.

Baker, S., Wentz, R., & Woods, M. (2009). Using virtual worlds in education: Second Life® as an educational tool. *Teaching of Psychology*, *36*(1), 59–64. doi:10.1080/00986280802529079

Barrett, L. (2011). *Beyond the brain: How body and environment shape animal and human minds*. Princeton, NJ: Princeton University Press.

Beard, L., Wilson, K., Morra, D., & Keelan, J. (2009). A survey of health-related activities on Second Life. *Journal of Medical Internet Research*, *11*(2), e17. doi:10.2196/jmir.1192

Beer, S. (1972). *Brain of the firm*. Chichester, UK: John Wiley & Sons.

Beer, S. (1979). *The heart of the enterprise*. Chichester, UK: John Wiley & Sons.

Beer, S. (1985). *Designing the system for organization*. Chichester, UK: John Wiley & Sons.

Bertrand, Y. (1995). *Contemporary theories and practice in education*. Madison, WI: Magna Publications.

Bignell, S., & Parson, V. (2010). *Best practice in virtual worlds- Teaching,* version 2.1. Retrieved 3, October, 2010, from: http://previewpsych.org/BPD2.0.pdf

Boellstorf, T. (2008). *Coming of age in Second Life: An anthropologist explores the virtually human*. Princeton, NJ: Princeton UP.

Braun, H., Hocevar, R., Quiroz, R., Cohen, M., Lucas-Moreira, J., & Jacques, J. … Samadani, R. (2009). *VhCVE: A collaborative virtual environment including facial animation and computer vision.* Retrieved 29 March, 2011, from www.sbgames.org/papers/sbgames09/compuring/full/cp25_09.pdf

Britain, S., & Liber, O. (1999). *A pedagogical framework for the evaluation of virtual learning environments*. Bangor, University of Wales. Retrieved 29 March 2011, from http://www.jtap.ac.uk

Britain, S., & Liber, O. (2004). *A framework for the pedagogical evaluation of e-learning environment*. Retrieved 29 March, 2011, from http://www.pgce.seton.ac.uk/IT/School_ICT/VLEusage/VLEpedagogy.pdf

Brocklesby, J., & Cummings, S. (1996). Designing a viable organization structure. *Long Range Planning*, *29*(1), 49–57. doi:10.1016/0024-6301(95)00065-8

Brown, E., Gordon, M., & Hobbs, M. (2008). Second Life as a holistic learning environment for problem-based learning and transferable skills. *Re Live '08: Proceedings of Researching Learning in Virtual Environments. International Conference* (20-21 November) (pp. 39-48). UK: The Open University.

Caetano, N., Knechtel, M., Resmini, R., Garcia, C., & Montenegro, A. (2009). *Simulated architecture and programming model for social proxy in Second Life*. Retrieved 29 March, 2011, from www.ic.uff.br/-ccaetano/artigos/iSociety_Social_Proxy.pdf

Callaghan, M. J., McCusker, K., Lopez Losada, J., Harkin, J. G., & Wilson, S. (2009, November). Engineering education island: Teaching engineering in virtual worlds. *ITALICS, 8*(3). Retrieved 23 April, 2010, from http://www.ics.hearacademy.ac.uk/italics/download_php?file=italics/vol8iss3/pdf/italicsVol8Iss3Nov2009Paper01.pdf

Childress, M. D., & Braswell, R. (2006). Using massively multiplayer online role-playing games for online learning. *Distance Education*, *27*(2), 187–197. doi:10.1080/01587910600789522

Cross, J., O' Driscoll, T., & Trondsen, E. (2007). Another life-virtual worlds as tools for learning. *E-learning magazine.* Retrieved 29 March, 2011, from http://elearnmag.org/subpage.cfm?section=articles&article=44-1

Davenport, T. H., & Prusak, L. (1998). *Working knowledge: How organizations manage what they know*. USA: Harvard Business School Press.

De Lucia, A., Francese, R., Passero, A., & Tortora, G. (2009). Development & evaluation of a virtual campus on Second life. The case of Second DMI. *Computers & Evaluation*, *52*, 220–233.

Dickover, N. (1994). Reflection-in-action: Modeling a specific organization through the viable system model. *Journal of Systemic Practice & Action Research*, *7*(1), 43–62.

Dillenbourg, P. (2002). Over scripting CSCL: The risks of blending collaborative learning with instructional design. In P. Kirschner (Ed.), *Three worlds of CSCL. Can we support CSCL?* (pp. 61–91). Nederland: Open Universiteit.

diSessa, A. (1995). Epistemology and systems design. In A. diSessa & C. Hoyles C. (Eds.), *Computers and exploratory learning* (pp. 15-29). Springer Verlag.

Dunn, R., Holder, D., & Rockinson-Szapkiw, A. J. (2010). Virtual worlds and learning communities for distributed pre-service educators. ISTE. Denver, CO. Retrieved 29 March, 2011, from http://center.uoregon.edu/ISTE/2010/program/search_results_details.php?sessionid=50074876

Earl, M. J., & Scott, I. A. (1999). What is a chief knowledge officer? *Sloan Management Review*, 29–38.

Embodied Research Group. (2007). *Embodiment, identity & presence in Second Life-New wine or new bottles*. Retrieved 29 March, 2011, from http://embodiedresearch.blogspot.com/2007/08/embodiment-identity-and-presence-in.html

Espejo, R., Bowling, D., & Hoverstadt, P. (1999). The viable system model and the Viplan software. *Kybernetes*, *28*(6/7), 661–678. doi:10.1108/03684929910282944

Espejo, R., & Gill, A. (2003). *The viable system model as a framework for understanding organizations*. Retrieved 3 May, 2011, from http://syncho.com

Espejo, R., & Harnden, R. (1989). *The viable system model: Interpretations and applications of Stafford Beer's VSM*. Chichester, UK: John Wiley & Sons.

Espejo, R., Schuhmann, W., Schwaninger, M., & Bibello, U. (1996). *Organizational transformation and learning: A cybernetic approach to management*. Chichester, UK: Wiley & Jons.

Gajenda, S., Wenjun, M., & Ye, Q. (2010). Second Life: A strong communication tool in social networking and business. *Information Technology Journal*, *9*(3), 524–534. doi:10.3923/itj.2010.524.534

Gazzard, A. (2009). Teleporters, tunnels & time: Understanding warp devices in video games. *Proceedings of the Digital Games Research Association* (DiGRA).

Genovese, J. (2003). *Piaget, pedagogy & evolutionary psychology*. Retrieved 3 October, 2011, from http://www.epjournal.net/filestore/ep01127137.pdf

Hansen, M. T., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge? *Harvard Business Review*, *77*(3-4), 106–116.

Hasan, H. (1999). The mediating role of technology in making sense of information in a knowledge-intensive industry. *Knowledge and Process Management*, *6*(2), 72–82. doi:10.1002/(SICI)1099-1441(199906)6:2<72::AID-KPM52>3.0.CO;2-X

Heiner, M., Schneckenberg, D., & Wilt, J. (2001). *Online pedagogy – Innovative teaching and learning strategies in ICT-environments.* Work package 1, Working group 7/8 Pedagogy, 3453/001-001 EDU-ELEARN. Retrieved January 2005 from http://www.cevu.org/reports/docs/WP1_WG7_8BP.pdf

Hilder, T. (1995). *The viable system model*. Retrieved 2 February, 2010, from http://www.users.globalnet.co.uk/~rxv/orgmgt/vsm.pdf

Hobbs, M., Gordon, M., & Brown, E. (2006). *A virtual world environment for group work*. Retrieved June 22, 2010, from http://www.formatex.org/micte2006/Downloadable-files/oral/A%20Virtual%20World.pdf

Hoverstadt, P., & Bowling, D. (2002). *Modeling organizations using the viable system model*. Systems Engineering Workshop. USA: Royal Academy of Engineering.

Hoyles, C. (1995). Exploratory software, exploratory cultures? In diSessa, A., & Hoyles, C. (Eds.), *Computers and exploratory learning* (pp. 199–219). Springer Verlag. doi:10.1007/978-3-642-57799-4_11

Jackson, M. C. (2000). *Systems approaches to management*. United States: Kluwer Academic.

Jantsch, E. (1975). *Design for evolution*. New York, NY: George Braziller.

Jarmon, L., Traphagan, T., Mayrath, M., & Trivedi, A. (2009). Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life. *Computers & Education*, *53*(1), 169–182. doi:10.1016/j.compedu.2009.01.010

Jennings, N., & Collins, C. (2007). Virtual or virtually U: Educational institutions in Second Life. *International Journal of Social Sciences*, *2*(3), 180–186.

Kay, J., & FitzGerald, S. (2008). *Educational uses of Second Life.* Retrieved 3 May, 2011, from http://www.sleducation.wikispaces.com/educationauses

Kemp, J., & Haycock, K. (2008). Immersive learning environments in parallel universes: Learning through Second Life. *School Libraries Worldwide*, *14*(2), 89–97.

Kemp, J., Livingstone, D., & Bloomfield, P. (2009). SLOODLE: Connecting VLE tools with emergent teaching practice in Second Life. *British Journal of Educational Technology*, *40*(3), 551–555. doi:10.1111/j.1467-8535.2009.00938.x

Kolas, L., & Stampe, A. (2004). *Implementing delivery methods by using pedagogical design patterns.* Retrieved 2 September, 2011, from www2.tisip.no/E-LEN/papers/EDMEDIA/SymposiaNTNU.pdf

Koleva, B. N., Schnadelbach, H. M., Benford, S. D., & Greenhalgh, C. M. (2006). Developing mixed reality boundaries. *Proceedings of Designing Augmented Reality Environments (DARE 2000)* (pp. 155–157). Elsinore, Denmark.

Liu, C. (2006). Second Life learning community: A peer-based approach to involving more faculty members in Second Life. In *SLCC '06: Proceedings of the 1st Second Life Education Workshop, Part of the Second Life Community Convention* (pp.6-11). UK: The University of Paisley.

Macedo, A., & Morgado, L. (2009). *Learning to teach in Second Life*. Retrieved 13 August, 2010, from http://www.eden-online.org/contents/conferences/OCRC's/Porto/AM_LM.pdf

Mansour, S., & Mostafa, E. S. (2008). The impact of multi-players serious games on social interaction among online students versus face-to-face students. *7th WSEAS International Conference on Applied Computer and applied Computational Science (ACACOS'08)* (pp. 772-778). Hangzhow, China.

Mason, R., & Rennie, F. (2008). *E-learning and social networking handbook: Resources for higher education*. New York, NY: Routledge.

Means, B. (1994). Introduction: Using technology to advance educational goals. In Means, B. (Ed.), *Technology and education reform: The reality behind the promise* (pp. 1–21). San Francisco, CA: Jossey-Bass.

Mumme, C., Olivier, H., & Pinkwart, S. (2008). *A framework for interaction analysis and feedback in collaborative virtual world*. Retrieved 29 March, 2011, from http://www.ve-forum.org/projects/408/ICE%202008/Collaborative%20 Systems/016.3%20-%20CWE23%20Mumme_Olivier_Pinkwart_Framework_for_CVE_analysis%20_final%20SS6_2.pdf

Ndlela, L. T., & du Toit, A. (2001). Establishing a knowledge management programme for competitive advantage in an enterprise. *International Journal of Information Management*, *21*, 151–165. doi:10.1016/S0268-4012(01)00007-X

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company*. USA: Oxford University Press.

Ozkan, S., Koseler, R., Baykal, N. (2009). Evaluating learning management systems: Adoption of hexagonal e-learning assessment model in higher education. *Transforming Government: People, Process and Policy, 3*(2).

Pereira, M., Harris, A., Duncan Davidson, R., & Niven, J. (2000). *Building a virtual learning space for C&IT staff development*. Centre for Open and Distance Learning.

Pfeifer, R., & Bongard, J. (2007). *How the body shapes the way we think: A new view of intelligence*. Cambridge, MA: MIT Press.

Redfern, S., & Naughton, N. (2002). Collaborative virtual environments to support communication and community in internet-based distance education. *Journal of Information Technology Education*, *1*(3), 201–211.

Rizzo, J., House, R., & Lirtzman, S. (1970). Role conflict and ambiguity in complex organizations. *Administrative Science Quarterly*, *15*(2), 150–163. doi:10.2307/2391486

Ruggles, R. (1998). The state of the notion: Knowledge management in practice. *California Management Review*, *40*(3), 80–89.

Salt, B., Atkins, C., & Blackall, L. (2008). *Engaging with Second Life: Real education in a virtual world*. Retrieved 3 May, 2011, from http://slenz.files.wordpress.com/2008/12/slliteraturereviewa1.pdf

Schroeder, R. (2008). Defining virtual worlds and virtual environments. *Journal of Virtual Worlds Research, Virtual Worlds Research: Past, Present & Future, 1*(1), 2-3. Retrieved 4 October, 2011, from: http://journals.tdl.org/jvwr/article/view/294/ 225

Smith, T. (2009). *Social cybernetic strategies for asynchronous learning*. Retrieved 12 November, 2011, from: http://www.iea.cc/ECEE/pdfs/art0222.pdf

Soloway, E. (1990). Quick, where do the computers go? *Communications of the ACM*, *34*(2), 29–33. doi:10.1145/102792.102797

Steed, A., & Tromp, J. (1998). Experiences with the evaluation of CVE applications. In *Proceedings of Collaborative Virtual Environment*, Manchester, UK. Retrieved 4 October, 2011, from http://www.cs.ucl.ac.uk/staff/a.steed/steed-tromp-cve98.pdf

Steers, R. M. (1977). Antecedents and outcomes of organizational commitment. *Administrative Science Quarterly*, *22*, 46–56. doi:10.2307/2391745

Steinkuehler, A., & Williams, D. (2006). Where everybody knows your (screen) name: Online games as "third places.". *Journal of Computer-Mediated Communication*, *11*, 885–909. doi:10.1111/j.1083-6101.2006.00300.x

Stephen, L., Quintas, P., & Ray, T. (2002). *Managing knowledge*. London, UK: SAGE Publications Ltd.

Thalmann, D. (2001). The role of virtual humans in virtual environment technology and interfaces. In Earnshaw, R., Guedj, R., & Vince, J. (Eds.), *Frontiers of human-centered computing, online communities and virtual environments*. New York, NY: Springer. doi:10.1007/978-1-4471-0259-5_3

Thomas, D., & Brown, J. (2009). Why virtual worlds can matter. *Journal of Learning and Media*, *3*(1), 37–49. doi:10.1162/ijlm.2009.0008

Vergnaud, G. (1987). About constructivism. *Proceedings of the Eleventh International Conference for the Psychology of Mathematics Education*, (pp. 42-55).

Vester, F. (2010). *Ecopolicy. A cybernetic environmental simulation game*.

Vidgen, R. (1998). Cybernetics and business processes: Using the viable system model to develop and enterprise process architecture. *Knowledge and Process Management*, *5*(2), 118–131. doi:10.1002/(SICI)1099-1441(199806)5:2<118::AID-KPM19>3.0.CO;2-3

Vosinakis, S., Koutsabasis, P., & Zaharias, P. (2011). *An exploratory study of problem-based learning in virtual worlds*. 3rd International Conference in Games and Virtual Worlds for Serious Applications (VS-Games 2011), May 4-6 2011, Technical University of Athens (NTUA), Athens, Greece.

Walker, J. (2001). *The viable systems model: A guide for co-operatives and federations*. Retrieved 4 June, 2011, from http://www.greybox.uklinux.net/vsmg_2.2/pdf/vsmg_2_2.pdf

Walker, V., & Rockinson-Szapkiw, A. J. (2009). Educational opportunities for clinical counseling simulations in Second Life. *Innovate, 5*(5). Retrieved 22 June, 2010, from http://www.innovateonline.info/index.php?view=article&id=711&action=synopsis

Wang, S., & Hsu, H. (2009). Using the ADDIE model to design Second Life activities for online learners. *TechTrends*, *53*(6), 76–81. doi:10.1007/s11528-009-0347-x

Wankel, C., & Kingsley, J. (2009). *Higher education in virtual worlds. Teaching and learning in Second Life*. USA: Emerald Group.

Warr, P., Cook, J., & Wall, T. (1979). Scales for the measurement of some work attitudes and aspects of psychological well-being. *Journal of Occupational Behavior*, *52*, 129–148.

Watt, P. (1997). Know it all. *Intranet*, 17-18.

Weaver, W., & Shannon, E. (1963). *The mathematical theory of communication*. University of Illinois Press.

Yahya, S., & Goh, W.-K. (2002). Managing human resources toward achieving knowledge management. *Journal of Knowledge Management*, *6*(5), 457–468. doi:10.1108/13673270210450414

Yang, J.-T., & Wan, C.-S. (2004). Advancing organizational effectiveness and knowledge management implementation. *Tourism Management*, *25*(5), 593–601. doi:10.1016/j.tourman.2003.08.002

Zaid, B., Jamaludin, R., & Hosam, A. (2011). Perceived satisfaction levels and student learning performance towards Second Life virtual environment for learning the Islamic concepts. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1860–1864.

KEY TERMS AND DEFINITIONS

3D Voice Chat: Contact with 3D sound intensity where the voice is modulated according to the distance the listener from the sound source.

Animation: “Animation or motion” of objects in space and time. The term can be used to describe the process of creating and recording images that change over time.

Cybernetic: The “Cybernetics”, belongs to the so-called “technological” learning theories, focusing on the technological revolution of the 20th century. Two key trends that thrived were in the educational field: (a) systemic (or systems theory) and (b) hypermedia environments (hypermedia). Regarding the first theory (systemic), we would say that it was used primarily for organizing the elements of teaching and the development of instructional design. It is noteworthy that in hypermedia systems lends a description of teaching elements of the pedagogical design. In the second case of hypermedia environments have mainly involved the use of technological media in teaching and the interaction of technological systems operated by PC.

Distance Education: Previously the term “distance learning” means the geographical separation between the academic institution and an educational institution by the trainees. Today this term has been replaced by other terms such as “distance learning”, “Learning through the Web” (web-based learning), “virtual learning” (virtual learning), “shared learning” (distributed learning) etc. These conditions mean that there is no more separation, no geographical or temporal, in the process of education and learning. The training takes place via the Internet (Network LAN: Local Area Network or WAN: Wide Area Network) and the World Wide Web and can be performed on completely virtual universities, where students can complete their studies without ever moving a real university or contain “mixed” forms of learning in real and virtual spaces.

Forterra Systems Inc: The Forterra Systems Inc provides a virtual world of Internet software, which allows customers-users to create their own secure and scalable collaborative applications. Users can collaborate, communicate, socialize and experiment on any network-server offered for a better experience and lower costs for the joint outreach.

Massive Multiplayer Online Role Playing Games (MMORPG’s): MMORPG’s began to make their appearance in the early ‘90s, providing network support to games-playing, in a wide range of users worldwide. The continued use of part-infinite imaginary world and the global mass turnout of users to servers such games were the reason for the genesis of many virtual worlds beyond.

Multi-User Virtual Environments (MUVE’s): Virtual multipurpose / multi-user environments and are the continuation of MUDs (Multi-user Dimensions). Also found in the literature and the term “Networked Virtual Environments” (NVE) or “virtual worlds” (VW) because allowing users who are dispersed spatially and temporally, to interact in real time.

System: A “system” has defined as a set of independent entities that interact collaborative and coordinated in a constantly changing environment.

Chapter 14
Towards a Beneficial Formalization of Cyber Entities' Interactions during the E-Learning Process in the Virtual World of "Second Life"

Pellas Nikolaos
University of the Aegean, Greece

ABSTRACT

This chapter investigates the new interactive dimension, which arises between cyber entities (avatars) that move around, meet others, and emulate their work in [D-] CIVEs ([Distributed-] Collaborative Immersive Virtual Environments). The active involvement and immersion in these "environments" elaborates the maximum possible total-relationship of the developmental users' forces (teachers and students) and creates "situations of real-life" in a 3D virtual system. The inspiration to deal with this issue originated through the prior knowledge that was gained from the previous educational studies in the virtual world of Second Life (SL), which was used as an environmental tool for action-based learning and research programs on Higher Education. The investigation and presentation of quality infrastructure that this interactive "world" hosts in was the objective of this research, through the presentation and promotion of academic communities' previous applications to enrich their curricula. The original contribution of this effort is to become a highly inexhaustible source of inspiration for the bibliographic data and interdisciplinary for the field of e-learning future.

DOI: 10.4018/978-1-4666-2098-8.ch014

INTRODUCTION

The use of computers becomes day by day more necessary, both at work and in everyday life. One of the major challenges today is to create interfaces with the computer, showing human form and interacts with the user (the anthropomorphic conversational user interface). According to the study of Reeves & Nass (1996), people have a normal social "behavior," when they interact with computers. But, the human and machine communication differs from communication between people. People talk, and use gestures in everyday interactions. Therefore, the interaction is entirely different to the standard-based keyboard, mouse and screen and for this reason; the new field of research, which focuses on conversational interfaces, including virtual assistants, called "avatars" are regularly based on artificial dimensional or three-dimensional characters. All these properties make the decisive use of avatars in various areas of life and consequently those of education. The basic approach that followed in this paper is based on the common axiom that highlights the improvements of the technologies' processes of pedagogical communication, if we want to achieve a better learning process. We must register to a "technocratic" approach and to more correctly read of this new "knowledge field" that is being generated through the construction of teaching and learning into virtual systems.

Meanwhile, computers have penetrated for good things in our lives, which will be easy, be found a look around from laptops, smart mobile phones and electronic devices. This raises the important question of *"what form should have interfaces with the user (User Interface - UI) for this new generation of computers?"* An important area of action in interactive graphics system, are conversational user interfaces where the primary objective is to display the computer a person with whom the user can interact (Siemens, 2005). This includes physical models dialogue-centered communication to interact with the computer, in which the user-driven model of the direct manipulation in the use of practical assistance. The kind of life-masks by using the avatar (avatar UI / digital alter-ego), includes the design and control of conversations, not only to convey information, but also to create a relationship with the user. Moreover, the system adapts to each user in the current situation and beyond the oral conversation develops, and can display the user's emotional state, with facial expressions; gestures and tone of voice similar (Cassell, 2000).

Pretty remarkable for this study is to investigate the importance of using three-dimensional virtual people (avatars) in the educational process and studying in great detail the mode of virtual tools and their contribution to interface with the user-student. Because of the imposing visual presence of plausible behavioral and educational strategies, the avatars are a great promise for the motivation and effectiveness of education and above this from a distance. One of the most interesting features that is being offered by these developments is the ability to create rich, three-dimensional environments with student-centered consisting of lifelike animated anthropomorphic images (Lester et al, 2004).

The existing research on e-learning shows that the participation "stages" for learners in a collaborative learning activity can provide numerous of the positive elements and circumstances, such as:

- Motivation, active engagement in the learning process (Nelson et al., 2007; Bereiter & Scardamalia, 1996).
- Expand and deepen learning experience, testing new ideas and more effective achievement of learning objectives (Pallof & Pratt, 2004; Picciano, 2002).
- Activation of perceptual capacity (Čyras & Lapin, 2009; Dillenbourg, 1999), interaction a social environment (Dede, 1996) and last but not least.

- Develop a sense of community even in an online environment (Tornincasa et al., 2005; Dede, 2004; Cogburn & Levinson 2003; Haythornthwaite et al., 2000).

The transfer of the definition "distance collaborative e-learning" (or collaborative e-learning), in a practical-teaching field, has been successfully been applied also in virtual environments (Pelet et al., 2011; Jedličková, 2009**;** Dalgarno & Lee, 2010**;** Franceschi et al., 2008**;** Merrick & Maher, 2007; Michailidou & Economides, 2003; McArdle et al., 2004). It indicates the manly work that carried out jointly between distributed users, who are usually employed in a learning activity and a project, giving a more social dimension to their experience.

This was the main reason, in which many settings added a large amount of multimedia sources like audio, video, image, streaming technology, animation, and media. However it does not leave much room for interactivity to their users. The virtual reality (VR) and image mapping technology, solves the facing problem of the electronic learning (Chiricota, 2003). Despite that, virtual reality cannot replace other forms of learning, but it can become a significantly application, which enhances both the experience and transfer of learning (Korosec & Holobar, 2002). It would be seen this technology in relation to the additional sensitivities that can offer the learner and the teacher: a sense of self, the lack of distance, the power of presence, sense of space and time, the ability of co-author, the pervasiveness of the practice, enriching experience, ease of real-time communication and participation in groups and communities.

Considering all the above we can easily conclude that virtual reality can offer highly interactive interface between human and computer, which integrates the feature interaction between real and virtual world (Johnson & Moher, 2002). An improved sense that *"there is,"* is seriously characterized as an order to the sense of space and not just that one observer that is provided through this technology. Alongside, the social and cultural identity that is lost through the LMS (Learning Management System) can be recovered through this new technology. Rich three-dimensional display models also allow students to experience many unidentified phenomena. The power of media through 3D environments may improve the delivery of material as it is possible (Alexander & Boud, 2001). So, in terms of enhancing the learning experience, it is clear that three-dimensional learning environments need to have some distinct advantages over traditional LMS.

WHY WE USE VIRTUAL REALITY?

Nowadays it is more usual to speak not for human intelligence, but for the "artificial" and not about reality, but *"virtual-artificial"* form. Those who have previously been dialed with computers, known for several years that virtual reality's technology and its applications in many fields of human activity may be more effective in our lives. From the perspective pilot in a flight simulator to the young children who use a video game, the feeling of an artificial world, in which nobody can live and move that we feel, is a very popular new reality of today's human. Already preparing virtual environments as a beautiful city with shops, which means using the Internet, will enable the picture-representative one human as he would have planned to "walk," to buy products to "meet" a fellow from the other side of the planet and talk with him.

Undoubtedly, advances in virtual reality technology have attracted considerable interest in recent years resulting in the development of a very large number of virtual reality systems for a wide range of applications. Thus, we try to classify these applications into four major categories, such as entertainment, architecture and design, education, and finally medicine. Continued cost reductions coupled with the tremendous growth of computer technology have brought the technology of virtual reality close to the general public through entertainment applications (Steurer, 1992).

A vast majority of areas that virtual reality has found a wide range of applications are electronic games, particularly online, which are a typical example of multi-user virtual environments. In such applications each player depicted in the form of an avatar (an anthropomorphic entity) through which they can interact with the environment and other users. Many large video game companies, like Nintendo and SEGA, have adopted the technology of virtual reality, and have seen a simultaneous reduction in the cost of VR peripherals used for this purpose (Mansour & Mostafa, 2008; Mazuryk & Gervautz, 1996). Naturally, the technology of virtual reality could not be left unaffected one of the most profitable entertainment industry, such as cinema productions centers. The use of special effects with the help of virtual reality is one of the most impressive elements of the film. Furthermore, in recent years they are creating more and more movies that are based entirely in virtual reality technology featuring virtual characters.

THE NATURE AND EVOLUTION OF VIRTUAL REALITY

For the further study of virtual worlds (or environments) issues, we initially thought that should be given, first of all, the definition of *"Virtual Reality"* (VR). The term is basically being used in various applications, concerning the technological infrastructure and the level of interaction, between human and PC (Personal Computer) and for this reason it is not so easy to give a precise definition. The key term *"Virtual Reality,"* was defined for the first time by Jaron Lanier (Kelly et al, 1989) as: *"An interactive three-dimensional environment, created by computer, which can be immersed"* (p. 110). Although, the idea of *Virtual Reality,* has its own roots in the 14th century and the first research efforts to the object was identified in the 80's, which was a parallel and rapid development of computers. Lanier is the first that dealt intensively with this object, creating the company VPL (Virtual Programming Languages), which had as main objective the study and development of virtual reality.

A second definition, which is better understood, used and then presents the VR technology as a simulation of a real or imagined environment within which enable a visual, audible and tactile interaction with the user (Blascovich & Bailenson, 2011; Burdea & Coffet, 2003; Grau, 2003; Rheingold, 2002; Hillis, 1999; Brooks, 1999; Lanier, 1992; Krueger, 1991). In other words, a virtual reality system creates the "illusion" of a virtual world, in which "experiencing" no one can feel and act, causing the reactions of this virtual world, as would be the case that the world was real. A successful "immersing" in a VR environment is to isolate the user or his senses from the real world and the simultaneous coating of stimuli equivalent to the virtual. Thus, the three most important human senses, namely sight, hearing and touch, to be provided by a virtual reality system. For this visual-vision is sufficient to provide the user with images from two different perspectives, one for each eye of the user, which together are seen as one dimensional (stereoscopic). The structural functional characteristic of the VR is the processing unit which is characterized as the *"heart"* of a Virtual Reality system. Is the component that receives the response of man (voice, touch, sight) through the input device and since the process generates the virtual stimuli (sound, image, touch), accepting humans to think that it is into a virtual world.

The output devices are those which undertake the transfer of virtual stimuli in humans and input devices are those that carry the reactions of humans to the processing unit. Below analyzed these three units are given to these facts. In practice, however, the term "virtual reality" includes a narrower scope. The key feature of a virtual reality system is (Okechukwu & Udoka, 2009; Hayward et al., 2004; Stanney et al., 1998; Goslin & Morie, 1996; Robinett, 1994; Kalawsky, 1993; Slater et al., 1993; Slater & Usoh, 1993):

- The production, as much as possible of realistic images from the computer and display to the user.
- The visualization of objects that represent, according to a method of real-world objects.
- The user interaction with the virtual environment.
- The playback sound, similar to the events of the virtual environment.
- The reaction of the objects of the environment, nature, to the actions of the user and their interactions.

The evolution of virtual reality systems tends to emulate the real world and feel feedback is as faithful as possible to be done. The realism that usually is offered in conjunction with the main requirements of the participants makes the virtual environment more acceptable to them. Meanwhile in this way they feel of "being there" and "being immersed" on it (Pietschmann, 2009; Guadagno, 2007; Murray, 1997; Tolga, 1997). The virtual reality technologies are being developed and enriched with new methods of representation of the natural world. As a feat of our days is the enrichment of virtual environments through the anthropomorphic representation (avatars and agents). Their aim is to improve the interaction and communication between humans and computers and be an interactive instrument in collaborative virtual environments.

AVATARS

Avatars (named also as cyber entities, virtual people or digital alter-ego of ourselves) are graphical representations of participants in virtual reality environments and can vary in their design realism. The realism in virtual representations of representations includes three factors: *realistic depiction, realistic motion and realistic behavior*. Virtual people can pass information on participation (presence), the position (location) and the role of the user (role-play) in a virtual reality environment, identifying the focus of attention of the VR system (orientation), the development of communicative functions among participants (conversation status), emotions and development activities involving users in virtual spaces (activity status). It also conveys information about the historical evolution of correspondents' actions in virtual reality environments (history of activities) and focusing on the attention of users at a particular point in Virtual Reality environments (manipulating other users' viewpoint).

The virtual representatives are well-known to the average residual or avatars. The word "avatar" comes from Indian mythology. A god, named as "*Vishnu*" is believed that has visited Earth for nine times to curb the vice. At each visit he took different forms (metamorphosis), which was called "avatar". This ability is elicited the names of these virtual representations of people so as researchers and manufacturers of virtual reality systems have offered a rich a variety of definitions. If we want to overview a fusion of all these definitions, we could characterize the process as avatar incarnation or representation of knowledge of users and its identification in a multi-user computing environment (Castronova, 2003). Specifically, as it's been defined, avatar's representation is a real 3D human being, which has developed into a virtual world. For example, a person could be represented at a meeting held in a virtual environment, or the teacher in a distance learning situation could be represented by the avatar in collaboration with distributed students. Therefore, an effective avatar needs to have human characteristics, including speech or language understanding and the externalization of users' emotional state.

Avatars have many possible properties such as: *identity, presence, obedience, authority, social facilitation*. Obedience is saying that they are under the direct control of the user, without significant control over their own actions (Bräutigam et al, 2011). Thus, avatars operation is under user's authority, offering facilities of communication and interaction while users are enable to understand better the personality and identity of the user base. Helpful, therefore, in this occasion is the creation of the sense of presence or the sense of "being there" (Bredl, 2010; Heeter, 1992).

THE VIRTUALLY ANTHROPOMORPHIC DIMENSION OF COMMUNICATION

Virtual people and their functions, which are supported in a virtual environment, considered to reinforce the concepts of "space" and "place". These avatars perform important functions, such as the visual embodiment of the user and provide additional means of interaction with the virtual world, movements and gestures. With these features that offered by virtual people, it has upgraded the status of ongoing behavior (behavioral framing), which provides three-dimensional virtual environments and especially improves the HCI (Human and Computer Interaction). Among the factors of using avatars are to:

1. Provide the physical representation of the user in the virtual world.
2. Create the impression that contact with real people.
3. Interact with the virtual database system.
4. Emphasize in user's interaction with the "physical" world.
5. Consider having avatars the ability to cause emotions such as would cause a man to body language. This is done by giving the avatar function expression of emotions and understanding of the body gestures and facial (Picard, 1997; Csikszentmihalyi & Rathunde, 1993). It makes the user feel some properties of the virtual world as if he was there.

This distinction very clearly indicates that any avatar represents a different user, so it is natural that each user is directed to the corresponding avatar, whenever it wishes communication. Although the technologies used and the equipment available permits, it is desirable that recruited some techniques, such as the following:

- **Speech:** The implementation of virtual characters with human speech is the best way of communication between humans.
- **Live Video Streaming:** Technique for increased realism of the virtual world. A prerequisite is to camcorders available on users' computers.
- **Facial Expressions:** Changes in the position of the eyebrows, the expression of the mouth and movements of the head and eyes (gaze) play an important role in a speech. Thus, can be coded a set of basic expressions.
- **Synchronize the Communication Channels:** This method, combined with the previous method and the first speech, helps express the psychology of the user and the production of realistic sound from avatars to a successful conversation.
- **Gestures:** This is pre-planned movement of the image (avatar animations), and play an essential role for visual transfer of meanings of the word.
- **Programming Movement:** Using methods of natural language processing (NLP - Natural Language Processing), recorded the human voice, assess emotional status, etc. Are recognized commands and then perform the avatar gestures, grimaces and other moves, depending on the program.

As we mentioned above, the user participant in a collaborative virtual environment is an important element of the environment and therefore should be represented to be realistic and effective. According to Thalmann (2001), the major features (avatars functions), which must fulfill the avatar is represented by:

1. Visual representation of user.
2. Modes of user interaction with the world.
3. Ways to feel the user properties in the world.

