SUPPLY CHAIN MANAGEMENT – PATHWAYS FOR RESEARCH AND PRACTICE

Edited by **Dilek Önkal** and **Emel Aktas**

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Published by InTech
Janeza Trdine 9, 51000 Rijeka, Croatia

Publishing Process Manager Iva Lipovic
Technical Editor Teodora Smiljanic
Cover Designer Jan Hyrat
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First published July, 2011
Printed in Croatia

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Supply Chain Management – Pathways for Research and Practice,
Edited by Dilek Önkal and Emel Aktas
p. cm.
ISBN 978-953-307-294-4

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Preface

Challenges faced by supply chains appear to be growing exponentially under the demands of increasingly complex business environments confronting the decision makers. The world we live in now operates under interconnected economies that put extra pressure on supply chains to fulfil ever-demanding customer preferences. Relative attractiveness of manufacturing as well as consumption locations changes very rapidly, which in consequence alters the economies of large scale production. Coupled with the recent economic swings, supply chains in every country are obliged to survive with substantially squeezed margins. Many supply chains do not have the necessary tools and flexibility to deal with such fast changing conjunctures at either the global or the local levels.

2010s are also witnessing further shortening of the product life cycles, forcing producers to continually work on expanding product categories. Moreover, raw material scarcity emerges as a gradually growing problem along with the increasing labour costs. In this book, we tried to compile a selection of papers focusing on a wide range of problems in the supply chain domain. Each chapter offers important insights into understanding these problems as well as approaches to attaining effective solutions.

The book starts with an investigation into *lean supply chain practices and performance* by Azman Daud and Suhaiza Zailani. *Service supply chain* concepts are explored in the 2nd chapter by Kavighta Mohan and Suhaiza Zailani. This is followed by a series of insightful chapters on the main theme of *quality management*, as examined by Lynn A. Fish in Chapter 3, Goknur Arzu Akyuz in Chapter 4, and Qin Su and Qiang Liu in Chapter 5. The next theme is *supply chain flexibility*, where managerial implications are discussed by Dilek Onkal and Emel Aktas in Chapter 6; while Javier Pereira Luciano Ahumada and Fernando Paredes discuss bullwhip effect and flexibility issues in Chapter 7. Manuel Diaz-Madronero and David Peidro present a fuzzy goal programming approach for *collaborative supply chains* in Chapter 8, followed by Mehdi Sajadifar, Rasoul Haji, Mostafa Hajiaghaei-Keshteli, and Amir Mahdi Hendi's focus on *information sharing* in Chapter 9. Improved supply chain performance and the associated *production and delivery policy* implications are investigated in Chapter 10 by Seung-Lae Kim and Khalid Habib Mokhashi. *Inter-organizational collaboration* issues are addressed by Adrian Tan and Hamid Noori in Chapter 11, while Chapter 12 presents work on *advanced supply chain planning systems* by Luis Antonio de Santa-Eulalia, Sophie D'Amours, Jean-Marc Frayret and Claudio Cesar. A new s*upply chain process management maturity model* is introduced by Oliviera Marcos in Chapter 13. Finally, the book concludes with a discussion of using *internet technologies for supply chain management* by Marincas Delia Adriana.

Supply Chain Management is an important and prolific domain that will continue to generate much research interest. We hope that the chapters collected in this book will serve as a guide to future work on the issues that will influence supply chain management practices, leading to efficient processes and effective decisions.

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Lean Supply Chain Practices and Performance in the Context of Malaysia

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1. Introduction

Supply chain nowadays becoming a vital entity to the organizations performance measurement and metrics, has received much attention from researchers and practitioners. To support this, Gunasekaran, Patel (2001) and McGaughy (2004) have discussed that the role of these measures and metrics in the success of an organization cannot be overstated because they affect strategic, tactical and operational planning and control. Some more, the revolution of SCM in the last decade has testified that an increasing number of companies seek to enhance performance beyond their own boundaries (Boyson et al., 1999; Proirier, 1999). Supply chain has been viewed on every perspective. According to Agarwal & Shankar (2002), a supply chain is an inter-linked set of relationships connecting customer to supplier, perhaps through a number of intermediate stages such as manufacturing, warehousing and distribution processes.