Even more important are the functions and interactions required in the versatile virtual environments (multi-user virtual environments), because in them the avatar of the user and an additional means of communication with other participants. These functions such as found in the literature:

1. Perception of space, if someone comes around him (perception).
2. Detection, i.e. the user to see who the other people (localization) are.
3. Identification, i.e. the user to recognize other people.
4. Visualization of the focal point of attention of others.
5. Visualization of the actions of others, to see what the other person the meaning of these through gestures (gestures).
6. The social representation of the user through the configuration and "decoration" of the avatar in order to know the role or responsibility; the state (status) of another person.
7. The presence, basic information to start interaction between participants.
8. The development of communicative functions among participants (Conversation status).
9. The representation of the participants' feelings.
10. The representation of the historical evolution of the actions of participants (history of activities).

As human interactions in the perception of other people often result from stereotypical interpretations of their appearance, so as applications and interactive users anticipate the behavior of agents by their appearance, creating and expectations that guide their behavior. This is why one of the main concepts in the design of the external appearance of avatars, this appearance is to give the right impression of the limits of their abilities. From inquiries made, the designers came to the fact that agents have pleasant looks positively predispose users and are considered to have personality. He has also found that the interaction of users is most effective when done by agents who have a human form (Davis et al., 2009; Barrtle, 2004).

The occurrence of an anthropomorphic image provides many channels for users' communication. Facial expressions can provide "physically" emotion, gestures which carry propositional and interactive message, but generally all forms of expression of the human form can be used as "media". It should also be noted that ethnicity is supposed to have interactive agents in human form, affects the perception of others. More specifically agents of the same nationality as the users are perceived as more loyal, more attractive and more convincing (Saleeb & Dafoulas, 2010). In a virtual application, students must have the choice to develop a specific form of their own avatar, which will interact, proposed by a number of idols. The images can differ in appearance, gender, ethnicity, age, to suit each individual student. The chosen image then interacts with the learner using synthetic speech and gestures (Simteach, 2011; Bitzer et al., 2010; Bitzer & Bretl, 2010).

BACKGROUND LITERATURE

The dominant learning technology is being used today like a system that organizes and delivers courses online, as a platform for learning management system (LMS) or as customary now to be called Virtual Learning Environment (VLE).

There are few times in the same terms Course Management System (CMS), Learning Content management System (LCMS), Managed Learning Environment (MLE), Learning Support System (LSS), Online Learning Centre (OLC) or end Learning Platform (LP). The term refers to a virtual environment for learning, rather than in virtual learning. Such systems management learning and development, electronic platforms, can be used to initiate and monitor e-learning courses and even enhance face-to-face teaching with online learning components in mixed (Blending learning). A vast majority of LMS such as WebCT, Blackboard, and Desire2Learn have already installed thousands of colleges and universities products for using by tens of thousands of teachers and students. The VLE takes learning content and to organize a standardized way, as a course divided into modules and lessons, supported with quizzes, tests and discussions. In many educational systems have now been incorporated as a learning system. In these systems, or someone learning some also manage the classroom, as happens in head-on teaching. First automates the management of learning and then record all activities of the student.

New technologies are well established in today's society and require the new generation of students to be acquainted with the use of multimedia, and bombarded by a "burst data" from the first classes of primary school. Additionally, it is necessary to create appropriate educational software, which includes teaching objectives, integrated scenarios, and metaphors to educational importance and will result of specific teaching and learning outcomes. For the development of modern human-teaching software is significant to use the anthropomorphic images (avatars). This attempt combines their potentially complex communicative functions and simulates the innate tendencies of human beings; their use will lead to significant developments and changes in the educational process (Gee, 2009; Yee, 2007; Abt, 1970)

The idea of simulation data is to create a virtual person - image. This "cyber-entity" speaks, interacts and helps many students to participate in the learning experience. Artifacts can be divided between those who make the virtual representation of the user and those representing their software agents. For example, people who interact in a virtual environment represented by the first image format. In contrast, an idol, which for example delivers an English lesson, is not intended to represent a particular real person but rather to represent a software agent or a function. In this case the attention will focus on the second image format and especially how it can be used effectively in education (Kzero, 2011; Witmer & Singer, 1998).

As a virtual community simulating human activities and have their characteristics (appearance, speech, gestures, expression) is a major challenge to develop avatars that show courses and doing all these, which would do with a real teacher, providing with a pleasant, incarnate and simple interface. The teacher's role is to guide, to motivate and to inspire students to identify their problems, advice, and monitoring with his instructions for each of them. Every teacher knows his students, recognizing their needs and sets - redefine both the selection and presentation of the content of courses taught and how teaching. Similarly to the implementation of the virtual teacher, in addition to creating a more natural, more friendly and homely environment for learning, should be given great importance

- A user-centered learning.
- The presentation of emotional reactions.
- The incentive.

A virtual teacher should always be able to provide information, answer questions, facilitate discussions, and administers a test (test or tests). Based on management's current examination, pinpoint areas of student weakness and adapted to the needs and peculiarities. Then it turns back to them, to repeat information or provide more detailed information and advice in order to solve the queries of the learner in any particular subject, but to judge him (Dörr, 2010; Benkert, 2001; Thomé, 1989). These considerations show the importance of knowledge of the character of each student since, as already mentioned, give the system the ability to tailor its training strategy to the specific characteristics of the learner, providing that information for teaching object that can be absorbed more effectively this time. At the same time, when an anthropomorphic character plays the role of the instructor, is always needed to inspire confidence that the content of his teaching is true, meaningful and valuable.

Nevertheless, to make the avatar-trainer, as effective as possible for the user, should be non-critical, not contradicted by the repeated questions and can be adapted to the educational needs of each student by offering a dynamic and intelligent way of providing knowledge. In other words, to enable personalized learning in a high level of trust and reliability. According to Cooper's (2000) research, the presentation of emotions and their understanding through facial expressions and body language is essential for the teacher-student interaction and student to student. This position can be integrated into a teaching avatar performing various functions / behaviors, including demonstration of different types of emotional reaction. For example, an image may present feeling of satisfaction if the student is doing well on an exam. In contrast, an image may show mild anger or alert the student who seems to lose concentration, for example when slow to respond to questions from the exam, which has a specific closing time (countdown). Avatars can also show when the student gets confused and gives a wrong answer animating and guiding him.

The anthropomorphic characters should bind and direct the attention of students by providing continuous incentives. An avatar can remind students to concentrate on a particular topic, encourage and investigate whether they are tired or bored. Boredom or fatigue results with lower overall activity by recording mouse clicks and keyboard options. In order to attract or focus students' attention, avatars will be able to follow a number of strategies. Constantly, can provide respite time to change the subject in a question or colors of the background of the work environment (Fritz, 2004). Also, can speak louder, telling a joke, make sounds, add music, but also to move more around the current theme or learning to present detailed information, to give greater emphasis to this. It should be emphasized that the role of fictional anthropomorphic idols in education is facultative. The images are intended both to facilitate the work of education, and improve the absorption of knowledge by students. Under no circumstances come to replace the real teacher. The image could be used to supplement the notes to the students, similar to a help section of a PC, providing detailed information and examples.

Students, therefore, have the opportunity to go and submit their questions in areas where they feel less confident about their knowledge and skills, and information and answers to their questions are presented after the image so clear that binds and supports attention of the student. The use of Virtual Reality favors is the passage to artificial worlds or learning spaces, and hence the removal of our fellow man. Students, however, be involved in the actual activities and not be completely absorbed and isolated within Distributed Virtual Environments (Lin & Gong, 2002). This emphasizes to the need for physics teaching, in which teachers must continue to teach, but also to monitor, mentor, and educate their students, helping them to develop and maintain - so essential - humanistic element.

Many scholars also point out that the anthropomorphic images enable experiential learning because it combines all the features of the media - that help in understanding and assimilating the content of teaching - with unlimited possibilities of interaction and thus can be successfully used in education. The avatars support sensory rich student-computer interaction, allowing the handling and processing of synthetic objects, as if they were objects in the real world. In this way it allows students to learn in a more interesting and alternative way (Pellas, 2010). Thus, students have the opportunity to visit museums or historical places, to conduct experiments in virtual laboratories with full equipment, without the need for immediate maintenance and watch the creative and innovative courses. Although, by using anthropomorphic entities in virtual environments, is even more appropriate when the specific subject includes dangerous, impossible, inappropriate or uncomfortable procedures. As the process through educational virtual environments, end without causing destruction or irreparable damage to the object or damage and environmental pollution.

A further idiosyncratic feature is that students must have an avatar's choice to interact and encourage personal (learning) process through active rather than passive participation. By openly and without specifying time limits, activities can resume whenever it wished since the idols neither tired nor confined by what time it is. Moreover, it is particularly important given the possibility to people with disabilities to attend and to participate in experiments and activities (Fallon, 2010; Lányi et al, 2006). As in human interactions, perceptions of other people often result from stereotypical interpretations of the show, so applications and interactive users anticipate the behavior of cyber entities by their appearance, creating and expectations that guide their behavior. This is why one of the main concepts in the design of the external appearance of avatars, this appearance is to give the right impression of the limits of their abilities. From these inquiries that are made, the designers came to the fact that agents have pleasant looks positively predispose users and are considered to have personality. He has also found that the interaction of users is most effective when done by agents who have a human form (Eschenbrenner et al., 2008; Gartner, 2007).

The importance of 3D visual representation in virtual environments (VE/or worlds) clearly reflects whether the role of the peoples' bodies in virtual reality. The human body provides immediate and ongoing information about the presence, identity, a person's attention, its activities, the availability and the expedition (Goodwin, 1986). Also, using non-verbal communication (body language, gestures, glances, facial expressions, change in tone of voice, or a combination of all these) (Argyle, 1988; McNeil, 1992; Sacks, 1992) helps management's interaction or talks smoothly and put together a social distance between interlocutors (Jiménez & Pantoja, 2008; Becker & Mark, 1998). Virtual representatives play the role of the human body in VE (Benford et al., 1997; Bowers et al., 1996). Their role is two-dimensional virtual representation as they provide the same user (user embodiment) in a virtual environment, while providing a virtual representation of the user to other participants in the VE. In the first dimension fulfill the following functions provide (Capin et al., 1998; Guye-Vuillieme et al., 1999):

- A visual representation of the user.
- An interaction with the "world."
- A better understanding of the properties of the world.

In terms of representation of the user to other participants in a 3D world, virtual representatives bear a series of functions, as originally presented by Benford et al. (1995a) and later expanded by others (Smith et al., 2000; Snowdon et al., 1995), convey information about the:

- Participation (presence) in a VE (basic information to start interaction among the users).
- Position (location) of the user.

- Identity of the user (which may be different from his real identity).
- Role of the user (role).
- A part that the user has turned his attention to the VE (orientation).
- Development of communicative functions among participants in VE (conversation status).
- Feelings of participants in VE.
- Development of actions involving users in the VE (activity status).
- Historical development of participants' actions VE (history of activities).
- Focusing of users' attention on a particular point of VE (manipulating other users' viewpoint).

TYPES OF VIRTUAL REALITY SYSTEMS

Despite the widespread use in recent years now, virtual reality is still a new and complex technology and for this reason, as we saw in the previous paragraph, there are many different approaches to the accurate determination of its meaning. Something similar happens in the classification systems. In recent years there have been many attempts to categorize the systems of virtual reality; however, each one of them addresses the problem from a different visual perspective by setting its own criteria. Most efforts to use criteria such as categorization: the technology and support equipment, the potential interaction with the user interface as well as how to use the same technology of virtual reality. Then this chapter will try to categorize the virtual reality systems into three broad categories based on the degree of user immersion in the virtual environment.

Desktop VR systems: "Desktop VR systems" are one of the most widespread applications of virtual reality, requiring the existence of a conventional personal computer without the support of specialized virtual reality peripheral equipment, such as helmets virtual reality, position sensors, etc. The operation's principle of these systems relies on the transfer of user in the virtual world through a conventional computer screen. The interaction with the virtual world is usually accomplished via mouse, keyboard or a conventional Joystick and sometimes with the help of virtual reality gloves or three-dimensional mice.

Projected VR Systems: "Projected VR systems" are the second class of virtual reality systems, whose technology is based on viewing images on a cinema screen. Typical examples of this category are *CAVE systems* that rely on stereoscopic images on the walls of a room. Using a wide field of view, the projected systems can increase the sense of immersion and the experience of the user's presence in the virtual world.

Immersive VR Systems: "Immersive systems" have the ultimate virtual reality experience, and allow the full immersion of the user in the virtual world. The user interacts with the system through a series of intelligent sensors and output units. The term of "immersion" is a description of the technology, which can be achieved by varying degrees and is essential to maintain at least one sensor organ (usually visual) (Ellis, 1991). The degree of immersion was increased by adding additional, consistent and details, greater localization of the body, richer representations of the body, reduced lag between body movements and changes that occur in sensory data, and so forth. Immersion, also, can lead to a sense of presence. This is a riveting psychological emergent property of the system, and refers to the participant's sense of "being there" in the world created by the system VE. We must note that immersion is necessary not sufficient condition for the presence of - sinking describes a type of technology, and describes the presence of a relative state of consciousness (Slater & Usoh, 2006).

Below, we present the most important features of these 3 categories such as presented by Kalawsky (1996) and are as follows (see Table 1).

Table 1. Characteristics of VR systems

Main characteristics of VR systems	Desktop	Projected	Immersive
Analysis	High	High	Low-Neutral
Perception scale	Low	High-Neutral	High
Navigation	Low	Neutral	High
Delay	Low	Low	Neutral-High
Sense of immersion	Low	Neutral-High	Neutral-High

[D-] CIVEs

Based on the fact that there is no clear and strict definition of the term *"virtual world"* or *"virtual environment,"* we try to give below, some of the most prevalent. The term itself is controversial and of course leads to misunderstandings and hours of philosophical discussions. On this occasion, we truly believe that we must construct a definition about virtual environments and finally re-thinking the applications that can be in these. With the average *"Virtual Environment"* (VE) we mean a computer system based on newer technology of three-dimensional applications, which simulates in the PC screen a "physical" space or place like this in real life and aims to present:

1. A visually interactive and multi-sensory "world."
2. Exclusively user's world.
3. The influence of the user in the "world."

The *"Virtual World"* (VW) is the result of a virtual environment's operational structure, which includes:

1. Representation of a natural environment and "variants" in connection with them but a fantasy, where users' roams freely without restrictions and commitments.
2. Virtual world's rules for building and interpreting data to support the operation of the "physical" environment as a computer system.
3. Capacity, i.e. the upcoming changes and developments that are promoted by the time and place.
4. A 3D environment that is hosted on a server or even in a form of software, which is stored on the PC's hard disk, gives users the impression that is to be established on a "solid state", where everything looks and move normally.

In addition to the above, we investigate and examine the tools and features that should be available in the virtual world, namely [D-] CIVE ([Distributed] Collaborative Immersive Virtual Environments) as for the main purpose to be the growth of learning process, and for this reason we decide to create a board (Table 2) that depicts crucial circumstances for implementing and supporting collaborative learning applications (based on virtual worlds' interaction we used the symbol Y for *"Yes"* and N for *"No")*.

A simple definition of a distributed collaborative immersive virtual environment ([D-] CIVE), is essentially a CVE (collaborative virtual environment) which is aimed not only to fail at least one but to cooperative and additional educational goals such as synchronous and asynchronous learning. A [D-] CIVE consists of a set of virtual worlds or a world, which offers educational service to its users (see Figure 1). Artifacts (the graphical) user populates the [D-] CIVE and provides ad-

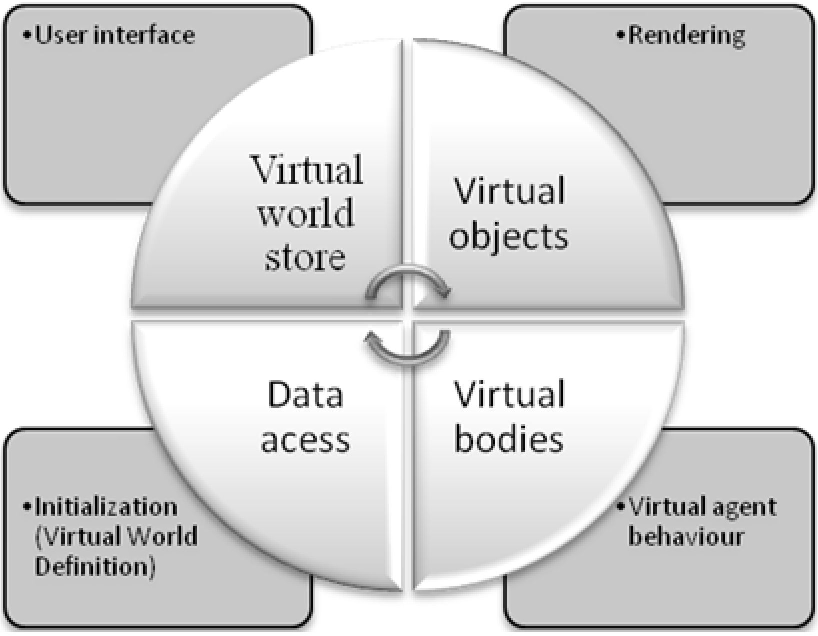
Table 2. Basic criteria for using [D-] CIVEs

Criteria	CROQUET	DIVE	ACTIVE WORLDS	QUEST ATLANTIS	MOOVE	THERE	PUZZLE PIRATES	SECOND LIFE
Interactive representation	Y	Y	Y	Y	Y	Y	Y	Y
Easy Representation of avatars	Y	-	Y	-	-	-	Y	Y
Create communities of practice	Y	-	Y	-	-	-	Y	Y
Role-play	Y	-	Y	-	Y	Y	Y	Y
Visual objects	Y	-	Y	-	Y	Y	Y	Y
Voice chat	Y	-	N	N	Y	Y	Y	Y
Video-conference	N	N	N	N	Y	N	N	N
Gestures	Y	-	Y	Y	Y	Y	Y	Y

ditional behavior such as gestures, interaction, movement and sound. With the implementation of an attractive, friendly and efficient user-oriented teamwork, learning environments provide modern and asynchronous educational services, including many technological and pedagogical issues. This section provides a brief description of the key components, issues and requirements of networked and virtual learning environments (like [D-] CIVEs).

A simple virtual environment (VE), is a computer system that produces a three dimensional virtual environment for users, in which interacts and receives real-time feedback. If multiple users are connected and interact with one another, the above definition is extended to a multi-user or

Figure 1. The core of a D-CIVE system



shared VE. A collaborative system of the virtual world (CVE: Collaborative Virtual Environment), aiming at a cooperative target, can produce a well-designed VR world, with additional educational tasks, such as synchronous and asynchronous communication, experience and deepening the collective presence of distributed users (Steed & Tromp, 1998; Bramlette & Bouchard, 1991; Chan et al., 1991). A [D-] CIVE is a whole virtual world or separated virtual worlds, supported by an educational function. Users are represented by avatars that populate a CVE and can be provided with additional behaviors such as gestures, interactions, movements and sounds. Each [D-] CIVE must be complying with a set of requirements to be widely used. Users are offered a high-level of presence through their representation of an image of their choice, which simulates some basic realistic effects, such as gestures and movements, which give them a shared sense of space, presence and time (Blanton & Wainwright, 1993; Cohoon & Paris, 1987). Users are also able to navigate in a shared three-dimensional space, in order to approach the content provided, to examine their knowledge, to interact with each other, to practice their skills and obtain information provided. Furthermore, users are informed of the presence of others (avatars), arrival and departure.

A [D-] CIVE should also provide users with many kinds of interactions in order to improve the development of active users as autonomous learners and learning context in the near term. Two types of interactions that are defined in a [D-] CIVE are:

- Multimodal user interaction-to-user chat, voice and gestures. This type of interaction is supported by the joint operation of three-dimensional objects. Important features are real-time applications such as audio communication, sharing of application and operation whiteboard.
- The user-system interaction, which is based on aid of navigation and commands that the system provided to the user for a specific function as well as the manipulation of three-dimensional objects. Additionally, users should be able to insert and change objects in a three-dimensional world, by sharing these activities with other users. This type of interaction gives users the ability to customize the entire design and offered the spectacle of VEs according to the needs of their specific issues. Therefore, the type of user-system interaction satisfies the need for adjustment.

Although, immersed applications are most effective by using VR technology. The main feature of these applications is interaction and not sinking (Corne et al., 1994). Furthermore, this type of application, which is designed for educational use, should be suitable for widespread use and mature technology in a specific place (e.g. schools or distance learning programs). Considering these requirements, the immersing VR technology is mature and precise. On the other hand, the desktop VR is more suitable for widespread use on the hardware and software requirements. A [D-] CIVE must be scalable for users to support large-scaled virtual communities. This set of users can be divided into each virtual world, as a part of a virtual community that is able to support a maximum number of concurrent users. The [D-] CIVE should be able to incorporate any digital course ware platform.

The above factors contribute two other features which are "consistency" and "coherence". "Consistency" makes the distribution and synchronization of the user, who entered as well as the independent user behavior in order to, achieve the impression of a single shared world. "Coherence" is probably being used in the sense of a uniform structure of services, primarily related to the practical and functional characteristics rather than the visual representation of the VEs. Apart from the advanced features that a [D-] CIVE supports, it must be able running under different hardware platforms and software, supporting different formats/protocols and attending adequate security mechanisms. The system should provide an easy and comprehensive management mechanism that allows an easier access of teaching materials from the users.

Finally, students are asked to solve problems, arising from everyday experience. In addition to the collaborative environment that a [D-] CIVE supports, is designed to provide flexibility through possible representations. Because of the scientific understanding concepts, is rare difficult and time-consuming for students explore only a few basic concepts. The strategy focuses on depth rather than to cover all the material in-depth. A [D-] CIVE facilitates the meta-cognitive awareness, by allowing students to express their comments and representations of knowledge about an object and then compare it with other (Vosniadou, 2008; Bigge & Shermis, 1992). Students are made aware of what they know and what to learn. Moreover, the variety of information types that can offer, resolving complex problems from different angles.

Enrichment Critical Characteristics for Authentic Activities in a [D-] CIVE

Our knowledge about the effect of conventional means of information visualization (map on papers), even more so the innovative graphical representations (map on the computer screen), in cognitive processes is limited. However, it is obvious that the graphics technology opens new perspectives in the educational process. For example, a cartographic educational software design based on one of the "paradigm" for processing spatial knowledge acquisition and simultaneously combines multimedia technology. It can attract the interest of the pupils, introducing concepts in a playful way and it is in phase to give able the users participate in the planning maps, helping of self-teaching (Hansen et al, 1999). A concept can be introduced in many ways, combining sound, dynamic images, etc., While an electronic map (media) can "explain" the content by using various means, enabling a wider range of optical variables (such as time, traffic, etc.), or through interaction with the user.

The effort to date in design and construction of educational software encounters difficulties to lack the necessary pedagogical study. Our proposal concerns the pedagogical methodology for designing and developing educational hypermedia software capabilities. Our model is centered on the pupil. An analysis of the model identifies the students' objectives, which are based on a classification according to the purpose we seek. In combination with appropriate pedagogical principles and teaching strategies for the selection of the instruments used and then draw the teaching methodology. The model we propose includes four parameters, the cognitive material, how to communicate with the user, technical features and teaching methodologies. The analysis herein focuses on teaching methodology, categorization of objectives and ways of achieving them. The summary will be fortified characteristics that could mobilize and make students engage in authentic learning activities, suggested are:

1. Providing learning multiple representations to enrich the content. The information in virtual environments, are presented through a variety of interactive media such as text (note-cards), visual viewing, headphones. In this way the environment offers many opportunities representations of both the users and the objects they use to learn.
2. Providing multiple options of expression and control of the situation they have. There are an option exercise and operations in different forms and require from students in different ways of expressing their answers (drag and drop, copy-paste word documents in note-cards).
3. Providing multiple options for information findings through mobilization. Students feel safe and confident when seeking answers

to questions. This sentiment is not possible without the flexibility that is offered by textual authoring tools and communication. It highlights the central role of the student is given the weight of self-motivated and creative dialogue with the teammates. The visual interactive character using hypertext and hypermedia, contribute to this very well through the interaction of contact offered by the virtual playing field, giving more control of both the virtual and the figure of the learning material.

4. Inextricable relationship and dynamic view of the interaction between real and virtual life, to promote structural changes in the mastery of knowledge.
5. Authentic context of activities, where the student is aware of the action and steer successfully through inter-tool communication with the professor and will inform for the development of knowledge.
6. Developing a true working relationship to achieve common goals, giving the opportunity to reflect on, and any alternatives.
7. Strengthening of this empirical knowledge by incorporating interdisciplinary sources that encourage alternatives ownership of knowledge resources.
8. Solving more easily problem situations head in the learning process. This is a critical point for the user as it faces the danger of *"external cognitive overload"*, i.e. to receive information without being able to process on it fully.
9. Permitting interconnection and inter-operation between states with the ergonomic features of the virtual system.
10. Allowing the sense of autonomy and freedom, as the user's physical presence can help in the creation of learning material, suggesting that there may be a steady pace, which will follow the student to progress his knowledge.
11. Including reliable sources of knowledge in databases accessible to all. Here we would say that it is useful to allow students to evaluate themselves, based on meta-cognitive skills content that will collect and use.
12. Directing assessment activities to obtain feedback and proper allocation of resources knowledge.

Also to allow system's responding and optimizing the above requirements that are considered mandatory for the growth of the teaching process, it should provide:

- Computing power within the framework of simultaneous calculation and use of data at the same time and at the same speed.
- At least it will be a reliable solution in case of failure (the system "gives" other mirror sites).
- Adequate scalability of virtual resources, such as knowledge and learning spaces for the continuous creation of new ones. It is noteworthy that the levels of adults' learning usually differ, as we have an approximate age homogeneity and heterogeneity of cognitive.
- Information robustness and maintenance of the system in order to be able to cope with the frequent changes or interventions on the part of students.
- Feedback prompts. The reuse of functionaries and the information contained action groups to give the possibility of repositioning and re-use functions to solve problems.

RESHAPING HUMAN INTERACTION WITH VIRTUAL WORLDS

The Virtual Reality, which supports the 1-D technology, could be described as a system of high-level interface, which produces real-time simulation and interactions through multiple channels. The promise was not detected in the reproduction of conventional reality, but the ability to generate synthetic realities without precedent. The three key ingredients are actually: *immersion, interaction, imagination* (I^3), but which are limited by human imagination (Burdea, 2000). With regard to the applications and the "denaturation" of the interaction of the 3D virtual reality effect, we would say that users' affect, are depending on the "input" devices (keyboard, mouse or joystick) or "output" (PC screen), which users utilize to "be immersed" in the "environment". These applications are divided into *"passive"*, where the user navigates in the virtual world that surrounds him without testing at exploration, in which the user has complete freedom without the possibility of intervention in the events, and *"explorative"* where there is a potential interaction with virtual objects and virtual environments are change. A virtual environment can be defined and changed the location, scale, density of information, interaction and response system and in the end the timing or level of users' involvement.

The technique of interaction is extended to include the possibility of parameterization of physical quantities. The interactive effects simulations help students to manage their own way of development conditions of a phenomenon, modify the variables that affect them and observe the results of these manipulations. During the learning process, students explore the changes of models or corresponding changes in the effects of changes in the models, when they try to change the variables that are involved and influenced the phenomenon, such as a distance objective lens. The modeling involves creating a mental framework that is enable for learners to realize the difference between reality and simulation model, as well as from the beginning could mislead students. The main characteristic of a large number of modern multimedia applications is the ability to provide the user interacts with the application. The purpose of interactivity is to adapt the application to the needs of each user, giving him the ability to determine certain characteristics of the presentation of the information provided (McMahan, 2003; Sheridan, 1994).

The new technology that is proposed for education with the help of computers based on constructive learning theories, looking for "rich quality technologies," and suggesting the 3D virtual reality as a useful educational tool. In addition, it should be assumed that learning is directly related to the action and interaction with the environment, with the most knowledge is produced and constructed through the interaction with virtual worlds. The interaction of student-user's environment is currently depending on "interface's" view, which is a combination of virtual worlds that provide multiple representations and implement dynamic linking information with interactive hypermedia nodes. An interactive application can contain three degrees of adaptability to the wishes of the user, concerning the definition of the range, speed and format for presenting information. Any application that supports at least one of these features includes an automatic presentation of information that accepts user commands, resulting in non-linear presentation of information. In contrast to applications that support linear or passive presentation of information, followed a predefined plan presentation on which the user has no effective control or power to intervene. In implementing navigation in the virtual world, beyond the design environment is equally important to allow the user a positive interactive virtual simulation that should include:

- The visit of the user in any location of the virtual world and wants to interact with the objects that surround him. Specifically, the user has the ability to move the character in any direction the visitor wishes to visit any part of the virtual world and choose to visit in any order chosen. Instructions for moving user's character on the screen by pressing a particular key specified by a specific application must be defined clearly. Also the user can request and be given information about the immersed area that surrounds it. Moreover, when wishing further information on any exhibit can choose to display the guide who takes a more detailed description of the exhibit. Finally, to facilitate the user is required to display informational message window at the entrance to certain areas and at the start of the application.

- The decision to follow the flow and execution of transactions when interacting with the environment. The application includes two degrees adaptability to the user's wishes concerning the order and format of information. The interaction in the implementation of the virtual world of the museum, largely implemented three ways listed below:
    - **Binding:** Allows the mapping of certain keys to certain actions. In this way the user supplied options by pressing the corresponding keys.
    - **Territorial:** Triggers (or "area triggers") which are the outline specific areas of the virtual world. Then, with implementation of appropriate methods of triggers specifies procedures are activated when the visitor is in confined areas and when entering or leaving.
    - **Behavioral***:* Because functions and methods that implement the interactive objects in the environment and determine the behavior of objects in specific circumstances.

The investigation of the interim needs of the present research, we selected the virtual world of Second Life (SL), which is perhaps the one of the most famous and crowded virtual environment, with thousands of social networking friends and trainees from universities to choose for both entertainment and learning respectively.

ORIENTATION TO SECOND LIFE

The evolution of technological power of the PCs and Internet, has given the opportunity to create innovative electronic environments for both entertainment and learning. The new technological infrastructure to accompany the rapid spread of broadband networks and additional developments, such as Web 2.0 applications and the creation of distributed 3D virtual environments (3DVEs), have changed far beyond traditional methods of distance education (Sivan, 2009; Spence, 2008; Conklin, 2007). Moreover, the rapid development of electronic social networks has changed the "cyberspace" in a rapidly growing communication system, bringing to the front many facets of *"networked collectivity."*

Second Life (better known by the abbreviation SL, see Figure 2), is a three-dimensional virtual world entirely created by its residents, and firstly developed by Linden Lab, on June 23, in 2003 and is available via the Internet. The client portion of the program called "Second Life Viewer"; it's free of charge and allows users, called as "residents" (or "gridizents"), to interact among themselves and with the environment itself through cyber-entities (avatars). SL is one of the well-linked virtual worlds that attract the interest of both social-networking friends and educational institutions (especially overseas).

The culture of digital culture and studying made many users more receptive to virtual environments, because of the possibility of "immersing" into them. The inspiration for the creation of virtual worlds was the literature of cyberpunk and especially on Neal's book *Snow Cash*. The main aim of the founder of Linden Lab, Rosedale Philip, was to create a world such as the *"Metaverse"* that Neal (1992) describes *a world where*

Figure 2. Introduction to Second Life (URL: http://secondlife.com/)

users can interact, play, work and communicate with other users distributed from around the world (p.19). The technical infrastructure completes on our personal computer screen, a three-dimensional virtual reality network system for supporting communication and collaboration with geographically distributed users, over 18 years old. Despite the fact, the first creative conception of SL was not being planned for any particular scientific research program, as those opposed from almost all three-dimensional virtual reality "systems", but clearly for entertainment. Among the factors of impressing, it doesn't prevent some universities to use it as "educational tool" for organizing, managing and transferring their "knowledge field" (Zaid et al., 2011; Macedo & Marcado, 2010; Inman et al., 2010; Danforth, 2010; Wang et al., 2009; Wang & Hsu, 2009; Gazzard, 2009; Smith & Berge, 2009; Bowers et al., 2009; Warburton, 2009; Hundsberger, 2009; Campbell, 2008; Maged et al., 2007; Arreguin, 2007; Prasolova-Førland et al., 2006; Cohen, 2006). Nowadays, SL is used as a creative *'canvas'* of knowledge that can be considered as a supplement (or not) for the traditional environment of a classroom, providing new opportunities even for an existing curriculum. Almost daily, new educational institutions are active on it and exploiting or developing exclusive e-learning programs to deliver high-quality services to a global audience at low cost (OECD, 2011; Broaddribb & Carter, 2009). Educational institutions can use SL's *"canvas"* to create secure geographical areas (Grid's) and enhance experiential or empirical e- learning activities.

Pretty remarkable is the fact that Second Life can be used also as a *"Metaverse Skin"* for LMS, because it supports a "client-program" technology. On this occasion, Kemp & Livingstone (2006), describe the strengths and weaknesses of a multi-complex virtual environment for teaching and exploring the potential benefits of integration with the traditional LMS. The conclusion that is reached, is that virtual environments and traditional learning systems (e.g. Moodle), seems to each have their advantages and disadvantages. Combined Second Life with a LMS, we can divide each platform offers and additional possibilities for the learning process. The linking of these two systems can allow designers of education systems and teachers, discovering new exciting opportunities to interact with the Web and virtual environments. Research shows that teachers interested in using the Second Life MUVE for teaching. The result

Figure 3. Team-work patterns in the virtual world of Second life (http://maps.secondlife.com/secondlife/Montclair%20State%20CEHSADP/132/61/23)

of the study of Cliburn & Gross (2008) reveals that students who attended a lecture in real life showed significantly higher scores than students who attended a lecture on the same issue in SL. In conclusion, the heads of research suggest that while education in virtual worlds such as SL, is still in its infancy, there are some critical ways to improve mainly by adding additional constraints and supervision (moderation) in the avatars of students with fixed interfaces.

Numerous potential advantages of these studies shows that SL may be an alternative future promise to traditional academic approaches of e-learning. In this new perspective, we found the term *"e-learning 2.0"*, which gives more emphasis on social learning and social media, like blogs, wikis and even virtual worlds, like Second Life. The multimedia - interactive applications can be regarded as a relatively new teaching tool that allows the application of modern teaching methods and strategies for e-learning (Koutsabasis et al., 2012; Pellas, 2011; De Freitas et al., 2010; Falloon, 2010). Students are discovering new areas of interest and become practically *"seekers of knowledge"* and not mere recipients of directives and regulations (see Figure 3).

Foundations of the Theoretical Problem

During to a university course, it is a clear lack of emphasis on the development dimension of teaching, which is a key driver of knowledge transfer from teacher to students. This usually leads to degradation of the problems of excessive information which has to deal with the teacher during instruction, which meditates, experiences and controls the process of creating and transmitting knowledge. The teacher as opposed to "education researcher" must make decisions under pressure of time, without being able to monitor and process all available information on the environment (Cross, 1981). The pressure of a successful performance in the demanding environment of higher education, the teacher pushes on track 'experiential expertise'. The awareness of important phenomena of learning and social interactions, the conscious use of "innovative" learning theories, but also the ability to act effectively as one teacher without time for extensive treatment of possible actions, are "hidden" objectives of the teacher who tries to implement a different pedagogical example in class. The teacher realizes that the challenge of learning environments looking for him and his students. Progress in understanding and using theories will be enhanced by involvement in action to "adjusted" himself and leave the classroom behaviors in line with the experience and reflection, which consciously guided or created between the students, using their theoretical knowledge.

Under this situation that is gradually formed, developed rapidly and it was mainly in the field of distance learning, made us thinking about the future of alternative platforms that could be implemented effectively. So in the example of Second Life is considered appropriate to highlight and present, in this investigation, the main efforts of Higher Education's courses, that are given: (a) today's users are seeking innovative learning environments and (b) are preceded by similar efforts to collect past and establish educational research in the fields of education, to enrich the literature.

OBJECTIVE OF THE RESEARCH

The systematic use and dissemination of e-learning, is frequently recapitulating with the expanding needs of both individual and social knowledge, led to a new generation system, such as virtual environments. The assistance that is offered by distributing learners flocked to a common multi-multimedia environment, coupled with the possibility of centralized planning and management courses with emphasis on collective, leading users to the co-creation and co-construction of knowledge. The interactivity and social form of modeling allows the design of learning activities in accordance with modern pedagogical approaches. Key questions that we must answer at the moment are:

1. Can Second Life be an environment for action-based learning and research, regarding the quality of infrastructure that is virtually interactive?
2. Can Second Life be considered as a useful platform for training providers and organizations that have used it for delivering their courses or research scripts?

According to the outline frame of this work reference, we would say that this part of the presentation of qualitative and functional characteristics of virtual reality to make "authentic" activities with emphasis on the [D-] CIVEs, which we could use in Higher Education. By the way, we can better understand the objective of our research, which was not different from the presentation and promotion of the previous applications of the university community from their curriculum in SL. In our research we eventually believe that we can put a "little stone" in existing literature, and our originality lies in the attempt to formalize and disclosure of educational applications in SL, so as to be better understood as a reliable source for e-learning.

The Contribution of this Effort

The contribution of our research in distance learning, through an effort of theoretical valuation of the teaching process of the trainees' uses of Second Life, could not be separated from what comprises a "sustainable" education system. In this sense we want to emphasize the special relationship that we believe can thrive between SL (as a "sustainable" means of education) and students respectively. Further utilization through the literature review we have presented an educational-research side, we made it clear that Second Life, can be part of the whole "system" of education (at least in Higher Education), implementing by the educational community with *"action-planed scripts,"* and avoiding any problems that are encountered today (mainly because of the technological infrastructure and economic factors). The contribution and originality, initially in theoretical-scientific level, stating:

- Through conducting an extensive literature review of major educational institutions and organizations that have implemented applications in Second Life.
- The educational value-added of the virtual "system" (Second Life) as a "sustainable" facility, which will provide an alternative way for the e-learning process, while contributing to important conclusions about how evolution and recognition of innovative teaching methods are previous studies be implemented.

THE UNVEIL OF VR INTERACTIONS THROUGH THE E-LEARNING PROCESS IN SECOND LIFE

The 3D virtual reality, in a theoretical context, can be characterized as a very powerful tool in education. The perhaps most important educational dimension of virtual realities is the ability to provide the user to explore innovative interact actively in cyberspace, not to study, as with a printed book, or browse through the Internet with the supernatant. In this respect, actively promotes the education and experiential learning, is combined with the experience of the individual to use virtual environments, in which are fixed and varying the position, scale, density of information, interaction and response, the timing and degree of user's involvement.

At the conceptual approach of designing and developing a virtual reality system for educators-interactive applications, it must be focused on cognitive, spiritual, social and emotional processes of the students. Surveys have found that teachers who use interactive teaching methods, aimed at promoting interaction and a sense of community among students (Nalbant & Bostan, 2006; Fress & Kessler, 2005; Hazel & Mawyn, 2005; Rovai, 2001). Indeed, strategies such as call a "cyber-environment," where the teacher is always available for students, the fast feedback with online answers and create a warm, pleasant and supportive learning environment, reflected by the term "cyber-caring," (Yamashita, 2006). A virtual learning environment exploits and highlights the characteristics of pedagogical principles and teaching and of course the theory of social constructivism and paves the way for development of new teaching approaches and theories (Bricken, 1990).

According to the above, it would be for research and determine whether the terms Education web site, "Virtual Campus" and "3D Environment / Virtual Reality Supported System" is quite broad, so that they can to describe clearly the term Virtual Learning Environment, which in theory is adjusted and the SL. More specifically to relate correctly this adjustment, which we discussed, you should describe what we consider as an educational virtual environment, whose features are:

- Not be considered fully as an educational site, although some use the term virtual learning environment to describe sites that contain just a few static pages with educational material.
- Not identical to a "virtual campus", as in this case should provide academic courses, while the term Virtual Learning Environment is not limited to this purpose. So the virtual campus can be considered as a subcategory Educational Virtual Environment.
- Not be limited to systems that include virtual reality and three-dimensional technology, since some environments include less complex interfaces, such as plain text.

All these features can easily track and the virtual space of Second Life for a more detailed, meaningful and efficient export of the functional requirements using 3D technology. However you should define the basic characteristics of the general sense. The features and interactions that occur and criteria are to separate from other environments, which are the following:

- The information space is clearly designed for educational use.
- The educational interactions that occur in the environment transform spaces into places of communication.
- The informative site fully represented in various ways ranging from simple text to three-dimensional virtual worlds.
- Students are not just passive receivers of information, but participate in creating the virtual space.
- Creating an educational space in Second Life, not limited to the provision of tele-education, but also contributes to the educational process in the classroom (Blended learning).
- It is proposed to integrate heterogeneous technologies that support different pedagogical approaches.
- A landscaped space or virtual site should have common features with those of natural environments.

Second Life is not designed exclusively for education, which creates an extra burden on participants. Yet, it seems that could be a suitable instrument for distance education and collaboration. Even the findings of previous surveys (Zarraonandia et al., 2011; Mon, 2010; Ronsivalle & Donno, 2010; Seung, & Bolebrush, 2009; Conrad et al., 2009), reveal an overall satisfaction of students because of their SL saves time for the transition to the place of education or collaboration and offers many of the tools necessary to work. More generally, we would say that in collaborative distance learning could help to maintain communication and cooperation, especially when users are geographically remote. Importantly, it manages to win their preference as a means of cooperation in comparison to the traditional method, which prefer more because of the immediacy it offers. In these lines, it suggests that teachers "take advantage" with appropriate instructional techniques and learning scenarios, a very important competitive advantage of the SL, i.e. stimulate the interest of participants.

Educational Fields

The transfer of real-world practices in the virtual can be having even more positive results in cooperation and the psychology of trainees. On the other hand, the adoption of new ones not correspond to the practical objects of the real world, can motivate them and increase their interest in online activities, opening prospects for new techniques, especially when they adapt into collaborative virtual environments.

With the concept of a learning process in the virtual environment of SL, we know that ultimately the final value of the instruction that is converted into something stronger than a formality. The difference then of SL by any other constructive environments, is that it is possible for students to be active, to make themselves "actors" of a novel process that will bring them closer to knowledge and increase their self-esteem. Although, the construction company, Linden Lab, has not yet provided any educational institution that emphasizes the effort to safeguard the educational environment, but more than 150 universities and education organizations to this day continues to support efforts to create authentic activities for their courses. Some of them are (Baker, 2009):

1. Princeton University, offers a unique music concert in Alexander Hall.
2. University of North Carolina that built and used a virtual clinic for students of medical parts.
3. University of Kentucky, maintains a service centre to virtual libraries where there are up to agents that can help readers to find books.

4. Bowling Green State University, that offers selected hours of service to the public on virtual offices.

Also remarkable efforts are (Kelton, 2007):

1. College of Humanities and Social Sciences at Montclair State University of New Jersey, where in collaboration with the Literature Alive![1], A program that helps educators to create immersive learning environments, suitable for delivery of literary texts.
2. Vassar College, where they built the chapel and the Cappella Sestina in this area created a learning environment
3. Modesto City Schools, in which through the student exchange program PacRimX[2] Kyoto of Japan, where firstly know each other for a year and then they try learning a foreign language.

Everything in Second Life (buildings, landscapes, creatures, etc.) has been created by "residents". So, it is primarily an exploration space, where imagination is left free for creation (Fetscherin & Lattemann, 2007). Communities and groups can be formed based on common interests and "residents" can "build" to build all the objects of their world. Indeed the range of educational activities that work to date (oldest or implemented), is particularly extensive. As a result, however, every effort mapping of these activities seems highly unlikely. The Institute of Eduserv Foundation, has previously carried out several studies evaluating educational activities of tertiary institutions within the multi-user environments (MUVEs), but the involvement of this activity is limited to the borders of the United Kingdom (Eduserv, 2009). More and more educational institutions acquire a "presence" in Second Life, in order to provide a more interactive, communicative and "immersed" way of e-learning. It is rather a parallel universe where we can develop social relationships, do business and learn with a low cost.

On the other hand, initiatives have been undertaken and the Australians creating a wiki, with a brief description of educational activities, this time on a global scale (Kay & Fitzeland, 2009). These researchers have even categorized these activities, trying to highlight the key framework for their implementation. We can briefly mention the following areas:

1. **Field of Health and Welfare**: Educators working in the field of medicine and health care seem to have used the characteristics of the SL. According to Antonacci & Modaress (2008), there is designed a virtual clinic, attracting more students to "experiment" with simulated "patients" (Diener et. al., 2009)
2. **Field of Tourist Development**: Knowing that users of SL can at the touch of a button to "teleport" in any area, many countries around the world took advantage of this capability and planned countries. Also, very useful is the fact that even embassies of these countries have embassies and created by handling the affairs of virtual inhabitants (Penfold, 2009).
3. **Field of Languages**: SL allows people to communicate with distributed users from the entire world map. In the case of understanding the multicultural standards and culture behind them, is catalytic. So, since the creation of institutes that have offered lessons of foreign languages (English, Spanish, French), it seems that users and employed in this way have an exponential increase in panels deliver to residents free classes (Deutschmann et al., 2009).
4. **Field of Economics and Business Activity:** The "real" economy that SL offers can create a new area of research and innovation activities from world class companies, like IBM, Dell etc. Many companies or even institutions, are using linden dollars (L$),

to make their financial transactions and operating with the minimal cost (Gajenda, et al., 2011; Switzer, 2011; Barwick & Drabic, 2011).

5. **Field of Architecture and interior design**: The easy use of the programming language (LSL: Linden Scripting Language), has attracted the interest of scientists involved in the so-called "practical" sciences (Esteves et al., 2009). In this way they can use the graphical representation of spaces and places, available with the ultimate aim of avoiding the "heavy" type programs like "Corel".
6. **Field of Fine Arts and Literature:** The project called Literature Alive by Beth Ritter-Guth and Eloise Pasteur is best known in the global community of educators. Used by students of Fine Arts, who with the help of desktop virtual reality, promoted significant works of literature, giving the required 'dip' needs (Bell et al., 2007).
7. **Virtual Communities of Practice (vCoP)**: The need for concentration of both members of a society in the virtual environment, and safeguards against "offenders", was the starting point for the creation of learning communities as:
    a. **The International Society for Technology in Education (ISTE):** ISTE is a nonprofit organization that seeks to integrate and use of new technologies in education. Since 2007, maintains a strong presence in SL with private rooms and a network of volunteer teachers who educate and welcome colleagues from around the world, over the functions of the SL platform of open spaces for the construction and use of three-dimensional objects (sandboxes).
    b. **NMC (New Media Consortium):** NMC is an international non-profit consortium of some 300 organizations with an educational orientation of the integration of ICT in teaching (colleges, universities, research centers).
    c. **Discovery Network Island:** Since 2008, operating a thriving global community, where teachers experiment the use of digital media and sources.
    d. **Lighthouse Learning Island:** It is an educational community that seeks to digital familiarity with the functional elements of the SL and integration in teaching. The action began in 2008 and is responsible for the program "Skoolaborate".
    e. **The Confederation of Democratic Simulators (CDS):** The CDS aims to create self-run community living in private or public buildings with particular historical topics from the middle Ages or the Roman era, with parallel applications democratic self-governance in SL.

The educational utilization of SL became better known through surveys conducted annually by the NMC (2007). The results that emerged from the findings gathered from 358 teachers showed that:

- Teachers are beginning to see in a whole new perspective now use virtual worlds and not even a "Wild West."
- Gradually begin to engage in activities that implement themselves easily without knowing any programming language specializing.
- Provides the clustering of teachers through social networks such as those attached to virtual worlds to exchange ideas and needs that they or their representative bodies for a common purpose.
- The experience of teachers working in SL and becoming more significant.

CONCLUSION

The phenomenon of virtual worlds, although considered relatively new, however, as characterized and Phillip Roselande, the official founder of Linden Lab, it looks like the evolution of the Internet in early 1990. However, there are educational institutions except the SL experiment with other like There, Active Worlds and Whyville. Previous studies have shown that even virtual worlds and especially that of BF, can provide educational benefits for specific learning techniques, and groups that need a special treatment or even experimental laboratory analysis (Bradshaw, 2006; Rousou et al., 2004; Slator, 2005; The Schome Community, 2007).

More than 150 universities have made their presence felt in the virtual world of SL and use it regularly for research projects and delivery of distance courses. Since February of 2007 already, information reported that more than 26,000 companies have been active in this virtual world, offering goods and services, such as in real life (DMD et al., 2007). This new interactive dimension that is unveiled at these nodes, supporting the development of communities, which are still difficult to organize the learning process in real environments. Ultimately it is important to mention that the main aim of providing best practices of interactions in the virtual environment of the SL, which is threefold:

1. Increasing interoperability and accessibility of digital collections through the use of widely accepted standards.
2. Ensuring high quality of digital content.
3. Reducing the recurrence's likelihood of the same process of digitization learning objects or resources which will guide future research by utilizing best practices for converting the originals into digital form and the long-term preservation of digital content.

In the face of this globalization image, we should mention that it is a common premise that personal contact (face to face or f2f) cannot be replaced by the distance, but it will be an effective offshoot to support the learning process, when it is not possible in the real world.

FUTURE DIRECTIONS

Educational organizations pursue and consolidate more and more strongly the presence of 3D virtual worlds, a traditional and an innovative approach to knowledge. In the first case, which is almost the most divided, we have teachers carrying organisms such as buildings, infrastructure and curriculum of real life in a virtual, having beforehand ensured the safety of pupils. However in the second case there is more autonomy and freedoms of users in the exploration and discovery of knowledge that exist within the environment, as students observe, comment and suggest alternative ways of using e-learning. If we want to effectively convey our true learning in a virtual life, we should both be very careful as the organizational structure of the learning environment which will deliver the programs and consider knowing in advance, how possible is to plan treatment of multiple interactions between users (teachers and students) for a more efficient feedback of their actions and re-use or not the applications of this platform.

REFERENCES

Abt, C. (1970). *Serious games*. New York, NY: The Viking Press.

Alexander, S., & Boud, D. (2001). Learners still learn from experience when online. In Stephenson, J. (Ed.), *Teaching and learning on-line: Pedagogies for new technologies* (pp. 3–15). London, UK: Kogan Page.

Antonacci, D., & Modaress, N. (2008). Envisioning the educational possibilities of user-created virtual worlds. *AACE Journal*, *16*(2), 115–126.

Argyle, M. (1988). *Bodily communication*. London, UK: Methuen.

Arreguin, C. (2007). *Reports from the field: Second Life community convention 2007 education track summary.* Retrieved December 2, 2007, from http://www.holymeatballs.org/pdfs/VirtualWorldsforLearningRoadmap_012008.pdf

Baker, S., Wentz, R., & Woods, M. (2009). Using virtual worlds in education: Second Life® as an educational tool. *Teaching of Psychology*, *36*(1), 59–64. doi:10.1080/00986280802529079

Bartle, R. (2004). *Designing virtual worlds*. Indianapolis, IN: New Riders Publishing.

Barwick, S., & Drabic, R. (2011). *Business ethics in Second Life*. Retrieved 23 January, 2011, from http://www.ethicapublishing.com/ethical/3CH11.pdf

Becker, B., & Mark, G. (1998). Social conversation in collaborative virtual environments. In D. Snowdon & E. Churchill (Eds.), *Proceedings of the Collaborative Virtual Environments (CVE'98)*, University of Manchester, June 17-19, (pp. 47-56).

Bell, L., Peters, T., & Pope, K. (2007). Get a (Second Life): Prospective for gold in a 3D world. *Computers in Libraries*, *27*(1), 10–15.

Benford, S. D., Bowers, J. M., Fahlén, L. E., Greenhalgh, C. M., & Snowdon, D. N. (1995a) User embodiment in collaborative virtual environments. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'95)*, Denver, CO, USA, May 7-11, ACM/SIGCHI, (pp. 242-249).

Benkert, S. (2001). *Erweiterte Prüfliste für Lernsysteme*. Retrieved 23 May, 2011, from http://benkert-rohlfs.de/Promotion/ EPL.pdf

Bereiter, C., & Scardamalia, M. (1996). Rethinking learning. In Olson, D. R., & Torrance, N. (Eds.), *The handbook of education and human development: New models of learning, teaching and schooling* (pp. 485–513). Cambridge, MA: Basil Blackwell.

Bigge, L., & Shermis, S. (1992). *Learning theories for teachers*. UK: Harper Collins.

Bigge, M. L., & Shermis, S. S. (1992). *Learning theories for teachers* (5th ed.). New York, NY: Harper Collins.

Bitzer, C., & Bredl, K. (2010). Research-adventure in the magic forest. Presentation at the Conference: Virtual World Best Practices in Education (VWBPE 2010). March 12-13.

Bitzer, C., Bredl, K., & Adler, F. (2010). Educational games in Web3D. *Proceedings of the IADIS International Conference Web Virtual Reality andThree-Dimensional Worlds 2010*. IADIS Press.

Blascovich, J., & Bailenson, J. (2011). *Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution*. UK: Harper Collins.

Bowers, J., Pycock, J., & O'Brien, J. (1996) Talk and embodiment in collaborative virtual environments. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'96)* (pp. 58-65). Vancouver, Canada: ACM Press.

Bradshaw, D. (2006). *New practices in flexible learning: Virtual worlds – Real learning!* Pedagogical reflections. Australian Flexible Learning Framework, Department of Education, Science and Training. Retrieved 12 December, 2010, from http://virtualworlds.flexiblelearning.net.au/reports/VWRL_pedagog_reflect.pdf

Bramlette, M. F., & Bouchard, E. E. (1991). Genetic algorithms in parametric design of aircraft. In Davis, L., & Van Nostrand, R. (Eds.), *The handbook of genetic algorithms* (pp. 109–123). New York.

Bräutigam, B., Herz, D., & Bredl, K. (2011). Von Avatar zu Avatar, Systemischorientierte-Beratung in virtuellen Welten. *Familiendynamik. Interdisziplinäre Zeitschrift für systemorientierte Praxis und Forschung,* 36(1), 14-21.

Bredl, K. (2009). *Immersive education in social virtual worlds*. Poster presented at the 15th Americas Conference on Information Systems (AMCIS 2009) in San Francisco, USA (August 06th - 09th).

Bricken, W. (1990, May). *Learning in virtual reality.* Retrieved 12 December, 2010, from http://www.wbricken.com/pdfs/03words/03education/02vr-education/01learn-in-VR.pdf

Broaddribb, S., & Carter, C. (2009). Using Second Life in human resource development. *British Journal of Educational Technology*, *40*(3), 547–550. doi:10.1111/j.1467-8535.2009.00950.x

Brooks, F. P. Jr. (1999). What's real about virtual reality? *IEEE Computer Graphics and Applications*, *19*(6), 16. doi:10.1109/38.799723

Burdea, G. (2000). *Haptic feedback for virtual reality*. Retrieved 2 June, 2011, from http://ti.rutgers.edu/publications/papers/2000_ijdir.pdf

Burdea, G., & Coffet, P. (2003). *Virtual reality technology* (2nd ed.). Washington, DC: Wiley-IEEE Press.

Campbell, C., & Jones, S. (2008). Using Second Life as an educational instructional tool with pre-service education students: A work in progress. In J. Luca & E. Weippl (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2008* (pp. 3638-3642). Chesapeake, VA: AACE.

Capin, T. K., Pandzic, I. S., Magnenat Thalmann, N., & Thalmann, D. (1998). Realistic avatars and autonomous virtual humans. In Earnshaw, R., & Vince, J. (Eds.), *VLNET networked virtual environments, virtual worlds in the internet* (pp. 157–174). Los Alamitos, CA: IEEE Computer Society Press.

Cassell, J., Sullivan, J., Prevost, S., & Churchill, E. (2000). *Embodied conversational agents*. Cambridge, MA: MIT Press.

Castronova, E. (2005). *Synthetic worlds: The business and culture of online games*. Chicago, IL: The University of Chicago Press.

Chambers, J. (2002). *The next hurdle in e-learning*. Retrieved April 3, 2009, from http://www.andersen.com/Website.nsf/Content/ResourcesPerformanceLearningeLearning!OpenDocument&highlight=2,next,hurdle,in,e-learning#02

Chan, H., Mazumder, P., & Shahookar, K. (1991). Macro-cell and module placement by genetic adaptive searching with bitmap-represented chromosome. *Integration VLSI Journal*, *12*, 49–77. doi:10.1016/0167-9260(91)90042-J

Chan, T., Wu, Y., Jong, B., Lin, T., & Liang, Y. (2000). *Applying virtual reality to cooperative learning grouping.* Retrieved 23 November, 2011, from http://www.hiceducation.org/edu_proceedings/TeYi%20Chan.pdf

Chiricota, Y. (2003). Three-dimensional garment modelling using attribute mapping. *International Journal of Clothing Science and Technology*, *15*(5), 348–353. doi:10.1108/09556220310492615

Cliburn, D., & Gross, J. (2008). *Education in Second Life: How it compares to real life*. Symposium conducted Hawaii International Conference on System Sciences, January 5-8, 2009, Waikoloa, HI.

Cogburn, D. L., & Levinson, N. S. (2003). US-Africa virtual collaboration in globalization studies: Success factors for complex, cross-national learning teams. *International Studies Perspectives*, *4*, 34–51. doi:10.1111/1528-3577.04103

Cohen, K. (2006). *Second Life offers students a virtually real education*. The Phoenix Media/Communications Group. Retrieved April 20, 2008, from http://thephoenix.com/Article.aspx?id=20561&page=1

Cohoon, J. P., & Paris, W. D. (1987). Genetic placement. *IEEE Transactions in Computer-Aided Design*, *6*, 956–964. doi:10.1109/TCAD.1987.1270337

Conklin, M. S. (2007). *101 uses for Second Life in the college classroom*. Retrieved December 2, 2007, from http://facstaff.elon.edu/mconklin/pubs/glshandout.pdf

Conrad, M., Pike, D., Sant, P., & Nwafor, C. (2009). *Teaching large student cohorts in Second Life: Scalability issues and student satisfaction in a virtual world.* Retrieved 8 December, 2011, from http://sl.sanfoh.com/csedu2009/scalability-InSecondLifeCSEDU2009.pdf

Cooper, W. (2000). MUDs, metaphysics, and virtual reality. *The Journal of Virtual Environments (Electronic Journal), 5*(11). Retrieved 5 June, 2010, from http:/ /www.brandeis.edu/pubs/jove/HTML/v5/cooper.htm

Corne, D., Ross, P., & Fang, H.-L. (1994). Fast practical evolutionary timetabling. In Fogarty, T. C. (Ed.), *Evolutionary computing* (pp. 250–263). Berlin, Germany: Springer. doi:10.1007/3-540-58483-8_19

Coyne, R. (1994). Heidegger & virtual reality: The implication of Heidegger's thinking for computer representations. *Leonardo*, *27*(1), 65–73. doi:10.2307/1575952

Cross, J. (2004). An informal history of e-learning. *Journal of. Horizon*, *12*(3), 103–110. doi:10.1108/10748120410555340

Cross, P. (1981). *Adults as learners: Increasing participation and facilitating learning*. San Francisco, CA: Jossey Bass.

Csikszentmihalyi, M., & Rathunde, K. (1993). The measurement of flow in everyday life: Towards a theory of emergent motivation. In J. E. Jacobs (Ed.), *Nebraska symposium on motivation, Vol. 40 - Developmental perspectives on motivation*. Lincoln, NE: University of Nebraska Press.

Čyras, V., & Lapin, K. (2009). *Learning support and legally ruled collaboration in the Virtual Life Virtual World Platform.* Retrieved April 12, 2011, from http://www.ict-virtuallife.eu/public/20091102-ADBIS-INTEL-EDU-Cyras-Lapin-color.pdf

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. doi:10.1111/j.1467-8535.2009.01038.x

Danforth, D. (2010). Development of an interactive virtual 3-D model of the human testes using the Second life platform. *International Journal of Virtual and Personal Learning Environments*, *1*(2), 45–58. doi:10.4018/jvple.2010040104

Davis, A., Murphy, J., Dawn, O., Deepak, K., & Zigurs, I. (2009). Avatars, people, and virtual worlds: Foundations for research in metaverses. *Journal of the Association for Information Systems, 10*(2), 90-117. Retrieved 4 May, 2011, from http://aisel.aisnet.org/jais/vol10/iss2/1

De Freitas, S., Rebolledo-Mendez, G., Liarokapis, F., Magoulas, G., & Poulovassilis, A. (2010). Learning as immersive experiences: Using the four-dimensional framework for designing and evaluating immersive learning experiences in a virtual world. *British Journal of Educational Technology*, *41*(1), 69–85. doi:10.1111/j.1467-8535.2009.01024.x

Dede, C. (1996). Emerging technologies in distance education for business. *Journal of Education for Business*, *71*(4), 197–204. doi:10.1080/08832323.1996.10116784

Dede, C. (2004). Enabling distributed-learning communities via emerging technologies. *Proceedings of the 2004 Conference of the Society for Information Technology in Teacher Education (SITE)* (pp. 3-12). Charlottesville, VA: American Association for Computers in Education.

Deutschmann, M., Panichi, L., & Molka-Danielsen, J. (2009, May). Designing oral participation in Second Life: A comparative study of two language proficiency courses. *ReCALL*, *21*(2), 206–226. doi:10.1017/S0958344009000196

Diener, S., Windsor, J., & Bodily, D. (2009). *Design and development of clinical simulations in Second Life.* Retrieved 23 May, 2011, from http://www.caudit.edu.au/educauseaustralasia09/assets/papers/monday/Scott-Diener.pdf

Dillenbourg, P. (1999). What do you mean by collaborative learning? In Dillenbourg, P. (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford, UK: Elsevier.

DMD. (2007). *The virtual brand footprint: The marketing opportunity in Second Life*. Diversified Media Design, combined storey, and Market Truths Limited.

Dörr, C. (2010). *Bewertung von Lernszenarien in virtuellen Welten hinsichtlich der Unterstützung von Lernprozessen am Beispiel von Second Life*. Unveröffentlichte Bachelorarbeit, Universität Augsburg.

Doyle, D. (2008). Immersed in learning: Developing and supporting creative practice in virtual worlds. *ReLive'08: Proceedings of International Conference on Researching Learning in Virtual Environments* (pp. 121-129). The Open University.

Eduserv. (2009). *Choosing virtual worlds for use in teaching and learning in UK higher education*. Retrieved 12 May, 2011, from http://virtualworldwatch.net/wordpress/wp-content/uploads/2009/10/VWW-Choosing-Virtual-Worlds-Oct-2009.pdf

Eschenbrenner, B., Nah, F. F.-H., & Siau, K. (2008). 3-D virtual worlds in education: Applications, benefits, issues, and opportunities. *Journal of Database Management*, *19*(4), 91–110. doi:10.4018/jdm.2008100106

Esteves, M., Fonseca, B., Morgado, L., & Martins, P. (2009). Using Second Life for problem based learning in computer science programming. *Pedagogy, Education and Innovation in 3-D Virtual Worlds, 2*(1). Retrieved 12 May, 2011, from http://journals.tdl.org/jvwr/article/viewArticle/419

Falloon, G. (2010). Using avatars and virtual environments in learning: What do they have to offer? *British Journal of Educational Technology*, *41*(1), 108–122. doi:10.1111/j.1467-8535.2009.00991.x

Franceschi, K., Lee, R., & Hinds, D. (2008). Engaging e-learning in virtual worlds: Supporting group collaboration. *Proceedings of the 41st Hawaii. International Conference on System Sciences*.

Fress, S., & Kessler, D. (2005). Precise and rapid interaction through scaled manipulation in immersive virtual environments. *IEEE Virtual Reality Conference* (pp. 99-106). Germany.

Fritz, J. (2004). *Das Spiel verstehen. Eine Einführung in Theorie und Bedeutung*. Weinheim: Juventa.

Gajenda, S., Ye, Q., Sun, W., & Dayling, Z. (2011). Significance of communication and e-business in Second Life virtual world. *Information Technology Research Journal*, *1*(1), 1–12.

Gartner. (2007). *Gartner says 80 percent of active internet users will have a "Second Life" in the virtual world by the end of 2011.* Press Releases of 2007. Retrieved 3 April, 2011, from http://www.gartner.com/it/page.jsp?id=503861

Gazzard, A. (2009). Teleporters, tunnels & time: Understanding warps devices in videogames. *Proceedings of the Digital Games Research Association (DiGRA).* Retrieved 24 June, 2011, from http://www.digra.org/dl/db/09287.21051.pdf

Gee, J. (2009). Deep learning properties of good digital games: How far can they go? In Ritterfeld, U., Cody, M., & Vorderer, P. (Eds.), *Serious games: Mechanism and effects* (pp. 67–83). New York, NY: Routledge, Taylor & Francis.

Goodwin, C. (1986). Gestures as a resource for the organization of mutual orientation. *Semiotica*, *62*(1/2), 29–49. doi:10.1515/semi.1986.62.1-2.29

Goslin, M., & Morie, J. F. (1996). Virtopia: Emotional experiences in virtual environments. *Leonardo*, *29*(2), 95–100. doi:10.2307/1576338

Grau, O. (2003). *Virtual art: From illusion to immersion*. Cambridge, MA: MIT Press Leonardo Book Series.

Guadagno, R. E., Blascovich, J., Bailenson, J. N., & McCall, C. (2007). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology*, *101*, 1–22.

Guye-Vuillieme, A., Capin, T. K., Pandzic, I. S., Magnenat Thalmann, N., & Thalmann, D. (1999). Non-verbal communication interface for collaborative virtual environments. *The Virtual Reality Journal*, *4*, 49–59. doi:10.1007/BF01434994

Hansen, M. T., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge? *Harvard Business Review*, *77*(3-4), 106–116.

Haythornthwaite, C., Kazmer, M. M., Robins, J., & Shoemaker, S. (2000). Community development among distance learners: Temporal and technological dimensions. *Journal of Computer-Mediated Communication, 6*(1). Retrieved 23 October, 2011, from http://jcmc.indiana.edu/vol6/issue1/haythornthwaite.html

Hayward, V., Astley, R., Cruz-Hernandez, M., Grant, D., Robles-De-La-Torre, G., & Haptic, M. (2004). Interfaces and devices. *Sensor Review*, *24*(1), 16–29. doi:10.1108/02602280410515770

Hazel, M., & Mawyn, J. (2005). Scenario-based spoken interaction for virtual agents. *Computer Assisted Language Learning*, *18*(3), 171–191. doi:10.1080/09588220500173344

Heeter, C. (1992). Being there: The subjective experience of presence. *Presence (Cambridge, Mass.)*, *1*, 262–271.

Hillis, K. (1999). *Digital sensations: Space, identity and embodiment in virtual reality*. Minneapolis, MN: University of Minnesota Press.

Hollins, P., & Robbins, S. (2008). *The educational affordances of multi user virtual environments (MUVE). ReLive'08: Proceedings of Researching Learning in Virtual Environments* (pp. 172–180). The Open University.

Hundsberger, S. (2009). *Foreign language learning in Second Life and the implications for resource provision in academic libraries.* Retrieved July, 5, 2010, from http://arcadiaproject.lib.cam.ac.uk/docs/second_life.pdf

Inman, C., Wright, V., & Hartman, J. (2010, Spring). Use of Second Life in K-12 and higher education: A review of research. *Journal of Interactive Online Learning*, *9*(1), 44–63.

Jedličková, P. S. (2009). *The role of virtual worlds in teaching and learning*. Decowe Conference. Ljubljana, Slovenia.

Jiménez, A. A., & Pantoja, B. T. (2008). Scaffolding tutoring strategy on virtual enviroments for training. *Ingeniare. Rev. chil. ing. 16*(1), 220-231.

Johnson, A., & Moher, T. (2002). Augmenting elementary school education with VR. *IEEE Computer Graphics and Applications*, *22*(2), 6–9. doi:10.1109/38.988740

Kalawsky, R. (1996). *Exploiting virtual reality techniques in education and training: Technological issues*. SIMA Report Series 1996.

Kalawsky, R. S. (1993). *The science of virtual reality and virtual environments: A technical, scientific and engineering reference on virtual environments*. Wokingham, UK: Addison-Wesley.

Kay, J., & FitzGerald, S. (2009). *Second Life in education.* Retrieved 2 May, 2011, from http://sleducation.wikispaces.com/educationaluses

Kelly, K., Heilbrun, A., & Stacks, B. (1989). Virtual reality: An interview with Jaron Lanier. Whole Earth Review, *64*(12) 108. Retrieved June 23, 2010, from http://www.jaronlanier.com/jaron%20whole%20earth%20review.pdf

Kelton, A. J. (2007). Second Life: Reaching into the virtual world for real-world learning. *EDUCAUSE Center for Applied Research (ECAR), Research Bulletin, 17*. Retrieved 3 May, 2010, from http://www.educause.edu/ir/library/pdf/ecar_so/erb/ERB0717.pdf

Kemp, J., & Livingstone, D. (2006). Putting a Second Life "metaverse" skin on learning management systems. *Proceedings of the First Second Life Education Workshop at SLCC*, (pp. 13-18). San Francisco.

Korosec, D., & Holobar, A. (2002). Dynamic VRML for simulated training in medicine: Computer-Based Medical Systems. *Proceeding of the 15th IEEE Symposium* (pp. 205-210). Germany.

Koutsabasis, P., Vosinakis, S., Malisova, K., & Paparounas, N. (2012). On the value of virtual worlds for collaborative design. *Design Studies, 33*(4). ISSN 0142-694X

Krueger, M. W. (1991). *Artificial reality II*. Reading, MA: Addison-Wesley.

KZero. (2011). *The virtual worlds universe*. Retrieved February 14, 2011, from http://www.kzero.co.uk/universe.php

Lanier, J. (1992). Virtual reality: The promise of the future. *Interactive Learning International*, *8*, 275–279.

Lányi, S., Geiszt, Z., Karolyi, P., Tilinger, A., & Magyar, V. (2006). Virtual reality in special needs in early education. *The International Journal of Virtual Reality*, *5*(4), 55–68.

Lester, C. J., Zettlemoyer, S. L., Grégoire, P. J., & Bares, H. W. (2004). *Explanatory lifelike avatars: Performing user-centred tasks in 3D learning environments*. Multimedia Laboratory, Department of Computer Science, North Carolina State University.

Li, Z., Yue, J., Antonio, D., & Jαuregui, G. (2003). *A new virtual reality environment used for e-learning.* Retrieved 23 November, 2011, from http://www-public.it-sudparis.eu/~horain/GomezJauregui/gomez_fichiers/A%20New%20Virtual%20Reality%20Environment%20Used%20for%20e-Learning.pdf

Lin, H., & Gong, J. (2002). Distributed virtual environments for managing country parks. *Photogrammetric Engineering and Remote Sensing*, *68*(4), 369–377.

Macedo, A., & Morgado, L. (2009). *Learning to teach in Second Life*. Retrieved 12 May, 2010, from http://www.eden-online.org/contents/conferences/OCRC's/Porto/AM_LM.pdf

Maged, N., Kamel, B., Hetherington, L., & Wheeler, S. (2007). Second Life: An overview of the potential of 3-D virtual worlds in medical and health education. *Health Information and Libraries Journal*, *24*(4), 233–245. doi:10.1111/j.1471-1842.2007.00733.x

Mansour, M., & Mostafa, S. (2008). The relationship between educational serious games, gender, and students' social interaction. *WSEAS Transactions on Computers*, *6*(7), 640–650.

Mazuryk, T., & Gervautz, M. (1996). *Virtual reality: History, applications, technology and future*. Technical Report TR.

McArdle, G., Monahan, T., Bertolotto, M., & Marginka, E. (2004). *A web-based multimedia virtual reality environment for e-learning.* Eurographics (Short presentation).

McMahan, A. (2003). Immersion, engagement, and presence: A method for analyzing 3-D video games. In Wolf, M., & Perron, B. (Eds.), *The video game, theory reader* (pp. 67–78). New York, NY: Routledge.

McNeil, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago, IL: The University of Chicago Press.

Merrick, K., & Maher, M. (2007). Motivated reinforcement learning for adaptive characters in open-ended simulation games. *Proceedings of the International Conference on Advances in Computer Entertainment Technology* (pp. 127-134). Salzburg, Austria.

Michailidou, A., & Economides, A. A. (2003). E-learn: Towards a collaborative educational virtual environment. *Journal of Information Technology Education*, *2*, 131–152.

Mon, L. (2010). Communication and education in a virtual world: Avatar-mediated teaching and learning in Second Life. *International Journal of Virtual and Personal Learning Environments*, *1*(2), 1–15. doi:10.4018/jvple.2010040101

Morstain, B. R., & Smart, J. C. (1974). Reasons for participating in adult education courses: A multivariate analysis of group differences. *Adult Education*, *24*(2), 82–98. doi:10.1177/074171367402400201

Murray, J. (1997). *Hamlet on the Holodeck: The future of narrative in cyberspace*. Cambridge, MA: MIT Press.

Nalbant, G., & Bostan, B. (2006). *Interaction in virtual reality*. Retrieved 23 May, 2011, from http://newmedia.yeditepe.edu.tr/pdfs/isimd_06/12.pdf

Nelson, B., & Ketelhut, D. J. (2007). Scientific inquiry in educational multi-user virtual environments. *Educational Psychology Review*, *19*(3), 265–283. doi:10.1007/s10648-007-9048-1

New Media Consortium (NMC) and EDUCAUSE Learning Initiative. (ELI). (2007). *The Horizon Report, 2007 Edition.* Austin, TX: The New Media Consortium. Retrieved 2 October, 2011, from http://www.nmc.org/pdf/2007_Horizon_Report.pdf

OECD. (2011). *Virtual worlds: Immersive online platforms for collaboration: Creativity and learning. OECD Digital Economy Papers, 184*. OECD Publishing.

Okechukwu, O., & Udoka, E. (2009). *Understanding virtual reality technology. Advances and Applications Advances in Computer Science and Engineering* (pp. 53–70). Springer.

Pallof, M. R., & Pratt, K. (2004). *Learning together in community: Collaboration online*. In 20th Annual Conference on Distance Teaching and Learning, Madison, Wisconsin. Retrieved 2 February, 2011, from http://www.oakland.k12.mi.us/Portals/0/Learning/04_1127.pdf

Pelet, J., Lecat, B., & Papadopoulou, P. (2011). Enhancing learning cooperation through digital virtual worlds. *International Conference on Education, Research and Innovation, IPEDR* 18, (pp. 24-28). IACSIT, Singapore.

Pellas, N. (2010). *Using CVE's (collaborative virtual environments) in K-12 education*. Virtual Worlds - Best Practices in Education, 1st International Conference in Second Life.

Pellas, N. (2011). *Distance learning in the virtual environment of Second Life*. Athens, Greece: Free Publishing.

Penfold, P. (2009). Learning through the world of Second Life—A hospitality and tourism experience. *Journal of Teaching in Travel & Tourism*, *8*(2-3), 139–160. doi:10.1080/15313220802634224

Picard, R. W. (1997). *Affective computing*. Cambridge, MA: MIT Press.

Picciano, A. (2002). Beyond student perceptions: Issues of interaction, presence, and performance in an online course. *Journal of Asynchronous Learning Networks*, *6*(1), 21–40.

Pietschmann, D. (2009). *Das Erleben virtueller Welten. Involvierung, Immersion und Engagement in Computerspielen*. Boizenburg, Germany: Verlag Werner Hülsbusch.

Prasolova-Førland, E., Sourin, A., & Sourina, O. (2006). Cyber campuses: Design issues and future directions. *The Visual Computer*, *22*(12), 1015–1028. doi:10.1007/s00371-006-0042-2

Reeves, B., & Nass, C. (1996). *The media equation: How people treat computers, television and new media like real people and places*. Cambridge, MA.

Rheingold, H. (1992). *Virtual reality*. New York, NY: Simon & Schuster.

Robinett, W. (1994). Interactivity and individual viewpoint in shared virtual worlds: The big screen vs. networked personal displays. *Computer Graphics*, *28*(2), 127. doi:10.1145/178951.178969

Ronsivalle, G., & Donno, V. (2010). *A model for the evaluation of learning effectiveness in Second Life.* Retrieved 8 December, 2011, from http://labelformazione.com/imgUpload/2.pdf

Roussou, M. (2004). Learning by doing and learning through play: An exploration of interactivity in virtual environments for children. *ACM Computers in Entertainment, 2*.

Rovai, A. P. (2001). Building classroom community at a distance: A case study. *Educational Technology Research and Development Journal*, *49*(4), 35–50.

Sacks, H. (1992). *Lectures on conversation*. Cambridge, MA: Blackwell.

Saleeb, N., & Dafoulas, G. (2010). Turning immigrants to citizens: Merits of the pedagogical shift in 3D virtual learning environments. *International Journal for Infonomics*, *3*(4), 369–381.

Seung, A., & Bolebrush, J. (2009). Avatar based advertising in Second Life: The role of presence and attractiveness of virtual spoke persons. *Journal of Interactive Advertising*, *10*(1), 51–60.

Sheridan, T. (2003). *Interaction, imagination and immersion some research needs.* Retrieved 14 February, 2011, from http://www.itfind.or.kr/Report01/200302/IITA/IITA-2021-002/IITA-2021-002.pdf

Sheridan, T. B. (1994). Further musings on the psychophysics of presence. *Presence (Cambridge, Mass.)*, *5*, 241–246.

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology & Distance Learning, 2*(1). Retrieved 25 May, 2011, from http://itdl.org/Journal/Jan_05/article01.htm

Sivan, Y. (2009). Overview: State of virtual worlds standards in 2009. *Technology, Economy, and Standards, 2*(3). Retrieved 30 February, 2010, from https://journals.tdl.org/jvwr/article/view/671/539

Slater, M., Steed, A., & Usoh, M. (1993). The virtual treadmill: A naturalistic metaphor for navigation in immersive virtual environments. In M. Goebel (Ed.), *First Euro Graphics Workshop on Virtual Reality*, (pp. 71-86). Spain.

Slater, M., & Usoh, M. (1993). The influence of a virtual body on presence in immersive virtual environments. *Virtual Reality International 93, Proceedings of the Third Annual Conference on Virtual Reality* (pp. 34–42). London, UK: Meckler.

Slator, B. M., Chaput, H., Cosmano, R., Dischinger, B., Imdieke, C., & Vender, B. (2005). A multi-user desktop virtual environment for teaching shop-keeping to children. *Virtual Reality (Waltham Cross)*, *9*(1), 49–56. doi:10.1007/s10055-005-0003-5

Smith, M. A., Farnham, S. D., & Drucker, S. M. (2000). The social life of small graphical chat spaces. *Proceedings of the Conference on Human Factors in Computing Systems (CHI'00)* (pp. 462-469). Hague, The Netherlands: ACM Press.

Snowdon, D. N., Greenhalgh, C. M., & Benford, S. D. (1995) What you see is not what I see: Subjectivity in virtual environments. *Proceedings of the Framework for Immersive Virtual Environments Conference (FIVE'95)* (pp. 53-69). London.

Spence, J. (2008). Demographics of virtual worlds. *Virtual Worlds Research: Consumer Behavior in Virtual Worlds," 1*(2). Retrieved 14 February, 2011, from http://journals.tdl.org/jvwr/article/download/360/272

Stanney, K. M. (Ed.). (2002). *Handbook of virtual environments: Design, implementation, and applications*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Steed, A., & Tromp, J. (1998). Experiences with the evaluation of CVE applications. *Proceedings of Collaborative Virtual Environments CVE*, *98*, 123–130.

Steurer, J. (1993). *Defining virtual reality: Dimensions determining tele-presence.* SRCT, Paper #104. Retrieved 14 February, 2011, from http://www.cybertherapy.info/pages/telepresence.pdf

Switzer, J. (2011). *Taxation of virtual worlds' economies: An empirical review*. IR 12.0: Performance and participation. Retrieved 23 January, 2011, from http://spir.aoir.org/papers/switzer_switzer.pdf

Thalmann, D. (2001). The role of virtual humans in virtual environment technology and interfaces. In Earnshaw, R., Guedj, R., & Vince, J. (Eds.), *Frontiers of human-centred computing, online communities and virtual environments*. Berlin, Germany: Springer. doi:10.1007/978-1-4471-0259-5_3

The Schome Community. (2007). *The Schome-NAGTY teen Second Life pilot final report: A summary of key findings and lessons learnt*. Milton Keynes, UK: The Open University.

Thomé, D. (1989). *Kriterien zur Bewertung von Lernsoftware. Mit einer exemplarischen Beurteilung von Deutsch-Lernprogrammen*. Heidelberg, Germany: Hüthig.

Tolga, C. (1997). Virtual human representation and communication in VLNET networked virtual environment. *VLNET*. *IEEE Computer Graphics and Applications*, *17*, 42–53.

Tornincasa, S., Vezzetti, E., & Violante, M. G. (2005). 3D interactive technologies: Supporting e-learning with collaborative virtual environments (CVE). In *XVII INDEGRAF-XV* (pp. 1-3). ADM, Siviglia.

Troconis, M. T., & Rodríguez-Iborras, M. (2002). *Evaluation criteria for assessing human factors in virtual learning environments (VLEs).* Retrieved June 23, 2009, from http://www.eergonomics.inuk.com/PDF/Portsmouth2002.pdf

Vosniadou, S. (1996). Learning environments for representational growth and cognitive flexibility. In Vosniadou, S., DeCorte, E., Glaser, R., & Mandl, H. (Eds.), *International perspectives on the design of technology supported learning environments* (pp. 13–24). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wang, C., Song, H., Xia, F., & Yan, Q. (2009). Integrating Second Life into an EFL program: Students perspectives. *Journal of Educational Technology Development and Exchange*, *2*(1), 1–16.

Wang, S., & Hsu, H. (2009). Using the ADDIE model to design Second Life activities for online learners. *TechTrends*, *53*(6), 76–81. doi:10.1007/s11528-009-0347-x

Warburton, S. (2009). Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. *British Journal of Educational Technology*, *40*(3), 414–426. doi:10.1111/j.1467-8535.2009.00952.x

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence (Cambridge, Mass.)*, *7*(3), 225–240. doi:10.1162/105474698565686

Yamashita, S. (2006). *What makes for effective online community building? 10 field-tested strategies you can use to boost student success.* Paper presented at the World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. 2006, Honolulu, Hawaii, USA.

Yee, N., Bailenson, J., Urbanek, M., Chang, F., & Merget, D. (2007). The unbearable likeness of being digital: The persistence of non verbal social norms in online virtual environments. *Cyberpsychology & Behavior*, *10*(1), 115–121. doi:10.1089/cpb.2006.9984

Zaid, B., Jamaludin, R., & Hosam, A. (2011). Perceived satisfaction levels and student learning performance towards Second Life virtual environment for learning the Islamic concepts. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1860–1864.

Zarraonandia, T., Francese, T., Passero, I., Aedo, I., Tortora, G., & Diaz, D. (2011). *Seminars in Second Life: Teacher and student views.* Retrieved 8 December, 2011, from http://www.ksi.edu/seke/dms11/DET/12_Telmo_Zarraonandia.pdf

KEY TERMS AND DEFINITIONS

Application Servers: The application servers are running on the server and account for 50% of client-server applications (client / server applications). The other 50% are client applications that run locally on their computers - and customers are the means by which customers can put a request to the application server. So, there are many types of client-server applications, with each application consisting of the portion of the server (server side), which runs on the server and the client part of the (client side) that runs locally on each computer - customer network.

CAVE Systems: These systems are creating the illusion of immersion with the view of stereoscopic images on the walls and floor of a cubic room. A group of people, who wears three-dimensional glasses, can be moved freely within the CAVE and motion sensors constantly adjust the stereoscopic projection of the chief person.

Client-Program: The "client" (client program), is an application (or system), which provides access to a remote service on another PC system (also known as a server, via a network). This term first applied to devices that were not capable of running its own stand-alone programs, but can interact with remote computers via a network, as is the case of Second Life. See http://en.wikipedia.org/wiki/Second_Life, accessed 21/4/2010.

E-Learning 2.0: The term "e-learning 2.0", is a "neologism" for distributed collaborative learning through PCs & Web-based technologies ([D-] CSCL), using the Web 2.0 This definition has begun and the initial transformation of conventional learning system's distance, which are used widely through the Internet. Unlike that of the application of "traditional" e-learning, the impulse that gives us this new generation of e-learning, focusing on cooperation and the social production of knowledge. However, it is useful to mention that e-learning and e-learning 2.0, is a single bit of distance learning.

Grid: Refers to the platform and the technology behind the 3D online virtual world of SL. Defined as "grid" and forms the basic structure of the virtual world. The "grid" is divided into thousands of geographic areas simulation. The largest virtual hectares of land, called "Grid's", are a global (virtual) system that provides access to resources and storage simulation via Internet. In this way it aims to turn the global network into a unified virtual computer. The company Linden Lab last year more and more often offers several virtual hectares of land, which organized several educational events.

Virtual Venues ("Spaces" or "Places"): Virtual "places" are differ from the" spaces," because involving social and cultural values as opposed to a simple spatial arrangement. The concept of a 'place' makes an environment to meet specific needs. The sense of place, and gives the feeling of "belonging", directs the behavior and arouses the emotions affect the activities. The place is more a discipline than a natural phenomenon, as is the common experience that makes sense of place really. But the ability to influence social behavior through the spatial organization in combination with the common cultural perception may be the same for all players in a specific spatial-temporal context. Therefore, the virtual constructive site is divided into a combination of operational and conceptual framework for action by users. This perspective can be very useful in the case of the e-learning in virtual environments, for the design and creation of objects visualized in 3D form, can include a socio-cultural and perceptual quality of learning that will closer to natural conditions.

VRML (Virtual Reality Modeling Language): VRML (or Virtual Reality Markup Language), is a description "language" of three-dimensional objects and combine these objects, environments or worlds. The language supports virtual reality applications implemented on personal computers without special devices, rather than just using a browser (browser) to VRML. The "language" allows the geometric description of objects that make up a virtual world. The three-dimensional virtual reality systems, "exploit" the computing power of personal computers (PCs), to display the virtual environment while the user interaction with the environment is achieved through input devices (e.g. keyboard, mouse).

ENDNOTES

1 http://literaturealive.wikispaces.com/

2 http://pacificrimx.wordpress.com/

About the Contributors

Paolo Renna is an Assistant Professor at Department of Environmental Engineering and Physics in the Engineering Faculty of Basilicata University (Italy). He took Ph.D. degree at Polytechnic of Bari in Advanced Production Systems. His academic researches principally deal with the development of innovative negotiation and production planning in distributed environments and manufacturing scheduling in dynamic environment. Several contributions have been presented on design Multi Agent Architecture and test by discrete event simulation in Business to Business environment. Among the contributions, he is co-author of two research books about e-marketplaces and production planning in production networks. Moreover, he has developed coordination approaches in multi-plant production planning environment and innovative scheduling approaches in flexible and reconfigurable manufacturing systems.

* * *

Yousry H. Abdelkader is Associate Professor in Mathematics Department, Faculty of Science, Alexandria University, Egypt. He is now working at Mathematics Department, Faculty of Science, Dammam University, KSA. He is eared Baccalaureate and Master's degrees from Alexandria University, Egypt and a Master's degree from Northeastern University, Boston, USA. He got his Doctorate degree (2000) from Alexandria University, Egypt. His area of interest are: stochastic PERT networks, order statistics, queueing theory, and reliability theory. He is a referee in many international journals. Dr. Abdelkader has contributed significantly in the area of stochastic PERT networks and order statistics. He has published many research articles in various journals such as: *European Journal of Operational Research, Annals of Operations Research, Kybernetika, Statistics and Probability Letter, Statistica, Journal of Indian Society of Statistical and Operations Research, Journal of Computational and Applied Mathematics, Statistical Papers, Statistical Methods & Applications*, and many others.

El-Houssaine Aghezzaf obtained his PhD in Applied Mathematics and Operations Research from the Center of Operations Research and Econometrics – CORE, at Catholic University of Louvain, Belgium in 1992. He is now professor of Industrial Engineering and Operations Research at the Faculty of Engineering and Architecture of Ghent University, Belgium. He is currently head of the department of Industrial Management. His research is mainly in the area of logistical networks design and optimization. He investigates, in particular, the issues of robust routing, production planning and scheduling in supply networks subject to demand and lead-times uncertainty. His research work has been published in many journals such as International Journal of Production Research, Journal of the Operational Research Society, European Journal of Operational Research, International Journal of Production Economics, Computers and Industrial Engineering.

Reza Tanha Aminlouei, an M.Sc alumnus in Industrial Engineering - Systems and Socio- Economics at Department of Industrial Engineering - University of Tehran, Iran - is working as a researcher at Research Institute of Energy Management and Planning (RIEMP). RIEMP is a joint institute between Ministry of Energy and faculty of Engineering at Tehran University; Reza is teaching at Payame Noor University in industrial department. Areas of interests include: operations research, optimization, production planning, environmental and energy research. Reza is interested in the fields of optimization under uncertainty, fuzzy production planning, mathematical programming, and energy management, energy planning, and environmental researches.

Zahia Guessoum is a “Maître de Conférences” (Associate Professor) at the University of Reims Champagne-Ardenne in France. She received her Doctorate/PhD (1996) and then her “habilitation à diriger des recherches” (2003), both in computer science and from University Pierre & Marie Curie (Paris 6), France. She is a member of the Multi-Agent Team of “Laboratoire d’Informatique de Paris 6” (LIP6). Her general research interests are about adaptive agents and multi-agent systems, fault-tolerant MAS, and multi-agent software engineering.

Samir Hamichi is an IT Consultant at the ONE POINT Group Ltd in France. He received his Engineer Degree (2003) at Tizi-Ouzou University and then his research Master’s (2006) from University of Reims Champagne-Ardenne in France and his Doctorate/PhD (2011) in Computer Science from University Pierre & Marie Curie (Paris 6), France. His general research interests are about agents and multi-agent systems and complex systems simulation.

Sungchul Hong is an Associate Professor in the Department of Computer & Information Sciences at Towson University, Maryland, USA. He received his B.S. in Computer Science from the Soongsil University in South Korea and a M.S. in Computer Science from the University of Texas at Dallas. He received his Ph.D. in Management Science from the University of Texas at Dallas. His major research interests are e-commerce related technologies, including automated algorithms in various markets, XML related applications, and intelligent agent systems. He has published in journals such as *INFORMS Journal on Computing* and *Journal of Information Systems Education*.

Martin Januska is Researcher and Lecturer at University of West Bohemia in Pilsen, Faculty of Economics, Department of Business Administration and Management. He has a Master’s degree in Commercial Electronics from Faculty of Electrical Engineering, University of West Bohemia in Pilsen. He finished his Ph.D. in the field of controlling of technological processes at Faculty of Electrical Engineering, University of West Bohemia in Pilsen. His dissertation thesis theme was Communication environment for Virtual Enterprise paradigm support. Present research activities of Martin Januska are in the field of process controlling and process risk managemet.

Mohamed Khaled received his first degree in Mechanical Engineering and his PhD in operations research. He was a faculty member of the Faculty of Engineering and Technology-Multimedia University for ten years teaching Operations Research and Operation Management. During that time, he served as chairperson of the Centre of Computer Design and Knowledge Manufacturing (CCADKM) and the Director of MSc program (Advanced Manufacturing Technology). Currently, he is a faculty member of the Nottingham University Business School-Malaysian campus where he teaches Operations Management and Project Management for MBA and MSc students. He is interested in the development and application of operations research models and methods to solve production planning and scheduling, supply chain. Current research projects include: supply chain optimization; fuzzy modelling of supply chain, modelling of cost of quality, production planning, and scheduling for various context.

Nan Kong is an Assistant Professor in the Weldon School of Biomedical Engineering at Purdue University. He received his Ph.D. degree in Industrial Engineering from the University of Pittsburgh in 2006. Prior to his current appointment, he was an Assistant Professor in the Department of Industrial and Management Systems Engineering at the University of South Florida. Dr. Kong's research interest includes stochastic optimization, integer programming, agent-based simulation, and modeling.

Diana Mangalagiu is Professor at the Smith School of Enterprise and Environment, Oxford University and Reims Management School, France. She has a dual background, in both natural sciences (Ph.D. in Artificial Intelligence, MSc in Physics, MSc in Microelectronics) and social sciences (MSc in Sociology and MSc in Management). Over the past decade, her research has been focusing on sustainability and social responsibility in corporate and public policy settings addressed through modeling, social experimentation and foresight. Diana is a Romanian and French national. Through her travels, she became fluent in seven languages. Recent publications include "Reframing the Problem of Climate Change: From Zero Sum Game to Win-Win Solutions," Earthscan, 2011 (with Jaeger, C., Hasselmann, K., Leipold, G. and Tàbara, J.D.) and "A New Growth Path for Europe: Creating Prosperity and Jobs in the Low-Carbon Economy," 2011 (with Jaeger, C., Paroussos, L., Kupers, R., Mandel, A. and Tàbara, J.D., http://www.newgrowthpath.eu/).

Ernesto Martínez is a Research Fellow of The National Research Council of Argentina (CONICET) and Chair Professor of Systems and Organizations in the Technical University of Argentina (UTN). He has published more than sixty journal papers and book chapters on systems modeling, control, and optimization. He has been a Visiting Professor at Lehigh University (USA), Nottingham University (UK), and Universidad de Valladolid (Spain). Awards received include the Senior Research fellowship from the Fulbright Commission (USA), Repsol-YPF 2000 Innovation award and The Ramón y Cajal Distinguished Fellowship award by the Ministry of Science and Technology of Spain. His main research interests are intelligent system optimization and control, learning algorithms, multi-agent systems, mechanism design, complex system supervision, game theory, enterprise modeling, and generative simulation modeling of artificial social systems.

Barin N. Nag is a Professor of E-Business & Technology Management at Towson University, Maryland, USA. He has a B.Tech and a M.Tech in Electrical Engineering from the Institute of Radio Physics & Electronics, University of Calcutta, India. He has a Ph.D. in Business Management (Management Science), in association with Computer Science, from the University of Maryland at College Park. He has diverse research interests in routing and scheduling, decision support systems, autonomous agents, and most recently in supply chain management. He has worked with NASA and the World Bank. He has published in many journals, such as *European Journal of Operational Research, Decision Support Systems, Decision Sciences, Annals of Operations Research,* and *Journal of Management Information Systems.*

Pellas S. Nikolaos is a Ph.D. Candidate at the Department of Product and Systems Design Engineering, University of the Aegean, Greece. He obtained a Master degree in Education with ICT, in the field of e-Learning through virtual worlds in 2010, at the Aristotle University of Thessaloniki. His thesis was about the handling of organizational complexity and flexibility interactions and the educational value-added of the qualitative or quantitative assessment of virtual worlds. He also was written a research book about the pedagogical value of e-learning process in virtual environments, in 2011. Nowadays, he starts his dissertation research, which addresses in configuring and using virtual worlds for learning applications with the teamwork technique "Puzzle" (Jigsaw) to investigate engagement factors and assortment learning presence of trainees' users. He has an extensive experience in education, especially teaching adult groups. His research interests include the use of ICT in education, with emphasis on learning through "Metaverse" skin or "Open-source" virtual worlds and modern instructional methodologies.

Milagros Rolón received an Engineering degree in Industrial Engineering in 2006 from the Technical University of Argentina (UTN). She got a Research Fellowship from the National Research Council of Argentina (CONICET) and obtained her PhD degree in Information Systems Engineering from UTN in 2012. Her main research interests are distributed production control, intelligent automation, multi-agent learning, game theory, and agent-based modeling and simulation.

Rauno Rusko, PhD, is a Lecturer of Management at the University of Lapland. His works have been published in the *Forest Policy and Economics, the International Journal of Business Environment, the International Journal of Tourism Research, European Management Journal, Industrial Marketing Management, International Journal of Technoentropreneurship,* and *International Journal of Innovation in the Digital Economy* (IJIDE) and others. His studies consider for example the branches of forest industry, tourism and information communication technology. His research interests include strategies, entrepreneurship and business incubation, industrial organization, business environment, and cooperation perspectives of management, especially coopetition and supply chain management.

Carles Sitompul obtained his PhD degree in Industrial Engineering and Operations Research from Ghent University Belgium in 2010. He is now teaching at the Department of Industrial Engineering, Parahyangan Catholic University Bandung (UNPAR) in Indonesia. He is also head of division for accreditation and certification, Quality Assurance Office of the university. His research interests are mainly in the area of supply chain, production systems and transportation. He has published many articles in journals such as *International Journal of Production Research, Computers and Operations Research, Computers and Industrial Engineering,* and *Journal of Quality in Maintenance Engineering*.

Yu Teng is a PhD candidate in the Weldon School of Biomedical Engineering at Purdue University. His research interests include agent-based modeling and simulation, communication networks, and resource allocation in healthcare systems. His dissertation topic is optimal screening strategy design for Chlamydia infection. He received his B.S. degree in Mechanical Engineering from Tsinghua University, Beijing, China, in 2007. He has recently accepted a position in the Prevention Effectiveness Fellowship program with the U.S. Centers for Disease Control and Prevention (CDC).

Dong-Qing Yao is a Professor of E-Business & Technology Management at Towson University, Maryland, USA. He received his B.S. in Industrial Engineering from Suzhou University, and a M.S. in Systems Engineering from Shanghai Jiao Tong University in China. He received his Ph.D. in Management Science from the University of Wisconsin-Milwaukee. His research interests are in the areas of global operation management, and internet-based supply chain management. He has published in journals such as *IIE Transactions, European Journal of Operational Research, International Society of Production Economics,* and *OMEGA*.

Compilation of References

Abdelkader, Y. H. (2003). Erlang distributed activity times in stochastic activity networks. *Kybernetika*, *39*(3), 347–358.

Abele, E., Meyer, T., Näher, U., Strube, G., & Sykes, R. (Eds.). (2008). *Global production: A handbook for strategy and implementation*. Berlin, Germany: Springer.

Abt, C. (1970). *Serious games*. New York, NY: The Viking Press.

Achterbergh, J., Beeres, R., & Vriens, D. (2003). Does the balanced score-card support organizational viability. *Kybernetes: The International Journal of systems & Cybernetics, 32*(9/10), 1387-1404.

Aghezzaf, E.-H. (2005). Capacity planning and warehouse location in supply chains with uncertain demands. *The Journal of the Operational Research Society*, *56*(4), 453–462. doi:10.1057/palgrave.jors.2601834

Aghezzaf, E.-H., Jamali, M. A., & Ait-Kadi, D. (2007). An integrated production and preventive maintenance planning model. *European Journal of Operational Research*, *181*(2), 679–685. doi:10.1016/j.ejor.2006.06.032

Aghezzaf, E.-H., & Najid, N. (2008). Integrated production planning and preventive maintenance in deteriorating production systems. *Information Sciences*, *178*, 679–685. doi:10.1016/j.ins.2008.05.007

Aghezzaf, E.-H., Sitompul, C., & Najid, N. (2010). Models for robust tactical planning in multi stage production systems with uncertain demands. *Computers & Operations Research*, *37*(5), 880–889. doi:10.1016/j.cor.2009.03.012

Ahlert, K.-H., Corsten, H., & Gossinger, R. (2009). Capacity management in order-driven production networks— A flexibility-oriented approach to determine the size of a network capacity pool. *International Journal of Production Economics*, *118*, 430–441. doi:10.1016/j.ijpe.2008.11.013

Aknine, S., Pinson, S., & Shakun, M. F. (2004). A multi-agent coalition formation method based on preference models. *Group Decision and Negotiation*, *13*, 513–538. doi:10.1007/s10726-005-3074-5

Albino, V., Carbonara, N., & Giannoccaro, I. (2007). Supply chain cooperation in industrial districts: A simulation analysis. *European Journal of Operational Research*, *177*(1), 261–280. doi:10.1016/j.ejor.2005.12.007

Alcaide, D., Rodriguez-Gonzales, A., & Sicilia, J. (2006). A heuristic approach to minimize expected makespan in open shops subject to stochastic processing times and failures. *International Journal of Flexible Manufacturing Systems*, *17*, 201–226. doi:10.1007/s10696-006-8819-1

Alexander, S., & Boud, D. (2001). Learners still learn from experience when online. In Stephenson, J. (Ed.), *Teaching and learning on-line: Pedagogies for new technologies* (pp. 3–15). London, UK: Kogan Page.

Al-Kalaani, Y. (2008). *Power generation scheduling algorithm using dynamic programming: Nonlinear analysis*. Elsevier Ltd. doi:10.1016/j.na. 11.082

Allwood, J. M., & Lee, J.-H. (2005). The design of an agent for modelling supply chain network dynamics. *International Journal of Production Research*, *43*, 4875–4898. doi:10.1080/00207540500168295

Alonso, F., Turner, K., Walter, B., Wrang, B., Clavel, P., & Sprenger, W. (1992). Present practices on load forecasting and load management: A survey. *Electra*, *145*, 69.

Al-Qahtani, K., & Elkamel, A. (2008). Multisite facility network integration design and coordination: An application to the refining industry. *Computers & Chemical Engineering*, *32*, 2189–2202. doi:10.1016/j.compchemeng.2007.10.017

Alvarez, M. (2006). *Second Life and school: The use of virtual world worlds in high education.* Trinity University, San Antonio, TX. Retrieved 29 March, 2011, from http://www.trinity.edu/adelwich/worlds/articles/trinity.manny.alvarez.pdf

Alvarez, E. (2007). Multi-plant production scheduling in SMEs. *Robotics and Computer-integrated Manufacturing*, *23*, 608–613. doi:10.1016/j.rcim.2007.02.006

Anderson-Inman, L., Richter, J., & Frisbee, M. (2007). Critical engagement of teachers in the Salamander Project. *Second Life Education Workshop 2007, Part of the Second Life Community Conversation* (pp. 19-26). Chicago, IL: Hilton.

Antonacci, D., & Modaress, N. (2008). Envisioning the educational possibilities of user-created virtual worlds. *AACE Journal*, *16*(2), 115–126.

Antonelli, C. (2000). Collective knowledge, communication and innovation: The evidence of technological districts. *Regional Studies*, *34*(6), 535–547. doi:10.1080/00343400050085657

Anussornnitisarn, P., Nof, S. Y., & Etzion, O. (2005). Decentralized control of cooperative and autonomous agents for solving the distributed resource allocation problem. *International Journal of Production Economics*, *98*(2), 114–128. doi:10.1016/j.ijpe.2004.05.015

Aprile, D., Garavelli, A. C., & Giannoccaro, I. (2005). Operations planning and flexibility in a supply chain. *Production Planning and Control*, *16*(1), 21–31. doi:10.1080/09537280412331313348

Argoneto, P., Bruccoleri, M., Lo Nigro, G., Perrone, G., Noto La Diega, S., Renna, P., & Sudhoff, W. (2006). High level planning of reconfigurable enterprises: A game theoretic approach. *CIRP Annals - Manufacturing Technology, 55*(1), 509-512.

Argoneto, P., Perrone, G., Renna, P., Lo Nigro, G., Bruccoleri, M., & Noto La Diega, S. (2008). *Production planning in production networks models for medium and short-term planning*. Springer.

Argoneto, P., & Renna, P. (2010). Production planning, negotiation and coalition integration: A new tool for an innovative e-business model. *Robotics and Computer-integrated Manufacturing*, *26*(1), 1–12. doi:10.1016/j.rcim.2009.01.001

Argyle, M. (1988). *Bodily communication*. London, UK: Methuen.

Armbruster, D., Beer, C., de Freitag, M., Jagalski, T., & Ringhofer, C. (2006). Autonomous control of production networks using a pheromone approach. *Physica A*, *363*(1), 104–114. doi:10.1016/j.physa.2006.01.052

Arntzen, B. C., Brown, G. G., Harrison, T. P., & Trafton, L. L. (1995). Global supply chain management at digital equipment corporation. *Interface*, *25*, 69–93. doi:10.1287/inte.25.1.69

Arreguin, C. (2007). *Reports from the field: Second Life community convention 2007 education track summary.* Retrieved December 2, 2007, from http://www.holymeatballs.org/pdfs/VirtualWorldsforLearningRoadmap_012008.pdf

Arthur, W. B., Durlauf, S. N., & Lane, D. A. (Eds.). (1997). *The economy as an evolving complex system II. Santa Fe Institute Studies in the Science of Complexity*. Reading, MA: Addison-Wesley.

Ashby, W. R. (1957). *An introduction to cybernetics, 2nd Impression*. London, UK: Chapman & Hall Ltd.

Audiodraft. (2011). *AudioDraft*. Retrieved January 8, 2011, from http://www.audiodraft.com/

Au, W. J. (2001). Playing God. *Lingua Franca: The Review of Academic Life*, *11*(7), 12–13.

Axelrod, R. (1984). *The evolution of co-operation*. New York, NY: Basic Books.

Aytug, H., Lawley, M., McKay, K., Mohan, S., & Uzsoy, R. (2005). Executing production schedules in the face of uncertainties: A review and some future directions. *European Journal of Operational Research*, *161*, 86–110. doi:10.1016/j.ejor.2003.08.027

Azevedo, A. L., Toscano, C., Sousa, J. P., & Soares, A. L. (2004). An advanced agent-based order planning system for dynamic networked enterprises. *Production Planning and Control*, *15*(2), 133–144. doi:10.1080/0953728041 0001662538

Baecker, D. (1997). Reintroducing communication to cybernetics. *Systemica*, *11*, 11–28.

Bagni, R., Berchi, R., & Cariello, P. (2002). A comparison of simulation models applied to epidemics. *Journal of Artificial Societies and Social Simulation*, *5*(3).

Baker, S., Wentz, R., & Woods, M. (2009). Using virtual worlds in education: Second Life® as an educational tool. *Teaching of Psychology*, *36*(1), 59–64. doi:10.1080/00986280802529079

Barata de Oliveira, J. (2004). Coalition based approach for shop floor agility: A multiagent approach. PhD Thesis, Universidade Nova de Lisboa.

Barbarosoglu, G., & Ozgur, D. (1999). Hierarchical design of two-echelon distribution system. *European Journal of Operational Research*, *118*, 464–484. doi:10.1016/S0377-2217(98)00317-8

Barlow, R. E., & Hunter, L. C. (1960). Optimum preventive maintenance policies. *Operations Research*, *8*, 90–100. doi:10.1287/opre.8.1.90

Barrett, L. (2011). *Beyond the brain: How body and environment shape animal and human minds*. Princeton, NJ: Princeton University Press.

Bartle, R. (2004). *Designing virtual worlds*. Indianapolis, IN: New Riders Publishing.

Barwick, S., & Drabic, R. (2011). *Business ethics in Second Life*. Retrieved 23 January, 2011, from http://www.ethicapublishing.com/ethical/3CH11.pdf

Battiston, S., Delli Gatti, D., Gallegati, M., Greenwald, B., & Stiglitz, J. (2007). Credit chains and bankruptcy propagation in production networks. *Journal of Economic Dynamics & Control*, *31*(6), 2061–2084. doi:10.1016/j.jedc.2007.01.004

Beard, L., Wilson, K., Morra, D., & Keelan, J. (2009). A survey of health-related activities on Second Life. *Journal of Medical Internet Research*, *11*(2), e17. doi:10.2196/jmir.1192

Beaudoinc, D., Frayretb, J.-M., & LeBela, L. (2010). Negotiation-based distributed wood procurement planning within a multi-firm environment. *Forest Policy and Economics*, *12*(2), 79–93. doi:10.1016/j.forpol.2009.07.007

Becattini, G. (1990). The Marshallian industrial district as a socio-economic concept. In Pyke, F., Becattini, G., & Sengenberger, W. (Eds.), *Industrial districts and inter-firm cooperation in Italy* (pp. 37–51). Geneva, Switzerland: International Institute for Labour Studies.

Becker, B., & Mark, G. (1998). Social conversation in collaborative virtual environments. In D. Snowdon & E. Churchill (Eds.), *Proceedings of the Collaborative Virtual Environments (CVE'98)*, University of Manchester, June 17-19, (pp. 47-56).

Beer, S. (1972). *Brain of the firm*. Chichester, UK: John Wiley & Sons.

Beer, S. (1979). *The heart of the enterprise*. Chichester, UK: John Wiley & Sons.

Beer, S. (1985). *Designing the system for organization*. Chichester, UK: John Wiley & Sons.

Behdania, B., Lukszo, Z., Adhitya, A., & Srinivasanb, R. (2010). Performance analysis of a multi-plant specialty chemical manufacturing enterprise using an agent-based model. *Computers & Chemical Engineering*, *34*(5). doi:doi:10.1016/j.compchemeng.2010.01.020

Bell, L., Peters, T., & Pope, K. (2007). Get a (Second Life): Prospective for gold in a 3D world. *Computers in Libraries*, *27*(1), 10–15.

Belussi, F. (2006). In search of a theory of spatial clustering: agglomeration versus active clustering. In Asheim, B., Cooke, P., & Martin, R. (Eds.), *Clusters and regional development* (pp. 69–89). London, UK: Routledge.

Bendell, A., Solomon, D., & Carter, J. M. (1995). Evaluating project completion times when activity times are Erlang distribution. *The Journal of the Operational Research Society*, *46*, 867–882.

Benford, S. D., Bowers, J. M., Fahlén, L. E., Greenhalgh, C. M., & Snowdon, D. N. (1995) User embodiment in collaborative virtual environments. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'95)*, Denver, CO, USA, May 7-11, ACM/SIGCHI, (pp. 242-249).

Benkert, S. (2001). *Erweiterte Prüfliste für Lernsysteme*. Retrieved 23 May, 2011, from http://benkert-rohlfs.de/Promotion/ EPL.pdf

Ben-Tal, A., & Nemirovski, A. (1998). Robust convex optimization. *Mathematics of Operations Research*, *23*, 769–805. doi:10.1287/moor.23.4.769

Bereiter, C., & Scardamalia, M. (1996). Rethinking learning. In Olson, D. R., & Torrance, N. (Eds.), *The handbook of education and human development: New models of learning, teaching and schooling* (pp. 485–513). Cambridge, MA: Basil Blackwell.

Bernhard, R. K., & Dissel, M. (2001). A toolset for building the virtual enterprise. *Journal of Intelligent Manufacturing*, *12*, 121–131. doi:10.1023/A:1011248409830

Bertrand, Y. (1995). *Contemporary theories and practice in education*. Madison, WI: Magna Publications.

Bhatnagar, R., Chandra, P., & Goyal, S. K. (1993). Models for multi-plant coordination. *European Journal of Operational Research*, *67*(2), 141–160. doi:10.1016/0377-2217(93)90058-U

Bigge, M. L., & Shermis, S. S. (1992). *Learning theories for teachers* (5th ed.). New York, NY: Harper Collins.

Bignell, S., & Parson, V. (2010). *Best practice in virtual worlds- Teaching,* version 2.1. Retrieved 3, October, 2010, from: http://previewpsych.org/BPD2.0.pdf

Bilgen, B. (2010). Application of fuzzy mathematical programming approach to the production allocation and distribution supply chain network problem. *Expert Systems with Applications*, *37*, 4488–4495. doi:10.1016/j.eswa.2009.12.062

Binbasioglu, M. (1999). Problem structuring support for collaboration and problem solving. *Journal of Computer Information Systems*, *40*(2), 54–63.

Bitran, G. R., Haas, E. A., & Hax, A. C. (1981). Hierarchical production planning: A single stage system. *Operations Research*, *29*(4), 717–743. doi:10.1287/opre.29.4.717

Bitran, G. R., & Hax, A. C. (1981). Disaggregation and resource allocation using convex knapsack problem with bounded variable. *Management Science*, *21*(40).

Bitran, G. R., & Tirupati, D. (1993). Hierarchical production planning. In Graves, S. C., Rinnooy Kan, A. H. G., & Zipkin, P. (Eds.), *Handbooks on operations research and management science* (*Vol. 4*, pp. 523–568). Amsterdam, The Netherlands: North-Holland.

Bitzer, C., & Bredl, K. (2010). Research-adventure in the magic forest. Presentation at the Conference: Virtual World Best Practices in Education (VWBPE 2010). March 12-13.

Bitzer, C., Bredl, K., & Adler, F. (2010). Educational games in Web3D. *Proceedings of the IADIS International Conference Web Virtual Reality andThree-Dimensional Worlds 2010*. IADIS Press.

Blascovich, J., & Bailenson, J. (2011). *Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution*. UK: Harper Collins.

Bloom, J. A., & Gallant, L. (1994). Modeling dispatch constraints in production cost simulations based on the equivalent load method. *IEEE Transactions on Power Systems*, *9*(2), 598–611. doi:10.1109/59.317684

Boellstorf, T. (2008). *Coming of age in Second Life: An anthropologist explores the virtually human*. Princeton, NJ: Princeton UP.

Bonabeau, E. (2002). *Agent-based modeling: Methods and techniques for simulating human systems* (*Vol. 99*, pp. 7280–7287). National Academy of Sciences. doi:10.1073/pnas.082080899

Bonfill, A., Espuna, L., & Puigjaner, L. (2008). Decisions support framework for coordination production and transport scheduling in SCM. *Computers & Chemical Engineering*, *32*, 1206–1224. doi:10.1016/j.compchemeng.2007.04.020

Bordini, R., Wooldridge, M., & Hübner, J. (2007). *Programming multi-agent systems in AgentSpeak using Jason*. Chichester, UK: John Wiley & Sons. doi:10.1002/9780470061848

Bowers, J., Pycock, J., & O'Brien, J. (1996) Talk and embodiment in collaborative virtual environments. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'96)* (pp. 58-65). Vancouver, Canada: ACM Press.

Brachman, R. (2002). Systems that know what they're doing. *IEEE Intelligent Systems*, *17*(6), 67–71. doi:10.1109/MIS.2002.1134363

Bradshaw, D. (2006). *New practices in flexible learning: Virtual worlds – Real learning!* Pedagogical reflections. Australian Flexible Learning Framework, Department of Education, Science and Training. Retrieved 12 December, 2010, from http://virtualworlds.flexiblelearning.net.au/reports/VWRL_pedagog_reflect.pdf

Bramlette, M. F., & Bouchard, E. E. (1991). Genetic algorithms in parametric design of aircraft. In Davis, L., & Van Nostrand, R. (Eds.), *The handbook of genetic algorithms* (pp. 109–123). New York.

Brandenburger, A., & Nalebuff, B. (1996). *Co-opetition*. New York, NY: Doubleday Currency.

Braun, H., Hocevar, R., Quiroz, R., Cohen, M., Lucas-Moreira, J., & Jacques, J. … Samadani, R. (2009). *VhCVE: A collaborative virtual environment including facial animation and computer vision.* Retrieved 29 March, 2011, from www.sbgames.org/papers/sbgames09/compuring/full/cp25_09.pdf

Bräutigam, B., Herz, D., & Bredl, K. (2011). Von Avatar zu Avatar, SystemischorientierteBeratung in virtuellen Welten. *Familiendynamik. Interdisziplinäre Zeitschrift für systemorientierte Praxis und Forschung,* 36(1), 14-21.

Bredl, K. (2009). *Immersive education in social virtual worlds*. Poster presented at the 15th Americas Conference on Information Systems (AMCIS 2009) in San Francisco, USA (August 06th - 09th).

Bricken, W. (1990, May). *Learning in virtual reality.* Retrieved 12 December, 2010, from http://www.wbricken.com/pdfs/03words/03education/02vr-education/01learn-in-VR.pdf

Britain, S., & Liber, O. (1999). *A pedagogical framework for the evaluation of virtual learning environments*. Bangor, University of Wales. Retrieved 29 March 2011, from http://www.jtap.ac.uk

Britain, S., & Liber, O. (2004). *A framework for the pedagogical evaluation of e-learning environment*. Retrieved 29 March, 2011, from http://www.pgce.seton.ac.uk/IT/School_ICT/VLEusage/VLEpedagogy.pdf

Broaddribb, S., & Carter, C. (2009). Using Second Life in human resource development. *British Journal of Educational Technology*, *40*(3), 547–550. doi:10.1111/j.1467-8535.2009.00950.x

Brocklesby, J., & Cummings, S. (1996). Designing a viable organization structure. *Long Range Planning*, *29*(1), 49–57. doi:10.1016/0024-6301(95)00065-8

Brooks, F. P. Jr. (1999). What's real about virtual reality? *IEEE Computer Graphics and Applications*, *19*(6), 16. doi:10.1109/38.799723

Brown, E., Gordon, M., & Hobbs, M. (2008). Second Life as a holistic learning environment for problem-based learning and transferable skills. *Re Live '08: Proceedings of Researching Learning in Virtual Environments. International Conference* (20-21 November) (pp. 39-48). UK: The Open University.

Bruccoleri, M., Lo Nigro, G., Perrone, G., Renna, P., & Noto La Diega, S. (2005). Production planning in reconfigurable enterprises and reconfigurable production systems. *CIRP Annals - Manufacturing Technology, 54*(1), 433-436.

Buddhikot, M. M. (2007). Understanding dynamic spectrum access: Models, taxonomy, and challenges. *2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks* (DySPAN) (pp. 649-663).

Burdea, G. (2000). *Haptic feedback for virtual reality*. Retrieved 2 June, 2011, from http://ti.rutgers.edu/publications/papers/2000_ijdir.pdf

Burdea, G., & Coffet, P. (2003). *Virtual reality technology* (2nd ed.). Washington, DC: Wiley-IEEE Press.

Burger-Helmchen, T., & Julien Pénin, J. (2010). *The limits of crowdsourcing inventive activities: What do transaction cost theory and the evolutionary theories of the firm teach us?* AIMS Workshop on Open Innovation, Caen, March 26, 2010.

Cachon, G., & Lariviere, M. (2005). Supply chain coordination with revenue sharing contracts: Strengths and limitations. *Management Science*, *51*, 30–44. doi:10.1287/mnsc.1040.0215

Caetano, N., Knechtel, M., Resmini, R., Garcia, C., & Montenegro, A. (2009). *Simulated architecture and programming model for social proxy in Second Life*. Retrieved 29 March, 2011, from www.ic.uff.br/-ccaetano/artigos/iSociety_Social_Proxy.pdf

Callaghan, M. J., McCusker, K., Lopez Losada, J., Harkin, J. G., & Wilson, S. (2009, November). Engineering education island: Teaching engineering in virtual worlds. *ITALICS, 8*(3). Retrieved 23 April, 2010, from http://www.ics.hearacademy.ac.uk/italics/download_php?file=italics/vol8iss3/pdf/italicsVol8Iss3Nov2009Paper01.pdf

Camarinha-Matos, L. M., & Afsarmanesh, H. (2005). Collaborative networks: A new scientific discipline. *Journal of Intelligent Manufacturing*, *16*(4–5), 439–452. doi:10.1007/s10845-005-1656-3

Camarinha-Matos, L. M., & Afsarmanesh, H. (2007). A comprehensive modeling framework for collaborative networked organizations. *Journal of Intelligent Manufacturing*, *18*(5), 529–542. doi:10.1007/s10845-007-0063-3

Camarinha-Matos, L. M., & Afsarmanesh, H. (2008). *Collaborative networks – Reference modeling*. New York, NY: Springer.

Camarinha-Matos, L. M., Afsarmanesh, H., Galeano, N., & Molina, A. (2009). Collaborative networked organizations – Concepts and practice in manufacturing enterprises. *Computers & Industrial Engineering*, *57*, 46–60. doi:10.1016/j.cie.2008.11.024

Camarinha-Matos, L. M., Afsarmanesh, H., & Ollus, M. (2008). *Methods and tools for collaborative networked organizations*. New York, NY: Springer. doi:10.1007/978-0-387-79424-2

Camm, J. D., Chorman, T. E., Dull, F. A., Evans, J. R., Sweeney, D. J., & Wegryn, G. W. (1997). Blending OR/MS judgement, and GIS: Restructuring P &G's supply chain. *Interfaces*, *27*(1), 128–142. doi:10.1287/inte.27.1.128

Campbell, C., & Jones, S. (2008). Using Second Life as an educational instructional tool with pre-service education students: A work in progress. In J. Luca & E. Weippl (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2008* (pp. 3638-3642). Chesapeake, VA: AACE.

Canavesio, M., & Martinez, E. (2007). Enterprise modeling of a project-oriented fractal company for SMEs networking. *Computers in Industry*, *54*, 794–813. doi:10.1016/j.compind.2007.02.005

Capin, T. K., Pandzic, I. S., Magnenat Thalmann, N., & Thalmann, D. (1998). Realistic avatars and autonomous virtual humans. In Earnshaw, R., & Vince, J. (Eds.), *VLNET networked virtual environments, virtual worlds in the internet* (pp. 157–174). Los Alamitos, CA: IEEE Computer Society Press.

Carbonara, N., Giannoccaro, I., & Pontrandolfo, P. (2002). Supply chains within industrial districts: A theoretical framework. *International Journal of Production Economics*, *76*(2), 159–176. doi:10.1016/S0925-5273(01)00159-1

Caricato, P., & Grieco, A. (2009). A DSS for production planning focused on customer service and technological aspects. *Robotics and Computer-integrated Manufacturing*, *25*(6), 871–878. doi:10.1016/j.rcim.2009.06.003

Caridi, M., & Cavalieri, S. (2004). Multi-agent systems in production planning and control: An overview. *Production Planning and Control*, *15*(2), 106–118. doi:10.1080/09537280410001662556

Caridi, M., Cigolini, R., & De Marco, M. (2005). Improving supply-chain collaboration by linking intelligent agents to CPFR. *International Journal of Production Research*, *43*(20), 4191–4218. doi:10.1080/00207540500142134

Carley, K. (2006). *Biodefense through city level multi-agent modeling of bio and chemical threats*. Paper presented at the Arizona Spring Biosurveillance Workshop.

Carrion, M., & Arroyo, J. M. (2006). A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem. *IEEE Transactions on Power Systems*, *21*, 1371–1378. doi:10.1109/TPWRS.2006.876672

Carvalho, J. D., Moreira, N., & Pires, L. C. M. (2005). Autonomous production systems in virtual enterprises. *Journal of Computer Integrated Manufacturing*, *18*, 357–366. doi:10.1080/09511920500081445

Cassell, J., Sullivan, J., Prevost, S., & Churchill, E. (2000). *Embodied conversational agents*. Cambridge, MA: MIT Press.

Castronova, E. (2005). *Synthetic worlds: The business and culture of online games*. Chicago, IL: The University of Chicago Press.

Ceroni, J. A., & Nof, S. Y. (2005). Task parallelism in distributed supply organizations: A case study in the shoe industry. *Production Planning & Control: The Management of Operations*, *16*(5), 500–513. doi:10.1080/09537280500121851

Chambers, J. (2002). *The next hurdle in e-learning.* Retrieved April 3, 2009, from http://www.andersen.com/Website.nsf/Content/ResourcesPerformanceLearningeLearning!OpenDocument&highlight=2,next,hurdle,in,e-learning#02

Chan, T., Wu, Y., Jong, B., Lin, T., & Liang, Y. (2000). *Applying virtual reality to cooperative learning grouping.* Retrieved 23 November, 2011, from http://www.hiceducation.org/edu_proceedings/TeYi%20Chan.pdf

Chan, F. T. S., Chung, S. H., & Chan, P. L. Y. (2005). An adaptive genetic algorithm with dominated genes for distrbution scheduling problems. *Expert Systems with Applications*, *29*(2), 364–371. doi:10.1016/j.eswa.2005.04.009

Chang, Y. C., & Lee, C. Y. (2004). Machine scheduling with job delivery coordination. *European Journal of Operational Research*, *158*, 470–487. doi:10.1016/S0377-2217(03)00364-3

Chan, H., Mazumder, P., & Shahookar, K. (1991). Macrocell and module placement by genetic adaptive searching with bitmap-represented chromosome. *Integration VLSI Journal*, *12*, 49–77. doi:10.1016/0167-9260(91)90042-J

Chauhan, S. S., & Proth, J.-M. (2005). Analysis of a supply chain partnership with revenue sharing. *International Journal of Production Economics*, *97*, 44–51. doi:10.1016/j.ijpe.2004.05.006

Chen, C. L., & Lee, W. C. (2004). Multi-objective optimization of multiechelon supply chain networks with uncertain product demands and prices. *Computers & Chemical Engineering*, *28*(6–7), 1131–1144. doi:10.1016/j.compchemeng.2003.09.014

Chen, C.-L., Yuan, T.-W., & Lee, W.-C. (2007). Multicriteria fuzzy optimization for locating warehouses and distribution centers in a supply chain network. *Journal of the Chinese Institute of Chemical Engineers*, *38*, 393–407. doi:10.1016/j.jcice.2007.08.001

Cheng, C. P., Liu, C. W., & Liu, C. C. (2000). Unit commitment by Lagrangian relaxation and genetic algorithms. *IEEE Transactions on Power Systems*, *15*, 707–714. doi:10.1109/59.867163

Cheng, L., Subrahmanian, E., & Westerberg, A. W. (2004). Multi-objective decisions on capacity planning and production-inventory control under uncertainty. *Industrial & Engineering Chemistry Research*, *43*(9), 2192–2208. doi:10.1021/ie0303404

Cheng, T. C. E., & Kovalyov, M. Y. (2001). Single supplier scheduling for multiple deliveries. *Annals of Operations Research*, *107*, 51–63. doi:10.1023/A:1014938712999

Chen, J. C., Wang, K. J., Wang, S. M., & Jang, S. J. (2008). Price negotiation for capacity sharing in two-factory environment using genetic algorithm. *International Journal of Production Research*, *46*(7), 1847–1868. doi:10.1080/00207540601008440

Chen, J., & Chen, F. F. (2003). Adaptive scheduling in random flexible manufacturing systems subject to machine breakdowns. *International Journal of Production Research*, *41*(9), 1927–1951. doi:10.1080/0020754031000119016

Chen, W.-L., Huang, C.-Y., & Lai, Y.-C. (2009). Collaborative e-work networks in industrial engineering. *Computers & Industrial Engineering*, *57*(1), 61–72. doi:10.1016/j.cie.2008.08.012

Chen, Y. J., & Wang, W.-L. (2009). Orders dispatching game for a multi-facility manufacturing system. *Expert Systems with Applications*, *36*(2), 1885–1892. doi:10.1016/j.eswa.2007.12.040

Chen, Z. L. (2004). *Integrated production and distribution operations: Taxonomy models and review*. Kluwer Academic Publishers.

Cheong, C., & Winikoff, M. (2005). Hermes: Designing goal-oriented agent interactions. In *Proceedings of the 6th International Workshop on Agent-Oriented Software Engineering*.

Cheong, C., & Winikoff, M. (2006). Improving flexibility and robustness in agent interactions: Extending Prometheus with Hermes. *Software Engineering for Multi-Agent Systems*, *6*, 189–206. doi:10.1007/11738817_12

Chiarvesio, M., & Di Maria, E. (2009). Internationalization of supply networks inside and outside clusters. *International Journal of Operations & Production Management*, *29*(11). doi:10.1108/01443570911000186

Chigona, W., Roode, D., Nabeel, N., & Pinnock, B. (2009). Investigating the impact of stakeholder management on the implementation of a public access project: The case of Smart Cape. *South African of Business Management*, *41*(2), 39–49.

Childress, M. D., & Braswell, R. (2006). Using massively multiplayer online role-playing games for online learning. *Distance Education*, *27*(2), 187–197. doi:10.1080/01587910600789522

Chiricota, Y. (2003). Three-dimensional garment modelling using attribute mapping. *International Journal of Clothing Science and Technology*, *15*(5), 348–353. doi:10.1108/09556220310492615

Chirn, J., & McFarlane, D. (2001). Building holonic systems in today's factories: A migration strategy. *Journal of Applied Systems Studies: Special Issue on Holonic and Multi-Agent Systems*, *2*, 82–105.

Chiung, M., & Seo, Y. (2005). Advanced planning for minimizing makespan with load balancing in multiplant chain. *International Journal of Production Research*, *43*(20), 4381–4396. doi:10.1080/00207540500142449

Chodur, M., Januska, M., Sulova, D., & Palka, P. (2009). Value chain of virtual enterprise - Possible modern management concepts and value drivers identification. *Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium,* Vienna. ISBN 1726-9679

Chung, S. H., Lau, H. C. W., Choy, K. L., Ho, G. T. S., & Tse, Y. K. (2009). Application of genetic approach for advanced planning in multi-factory. *International Journal of Production Economics*, *127*(2). doi:doi:10.1016/j.ijpe.2009.08.019

Cliburn, D., & Gross, J. (2008). *Education in Second Life: How it compares to real life*. Symposium conducted Hawaii International Conference on System Sciences, January 5-8, 2009, Waikoloa, HI.

Cochran, J. K., & Ramanujam, B. (2006). Carrier-mode logistics optimization of inbound supply chains for electronics manufacturing. *International Journal of Production Economics*, *103*, 826–840. doi:10.1016/j.ijpe.2006.01.005

Cogburn, D. L., & Levinson, N. S. (2003). US-Africa virtual collaboration in globalization studies: Success factors for complex, cross-national learning teams. *International Studies Perspectives*, *4*, 34–51. doi:10.1111/1528-3577.04103

Cohen, K. (2006). *Second Life offers students a virtually real education*. The Phoenix Media/Communications Group. Retrieved April 20, 2008, from http://thephoenix.com/Article.aspx?id=20561&page=1

Cohen, A. I., & Yoshimura, M. (1983). A branch-and-bound algorithm for unit commitment. *IEEE Transactions on Power Apparatus and Systems*, *102*, 444–451. doi:10.1109/TPAS.1983.317714

Cohen, M. A., & Lee, H. L. (1989). Resource deployment analysis of global manufacturing and distribution networks. *Journal of Manufacturing Operations and Management*, *2*, 81–104.

Cohoon, J. P., & Paris, W. D. (1987). Genetic placement. *IEEE Transactions in Computer-Aided Design*, *6*, 956–964. doi:10.1109/TCAD.1987.1270337

Conklin, M. S. (2007). *101 uses for Second Life in the college classroom*. Retrieved December 2, 2007, from http://facstaff.elon.edu/mconklin/pubs/glshandout.pdf

Conrad, M., Pike, D., Sant, P., & Nwafor, C. (2009). *Teaching large student cohorts in Second Life: Scalability issues and student satisfaction in a virtual world.* Retrieved 8 December, 2011, from http://sl.sanfoh.com/csedu2009/scalabilityInSecondLifeCSEDU2009.pdf

Conte, R., Andrighetto, G., Campennì, M., & Paolucci, M. (2007). Emergent and immergent effects in complex social systems. *Proceedings of AAAI Symposium, Social and Organizational Aspects of Intelligence,* Washington DC.

Cooper, W. (2000). MUDs, metaphysics, and virtual reality. *The Journal of Virtual Environments (Electronic Journal), 5*(11). Retrieved 5 June, 2010, from http://www.brandeis.edu/pubs/jove/HTML/v5/cooper.htm

Corne, D., Ross, P., & Fang, H.-L. (1994). Fast practical evolutionary timetabling. In Fogarty, T. C. (Ed.), *Evolutionary computing* (pp. 250–263). Berlin, Germany: Springer. doi:10.1007/3-540-58483-8_19

Corporation, I. B. M. (2006). *An architectural blueprint for autonomic computing*. Retrieved May 14, 2010, from http://www-01.ibm.com/software/tivoli/autonomic/pdfs/AC_Blueprint_White_Paper_4th.pdf

Cova, B., & Salle, R. (2008). Marketing solutions in the accordance with the S-D logic: Co-creation value with customer network actors. *Industrial Marketing Management*, *37*, 270–277. doi:10.1016/j.indmarman.2007.07.005

Covanich, W., & McFarlane, D. (2009). Assessing ease of reconfiguration o conventional and Holonic manufacturing systems: Approach and case study. *Engineering Applications of Artificial Intelligence*, *22*(7), 1015–1024. doi:10.1016/j.engappai.2009.01.001

Coyne, R. (1994). Heidegger & virtual reality: The implication of Heidegger's thinking for computer representations. *Leonardo*, *27*(1), 65–73. doi:10.2307/1575952

Cross, J., O' Driscoll, T., & Trondsen, E. (2007). Another life-virtual worlds as tools for learning. *E-learning magazine.* Retrieved 29 March, 2011, from http://elearnmag.org/subpage.cfm?section=articles&article=44-1

Cross, J. (2004). An informal history of e-learning. *Journal of. Horizon*, *12*(3), 103–110. doi:10.1108/10748120410555340

Cross, P. (1981). *Adults as learners: Increasing participation and facilitating learning*. San Francisco, CA: Jossey Bass.

CSELT. (2009). *Java agent developed framework*. Retrieved May 14, 2010, from http://jade.cselt.it

Csikszentmihalyi, M., & Rathunde, K. (1993). The measurement of flow in everyday life: Towards a theory of emergent motivation. In J. E. Jacobs (Ed.), *Nebraska symposium on motivation, Vol. 40 - Developmental perspectives on motivation*. Lincoln, NE: University of Nebraska Press.

Čyras, V., & Lapin, K. (2009). *Learning support and legally ruled collaboration in the Virtual Life Virtual World Platform.* Retrieved April 12, 2011, from http://www.ict-virtuallife.eu/public/20091102-ADBIS-INTEL-EDU-Cyras-Lapin-color.pdf

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. doi:10.1111/j.1467-8535.2009.01038.x

Danforth, D. (2010). Development of an interactive virtual 3-D model of the human testes using the Second life platform. *International Journal of Virtual and Personal Learning Environments*, *1*(2), 45–58. doi:10.4018/jvple.2010040104

Dantzig, G. B., & Wolfe, P. (1960). Decomposition principle for linear programs. *Operations Research*, *8*, 101–110. doi:10.1287/opre.8.1.101

Das, A., Narasimhan, R., & Talluri, S. (2006). Supplier integration – Finding an optimal con□guration. *Journal of Operations Management*, *24*(5), 563–582. doi:10.1016/j.jom.2005.09.003

D'Aveni, R. (1998). Waking up to the new era of hypercompetition. *The Washington Quarterly*, (Winter): 183–195. Retrieved from http://www.twq.com/98winter/daveni.pdfdoi:10.1080/01636609809550302

Davenport, T. H., & Prusak, L. (1998). *Working knowledge: How organizations manage what they know*. USA: Harvard Business School Press.

Davis, A., Murphy, J., Dawn, O., Deepak, K., & Zigurs, I. (2009). Avatars, people, and virtual worlds: Foundations for research in metaverses. *Journal of the Association for Information Systems, 10*(2), 90-117. Retrieved 4 May, 2011, from http://aisel.aisnet.org/jais/vol10/iss2/1

De Freitas, S., Rebolledo-Mendez, G., Liarokapis, F., Magoulas, G., & Poulovassilis, A. (2010). Learning as immersive experiences: Using the four-dimensional framework for designing and evaluating immersive learning experiences in a virtual world. *British Journal of Educational Technology*, *41*(1), 69–85. doi:10.1111/j.1467-8535.2009.01024.x

De Lucia, A., Francese, R., Passero, A., & Tortora, G. (2009). Development & evaluation of a virtual campus on Second life. The case of Second DMI. *Computers & Evaluation*, *52*, 220–233.

Dede, C. (2004). Enabling distributed-learning communities via emerging technologies. *Proceedings of the 2004 Conference of the Society for Information Technology in Teacher Education (SITE)* (pp. 3-12). Charlottesville, VA: American Association for Computers in Education.

Dede, C. (1996). Emerging technologies in distance education for business. *Journal of Education for Business*, *71*(4), 197–204. doi:10.1080/08832323.1996.10116784

Delli Gatti, D., Di Guilmi, C., Gaffeo, E., Gianfranco, G., Gallegati, M., & Palestrini, A. (2005). A new approach to business fluctuations: heterogeneous interacting agents, scaling laws and financial fragility. *Journal of Economic Behavior & Organization*, *56*(4), 489–512. doi:10.1016/j.jebo.2003.10.012

Dempster, M. A. H., L., F. M., Jansen, L., Lageweg, B. J., Lenstra, J. K., & Rinnooy Kan, A. H. G. (1983). Analysis of heuristics for stochastic programming: Results for hierarchical scheduling problems. *Mathematics of Operations Research*, *8*, 525–537. doi:10.1287/moor.8.4.525

Deutschmann, M., Panichi, L., & Molka-Danielsen, J. (2009, May). Designing oral participation in Second Life: A comparative study of two language proficiency courses. *ReCALL*, *21*(2), 206–226. doi:10.1017/S0958344009000196

Dhaenens-Flipo, C., & Finke, G. (2001). An integrated model for an industrial production-distribution problem. *IIE Transactions*, *33*, 705–715. doi:10.1080/07408170108936867

Dickover, N. (1994). Reflection-in-action: Modeling a specific organization through the viable system model. *Journal of Systemic Practice & Action Research*, *7*(1), 43–62.

Diener, S., Windsor, J., & Bodily, D. (2009). *Design and development of clinical simulations in Second Life.* Retrieved 23 May, 2011, from http://www.caudit.edu.au/educauseaustralasia09/assets/papers/monday/Scott-Diener.pdf

Dillenbourg, P. (2002). Over scripting CSCL: The risks of blending collaborative learning with instructional design. In P. Kirschner (Ed.), *Three worlds of CSCL. Can we support CSCL?* (pp. 61–91). Nederland: Open Universiteit.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In Dillenbourg, P. (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford, UK: Elsevier.

diSessa, A. (1995). Epistemology and systems design. In A. diSessa & C. Hoyles C. (Eds.), *Computers and exploratory learning* (pp. 15-29). Springer Verlag.

DMD. (2007). *The virtual brand footprint: The marketing opportunity in Second Life*. Diversified Media Design, combined storey, and Market Truths Limited.

Dogan, K., & Goetschalckx, M. (1999). A primal decomposition method for the integrated design of multi-period production-distribution systems. *IIE Transactions*, *31*, 1027–1036. doi:10.1080/07408179908969904

Dolgui, A., & Prodhon, C. (2007). Supply planning under uncertainties in MRP environments: A state of the art. *Annual Reviews in Control*, *31*, 269–279. doi:10.1016/j.arcontrol.2007.02.007

Donaldson, T., & Preston, L. (1995). The stakeholder theory of the corporation: Concepts, evidence, and implications. *Academy of Management Review*, *20*(1), 65–91.

Dondo, R., Mendez, C. A., & Cerda, J. (2008). Optimal management of logistic activities in multi-site environments. *Computers & Chemical Engineering*, *32*, 2457. doi:10.1016/j.compchemeng.2007.10.002

Dörr, C. (2010). *Bewertung von Lernszenarien in virtuellen Welten hinsichtlich der Unterstützung von Lernprozessen am Beispiel von Second Life*. Unveröffentlichte Bachelorarbeit, Universität Augsburg.

Dotzauer, E. (2001). *Energy system operation by Lagrangian relaxation.* Doctoral thesis, Linköping University, Department of Mathematics, Sweden.

Dowlatshahi, S., & Qing, C. (2006). The relationships among virtual enterprise, information technology, and business performance in agile manufacturing. *European Journal of Operational Research*, 174.

Doyle, D. (2008). Immersed in learning: Developing and supporting creative practice in virtual worlds. *ReLive'08: Proceedings of International Conference on Researching Learning in Virtual Environments* (pp. 121-129). The Open University.

Dudek, G. (2004). *Collaborative planning in supply chains*. Berlin, Germany: Springer.

Dudek, G. (2009). *Collaborative planning in supply chains: A negotiation-based approach* (2nd ed.). Springer. doi:10.1007/978-3-540-92176-9

Dudek, G., & Stadler, H. (2005). Negotiation based collaborative planning between supply chains partners. *European Journal of Operational Research*, *163*, 668–687. doi:10.1016/j.ejor.2004.01.014

Duffie, N. A., Roy, D., & Shi, L. (2008). Dynamic modeling of production networks of autonomous work systems with local capacity control. *CIRP Annals - Manufacturing Technology, 57*, 463–466.

Duffie, D., & Pan, J. (1997). An overview of value at risk. *Journal of Derivatives*, *4*(3), 7–49. doi:10.3905/jod.1997.407971

Dunn, R., Holder, D., & Rockinson-Szapkiw, A. J. (2010). Virtual worlds and learning communities for distributed pre-service educators. ISTE. Denver, CO. Retrieved 29 March, 2011, from http://center.uoregon.edu/ISTE/2010/program/search_results_details.php?sessionid=50074876

Durbach, I. N., & Stewart, T. J. (2009). Using the expected values to simplify decision making under uncertainty. *Omega*, *37*, 312–330. doi:10.1016/j.omega.2007.02.001

Dyer, J., & Nobeoka, K. (2000). Creating and managing a high-performance knowledge-sharing network: The Toyota case. *Strategic Management Journal*, *21*(3), 345–367. doi:10.1002/(SICI)1097-0266(200003)21:3<345::AID-SMJ96>3.0.CO;2-N

Earl, M. J., & Scott, I. A. (1999). What is a chief knowledge officer? *Sloan Management Review*, 29–38.

Eduserv. (2009). *Choosing virtual worlds for use in teaching and learning in UK higher education*. Retrieved 12 May, 2011, from http://virtualworldwatch.net/wordpress/wp-content/uploads/2009/10/VWW-Choosing-Virtual-Worlds-Oct-2009.pdf

El Maraghy, H. (2009). The cognitive factory. In El Maraghy, H. (Ed.), *Changeable and reconfigurable manufacturing systems* (pp. 355–371). London, UK: Springer. doi:10.1007/978-1-84882-067-8

Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. New York, NY: Wiley.

Elmaghraby, S. E. (2005). On the fallacy of averages in project risk management. *European Journal of Operational Research*, *165*, 307–313. doi:10.1016/j.ejor.2004.04.003

Embodied Research Group. (2007). *Embodiment, identity & presence in Second Life-New wine or new bottles*. Retrieved 29 March, 2011, from http://embodiedresearch.blogspot.com/2007/08/embodiment-identity-and-presence-in.html

Epstein, J. M. (2006). *Generative social science: Studies in agent-based computational modeling*. Princeton, NJ: Princeton University Press.

Epstein, J., & Axtell, R. (1996). *Growing artificial societies. Social science from the bottom-up*. Washington, DC: Brooking Institution Press.

Erengüç, S. S., Simpson, N., & Vakharia, A. (1999). An integrated production/distribution planning in supply chains: An invited review. *European Journal of Operational Research*, *115*, 219–236. doi:10.1016/S0377-2217(98)90299-5

Eriksen, P. B. (2001). Economic and environmental dispatch of power/CHP production systems. *Electric Power Systems Research*, *57*, 33–39. doi:10.1016/S0378-7796(00)00116-4

Ertogral, K., & Wu, S. D. (2000). Auction-theoretic coordination of production planning in the supply chain. *IEE Transactions*, *32*, 931–940. doi:10.1080/07408170008967451

Eschenbrenner, B., Nah, F. F.-H., & Siau, K. (2008). 3-D virtual worlds in education: Applications, benefits, issues, and opportunities. *Journal of Database Management*, *19*(4), 91–110. doi:10.4018/jdm.2008100106

Espejo, R., & Gill, A. (2003). *The viable system model as a framework for understanding organizations*. Retrieved 3 May, 2011, from http://syncho.com

Espejo, R., Bowling, D., & Hoverstadt, P. (1999). The viable system model and the Viplan software. *Kybernetes*, *28*(6/7), 661–678. doi:10.1108/03684929910282944

Espejo, R., & Harnden, R. (1989). *The viable system model: Interpretations and applications of Stafford Beer's VSM*. Chichester, UK: John Wiley & Sons.

Espejo, R., Schuhmann, W., Schwaninger, M., & Bibello, U. (1996). *Organizational transformation and learning: A cybernetic approach to management*. Chichester, UK: Wiley & Jons.

Esteves, M., Fonseca, B., Morgado, L., & Martins, P. (2009). Using Second Life for problem based learning in computer science programming. *Pedagogy, Education and Innovation in 3-D Virtual Worlds, 2*(1). Retrieved 12 May, 2011, from http://journals.tdl.org/jvwr/article/viewArticle/419

Everitt, D., & Manfield, D. (1989). Performance analysis of cellular mobile communication systems with dynamic channel assignment. *IEEE Journal on Selected Areas in Communications*, *7*(8), 1172–1180. doi:10.1109/49.35562

Falloon, G. (2010). Using avatars and virtual environments in learning: What do they have to offer? *British Journal of Educational Technology*, *41*(1), 108–122. doi:10.1111/j.1467-8535.2009.00991.x

Fang, C., Kimbrough, S. O., Pace, S., Valluri, A., & Zheng, Z. (2002). On adaptive emergence of trust behavior in the game of stag hunt. *Group Decision and Negotiation*, *11*(6), 449–467. doi:10.1023/A:1020639132471

Ferber, J. (1999). *Multi-agent systems. An introduction to distributed artificial intelligence*. Boston, MA: Addison-Wesley.

Folcik, V., & Orosz, C. G. (2006). *An agent-based model demonstrates that the immune system behaves like a complex system and a scale-free network*. Paper presented at the SwarmFest 2006.

Follett, M. P. (1941). Dynamic administration. In Metcalf, H. C., & Urwick, L. (Eds.), *The collected papers of Mary Parker Follett*. New York, NY: Harper and Brothers publications.

Ford, L. R., & Fulkerson, D. R. (1958). A suggested computation for maximal multicommodity network flows. *Management Science*, *5*, 97–101. doi:10.1287/mnsc.5.1.97

Fox, M., Barbuceanu, M., & Teigen, R. (2000). Agent-oriented supply chain management. *International Journal of Flexible Manufacturing Systems*, *12*(2/3), 165–188. doi:10.1023/A:1008195614074

Francas, D., & Minner, S. (2009). Manufacturing network configuration in supply chains with product recovery. *Omega*, *37*, 757–769. doi:10.1016/j.omega.2008.07.007

Franceschi, K., Lee, R., & Hinds, D. (2008). Engaging e-learning in virtual worlds: Supporting group collaboration. *Proceedings of the 41st Hawaii. International Conference on System Sciences*.

Frayret, J.-M. D., & Montreuil, B. (2004). Co-ordination and control in distributed and agent-based manufacturing systems. *Production Planning and Control*, *15*(1), 1–13. doi:10.1080/09537280410001658344

Freeman, R. E., & Reed, D. L. (1983). Stockholders and stakeholders: A new perspective on corporate governance. *California Management Review*, *25*(3), 88–106.

Fress, S., & Kessler, D. (2005). Precise and rapid interaction through scaled manipulation in immersive virtual environments. *IEEE Virtual Reality Conference* (pp. 99-106). Germany.

Fritz, J. (2004). *Das Spiel verstehen. Eine Einführung in Theorie und Bedeutung*. Weinheim: Juventa.

Fritz, M., & Hausen, T. (2009). Electronic supply network coordination in agrifood networks- Barriers, potentials, and path dependencies. *International Journal of Production Economics*, *121*, 441–453. doi:10.1016/j.ijpe.2007.02.025

Fung, R. Y. K., Tang, J., & Wang, D. (2003). Multiproduct aggregate production planning with fuzzy demands and fuzzy capacities. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *33*(3), 302–313. doi:10.1109/TSMCA.2003.817032

Gajenda, S., Wenjun, M., & Ye, Q. (2010). Second Life: A strong communication tool in social networking and business. *Information Technology Journal*, *9*(3), 524–534. doi:10.3923/itj.2010.524.534

Gajenda, S., Ye, Q., Sun, W., & Dayling, Z. (2011). Significance of communication and e-business in Second Life virtual world. *Information Technology Research Journal*, *1*(1), 1–12.

Galbreath, J. (2006). Does primary stakeholder management positively affect the bottom line? Some evidence from Australia. *Management Decision*, *44*(8), 1106–1121. doi:10.1108/00251740610690649

Garcia, J. M., Lozano, S., & Canca, D. (2004). Coordinated scheduling of production and delivery from multiple plants. *Robotics and Computer-integrated Manufacturing*, *20*, 191–198. doi:10.1016/j.rcim.2003.10.004

Gartner. (2007). *Gartner says 80 percent of active internet users will have a "Second Life" in the virtual world by the end of 2011*. Press Releases of 2007. Retrieved 3 April, 2011, from http://www.gartner.com/it/page.jsp?id=503861

Garvare, R., & Johansson, P. (2010). Management for sustainability – A stakeholder theory. *Total Quality Management*, *21*(7), 737–744. doi:10.1080/14783363.2010.483095

Gazzard, A. (2009). Teleporters, tunnels & time: Understanding warp devices in video games. *Proceedings of the Digital Games Research Association* (DiGRA).

Geary, S., Childerhouse, P., & Towill, D. (2002). Uncertainty and the seamless supply chain. *Supply Chain Management Review*, *6*(4), 52–60.

Gee, J. (2009). Deep learning properties of good digital games: How far can they go? In Ritterfeld, U., Cody, M., & Vorderer, P. (Eds.), *Serious games: Mechanism and effects* (pp. 67–83). New York, NY: Routledge, Taylor & Francis.

Genovese, J. (2003). *Piaget, pedagogy & evolutionary psychology*. Retrieved 3 October, 2011, from http://www.epjournal.net/filestore/ep01127137.pdf

Geoffrion, A. M., & Graves, G. W. (1974). Multicommodity distribution design by Benders decomposition. *Management Science*, *20*(5), 822–844. doi:10.1287/mnsc.20.5.822

Gesbert, D., Kiani, S. G., Gjendemsjø, A., & Øien, G. E. (2007). Adaption, coordination, and distributed resource allocation in interference-limited wireless networks. *Proceedings of the IEEE*, *95*(12), 2393–2409. doi:10.1109/JPROC.2007.907125

Giannoccaro, I., & Pontrandolfo, P. (2004). Supply chain coordination by revenue sharing contracts. *International Journal of Production Economics*, *89*, 131–139. doi:10.1016/S0925-5273(03)00047-1

Giesen, E., Ketter, W., & Zuidwijk, R. (2009). *An agent-based approach to improving resource allocation in the Dutch youth health care sector*. Paper presented at the European Conference on Information Systems (ECIS), Verona, Italy.

Gilbert, N. (2002). *Varieties of emergence*. Paper presented at the Agent Conference: Social agents: Ecology, Exchange, and Evolution, Chicago.

Gilbert, N. (2008). *Agent-based models*. London, UK: Sage Publications.

Gill, P. E., Murray, W., & Wright, M. H. (1981). *Practical optimization*. London, UK: Academic Press.

Goetschalckx, M., Vidal, J., & Koray, D. C. (2002). Modelling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. *European Journal of Operational Research*, *143*, 1–18. doi:10.1016/S0377-2217(02)00142-X

Golenko (Ginzburg), D. I. (1989). A new approach to the activity-time distribution in PERT. *The Journal of the Operational Research Society*, *40*, 389–393.

Golovin, J. J. (1975). *Hierarchical integration of planning and control technique report.* Operation research center M.I.T. No. 116.

Gomes, B. A., & Saraiva, J. T. (2009). Demand and generation cost uncertainty modelling in power system optimization studies. *Electric Power Systems Research*, *79*(6). doi:10.1016/j.epsr.2008.12.010

Goodwin, C. (1986). Gestures as a resource for the organization of mutual orientation. *Semiotica*, *62*(1/2), 29–49. doi:10.1515/semi.1986.62.1-2.29

Goranson, H. T. (1999). *The agile virtual enterprise: Cases, metrics, tools*. Quorum Books.

Goransson, L., & Johnsson, F. (2009). Dispatch modeling of a regional power generation system Integrating wind power. *Renewable Energy*, *34*, 1040–1049. doi:10.1016/j.renene.2008.08.002

Goslin, M., & Morie, J. F. (1996). Virtopia: Emotional experiences in virtual environments. *Leonardo*, *29*(2), 95–100. doi:10.2307/1576338

Göttlich, S., Herty, M., & Ringhofer, C. (2010). Optimization of order policies in supply networks. *European Journal of Operational Research*, *202*, 456–465. doi:10.1016/j.ejor.2009.05.028

Grau, O. (2003). *Virtual art: From illusion to immersion*. Cambridge, MA: MIT Press Leonardo Book Series.

Graves, S. B., & Ringuest, J. L. (2009). Probabilistic dominance criteria for comparing uncertain alternatives: A tutorial. *Omega*, *37*, 346–357. doi:10.1016/j.omega.2007.03.001

Graves, S. C., & Willems, S. P. (2000). Optimizing strategic safety stock placement in supply chains. *Manufacturing and Service Operations Management*, *2*(1), 68–83. doi:10.1287/msom.2.1.68.23267

Grunow, M., Günther, H. O., Burdenik, H., & Alting, L. (2007). Evolving production network structures. *CIRP Annals - Manufacturing Technology, 56*(1), 427-430.

Guadagno, R. E., Blascovich, J., Bailenson, J. N., & McCall, C. (2007). Virtual humans and persuasion: The effects of agency and behavioral realism. *Media Psychology*, *101*, 1–22.

Guan, Y., Ahmed, S., Nemhauser, G. L., & Miller, A. J. (2006). A branch and cut algorithm for the stochastic uncapacitated lot-sizing problem. *Mathematical Programming*, *105*(1), 55–84. doi:10.1007/s10107-005-0572-9

Guessoum, Z., & Briot, J. P. (1999). From active object to autonomous agents. *IEEE Concurrency*, *7*(3), 68–78. doi:10.1109/4434.788781

Gunasekaran, A., Lai, K.-H., & Edwin Cheng, T. C. (2008). Responsive supply chain: A competitive strategy in a networked economy. *Omega*, *36*(4), 549–564. doi:10.1016/j.omega.2006.12.002

Gupta, A. K., & Sivakumar, A. I. (2006). A job shop scheduling techniques in semiconductor manufacturing. *International Journal of Advanced Manufacturing Technology*, *27*, 1163–1169. doi:10.1007/s00170-004-2296-z

Gupta, A., & Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & Chemical Engineering*, *27*, 1219–1227. doi:10.1016/S0098-1354(03)00048-6

Gupta, D., & Weerawat, W. (2006). Supplier-manufacturer coordination in capacited two-stage supply chains. *European Journal of Operational Research*, *175*, 67–89. doi:10.1016/j.ejor.2005.04.021

Guye-Vuillieme, A., Capin, T. K., Pandzic, I. S., Magnenat Thalmann, N., & Thalmann, D. (1999). Non-verbal communication interface for collaborative virtual environments. *The Virtual Reality Journal*, *4*, 49–59. doi:10.1007/BF01434994

Hadeli, K., Valckenaers, P., Kollingbaumb, M., & Van Brussel, H. (2004). Multi-agent coordination and control based on stigmergy. *Computers in Industry*, *53*, 75–96. doi:10.1016/S0166-3615(03)00123-4

Hahn, E. D. (2008). Mixture densities for project management activity times: A robust approach to PERT. *European Journal of Operational Research*, *188*, 450–459. doi:10.1016/j.ejor.2007.04.032

Hakonen, H. (1996). *Unit commitment optimization of backpressure power plants in cogeneration planning* (In Finnish). Master thesis, Systems Analysis Laboratory, Helsinki University of Technology.

Hamichi, S., Brée, D., Guessoum, Z., & Mangalagiu, D. (2009). A multi-agent system for adaptive production networks. In G. Di Tosto & H. V. D. Parunak (Eds.), *Multi-Agent-Based Simulation Vol. 5683 of Lecture Notes in Computer Science* (pp. 49-60). Berlin, Germany Springer.

Hamichi, S., Guessoum, Z., & Mangalagiu, D. (2009). A multi-agent system of adaptive production networks. In S. Decker, J. Sichman, C. Sierra, & C. Castelfranchi (Eds.), *Proceedings of 8th Int. Conf. on Autonomous Agents and Multiagent Systems* (pp. 1311-1312). Budapest, Hungary.

Hansen, M. T., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge? *Harvard Business Review*, *77*(3-4), 106–116.

Haq, A. N., Vrat, P., & Kanda, A. (1991). An integrated production inventory and distrbution model for manufacturing of urea: A case. *International Journal of Production Economics*, *25*, 39–50. doi:10.1016/0925-5273(91)90129-H

Harland, C. M., & Knight, L. A. (2001). Supply network strategy: Role and competence requirements. *International Journal of Operations & Production Management*, *21*(4), 476–489. doi:10.1108/01443570110381381

Harris, B., Cook, D. J., & Lewis, F. (1998). Machine planning for manufacturing: dynamic resource allocation and on-line supervisory control. *Journal of Intelligent Manufacturing*, *9*(5), 413–430. doi:10.1023/A:1008888215052

Hasan, H. (1999). The mediating role of technology in making sense of information in a knowledge-intensive industry. *Knowledge and Process Management*, *6*(2), 72–82. doi:10.1002/(SICI)1099-1441(199906)6:2<72::AID-KPM52>3.0.CO;2-X

Hausen, T., Fritz, M., & Schiefer, G. (2006). Potential of electronic trading in complex supply chains: An experimental study. *International Journal of Production Economics*, *104*, 580–597. doi:10.1016/j.ijpe.2005.04.010

Hax, A. C., & Meal, H. C. (1975). Hierarchical integration of production planning scheduling. In Giesler, M. A. (Ed.), *Studies in management sciences, logistic* (*Vol. 1*, pp. 53–69). North Holland.

Haythornthwaite, C., Kazmer, M. M., Robins, J., & Shoemaker, S. (2000). Community development among distance learners: Temporal and technological dimensions. *Journal of Computer-Mediated Communication, 6*(1). Retrieved 23 October, 2011, from http://jcmc.indiana.edu/vol6/issue1/haythornthwaite.html

Hayward, V., Astley, R., Cruz-Hernandez, M., Grant, D., Robles-De-La-Torre, G., & Haptic, M. (2004). Interfaces and devices. *Sensor Review*, *24*(1), 16–29. doi:10.1108/02602280410515770

Hazel, M., & Mawyn, J. (2005). Scenario-based spoken interaction for virtual agents. *Computer Assisted Language Learning*, *18*(3), 171–191. doi:10.1080/09588220500173344

Heeter, C. (1992). Being there: The subjective experience of presence. *Presence (Cambridge, Mass.)*, *1*, 262–271.

Heiner, M., Schneckenberg, D., & Wilt, J. (2001). *Online pedagogy – Innovative teaching and learning strategies in ICT-environments.* Work package 1, Working group 7/8 Pedagogy, 3453/ 001-001 EDU-ELEARN. Retrieved January 2005 from http://www.cevu.org/reports/docs/WP1_WG7_8BP.pdf

Hilder, T. (1995). *The viable system model*. Retrieved 2 February, 2010, from http://www.users.globalnet.co.uk/~rxv/orgmgt/vsm.pdf

Hillier, C. F., & Liberman, G. J. (1980). *Introduction to operation research* (3rd ed.).

Hillis, K. (1999). *Digital sensations: Space, identity and embodiment in virtual reality*. Minneapolis, MN: University of Minnesota Press.

Hillman, A., & Keim, G. (2001). Shareholder value, stakeholder management, and social issues: What's the bottom line? *Strategic Management Journal*, *22*(2), 125–139. doi:10.1002/1097-0266(200101)22:2<125::AID-SMJ150>3.0.CO;2-H

Hill, R. R., Carl, R. G., & Champagne, L. E. (2006). Using agent-based simulation to empirically examine search theory using a historical case study. *Journal of Simulation*, *1*(1), 29–38. doi:10.1057/palgrave.jos.4250003

Hobbs, M., Gordon, M., & Brown, E. (2006). *A virtual world environment for group work*. Retrieved June 22, 2010, from http://www.formatex.org/micte2006/Downloadable-files/oral/A%20Virtual%20World.pdf

Hobbs, W. J., Hermon, G., Warner, S., & Sheble, G. B. (1988). An enhanced dynamic programming approach for unit commitment. *IEEE Transactions on Power Systems*, *3*, 1201–1205. doi:10.1109/59.14582

Hollins, P., & Robbins, S. (2008). *The educational affordances of multi user virtual environments (MUVE). ReLive' 08: Proceedings of Researching Learning in Virtual Environments* (pp. 172–180). The Open University.

Hongmel, G., Biqing, J., Wenhuang, L., Yu, L., & Shluku, R. (2003, April). Computers in industry, Vol. 50. *Operation Management of Virtual Enterprise*, *3*, 333–352.

Hong, S., Nag, B. N., & Yao, D. (2007). Modeling agent auctions in a supply chain environment. *International Journal of Intelligent Information Technologies*, *3*(1), 14–36. doi:10.4018/jiit.2007010102

Hong, S., Nag, B. N., & Yao, D. (2008). Improving e-trade auction volume by consortium. In Sugumaran, V. (Ed.), *Distributed artificial intelligence, agent technologies, and collaborative applications*. Hershey, PA: IGI Global. doi:10.4018/978-1-60566-144-5.ch005

Hoverstadt, P., & Bowling, D. (2002). *Modeling organizations using the viable system model*. Systems Engineering Workshop. USA: Royal Academy of Engineering.

Howe, J. (2006). The rise of crowdsourcing. *Wired*. Retrieved January 8, 2011, from http://www.wired.com/wired/archive/14.06/crowds.html

Hoyles, C. (1995). Exploratory software, exploratory cultures? In diSessa, A., & Hoyles, C. (Eds.), *Computers and exploratory learning* (pp. 199–219). Springer Verlag. doi:10.1007/978-3-642-57799-4_11

Hsu, H. M., & Wang, W. P. (2001). Possibilistic programming in production planning of assemble-to-order environments. *Fuzzy Sets and Systems*, *119*, 59–70. doi:10.1016/S0165-0114(99)00086-X

Hsu, H.-C., & Li, H.-C. (2009). An integrated plant capacity and production planning model for high-tech manufacturing firms with economies of scale. *International Journal of Production Economics*, *118*(2), 486–500. doi:10.1016/j.ijpe.2008.09.015

Huang, C. Y., Huang, C. C., & Liu, C. Y. (2008). Order confirmation mechanism for collaborative production networks. *International Journal of Production Research*, *46*(3), 595–620. doi:10.1080/00207540600844019

Huang, C.-Y., Sun, C.-T., Hsieh, J.-L., & Lin, H. (2004). Simulating SARS: Small-world epidemiological modeling and public health policy assessments. *Journal of Artificial Societies and Social Simulation*, *7*(4).

Hundsberger, S. (2009). *Foreign language learning in Second Life and the implications for resource provision in academic libraries.* Retrieved July, 5, 2010, from http://arcadiaproject.lib.cam.ac.uk/docs/second_life.pdf

Ikeda, Y., Aoyama, H., Iyetomi, H., Fujiwara, Y., Soumad, W., & Kaizoji, T. (2007). Response of firm agent network to exogenous shock. *Physica A: Statistical Mechanics and its Applications, 382*(1), 138-148.

Ikeda, Y., Souma, W., Aoyama, H., Iyetomi, H., Fujiwara, Y., & Kaizoji, T. (2007). Quantitative agent-based firm dynamics simulation with parameters estimated by financial and transaction data analysis. *Physica A: Statistical Mechanics and its Applications, 375*(2), 651-667.

Ikeda, Y., Aoyama, H., Iyetomi, H., Fujiwara, Y., & Souma, W. (2008). Correlated performance of firms in a transaction network. *Journal of Economic Interaction and Coordination*, *3*(1), 73–80. doi:10.1007/s11403-008-0035-5

Illerhaus, S. W., & Verstege, J. F. (1999). *Optimal operation of industrial CHP-based power systems in liberalized energy markets*. In IEEE Power Tech'99 Conference, Budapest, Hungary, August 29–September 2.

Inman, C., Wright, V., & Hartman, J. (2010, Spring). Use of Second Life in K-12 and higher education: A review of research. *Journal of Interactive Online Learning*, *9*(1), 44–63.

Intelligent Software Agents. (n.d.). *Website*. Retrieved August 13, 2009, from http://www.cs.cmu.edu/~softagents/

Jackson, M. C. (2000). *Systems approaches to management*. United States: Kluwer Academic.

Jalilzadeh, S., Shayeghi, H., & Hadadian, H. (2009). Integrating generation and transmission networks reliability for unit commitment solution. *Energy Conversion and Management*, *50*, 777–785. doi:10.1016/j.enconman.2008.09.027

Jantsch, E. (1975). *Design for evolution*. New York, NY: George Braziller.

Januska, M. (2011). *Communication as a key factor in virtual enterprise paradigm support*. In Innovation and Knowledge Management: A Global Competitive Advantage, Kuala Lumpur, Malaysia. ISBN 978-0-9821489-5-2

Januska, M., & Kurkin, O. (2010). *Communication environment designed for project cooperation of small and medium enterprises.* In The 21th International DAAAM SYMPOSIUM "Intelligent Manufacturing & Automation: Theory, Practice & Education", Zadar, DAAAM International Vienna 2010, ISBN 978-3-901509-73-5

Januska, M., Kurkin, O., & Miller, A. (2010). *Communication environment for small and medium enterprises.* In The 14th International Business Information Management Association Conference, Istanbul, 2010. ISBN 978-0-9821489-3-8

Januska, M., & Chodur, M. (2009). *Virtual enterprise network. Internation Spring Seminar of Electronics Technology ISSE2009*. Piscataway, NJ: IEEE.

Jarmon, L., Traphagan, T., Mayrath, M., & Trivedi, A. (2009). Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life. *Computers & Education*, *53*(1), 169–182. doi:10.1016/j.compedu.2009.01.010

Jayaraman, V., & Prikul, H. (2001). Planning and coordination of production and distribution facilities for multiple commodities. *European Journal of Operational Research*, *133*, 394–408. doi:10.1016/S0377-2217(00)00033-3

Jedličková, P. S. (2009). *The role of virtual worlds in teaching and learning*. Decowe Conference. Ljubljana, Slovenia.

Jennings, N. (2000). On agent-based software engineering. *Artificial Intelligence*, *117*, 277–296. doi:10.1016/S0004-3702(99)00107-1

Jennings, N., & Collins, C. (2007). Virtual or virtually U: Educational institutions in Second Life. *International Journal of Social Sciences*, *2*(3), 180–186.

Jia, C. (2001). Stochastic single machine scheduling with an exponentially distributed due date. *Operations Research Letters*, *28*, 199–203. doi:10.1016/S0167-6377(01)00065-7

Jia, H. Z., Ong, S. K., Fuh, J. Y. H., Zhang, Y. F., & Nee, A. Y. C. (2004). An adaptive and upgradable agent-based system for coordinated product development and manufacture. *Robotics and Computer-integrated Manufacturing*, *20*(2), 79–90. doi:10.1016/j.rcim.2003.08.001

Jiménez, A. A., & Pantoja, B. T. (2008). Scaffolding tutoring strategy on virtual enviroments for training. *Ingeniare. Rev. chil. ing. 16*(1), 220-231.

Johnson, A., & Moher, T. (2002). Augmenting elementary school education with VR. *IEEE Computer Graphics and Applications*, *22*(2), 6–9. doi:10.1109/38.988740

Johnson, D. (1997). The triangular distribution as a proxy for beta distribution in risk analysis. *The Statistician*, *46*(3), 387–398. doi:10.1111/1467-9884.00091

Jolayemi, J., & Olorunniwo, F. (2004). A deterministic model for planning production quantities in a multi-plant, multi-warehouse environment with extensible capacities. *International Journal of Production Economics*, *87*(2), 99–113. doi:10.1016/S0925-5273(03)00095-1

Kalawsky, R. (1996). *Exploiting virtual reality techniques in education and training: Technological issues*. SIMA Report Series 1996.

Kalawsky, R. S. (1993). *The science of virtual reality and virtual environments: A technical, scientific and engineering reference on virtual environments*. Wokingham, UK: Addison-Wesley.

Kaleva. (2010, 13 November). Ääntä Avoimella Kisalla. *Kaleva*.

Kallrath, J. (2005). Solving planning and design problems in the process industry using mixed integer and global optimization. *Annals of Operations Research*, *140*, 339–373. doi:10.1007/s10479-005-3976-2

Kallrath, J., & Maindl, T. I. (2006). *Real optimization with SAP-APO*. Heidelberg, Germany: Springer.

Kambil, A., Friesen, G. B., & Sundaram, A. (1999). Co-creation: A new source of value. *Outlook Journal*, *2*, 38–43.

Kamburowski, J. (1985). An upper bound on the expected completion time of PERT networks. *European Journal of Operational Research*, *21*, 206–212. doi:10.1016/0377-2217(85)90032-3

Kanyalkar, A. P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 4431–4454. doi:10.1080/00207540500142332

Kanyalkar, P., & Adil, G. K. (2005). An integrated aggregate and detailed planning in a multi-site production environment using linear programming. *International Journal of Production Research*, *43*(20), 31–54. doi:10.1080/00207540500142332

Kaut, M., & Wallace, S. W. (2007). Evaluation of scenario-generation methods for stochastic programming. *Pacific Journal of Optimization*, *3*(2), 257–271.

Kay, J., & FitzGerald, S. (2008). *Educational uses of Second Life.* Retrieved 3 May, 2011, from http://www.sleducation.wikispaces.com/educationauses

Kay, J., & FitzGerald, S. (2009). *Second Life in education.* Retrieved 2 May, 2011, from http://sleducation.wikispaces.com/educationaluses

Kazarlis, S. A., Bakirtzis, A. G., & Petridis, V. (1996). A genetic algorithm solution to the unit commitment problem. *IEEE Transactions on Power Systems*, *11*, 83–92. doi:10.1109/59.485989

Kelly, K., Heilbrun, A., & Stacks, B. (1989). Virtual reality: An interview with Jaron Lanier. Whole Earth Review, *64*(12) 108. Retrieved June 23, 2010, from http://www.jaronlanier.com/jaron%20whole%20earth%20review.pdf

Kelton, A. J. (2007). Second Life: Reaching into the virtual world for real-world learning. *EDUCAUSE Center for Applied Research (ECAR), Research Bulletin, 17*. Retrieved 3 May, 2010, from http://www.educause.edu/ir/library/pdf/ecar_so/erb/ERB0717.pdf

Kemp, J., & Livingstone, D. (2006). Putting a Second Life "metaverse" skin on learning management systems. *Proceedings of the First Second Life Education Workshop at SLCC*, (pp. 13-18). San Francisco.

Kemp, J., & Haycock, K. (2008). Immersive learning environments in parallel universes: Learning through Second Life. *School Libraries Worldwide*, *14*(2), 89–97.

Kemp, J., Livingstone, D., & Bloomfield, P. (2009). SLOODLE: Connecting VLE tools with emergent teaching practice in Second Life. *British Journal of Educational Technology*, *40*(3), 551–555. doi:10.1111/j.1467-8535.2009.00938.x

Kephart, J., & Chess, D. M. (2003). The vision of autonomic computing. *Computer*, *36*(1), 41–50. doi:10.1109/MC.2003.1160055

Kijima, M., & Ohnishi, M. (1993). Mean-risk analysis of risk aversion and wealth effects on optimal portfolios with multiple investment opportunities. *Annals of Operations Research*, *45*, 147–163. doi:10.1007/BF02282046

Kim, S. W., & Park, S. (2008). Development of a three-echelon SC model to optimize coordination costs. *European Journal of Operational Research*, *184*(3), 1044–1061. doi:10.1016/j.ejor.2006.11.033

Kira, D., Kusy, M., & Rakita, I. (1997). A stochastic linear programming approach to hierarchical production planning. *The Journal of the Operational Research Society*, *48*, 207–211.

Kleindorfer, G. B. (1971). Bounding distributions for a stochastic acyclic network. *Operations Research*, *19*(7), 1586–1601. doi:10.1287/opre.19.7.1586

Kletti, J. (2007). *Manufacturing execution systems – MES*. Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-540-49744-8

Ko, H. J., & Evans, G. W. (2007). A genetic algorithm based heuristic for the dynamic integrated forward/reverse logistic network for 3PLs. *Computers & Operations Research*, *34*(2), 346–366. doi:10.1016/j.cor.2005.03.004

Kohler, T. A., Gumerman, G. J., & Reynolds, R. G. (2005). Simulating ancient societies. *Scientific American*, *293*(1), 76–84. doi:10.1038/scientificamerican0705-76

Kolas, L., & Stampe, A. (2004). *Implementing delivery methods by using pedagogical design patterns.* Retrieved 2 September, 2011, from www2.tisip.no/E-LEN/papers/EDMEDIA/SymposiaNTNU.pdf

Koleva, B. N., Schnadelbach, H. M., Benford, S. D., & Greenhalgh, C. M. (2006). Developing mixed reality boundaries. *Proceedings of Designing Augmented Reality Environments (DARE 2000)* (pp. 155–157). Elsinore, Denmark.

Kong, N., Schaefer, A. J., Hunsaker, B., & Roberts, M. S. (2010). Maximizing the efficiency of the U.S. liver allocation system through region design. *Management Science*, *56*(12), 2111–2122. doi:10.1287/mnsc.1100.1249

Konno, H., & Yamazaki, H. (1991). A mean-absolute deviation portfolio optimization model and its application to Tokyo stock market. *Management Science*, *37*, 519–531. doi:10.1287/mnsc.37.5.519

Korosec, D., & Holobar, A. (2002). Dynamic VRML for simulated training in medicine: Computer-Based Medical Systems. *Proceeding of the 15th IEEE Symposium* (pp. 205-210). Germany.

Kosakaya, J., & Yamaoka, K. (2001) Co-operative multi-agent intelligent field terminals. *Proceedings of the Fifth International Conference on Autonomous Agents*, (pp. 348-354).

Koutsabasis, P., Vosinakis, S., Malisova, K., & Paparounas, N. (2012). On the value of virtual worlds for collaborative design. *Design Studies, 33*(4). ISSN 0142-694X

Krueger, M. W. (1991). *Artificial reality II*. Reading, MA: Addison-Wesley.

Kulkarni, V. G., & Adlakha, V. G. (1986). Markov and Markov regenerative PERT networks. *Operations Research*, *34*(5), 769–781. doi:10.1287/opre.34.5.769

Kumar, S., & Naresh, R. (2009). Nonconvex economic load dispatch uses an efficient real-coded genetic algorithm. *Applied Soft Computing*, *9*, 321–329. doi:10.1016/j.asoc.2008.04.009

KZero. (2011). *The virtual worlds universe*. Retrieved February 14, 2011, from http://www.kzero.co.uk/universe.php

Laguna, M. (1998). Applying robust optimization to capacity expansion for one location in telecommunications with demand uncertainty. *Management Science*, *44*(11), 101–110. doi:10.1287/mnsc.44.11.S101

Lai, Y. J., & Hwang, C. L. (1992). A new approach to some possibilistic linear programming problems. *Fuzzy Sets and Systems*, *49*, 121–133. doi:10.1016/0165-0114(92)90318-X

Lanier, J. (1992). Virtual reality: The promise of the future. *Interactive Learning International*, *8*, 275–279.

Lan, Y., Liu, Y., & Sun, G. (2010). An approximation-based approach for fuzzy multi-period production planning problem with credibility objective. *Applied Mathematical Modelling*, *34*(11). doi:10.1016/j.apm.2010.02.013

Lányi, S., Geiszt, Z., Karolyi, P., Tilinger, A., & Magyar, V. (2006). Virtual reality in special needs in early education. *The International Journal of Virtual Reality*, *5*(4), 55–68.

Lappalainen, M. (2009). *Entrepreneurial orientation at the level of dyad relationships in supply chains and networks. Jyväskylä Studies in Business and Economics, 85*. University of Jyväskylä.

LeBaron, B. (2002). *Short-memory traders and their impact on group learning in financial markets* (*Vol. 99*, pp. 7201–7206). National Academy of Sciences. doi:10.1073/pnas.072079699

Lee, S., & Kumara, S. (2007). Decentralized supply chain coordination through action markets: Dynamic lot-sizing in distribution network. *International Journal of Production Research*, *45*, 4715–4733. doi:10.1080/00207540600844050

Lee, Y. H., Jeong, C. J., & Moon, C. (2002). Advanced planning and scheduling with outsourcing in manufacturing supply chain. *Computers & Industrial Engineering*, *43*(1-2), 351–374. doi:10.1016/S0360-8352(02)00079-7

Lee, Y. H., & Kwon, S. G. (2010). The hybrid planning algorithm for the distribution center operation using tabu search and decomposed optimization. *Expert Systems with Applications*, *37*(4), 3094–3103. doi:10.1016/j.eswa.2009.09.020

Leimeister, J., Huber, M., Bretschneider, U., & Krcmar, H. (2009). Leveraging crowdsourcing - Activation-supporting components for IT-based idea competitions. *Journal of Management Information Systems*, *26*(1). doi:10.2753/MIS0742-1222260108

Leitão, P. (2009). Agent-based distributed manufacturing control: A state-of-the-art survey. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.005

Leitão, P., Colombo, A., & Restivo, F. (2005). ADACOR: A collaborative production automation and control architecture. *IEEE Intelligent Systems*, *20*, 58–66. doi:10.1109/MIS.2005.2

Leshno, M., & Levy, H. (2002). Preferred by 'all' and preferred by 'most' decision makers: Almost stochastic dominance. *Management Science*, *48*(8), 1074–1085. doi:10.1287/mnsc.48.8.1074.169

Lesnaia, E., Vasilescu, I., & Graves, S. C. (2004). *The complexity of safety stock placement in general-network supply chains: Innovation in Manufacturing Systems and Technology (IMST)*. Massachusetts Institute of Technology.

Lester, C. J., Zettlemoyer, S. L., Grégoire, P. J., & Bares, H. W. (2004). *Explanatory lifelike avatars: Performing user-centred tasks in 3D learning environments*. Multimedia Laboratory, Department of Computer Science, North Carolina State University.

Leung, S. C. H., Tsang, S. O. S., Ng, W. L., & Wu, Y. (2007). A robust optimization model for multi-site production planning problem in an uncertain environment. *European Journal of Operational Research*, *181*(1), 224–238. doi:10.1016/j.ejor.2006.06.011

Leung, S. C. H., & Wu, Y. (2004). A robust optimization model for stochastic aggregate planning. *Production Planning and Control*, *15*(5), 502–514. doi:10.1080/09537280410001724287

Leung, S. C. H., Wu, Y., & Lai, K. K. (2006). A stochastic programming approach for multi-site aggregate production planning. *The Journal of the Operational Research Society*, *57*(2), 123–132.

Leus, R., & Herroelen, W. (2005). The complexity of machine scheduling for stability with a single disrupted job. *Operations Research Letters*, *33*, 151–156. doi:10.1016/j.orl.2004.04.008

Levis, A. A., & Papageorgiou, L. G. (2004). A hierarchical solution approach for multi-site capacity planning under uncertainty in the pharmaceutical industry. *Computers & Chemical Engineering*, *28*(5), 707–725. doi:10.1016/j.compchemeng.2004.02.012

Levy, H. (1998). *Stochastic dominance: Investment decision making under uncertainty*. Boston, MA: Kluwer.

Li, Z., Yue, J., Antonio, D., & Jαuregui, G. (2003). *A new virtual reality environment used for e-learning.* Retrieved 23 November, 2011, from http://www-public.it-sudparis.eu/~horain/GomezJauregui/gomez_fichiers/A%20New%20Virtual%20Reality%20Environment%20Used%20for%20e-Learning.pdf

Liang, T. F. (2006). Integrating production-transportation planning decision with fuzzy multiple goals in supply chains. *International Journal of Production Research*, *46*(6), 1477–1494. doi:10.1080/00207540600597211

Liao, C. J., & Chen, W. J. (2004). Scheduling under machine breakdown in a continuous process industry. *Computers & Operations Research*, *31*, 415–428. doi:10.1016/S0305-0548(02)00224-1

Li, K., Ganesan, V. K., & Sivakumar, A. I. (2006). Scheduling of single stage assembly with air transportation in a consumer electronic supply chain. *Computers & Industrial Engineering*, *51*, 264–278. doi:10.1016/j.cie.2006.02.007

Li, K., Ganesan, V. K., & Sivakumar, A. I. (2008). Complexity and algorithms for synchronised scheduling of parallel machine assembly and air transportation in consumer electronics supply chain. *European Journal of Operational Research*, *187*, 442–455. doi:10.1016/j.ejor.2007.03.006

Lima, R. M., Sousa, R. M., & Martins, P. J. (2006). Distributed production planning and control agent-based system. *International Journal of Production Research*, *44*(18), 3693–3709. doi:10.1080/00207540600788992

Lin, H., & Gong, J. (2002). Distributed virtual environments for managing country parks. *Photogrammetric Engineering and Remote Sensing*, *68*(4), 369–377.

Lin, J. T., & Chen, Y.-Y. (2007). A multi-site supply network planning problem considering variable time buckets–A TFT-LCD industry case. *International Journal of Advanced Manufacturing Technology*, *33*, 1031–1044. doi:10.1007/s00170-006-0537-z

Linux. (2011). *About us*. Retrieved January 3, 2011, from http://www.linux.org/about/

List, G. F., Wood, B., Nozick, L. K., Turnquist, M. A., Jones, D. A., & Kjeldgaard, E. A. (2003). Robust optimization for fleet planning under uncertainty. *Transportation Research Part E, Logistics and Transportation Review*, *39*, 209–227. doi:10.1016/S1366-5545(02)00026-1

Liu, C. (2006). Second Life learning community: A peer-based approach to involving more faculty members in Second Life. In *SLCC '06: Proceedings of the 1st Second Life Education Workshop, Part of the Second Life Community Convention* (pp.6-11). UK: The University of Paisley.

Liu, Z., Lai, M., & Jiang, J. (2004). Computer supported cooperative work in design. In *Cooperation Model in Virtual Enterprises*, (pp. 72-77).

Liu, B., & Liu, Y. K. (2002). Expected value of fuzzy variable and fuzzy expected value models. *IEEE Transactions on Fuzzy Systems*, *10*(4), 445–450. doi:10.1109/TFUZZ.2002.800692

Liu, L., Gu, H.-Y., & Xi, Y.-G. (2007). Robust and stable scheduling of a single machine with random machine breakdowns. *International Journal of Advanced Manufacturing Technology*, *31*, 645–654. doi:10.1007/s00170-005-0237-0

Li, X. (2002). A new interpretation of NBUE property of life distribution with some applications. *Chinese Journal of Applied Probability and Statistics*, *16*(1), 67–72.

Li, X., Qin, Z., & Kar, S. (2010). Mean-variance-skewness model for portfolio selection with fuzzy returns. *European Journal of Operational Research*, *202*, 239–247. doi:10.1016/j.ejor.2009.05.003

Li, X., & Wang, Q. (2007). Coordination mechanisms of supply chain systems. *European Journal of Operational Research*, *179*(1), 1–16. doi:10.1016/j.ejor.2006.06.023

Li, Z., & Ierapetritou, M. (2008). Process scheduling under uncertainty: review and challenges. *Computers & Chemical Engineering*, *32*, 715–727. doi:10.1016/j.compchemeng.2007.03.001

Lo Nigro, G., Bruccoleri, M., & Perrone, G. (2006). Negotiation in distributed production planning environments. *International Journal of Production Research*, *44*(18), 3743–3758. doi:10.1080/00207540600575787

Lo Nigro, G., Noto La Diega, S., Perrone, G., & Renna, P. (2003). Coordination policies to support decision making in distributed production planning. *Robotics and Computer-integrated Manufacturing*, *19*, 521–531. doi:10.1016/S0736-5845(03)00062-0

Lu, L., & Wang, G. (2008). A study on multi-agent supply chain framework based on network economy. *Computers & Industrial Engineering*, *54*, 288–300. doi:10.1016/j.cie.2007.07.010

Luo, Y. (2004). A coopetition perspective of MNC-host government relations. *Journal of International Management*, *10*, 431–451. doi:10.1016/j.intman.2004.08.004

Lusa, A., Corominas, A., & Munoz, N. (2008). A multistage scenario optimisation procedure to plan annualised working hours under demand uncertainty. *International Journal of Production Economics*, *113*, 957–968. doi:10.1016/j.ijpe.2007.11.009

Lusch, R., & Vargo, S. (2006). Service-dominant logic: Reactions, reflections and refinements. *Marketing Theory*, *6*(3), 281–288. doi:10.1177/1470593106066781

Lu, T. P., Chang, T. M., & Yih, S. (2005). Production control framework for supply chain management—an application in the elevator manufacturing industry. *International Journal of Production Research*, *43*(20), 4219–4233. doi:10.1080/00207540500142167

Macal, C. M. (2004). *Emergent structures from trust relationships in supply chains*. Paper presented at the Agent 2004 Conference on Social Dynamics: Interaction, Reflexivity and Emergence, Chicago, IL.

Macal, C. M., & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation*, *4*, 151–162. doi:10.1057/jos.2010.3

Macedo, A., & Morgado, L. (2009). *Learning to teach in Second Life*. Retrieved 13 August, 2010, from http://www.eden-online.org/contents/conferences/OCRC's/Porto/AM_LM.pdf

Madey, G., Freeh, V., Tynan, R., Gao, Y., & Hoffman, C. (2003). *Agent-based modeling and simulation of collaborative social networks*. Paper presented at the Americas Conference on Information Systems AMCIS 2003.

Maged, N., Kamel, B., Hetherington, L., & Wheeler, S. (2007). Second Life: An overview of the potential of 3-D virtual worlds in medical and health education. *Health Information and Libraries Journal*, *24*(4), 233–245. doi:10.1111/j.1471-1842.2007.00733.x

Mahdavi, I., Mohebbi, S., Zandakbari, M., Cho, N., & Mahdavi-Amiri, N. (2009). Agent-based web service for the design of a dynamic coordination mechanism in supply networks. *Journal of Intelligent Manufacturing*, *20*(6). doi:10.1007/s10845-008-0173-6

Malcolm, D. G., Roseeboom, J. H., Clark, C. E., & Fazar, W. (1959). Application of technique for research and development program evaluation. *Operations Research*, *7*, 646–669. doi:10.1287/opre.7.5.646

Malcom, S. A., & Zenios, S. A. (1994). Robust optimization of power systems capacity expansion under uncertainty. *The Journal of the Operational Research Society*, *45*, 1040–1049.

Mann, D. (2005). *Creating a lean culture*. New York, NY: ProductivityPress.

Mansour, S., & Mostafa, E. S. (2008). The impact of multi-players serious games on social interaction among online students versus face-to-face students. *7th WSEAS International Conference on Applied Computer and applied Computational Science (ACACOS'08)* (pp. 772-778). Hangzhow, China.

Mansour, M., & Mostafa, S. (2008). The relationship between educational serious games, gender, and students' social interaction. *WSEAS Transactions on Computers*, *6*(7), 640–650.

Mapes, J. (1992). The effect of capacity limitations on safety stock. *International Journal of Operations & Production Management*, *13*, 26–33. doi:10.1108/01443579310045536

Maritan, C. A., Brush, T. H., & Karnani, A. G. (2004). Plant roles and decision autonomy in multi-national plant networks. *Journal of Operations Management*, *22*, 489–503. doi:10.1016/j.jom.2004.05.007

Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, *7*, 77–91.

Markowitz, H. (1959). *Portfolio selection: Efficient diversification of investments*. New York, NY: Wiley.

Marshall, A. (1890). *Principles of economics* (Guillebaud, C. W., Ed.). MacMillan.

Mason, R., & Rennie, F. (2008). *E-learning and social networking handbook: Resources for higher education*. New York, NY: Routledge.

Mathieu, P., Routier, J.-C., & Secq, Y. (2002). Principles for dynamic multi-agent organizations. In K. Kuwabara & J. Lee, (Eds.), *Intelligent Agents and Multi-Agent Systems, Vol. 2413 of Lecture Notes in Computer Science,* (pp. 663-670). Berlin, Germany Springer.

Matta, R., & Miller, T. (2004). Production and interfacility transportation scheduling for a process industry. *European Journal of Operational Research*, *158*, 72–88. doi:10.1016/S0377-2217(03)00358-8

Mazuryk, T., & Gervautz, M. (1996). *Virtual reality: History, applications, technology and future*. Technical Report TR.

Mazzola, E., Bruccoleri, M., & Perrone, G. (2009). A strategic framework for firm networks in manufacturing industry: An empirical survey. *CIRP Annals - Manufacturing Technology, 58*(1), 387-390.

McArdle, G., Monahan, T., Bertolotto, M., & Marginka, E. (2004). *A web-based multimedia virtual reality environment for e-learning.* Euro-graphics (Short presentation).

McLuhan, M., & Nevitt, B. (1972). *Take today, the executive as drop out*. New York, NY: Harcourt Brace Jovanovich.

McMahan, A. (2003). Immersion, engagement, and presence: A method for analyzing 3-D video games. In Wolf, M., & Perron, B. (Eds.), *The video game, theory reader* (pp. 67–78). New York, NY: Routledge.

McNeil, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago, IL: The University of Chicago Press.

Means, B. (1994). Introduction: Using technology to advance educational goals. In Means, B. (Ed.), *Technology and education reform: The reality behind the promise* (pp. 1–21). San Francisco, CA: Jossey-Bass.

Medina, J., Quintana, V. H., & Conejo, A. J. (1999). A clipped-off interior point technique for medium-term hydro-thermal coordination. *IEEE Transactions on Power Systems*, *14*, 266–273. doi:10.1109/59.744542

Mehta, S. V., & Uzsoy, R. (1999). Predictable scheduling of a single machine subject to breakdowns. *International Journal of Computer Integrated Manufacturing*, *12*(1), 15–38. doi:10.1080/095119299130443

Meijboom, B., & Obel, B. (2007). Tactical coordination in a multi-location and multistage operations structure: A model and a pharmaceutical company case. *Omega*, *35*, 258–273. doi:10.1016/j.omega.2005.06.003

Merrick, K., & Maher, M. (2007). Motivated reinforcement learning for adaptive characters in open-ended simulation games. *Proceedings of the International Conference on Advances in Computer Entertainment Technology* (pp. 127-134). Salzburg, Austria.

Michaelewicz, Z. (1994). *Genetic algorithms + data structures = evolution programs*. Berlin, Germany: Springer-Verlag.

Michailidou, A., & Economides, A. A. (2003). E-learn: Towards a collaborative educational virtual environment. *Journal of Information Technology Education*, *2*, 131–152.

Miller, E. J., Roorda, M. J., & Carrasco, J. A. (2005). A tour-based model of travel mode choice. *Transportation*, *32*, 399–422. doi:10.1007/s11116-004-7962-3

Miller, J., & Page, S. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton, NJ: Princeton University Press.

Moffat, J., Smith, J., & Witty, S. (2006). Emergent behaviour: Theory and experimentation using the MANA model. *Journal of Applied Mathematics and Decision Sciences*, *2006*, 1–13. doi:10.1155/JAMDS/2006/54846

Mon, L. (2010). Communication and education in a virtual world: Avatar-mediated teaching and learning in Second Life. *International Journal of Virtual and Personal Learning Environments*, *1*(2), 1–15. doi:10.4018/jvple.2010040101

Monostori, L., Csaji, B. C., & Kadar, B. (2004). Adaptation and learning in distributed production control. *CIRP Annals Manufacturing Technology*, *53*(1), 349–352. doi:10.1016/S0007-8506(07)60714-8

Monostori, L., Vancza, J., & Kumara, S. (2006). Agent-based systems for manufacturing. *CIRP Annals Manufacturing Technology*, *55*(2), 697–720. doi:10.1016/j.cirp.2006.10.004

Monteiro, T., Roy, D., & Anciaux, D. (2007). Multi-site coordination using a multi-agent system. *Computers in Industry*, *58*, 367–377. doi:10.1016/j.compind.2006.07.005

Mood, A. M., Graybill, F. A., & Boes, D. C. (1974). *Introduction to the theory of statistics*. London, UK: McGraw-Hill.

Moon, C., & Seo, Y. (2005). Evolutionary algorithm for advanced process planning and scheduling in a multi-plant. *Computers & Industrial Engineering*, *48*, 311–325. doi:10.1016/j.cie.2005.01.016

Moon, I., Lee, S., & Bae, H. (2008). Genetic algorithms for job-shop scheduling problems with alternative routings. *International Journal of Production Research*, *46*(10), 2695–2705. doi:10.1080/00207540701244820

Morstain, B. R., & Smart, J. C. (1974). Reasons for participating in adult education courses: A multivariate analysis of group differences. *Adult Education*, *24*(2), 82–98. doi:10.1177/074171367402400201

Muckstadt, J. A., & Koenig, S. A. (1977). An application of Lagrangian relaxation to scheduling in power-generation systems. *Operations Research*, *25*, 387–403. doi:10.1287/opre.25.3.387

Mula, J. (2006). Models for production planning under uncertainty: A review. *International Journal of Production Economics*, *103*, 271–285. doi:10.1016/j.ijpe.2005.09.001

Mula, J., Poler, R., Garcia-Sabater, J. P., & Lario, F. C. (2006). Models for production planning under uncertainty: A review. *International Journal of Production Economics*, *103*, 271–285. doi:10.1016/j.ijpe.2005.09.001

Mulvey, J. M., Vanderbei, R. J., & Zenios, S. A. (1995). Robust optimization of large scale systems. *Operations Research*, *43*(2), 264–281. doi:10.1287/opre.43.2.264

Mumme, C., Olivier, H., & Pinkwart, S. (2008). *A framework for interaction analysis and feedback in collaborative virtual world*. Retrieved 29 March, 2011, from http://www.ve-forum.org/projects/408/ICE%202008/Collaborative%20Systems/016.3%20-%20CWE23%20Mumme_Olivier_Pinkwart_Framework_for_CVE_analysis%20_final%20SS6_2.pdf

Murray, J. (1997). *Hamlet on the Holodeck: The future of narrative in cyberspace*. Cambridge, MA: MIT Press.

Nabona, N., & Pages, A. (2002). *Long-term electric power planning in a competitive market using the Bloom and Gallant procedure and a modeling language.* Technical Report DR2002/24, Dept. Estadıstica i Inv. Operativa, Univ. Politec. de Catalunya, Barcelona. Retrieved from http://www-eio.upc.es/gnom

Nabona, N., Gil, C., & Albrecht, J. (2001). Long-term thermal power planning at VEW ENERGIE using a multi-interval Bloom and Gallant method. *IEEE Transactions on Power Systems*, *16*(1), 69–77. doi:10.1109/59.910783

Nabona, N., & Pages, A. (2004). Long-term electric power planning in liberalized markets using the Bloom and Gallant formulation. In Alonso-Ayuso, A., Cerda, E., Escudero, L. F., & Sala, R. (Eds.), *Optimizacio n bajo incertidumbre* (pp. 185–211). Valencia, Spain: Tirant lo Blanch.

Nachiappan, S. P., & Jawahar, N. (2007). A genetic algorithm for optimal operating parameters of VMI system in a two-echelon supply chain. *European Journal of Operational Research*, *182*, 1433–1452. doi:10.1016/j.ejor.2006.09.040

Nag, B. (2008). A Blackboard agent community architecture in a supply chain environment. *Design Principles and Practices: An International Journal*, *1*(1), 91–104.

Nair, A., & Closs, D. J. (2006). An examination of the impact of coordinating supply chain policies and price markdowns on short lifecycle product retail performance. *International Journal of Production Economics*, *102*(2), 379–392. doi:10.1016/j.ijpe.2005.04.009

Nalbant, G., & Bostan, B. (2006). *Interaction in virtual reality*. Retrieved 23 May, 2011, from http://newmedia.yeditepe.edu.tr/pdfs/isimd_06/12.pdf

Ndlela, L. T., & du Toit, A. (2001). Establishing a knowledge management programme for competitive advantage in an enterprise. *International Journal of Information Management*, *21*, 151–165. doi:10.1016/S0268-4012(01)00007-X

Neiger, D., Rotaru, K., & Churilvo, L. (2009). Supply chain risk identification with value-focused process engineering. *Journal of Operations Management*, *27*, 154–168. doi:10.1016/j.jom.2007.11.003

Nelson, B., & Ketelhut, D. J. (2007). Scientific inquiry in educational multi-user virtual environments. *Educational Psychology Review*, *19*(3), 265–283. doi:10.1007/s10648-007-9048-1

New Media Consortium (NMC) and EDUCAUSE Learning Initiative. (ELI). (2007). *The Horizon Report, 2007 Edition.* Austin, TX: The New Media Consortium. Retrieved 2 October, 2011, from http://www.nmc.org/pdf/2007_Horizon_Report.pdf

Nof, S. Y., Morel, G., Monostori, L., Molina, A., & Filip, F. (2006). From plant and logistics control to multi-enterprise collaboration. *Annual Reviews in Control*, *30*(1), 55–68. doi:10.1016/j.arcontrol.2006.01.005

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company*. USA: Oxford University Press.

North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent-based modeling and simulation*. New York, NY: Oxford University Press.

North, M. J., Macal, C. M., Aubin, J. S., Thimmapuram, P., Bragen, M., & Hahn, J. (2010). Multiscale agent-based consumer market modeling. *Complexity*, *15*(5), 37–47.

North, M., & Macal, M. (2007). *Managing business complexity: Discovering strategic solution with agent-based modeling and simulation*. Oxford, UK: Oxford University Press.

Nuyens, M., & Wierman, A. (2008). The foreground-background queue: A survey. *Performance Evaluation*, *65*, 286–307. doi:10.1016/j.peva.2007.06.028

OECD. (2011). *Virtual worlds: Immersive online platforms for collaboration: Creativity and learning. OECD Digital Economy Papers, 184*. OECD Publishing.

Okechukwu, O., & Udoka, E. (2009). *Understanding virtual reality technology. Advances and Applications Advances in Computer Science and Engineering* (pp. 53–70). Springer.

Ozdamar, L., Atli, A. O., & Bozyel, M. A. (1996). Hueristic family disaggregation technique for Hierarchical production planning systems. *Integration Journal of Production Research*, *34*, 2613–2628. doi:10.1080/00207549608905047

Ozkan, S., Koseler, R., Baykal, N. (2009). Evaluating learning management systems: Adoption of hexagonal e-learning assessment model in higher education. *Transforming Government: People, Process and Policy, 3*(2).

Padgham, L., & Winikoff, M. (2004). *Developing intelligent agent systems: A practical guide*. Chichester, UK: John Wiley & Sons. doi:10.1002/0470861223

Pages, A., & Nabona, N. (2002). *Long-term electric power planning using the Bloom and Gallant's linear model: A comparison of solution techniques*. Technical report DR2002/25, Dept. Estadı´stica i Inv. Operativa, Univ. Politec. de Catalunya, Barcelona.

Pages, A. (2002). *Procediment de Bloom i Gallant de planificacio´ a llarg termini d'unitats te`rmiques de generacio´ ele`ctrica usant la descomposicio´ de Dantzig–Wolfe. Final-year project, Facultat de Matematiques i Estadıstica, Univ*. Barcelona: Polite`cnica de Catalunya.

Pallof, M. R., & Pratt, K. (2004). *Learning together in community: Collaboration online*. In 20th Annual Conference on Distance Teaching and Learning, Madison, Wisconsin. Retrieved 2 February, 2011, from http://www.oakland.k12.mi.us/Portals/0/Learning/04_1127.pdf

Park, K., & Kim, W. (2001). A systolic parallel simulation system for dynamic traffic assignment: SPSS-DTA. *Expert Systems with Applications*, *21*(4), 217–227. doi:10.1016/S0957-4174(01)00041-0

Park, Y. B. (2005). An integrated approach for production and distribution planning in supply chain management. *International Journal of Production Research*, *43*(6), 1205–1224. doi:10.1080/00207540412331327718

Parunak, V., & Vanderbok, R. (1998). *Modeling the extended supply network*. Presented at ISA-Tech'98, Houston, TX, 1998, Stadtler, H. (2005). Supply chain management and advanced planning—Basics, overview and challenges. *European Journal of Operational Research*, *163*, 575–588.

Patra, S., & Goswami, S. K. (2009). Fuzzy and simulated annealing based dynamic programming for the unit commitment problem. *Expert Systems with Applications*, *36*, 5081–5086. doi:10.1016/j.eswa.2008.06.039

Pelet, J., Lecat, B., & Papadopoulou, P. (2011). Enhancing learning cooperation through digital virtual worlds. *International Conference on Education, Research and Innovation, IPEDR* 18, (pp. 24-28). IACSIT, Singapore.

Pellas, N. (2010). *Using CVE's (collaborative virtual environments) in K-12 education*. Virtual Worlds - Best Practices in Education, 1st International Conference in Second Life.

Pellas, N. (2011). *Distance learning in the virtual environment of Second Life*. Athens, Greece: Free Publishing.

Penfold, P. (2009). Learning through the world of Second Life—A hospitality and tourism experience. *Journal of Teaching in Travel & Tourism*, *8*(2-3), 139–160. doi:10.1080/15313220802634224

Pennisi, M., Catanuto, R., Pappalardo, F., & Motta, S. (2008). Optimal vaccination schedules using simulated annealing. *Bioinformatics (Oxford, England)*, *24*(15), 1740–1742. doi:10.1093/bioinformatics/btn260

Pereira, M., Harris, A., Duncan Davidson, R., & Niven, J. (2000). *Building a virtual learning space for C&IT staff development*. Centre for Open and Distance Learning.

Perez-Ruiz, J., & Conejo, A. J. (2000). Multi-period probabilistic production cost model including dispatch constraints. *IEEE Transactions on Power Systems*, *15*(2), 502–507. doi:10.1109/59.867132

Perrone, G. (2005). Manufacturing e-marketplaces: innovative tools for the extended enterprise. In Perrone, G., Bruccoleri, M., & Renna, P. (Eds.), *Designing and evaluating value added services in manufacturing e-marketplace*. Berlin, Germany: Springer. doi:10.1007/1-4020-3152-1_1

Pfeifer, R., & Bongard, J. (2007). *How the body shapes the way we think: A new view of intelligence*. Cambridge, MA: MIT Press.

Picard, R. W. (1997). *Affective computing*. Cambridge, MA: MIT Press.

Picciano, A. (2002). Beyond student perceptions: Issues of interaction, presence, and performance in an online course. *Journal of Asynchronous Learning Networks*, *6*(1), 21–40.

Pietschmann, D. (2009). *Das Erleben virtueller Welten. Involvierung, Immersion und Engagement in Computerspielen*. Boizenburg, Germany: Verlag Werner Hülsbusch.

Pisano, G., & Verganti, R. (2008). What kind of collaboration is right for you? *Harvard Business Review*, (December): 78–86.

Porter, M. (1990). *The competitive advantage of nations. MacMillan*. The MIT Press.

Powell, W. B. (1996). A stochastic formulation of the dynamic assignment problem, with an application to truckload motor carriers. *Transportation Science*, *30*(3), 195–219. doi:10.1287/trsc.30.3.195

Prahalad, C. K., & Ramaswamy, V. (2004). *The future of competition*. Harvard Business School Press.

Prasolova-Førland, E., Sourin, A., & Sourina, O. (2006). Cyber campuses: Design issues and future directions. *The Visual Computer*, *22*(12), 1015–1028. doi:10.1007/s00371-006-0042-2

Pritsker, A. A. B., David, L. M., Janet, S. R., Mary Ann, W., Daily, O. P., Ann, M. H., et al. (1995). Organ transplantation policy evaluation. *Proceedings of the 27th Conference on Winter Simulation*, (pp. 1314-1323).

Psaraftis, H. N. (1980). A dynamic programming solution to the single vehicle many-to-many immediate request dial-a-ride problem. *Transportation Science*, *14*(2), 130–154. doi:10.1287/trsc.14.2.130

Puigjaner, L., & Heyen, G. (2006). *Computer aided process and production engineering*. Wiley & Son. ISBN: 9783527308040

Pyke, D. F., & Cohen, M. (1993). Performance characteristics of stochastic integrated production-destruction systems. *European Journal of Operational Research*, *68*, 23–48. doi:10.1016/0377-2217(93)90075-X

Pyke, D. F., & Cohen, M. (1994). Multiproduct integrated production-distribution systems. *European Journal of Operational Research*, *74*, 18–49. doi:10.1016/0377-2217(94)90201-1

Raa, B., & Aghezzaf, E.-H. (2005). A robust dynamic planning strategy for lot-sizing problem with stochastic demands. *Journal of Intelligent Manufacturing*, *16*(2), 207–247. doi:10.1007/s10845-004-5889-3

Redfern, S., & Naughton, N. (2002). Collaborative virtual environments to support communication and community in internet-based distance education. *Journal of Information Technology Education*, *1*(3), 201–211.

Reeves, B., & Nass, C. (1996). *The media equation: How people treat computers, television and new media like real people and places*. Cambridge, MA.

Renna, P., & Argoneto, P. (2010). A game theoretic coordination for trading capacity in multi-site factory environment. *International Journal of Advanced Manufacturing Technology*, *47*(9), 1241–1252. doi:10.1007/s00170-009-2254-x

Rheingold, H. (1992). *Virtual reality*. New York, NY: Simon & Schuster.

Ringuest, J. L., Graves, S. B., & Case, R. H. (2000). Conditional stochastic dominance in R&D portfolio selection. *IEEE Transactions on Engineering Management*, *74*(4), 478–484. doi:10.1109/17.895342

Rizzo, J., House, R., & Lirtzman, S. (1970). Role conflict and ambiguity in complex organizations. *Administrative Science Quarterly*, *15*(2), 150–163. doi:10.2307/2391486

Robinett, W. (1994). Interactivity and individual viewpoint in shared virtual worlds: The big screen vs. networked personal displays. *Computer Graphics*, *28*(2), 127. doi:10.1145/178951.178969

Rolón, M., & Martinez, E. (2010), Agent-based simulation modeling of an interaction mechanism for detailed design of autonomic manufacturing execution systems. *Proceedings of the 43rd CIRP International Conference on Manufacturing Systems* (pp. 1036 -1043). Vienna, Austria: Vienna University of Technology and Fraunhofer Austria Research GmbH.

Rolón, M., Canavesio, M., & Martinez, E. (2009). Agent based modelling and simulation of intelligent distributed scheduling systems. *Computer Aided Chemical Engineering*, *26*, 985–990. doi:10.1016/S1570-7946(09)70164-6

Rong, A., Hakonen, H., & Lahdelma, R. (2008). A variant of dynamic programming algorithm for unit commitment of combined heat and power systems. *European Journal of Operational Research*, *190*, 741–755. doi:10.1016/j.ejor.2007.06.035

Rong, A., Hakonen, H., & Lahdelma, R. (2009). A dynamic regrouping based sequential dynamic programming algorithm for unit commitment of combined heat and power systems. *Energy Conversion and Management*, *50*(4). doi:10.1016/j.enconman.2008.12.003

Rong, A., Lahdelma, R., & Grunow, M. (2009). An improved unit decommitment algorithm for combined heat and power systems. *European Journal of Operational Research*, *195*, 552–562. doi:10.1016/j.ejor.2008.02.010

Ronsivalle, G., & Donno, V. (2010). *A model for the evaluation of learning effectiveness in Second Life.* Retrieved 8 December, 2011, from http://labelformazione.com/imgUpload/2.pdf

Rosenblatt, M. J., & Lee, H. L. (1987). A robustness approach to facilities design. *International Journal of Production Research*, *25*(4), 479–486. doi:10.1080/00207548708919855

Ross, S. M. (1983). *Stochastic process*. New York, NY: John Wiley & Sons.

Roussou, M. (2004). Learning by doing and learning through play: An exploration of interactivity in virtual environments for children. *ACM Computers in Entertainment, 2*.

Rovai, A. P. (2001). Building classroom community at a distance: A case study. *Educational Technology Research and Development Journal*, *49*(4), 35–50.

Rudberg, M., & West, M. (2008). Global operations strategy: Coordinating manufacturing networks. *Omega*, *36*, 91–106. doi:10.1016/j.omega.2005.10.008

Ruggles, R. (1998). The state of the notion: Knowledge management in practice. *California Management Review*, *40*(3), 80–89.

Rusko, R. (2008). Unintentional coopetition and supply chain management. In J. Kujala & P. Iskanius (Eds.), *Proceeding of the 13th International Conference on Productivity and Quality Research, ICPQR2008*, Oulu, 25–27 June, (pp. 642–653).

Rusko, R. (2010). Exploring the concept of coopetition: A typology for the strategic moves of the Finnish forest industry. *Industrial Marketing Management*, *40*, 311–320. doi:10.1016/j.indmarman.2010.10.002

Ryu, J., & Pistikopoulos, E. N. (2007). Multiperiod planning of enterprise-wide supply chains using an operation policy. *Industrial & Engineering Chemistry Research*, *46*, 8058. doi:10.1021/ie070508b

Sacks, H. (1992). *Lectures on conversation*. Cambridge, MA: Blackwell.

Sadeghi, K. H. R., Ghaderi, S. F., Azadeh, A., & Razmi, J. (2009). Forecasting electricity consumption by clustering data in order to decrease the periodic variable's effects and by simplifying the pattern. *Energy Conversion and Management*, *50*, 829–836. doi:10.1016/j.enconman.2008.09.036

Sakawa, M., Kato, K., & Ushiro, S. (2002). Operational planning of district heating and cooling plants through genetic algorithms for mixed 0–1 linear programming. *European Journal of Operational Research*, *137*, 677–687. doi:10.1016/S0377-2217(01)00095-9

Saleeb, N., & Dafoulas, G. (2010). Turning immigrants to citizens: Merits of the pedagogical shift in 3D virtual learning environments. *International Journal for Infonomics*, *3*(4), 369–381.

Salt, B., Atkins, C., & Blackall, L. (2008). *Engaging with Second Life: Real education in a virtual world.* Retrieved 3 May, 2011, from http://slenz.files.wordpress.com/2008/12/slliteraturereviewa1.pdf

Sambasivan, M., & Yahya, S. (2005). A Lagrangean-based heuristic for multi-plant, multi-item, multi-period capacitated lot-sizing problems with inter-plant transfers. *Computers & Operations Research*, *32*, 537–555. doi:10.1016/j.cor.2003.08.002

Sauer, J. (2006). Modeling and solving multi-site scheduling problems. In van Wezel, W., Jorna, R. J., & Meystel, A. M. (Eds.), *Planning in intelligent systems: Aspects, motivations and methods* (pp. 281–299). Hoboken, NJ: John Wiley & Sons. doi:10.1002/0471781266.ch9

Savkin, A. V., & Somlo, J. (2009). Optimal distributed real-time scheduling of flexible manufacturing networks modeled as hybrid dynamical systems. *Robotics and Computer-integrated Manufacturing*, *25*(3), 597–609. doi:10.1016/j.rcim.2008.04.004

Schelling, T. C. (1978). *Micromotives and macrobehavior*. New York, NY: Norton.

Schenk, E., & Guittard, C. (2009). *Crowdsourcing: What can be outsourced to the crowd, and why?* Retrieved January 3, 2011, from http://halshs.archives-ouvertes.fr/halshs-00439256/

Schenk, M., Wirth, S., & Müller, E. (2010). *Factory planning model: Situation-driven production facility planning*. Springer.

Schneeweiss, C., & Zimmer, K. (2004). Hierarchical coordination mechanisms within the supply chain. *European Journal of Operational Research*, *153*, 687–703. doi:10.1016/S0377-2217(02)00801-9

Scholl, H. (2001). Applying stakeholder theory to egovernment: Benefits and limits. *Proceedings of the IFIP Conference on Towards the E-Society: E-Commerce, EBusiness, E-Government,* Deventer, Netherlands.

Schroeder, R. (2008). Defining virtual worlds and virtual environments. *Journal of Virtual Worlds Research, Virtual Worlds Research: Past, Present & Future, 1*(1), 2-3. Retrieved 4 October, 2011, from: http://journals.tdl.org/jvwr/article/view/294/ 225

Sennott, L., Vanoyen, M., & Iravani, S. (2006). Optimal dynamic assignment of a flexible worker on an open production line with specialists. *European Journal of Operational Research*, *170*(2), 541–566. doi:10.1016/j.ejor.2004.06.030

Sen, S., & Kothari, D. P. (1998). Optimal thermal generating unit commitment: A review. *Electric Power Energy Systems*, *20*, 443–451. doi:10.1016/S0142-0615(98)00013-1

Seung, A., & Bolebrush, J. (2009). Avatar based advertising in Second Life: The role of presence and attractiveness of virtual spoke persons. *Journal of Interactive Advertising*, *10*(1), 51–60.

Shalit, H., & Yitzhaki, S. (1989). Evaluating the mean Gini approach to portfolio selection. *The International Journal of Finance*, *1*(2), 15–31.

Shapiro, C., & Varian, H. R. (1999). *Information rules: A strategic guide to the network economy*. Harvard Business School Press.

Shapiro, J. F. (2001). *Modeling the supply chain*. Pacific Grove, CA: Duxbury.

Sheble, G. B., & Fahd, G. N. (1994). Unit commitment literature synopsis. *IEEE Transactions on Power Systems*, *9*, 128–135. doi:10.1109/59.317549

Shechter, S. M., Bryce, C. L., Alagoz, O., Kreke, J. E., Stahl, J. E., Schaefer, A. J., et al. (2005). *A clinically based discrete-event simulation of end-stage liver disease and the organ allocation process* (Vol. 25, pp. 199-209).

Sheridan, T. (2003). *Interaction, imagination and immersion some research needs.* Retrieved 14 February, 2011, from http://www.itfind.or.kr/Report01/200302/IITA/IITA-2021-002/IITA-2021-002.pdf

Sheridan, T. B. (1994). Further musings on the psychophysics of presence. *Presence (Cambridge, Mass.)*, *5*, 241–246.

Shnerb, N. M., Louzoun, Y., Bettelheim, E., & Solomon, S. (2000). The importance of being discrete: Life always wins on the surface. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(19), 10322–10324. doi:10.1073/pnas.180263697

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology & Distance Learning, 2*(1). Retrieved 25 May, 2011, from http://itdl.org/Journal/Jan_05/article01.htm

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2008). *Designing and managing the supply chain: Concepts, strategies and case studies*. McGraw- Hill Inc.

Sitompul, C., & Aghezzaf, E.-H. (2008). *Robust production planning: An alternative to scenario based optimization model.* Paper presented at the Modelling, Computation and Optimization in Information Systems and Management Sciences, Metz, France.

Sitompul, C., Aghezzaf, E.-H., Van Landeghem, H., & Dullaert, W. (2008). Safety stock placement problems in capacitated supply chains. *International Journal of Production Research*, *46*, 4709–4727. doi:10.1080/00207540701278406

Sivan, Y. (2009). Overview: State of virtual worlds standards in 2009. *Technology, Economy, and Standards, 2*(3). Retrieved 30 February, 2010, from https://journals.tdl.org/jvwr/article/view/671/539

Slater, M., & Usoh, M. (1993). The influence of a virtual body on presence in immersive virtual environments. *Virtual Reality International 93, Proceedings of the Third Annual Conference on Virtual Reality* (pp. 34–42). London, UK: Meckler.

Slater, M., Steed, A., & Usoh, M. (1993). The virtual treadmill: A naturalistic metaphor for navigation in immersive virtual environments. In M. Goebel (Ed.), *First Euro Graphics Workshop on Virtual Reality*, (pp. 71-86). Spain.

Slator, B. M., Chaput, H., Cosmano, R., Dischinger, B., Imdieke, C., & Vender, B. (2005). A multi-user desktop virtual environment for teaching shop-keeping to children. *Virtual Reality (Waltham Cross)*, *9*(1), 49–56. doi:10.1007/s10055-005-0003-5

Smith, M. A., Farnham, S. D., & Drucker, S. M. (2000). The social life of small graphical chat spaces. *Proceedings of the Conference on Human Factors in Computing Systems (CHI'00)* (pp. 462-469). Hague, The Netherlands: ACM Press.

Smith, T. (2009). *Social cybernetic strategies for asynchronous learning*. Retrieved 12 November, 2011, from: http://www.iea.cc/ECEE/pdfs/art0222.pdf

Snowdon, D. N., Greenhalgh, C. M., & Benford, S. D. (1995) What you see is not what I see: Subjectivity in virtual environments. *Proceedings of the Framework for Immersive Virtual Environments Conference (FIVE'95)* (pp. 53-69). London.

Snyder, W. L., Powell, H. D., & Rayburn, J. C. (1987). Dynamic programming approach to unit commitment. *IEEE Transactions on Power Systems*, *2*, 339–350. doi:10.1109/TPWRS.1987.4335130

Soloway, E. (1990). Quick, where do the computers go? *Communications of the ACM*, *34*(2), 29–33. doi:10.1145/102792.102797

Sousa, R., Shah, N., & Papageorgiou, L. (2008). Supply chain design and multilevel planning—An industrial case. *Computers & Chemical Engineering*, *32*, 2643. doi:10.1016/j.compchemeng.2007.09.005

Spence, J. (2008). Demographics of virtual worlds. *Virtual Worlds Research: Consumer Behavior in Virtual Worlds," 1*(2). Retrieved 14 February, 2011, from http://journals.tdl.org/jvwr/article/download/360/272

Srinivasan, K. K., & Bhargavi, P. (2007). Longer-term changes in mode choice decisions in Chennai: A comparison between cross-sectional and dynamic models. *Transportation*, *34*, 355–374. doi:10.1007/s11116-007-9116-x

Stadtler, H. (2005). Supply chain management and advanced planning – Basics, overview and challenges. *European Journal of Operational Research. Supply Chain Management and Advanced Planning*, *163*(3), 575–588.

Stanney, K. M. (Ed.). (2002). *Handbook of virtual environments: Design, implementation, and applications*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Steed, A., & Tromp, J. (1998). Experiences with the evaluation of CVE applications. In *Proceedings of Collaborative Virtual Environment*, Manchester, UK. Retrieved 4 October, 2011, from http://www.cs.ucl.ac.uk/staff/a.steed/steed-tromp-cve98.pdf

Steed, A., & Tromp, J. (1998). Experiences with the evaluation of CVE applications. *Proceedings of Collaborative Virtual Environments CVE*, *98*, 123–130.

Steers, R. M. (1977). Antecedents and outcomes of organizational commitment. *Administrative Science Quarterly*, *22*, 46–56. doi:10.2307/2391745

Steinkuehler, A., & Williams, D. (2006). Where everybody knows your (screen) name: Online games as "third places.". *Journal of Computer-Mediated Communication*, *11*, 885–909. doi:10.1111/j.1083-6101.2006.00300.x

Stephen, L., Quintas, P., & Ray, T. (2002). *Managing knowledge*. London, UK: SAGE Publications Ltd.

Steurer, J. (1993). *Defining virtual reality: Dimensions determining tele-presence.* SRCT, Paper #104. Retrieved 14 February, 2011, from http://www.cybertherapy.info/pages/telepresence.pdf

Strati, F., Schleicher-Tappeser, R., Loiselle, S., Hansen L. G., Di Paolo, A. M., Rosenbrand, A., & Ojeda, S. (2004). Sustainable district logistics: A theoretical framework for understanding a new paradigm. INNESTO Discussion paper, June 2004.

Swaminathan, J. M., Smith, S. F., & Sadeh, N. M. (1996). A multi-agent frame work for supply chain dynamics. *Proceedings of NSF Research Planning Workshop on AI & Manufacturing,* Albuquerque, NM, 1996.

Swink, M., Narasimhan, R., & Wang, C. (2007). Managing beyond the factory walls: Effects of four types of strategic integration on manufacturing plant performance. *Journal of Operations Management*, *25*(1), 148–164. doi:10.1016/j.jom.2006.02.006

Switzer, J. (2011). *Taxation of virtual worlds' economies: An empirical review*. IR 12.0: Performance and participation. Retrieved 23 January, 2011, from http://spir.aoir.org/papers/switzer_switzer.pdf

Tang, C. S. (2006). Perspective in supply chain risk management. *International Journal of Production Economics*, *103*(2), 451–488. doi:10.1016/j.ijpe.2005.12.006

Tang, J., Fung, R. Y. K., & Yong, K. L. (2003). Fuzzy modeling and simulation for aggregate production planning. *International Journal of Systems Science*, *34*(12/13), 661–673. doi:10.1080/00207720310001624113

Tang, J., Wang, D., & Fung, R. Y. K. (2000). Fuzzy formulation for multi-product aggregate production planning. *Production Planning and Control*, *11*, 670–676. doi:10.1080/095372800432133

Tanha, R., & Ghaderi, S. F. (2007). *Hierarchical production planning in a fuzzy environmental.* International Conference of Iranian Operations Research Society, IORC2007 Sharif Technology and Kish University of Iran.

Taranto, S. E., Harper, A. M., Edwards, E. B., Rosendale, J. D., McBride, M. A., Daily, O. P., et al. (2000). Developing a national allocation model for cadaveric kidneys. *Proceedings of the 26th Conference on Winter Simulation,* (pp. 1971-1977).

Thalmann, D. (2001). The role of virtual humans in virtual environment technology and interfaces. In Earnshaw, R., Guedj, R., & Vince, J. (Eds.), *Frontiers of human-centered computing, online communities and virtual environments*. New York, NY: Springer. doi:10.1007/978-1-4471-0259-5_3

The Schome Community. (2007). *The Schome-NAGTY teen Second Life pilot final report: A summary of key findings and lessons learnt*. Milton Keynes, UK: The Open University.

Thomas, D., & Brown, J. (2009). Why virtual worlds can matter. *Journal of Learning and Media*, *3*(1), 37–49. doi:10.1162/ijlm.2009.0008

Thomé, D. (1989). *Kriterien zur Bewertung von Lernsoftware. Mit einer exemplarischen Beurteilung von Deutsch-Lernprogrammen*. Heidelberg, Germany: Hüthig.

Thorin, E., Brand, H., & Weber, C. (2005). Long-term optimization of cogeneration systems in a competitive market environment. *Applied Energy*, *81*(2), 152–169. doi:10.1016/j.apenergy.2004.04.012

Timpe, C. H., & Kallrath, J. (2000). Optimal planning in large multi-site production networks. *European Journal of Operational Research*, *126*, 422–435. doi:10.1016/S0377-2217(99)00301-X

Toffler, A. (1980). *Third wave*. Bantam Books.

Tolga, C. (1997). Virtual human representation and communication in VLNET networked virtual environment. *VLNET. IEEE Computer Graphics and Applications*, *17*, 42–53.

Torabi, S. A., & Hassani, E. (2009). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19), 5475–5499. doi:10.1080/00207540801905460

Torabi, S. A., & Hassani, E. (2009). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19), 5475–5499. doi:10.1080/00207540801905460

Torabi, S. A., & Hassini, E. (2008). An interactive possibilistic programming approach for multiple objective supply chain master planning. *Fuzzy Sets and Systems*, *159*, 193–214. doi:10.1016/j.fss.2007.08.010

Torabi, S. A., & Hassini, E. (2008). Multi-site production planning integrating procurement and distribution plans in multi-echelon supply chains: An interactive fuzzy goal programming approach. *International Journal of Production Research*, *47*(19).

Tornincasa, S., Vezzetti, E., & Violante, M. G. (2005). 3D interactive technologies: Supporting e-learning with collaborative virtual environments (CVE). In *XVII INDEGRAF-XV* (pp. 1-3). ADM, Siviglia.

Troconis, M. T., & Rodríguez-Iborras, M. (2002). *Evaluation criteria for assessing human factors in virtual learning environments (VLEs).* Retrieved June 23, 2009, from http://www.eergonomics.inuk.com/PDF/Portsmouth2002.pdf

Tseng, Y.-J., & Huang, F.-Y. (2009). A multi-plant tolerance allocation model for products manufactured in a multi-plant collaborative manufacturing environment. *International Journal of Production Research*, *47*(3), 733–749. doi:10.1080/00207540701528792

Tsiakis, P., & Papageorgiou, L. G. (2008). Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics*, *111*, 468–483. doi:10.1016/j.ijpe.2007.02.035

Ueda, K., Fujii, N., & Inoue, R. (2004). Emergent synthesis approaches to control and planning in make to order manufacturing environments. *CIRP Annals - Manufacturing Technology, 53*(1), 385-388.

Ueda, N. (1992). A concept for bionic manufacturing systems based on DNA-type information. In *Proceedings of the IFIP TC5 / WG5.3 Eight International PROLAMAT Conference on Human Aspects in Computer Integrated Manufacturing, B-3* (pp. 853-863).

Ulieru, M., & Cobzaru, M. (2005). Building holonic supply chain management systems: An e-Logistics application for the telephone manufacturing industry. *IEEE Transactions in Industrial Informatics*, *1*, 18–30. doi:10.1109/TII.2005.843827

Ummels, B. C., Gibescue, M., Pelgrum, E., Kling, W. L., & Brand, A. J. (2007). Impact of power on thermal generation unit commitment and dispatch. *IEEE Transactions on Power Systems*, *22*, 44–51.

Vaario, J., & Ueda, K. (1998). An emergent modelling method for dynamic scheduling. *Journal of Intelligent Manufacturing*, *9*(2), 129–140. doi:10.1023/A:1008863811960

Valckenaers, P., & Van Brussel H. (2005). Holonic manufacturing execution systems. *CIRP Annals - Manufacturing Technology, 54*(1), 427-432.

Valckenaers, P. H., Kollingbaum, M., & Van Brussel, H. (2004). Multiagent coordination and control using stigmergy. *Computers in Industry*, *53*, 75–96. doi:10.1016/S0166-3615(03)00123-4

Valckenaers, P., Van Brussel, H., Verstraete, P., & Saint Germain, P., & Hadeli. (2007). Schedule execution in autonomic manufacturing execution systems. *Journal of Manufacturing Systems*, *26*, 75–84. doi:10.1016/j.jmsy.2007.12.003

Van Brussel, H., Wyns, J., Valckenaers, P., & Bongaerts, L. (1998). Reference architecture for holonic manufacturing systems: PROSA. *Computers in Industry*, *37*, 255–274. doi:10.1016/S0166-3615(98)00102-X

Van den broecke, F., Aghezzaf, E.-H., & Van Landeghem, H. (2008). Cyclical volume planning and fair share mix decisions, delivery a more robust service level. *Production Planning and Control, 19*(7), 668-676.

van den Hout, W. B., Smits, J. M., Deng, M. C., Hummel, M., Schoendube, F., & Scheld, H. H. (2003). The heart-allocation simulation model: a tool for comparison of transplantation allocation policies. *Transplantation*, *76*(10), 1492–1497. doi:10.1097/01.TP.0000092005.95047.E9

Van Landeghem, H., & Vanmaele, H. (2002). Robust planning: A new paradigm for demand chain planning. *Journal of Operations Management*, *20*, 769–783. doi:10.1016/S0272-6963(02)00039-6

van Wezel, W., Jorna, R., & Meystel, A. (2006). *Planning in intelligent systems*. Wiley & Son. ISBN: 9780471734277

Vancza, J., Egri, P., & Monostori, L. (2008). A coordination mechanism for rolling horizon planning in supply networks. *CIRP Annals - Manufacturing Technology, 57*, 455–458.

Vancza, J., & Egri, P. (2006). Coordinating supply networks in customized mass production—A contract-based approach. *CIRP Annals Manufacturing Technology*, *55*(1), 489–492.

Vargo, S. L., Maglio, P., & Akaka, M. (2008). On value and value co-creation: A service systems and service logic perspective. *European Management Journal*, *26*(3), 145–152. doi:10.1016/j.emj.2008.04.003

Varma, V. A., Reklaitis, G. V., Blau, G. E., & Pekny, J. F. (2007). Enterprise-wide modeling & optimization—An overview of emerging research challenges and opportunities. *Computers & Chemical Engineering*, *31*, 692. doi:10.1016/j.compchemeng.2006.11.007

Verderame, P. M., & Floudas, C. A. (2009). Operational planning framework for multisite production and distribution networks. *Computers & Chemical Engineering*, *33*, 1036–1050. doi:10.1016/j.compchemeng.2008.09.008

Vergnaud, G. (1987). About constructivism. *Proceedings of the Eleventh International Conference for the Psychology of Mathematics Education*, (pp. 42-55).

Verstraete, P., Valckenaers, P., Van Brussel, H., Saint Germain, B., Hadeli, K., & Van Belle, J. (2008). Towards robust and efficient planning execution. *Engineering Applications of Artificial Intelligence*, *21*, 304–314. doi:10.1016/j.engappai.2007.09.002

Verwijmeren, M. (2004). Software component architecture in supply chain management. *Computers in Industry*, *53*, 165–178. doi:10.1016/j.compind.2003.07.004

Vester, F. (2010). *Ecopolicy. A cybernetic environmental simulation game*.

Vidal, J. (2009). *Fundamentals of multiagent systems with netlogo examples*. Unpublished textbook. Retrieved May 14, 2010, from http://www.scribd.com/doc/2094479/Fundamentals-of-Multiagent-Systems

Vidal, C. J., & Goetschalckx, M. (2000). Modeling the effect of uncertainties on global logistic systems. *Journal of Business Logistics*, *21*(1), 95–120.

Vidal, C., & Goetschalckx, M. (1997). Strategic production–distribution models: A critical review with emphasis on global supply chain models. *European Journal of Operational Research*, *98*, 1–18. doi:10.1016/S0377-2217(97)80080-X

Vidgen, R. (1998). Cybernetics and business processes: Using the viable system model to develop and enterprise process architecture. *Knowledge and Process Management*, *5*(2), 118–131. doi:10.1002/(SICI)1099-1441(199806)5:2<118::AID-KPM19>3.0.CO;2-3

Virmani, S., Imhof, K., & Mukherjee, S. (1989). Implementation of a Lagrangian relaxation based unit commitment problem. *IEEE Transactions on Power Systems*, *4*, 1373–1379. doi:10.1109/59.41687

Vosinakis, S., Koutsabasis, P., & Zaharias, P. (2011). *An exploratory study of problem-based learning in virtual worlds*. 3rd International Conference in Games and Virtual Worlds for Serious Applications (VS-Games 2011), May 4-6 2011, Technical University of Athens (NTUA), Athens, Greece.

Vosniadou, S. (1996). Learning environments for representational growth and cognitive flexibility. In Vosniadou, S., DeCorte, E., Glaser, R., & Mandl, H. (Eds.), *International perspectives on the design of technology supported learning environments* (pp. 13–24). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Voß, S., & Woodruff, D. L. (2006). *Introduction to computational optimization models for production planning in a supply chain* (2nd ed.). Springer.

Wagner, H. M., & Whitin, T. M. (1958). The dynamic version of the economic lot size. *Management Science Magazine* (US), October 1958.

Wagner, C., & Nyhuis, P. (2009). A systematic approach to analysis and design of global production networks. *Production Engineering and Research Development*, *3*, 295–303. doi:10.1007/s11740-009-0167-z

Walker, J. (2001). *The viable systems model: A guide for co-operatives and federations*. Retrieved 4 June, 2011, from http://www.greybox.uklinux.net/vsmg_2.2/pdf/vsmg_2_2.pdf

Walker, V., & Rockinson-Szapkiw, A. J. (2009). Educational opportunities for clinical counseling simulations in Second Life. *Innovate, 5*(5). Retrieved 22 June, 2010, from http://www.innovateonline.info/index.php?view=article&id=711&action=synopsis

Walley, K. (2007). Coopetition: An introduction to the subject and an agenda for research. *International Studies and Management & Organization*, *37*(2), 11–31. doi:10.2753/IMO0020-8825370201

Walther, G. (2008). Negotiation-based coordination in product recovery networks. *International Journal of Production Economics*, *111*, 334–350. doi:10.1016/j.ijpe.2006.12.069

Wang, C., Song, H., Xia, F., & Yan, Q. (2009). Integrating Second Life into an EFL program: Students perspectives. *Journal of Educational Technology Development and Exchange*, *2*(1), 1–16.

Wang, D., & Fang, S. C. (1997). A genetics-based approach for aggregate production planning in a fuzzy environment. *IEEE Transactions on Systems, Man, and Cybernetics. Part A, Systems and Humans*, *27*(5), 636–645. doi:10.1109/3468.618262

Wang, H. W., Guo, M., & Efstathiou, J. (2004). A game-theoretical cooperative mechanism design for a two-echelon decentralized supply chain. *European Journal of Operational Research*, *157*(2), 372–388. doi:10.1016/S0377-2217(03)00233-9

Wang, J., & Hwang, W. L. (2007). A fuzzy set approach for R&D portfolio selection using real options valuation model. *Omega*, *35*(3), 247–257. doi:10.1016/j.omega.2005.06.002

Wang, J., & Shu, Y.-F. (2007). A probabilistic decision model for new product supply chain design. *European Journal of Operational Research*, *177*, 1044–1061. doi:10.1016/j.ejor.2005.12.032

Wang, M., Wang, H., Vogel, D., Kumar, K., & Chiu, D. K. W. (2009). Agent-based negotiation and decision making for dynamic supply chain formation. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.001

Wang, M., Wang, H., Vogel, D., Kumar, K., & Chiu, D. K. W. (2009). Agent-based negotiation and decision making for dynamic supply chain formation. *Engineering Applications of Artificial Intelligence*, *22*(7). doi:10.1016/j.engappai.2008.09.001

Wang, R. C., & Fang, H. H. (2001). Aggregate production planning with multiple objectives in a fuzzy environment. *European Journal of Operational Research*, *133*, 521–536. doi:10.1016/S0377-2217(00)00196-X

Wang, R. C., & Liang, T. F. (2004). Application of fuzzy multiobjective linear programming to aggregate production planning. *Computers & Industrial Engineering*, *46*(1), 17–41. doi:10.1016/j.cie.2003.09.009

Wang, R. C., & Liang, T. F. (2005). Applying possibilistic linear programming to aggregate production planning. *International Journal of Production Economics*, *98*, 328–341. doi:10.1016/j.ijpe.2004.09.011

Wang, S., & Hsu, H. (2009). Using the ADDIE model to design Second Life activities for online learners. *TechTrends*, *53*(6), 76–81. doi:10.1007/s11528-009-0347-x

Wang, Y., & Usher, J. (2004). Application of reinforcement learning for agent-based production scheduling. *Engineering Applications of Artificial Intelligence*, *18*, 73–82. doi:10.1016/j.engappai.2004.08.018

Wankel, C., & Kingsley, J. (2009). *Higher education in virtual worlds. Teaching and learning in Second Life*. USA: Emerald Group.

Warburton, S. (2009). Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. *British Journal of Educational Technology*, *40*(3), 414–426. doi:10.1111/j.1467-8535.2009.00952.x

Warnecke, H. J. (1993). *The fractal company: A revolution in corporate culture*. Berlin, Germany: Springer-Verlag. doi:10.1007/978-3-642-55776-7_3

Warr, P., Cook, J., & Wall, T. (1979). Scales for the measurement of some work attitudes and aspects of psychological well-being. *Journal of Occupational Behavior*, *52*, 129–148.

Watt, P. (1997). Know it all. *Intranet*, 17-18.

Weaver, W., & Shannon, E. (1963). *The mathematical theory of communication*. University of Illinois Press.

Webster, S. (2008). *Principles and tools for supply chain management* (13th ed.). Boston, MA: McGraw-Hill/Irwin.

Weinstein, L., & Chung, C. H. (1999). Integrating maintenance and production decisions in a hierarchical production planning environment. *Computers & Operations Research*, *26*, 1059–1074. doi:10.1016/S0305-0548(99)00022-2

Weisbuch, G. (2006). Self-organized patterns in production networks. *Complexus*, *2*, 217–227. doi:10.1159/000093692

Weisbuch, G., & Battiston, S. (2007). From production networks to geographical economics. *Journal of Economic Behavior & Organization*, *64*(3-4), 448–469. doi:10.1016/j.jebo.2006.06.018

Wiendahl, H., El Maraghy, H., Nyhuis, P., Zäh, M., Wiendahl, H., Duffie, N., & Brieke, M. (2007), Changeable manufacturing – Classification, design and operation. *CIRP Annals - Manufacturing Technology, 56*(2), 783-809.

Wiendahl, H. P., & Lutz, S. (2002). Production networks. *Annals of CIRP on Manufacturing Technologies*, *51*(2), 573–586. doi:10.1016/S0007-8506(07)61701-6

Wiendahl, H.-P., & Lutz, S. (2002). Production networks. *Annals of CIRP*, *51*(2), 5–22. doi:10.1016/S0007-8506(07)61701-6

Wilensky, U. (1999). *Netlogo modeling environment*. Retrieved May 14, 2010, from http://ccl.northwestern.edu/netlogo/download.shtml

Williams, J. F. (1983). A hybrid algorithm for simultaneous scheduling of production and distribution in multi-echelon structure. *Management Science*, *29*, 77–92. doi:10.1287/mnsc.29.1.77

Williams, T. W. (1992). Practical use of distributions in network analysis. *The Journal of the Operational Research Society*, *43*, 265–270.

Windt, K., & Hülsmann, M. (2007). Changing paradigms in logistics - Understanding the shift from conventional control to autonomous cooperation and control. In Hülsmann, M., & Windt, K. (Eds.), *Understanding autonomous cooperation & control - The impact of autonomy on management, information, communication, and material flow* (pp. 4–16). Berlin, Germany: Springer. doi:10.1007/978-3-540-47450-0_1

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence (Cambridge, Mass.)*, *7*(3), 225–240. doi:10.1162/105474698565686

Wooldridge, M. J. (2001). *Multi-agent systems: An introduction*. Chichester, UK: John Wiley & Sons.

Wu, D., & Olson, D. L. (2008). Supply chain risk, simulation, and vendor selection. *International Journal of Production Economics*, *114*, 646–655. doi:10.1016/j.ijpe.2008.02.013

Wu, M. C., & Chang, W. J. (2007). A short-term capacity trading method for semiconductor fabs with partnership. *Expert Systems with Applications*, *33*(2), 476–483. doi:10.1016/j.eswa.2006.05.012

Xia, Y., Chen, B., & Yue, J. (2008). Job sequencing and due date assignment in a single machine shop with uncertain processing times. *European Journal of Operational Research*, *184*, 63–75. doi:10.1016/j.ejor.2006.10.058

Yahya, S., & Goh, W.-K. (2002). Managing human resources toward achieving knowledge management. *Journal of Knowledge Management*, *6*(5), 457–468. doi:10.1108/13673270210450414

Yamashita, S. (2006). *What makes for effective online community building? 10 field-tested strategies you can use to boost student success.* Paper presented at the World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. 2006, Honolulu, Hawaii, USA.

Yang, H., Ye, M., Tang, W. H., & Wong, S. C. (2003). Modeling urban taxi services: A literature survey and an analytical example. In Lam, W. H. K., & Bell, M. G. H. (Eds.), *Advanced modeling for transit operations and service planning* (pp. 257–286). Oxford, UK: Pergamon.

Yang, J.-T., & Wan, C.-S. (2004). Advancing organizational effectiveness and knowledge management implementation. *Tourism Management*, *25*(5), 593–601. doi:10.1016/j.tourman.2003.08.002

Yee, N., Bailenson, J., Urbanek, M., Chang, F., & Merget, D. (2007). The unbearable likeness of being digital: The persistence of non verbal social norms in online virtual environments. *Cyberpsychology & Behavior*, *10*(1), 115–121. doi:10.1089/cpb.2006.9984

Yitzhaki, S. (1982). Stochastic dominance and Gini's mean difference. *The American Economic Review*, *72*(1), 178–185.

You, F., & Grosmann, I. E. (2008). Mixed-integer nonlinear programming models and algorithms for large-scale supply chain design with stochastic inventory management. *Industrial & Engineering Chemistry Research*, *47*, 7802–7817. doi:10.1021/ie800257x

Yu, C.-S., & Li, H.-L. (2000). A robust optimization model for stochastic logistic problems. *International Journal of Production Economics*, *64*, 385–397. doi:10.1016/S0925-5273(99)00074-2

Zaid, B., Jamaludin, R., & Hosam, A. (2011). Perceived satisfaction levels and student learning performance towards Second Life virtual environment for learning the Islamic concepts. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1860–1864.

Zarraonandia, T., Francese, T., Passero, I., Aedo, I., Tortora, G., & Diaz, D. (2011). *Seminars in Second Life: Teacher and student views.* Retrieved 8 December, 2011, from http://www.ksi.edu/seke/dms11/DET/12_Telmo_Zarraonandia.pdf

Zegordi, S. H., Kamal Abadi, I. N., & Beheshti, M. A. (2010). A novel genetic algorithm for solving production and transportation scheduling in a two-stage supply chain. *Computers & Industrial Engineering*, *58*, 373–381. doi:10.1016/j.cie.2009.06.012

Zhang, D. Z. W., Anosike, A. I., Lim, M. K., & Akanle, O. M. (2006). An agent-based approach for e-manufacturing and supply chain integration. *Computers & Industrial Engineering*, *51*(2), 343–360. doi:10.1016/j.cie.2006.02.012

Zhao, G., Deng, J., & Shen, W. (2001). CLOVER: An agent-based approach to systems interoperability in cooperative design systems. *Computers in Industry*, *45*, 261–276. doi:10.1016/S0166-3615(01)00097-5

Zhao, Q., & Sadler, B. M. (2007). A survey of dynamic spectrum access: Signal processing, networking, and regulatory policy. *IEEE Signal Processing Magazine*, *24*(3), 79–89.

Zho, S. C., Ramirez-Serrano, A., & Brennan, R. W. (2006). Cooperative multi-agent reconfigurable manufacturing environments. *International Journal of Manufacturing Technology and Management*, *8*, 283–303. doi:10.1504/IJMTM.2006.008799

Zhuang, F., & Galiana, F. D. (1988). Towards a more rigorous and practical unit commitment by Lagrangian relaxation. *IEEE Transactions on Power Systems*, *3*, 763–773. doi:10.1109/59.192933

INDEX

Index Terms	Links			