Accordingly, Harland (1996) have clearly stated that supply chain also often refers either to a process-oriented management approach to sourcing, producing, and delivering goods and services to end customers or, in a broader meaning, to the co-ordination of the various actors belonging to the same supply chain. Intense competition compels companies to create close relationships with their upstream and downstream partner (Togar & Ramaswami, 2004). In the competitive environment, most leading edge companies realized that by transferring costs either upstream or downstream, they are actually not increasing their competitiveness, since all costs ultimately make their way to consumers (Cigolini, Cozzi & Perona, 2004). Hence, Cigolini, Cozzi and Perona (2004), have mentioned that supply chain management guides firms to co-operate with a common goal to increase the overall channel sales and profitability, rather than competing for a bigger share of a fixed profit. One strategy for coordinating within and between firms with a focus on achieving efficiency, eliminating waste or overburden and creating value in products is the concept of lean management (Womack & Jones, 1996). Consequently, Vonderembse, Uppal, Huang, and Dismukes (2006), highlighted on the strategies and methodologies for designing supply chains that meet specific customer expectations. According to them, three different types of supply chains can be defined:

1. A lean supply chain, which employs continuous improvement efforts which focuses on eliminating waste or non-value steps along the chain.

2. An agile supply chain, which responds to rapidly changing, continually fragmenting global markets by being dynamic, context-specific, growth-oriented, and customer focused.
3. A hybrid supply chain, which combines the capabilities of lean and agile supply chains to create a supply network that, meets the needs of complex products.

Lean thinking is focused on eliminating waste from all processes while enhancing material and information flow along the supply chain (McCullen & Towill, 2001). The impact of lean thinking as a strategy for the supply chain and not just manufacturing is important and has received a lot of interest from both industry (including service) and academia. Hence, the purpose of this paper is to explore the implementation of lean supply chain management practices in manufacturing industry in Malaysia, and identifies the impact of these practices on lean supply chain performance.

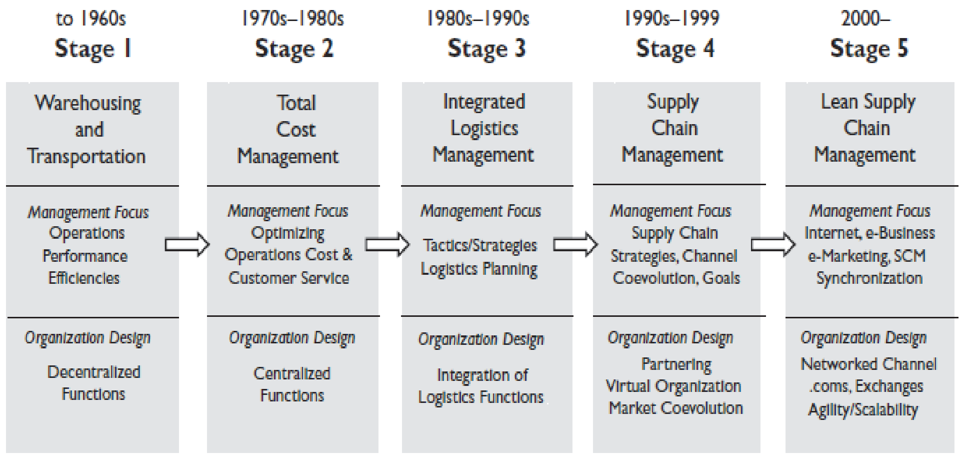
2. Literature review

2.1 Lean basics

There are lots of definitions available to define "Lean". For example, The National Institute of Science and Technology (NIST/MEP, 1998) defines Lean as "A systematic approach to indentifying and eliminating waste (non-value added activities) through continuous improvement by following the product at the pull of the customer in pursuit of perfection"(Buzby, Gerstemfeld, Voss & Zeng, 2002). Simply, lean means to create more value for customers with fewer resources, in other words, the fundamental ideas is to maximize customer value while minimizing waste. Actually, the word "Lean" was first used in the Future Car Investigation by MIT professors to interpret Japan's new production system that do away with mass production (Womack et al., 1991; Macduffie & Helper, 1997; Conti et al., 2006) since it produces much waste. "Waste" is defined as anything that interferes with the smooth flow of production (Macduffie & Helper, 1997). The eight wastes highlighted in TPS are overproduction, waiting, conveyance, over processing, excess inventory, movement, defects and unused employee creativity, and the biggest one being overproduction (Monden, 1998; Liker, 2004).

Wu and Wee (2009) concluded that the term "lean" means a series of activities or solutions to eliminate waste, reduce non-value added (NVA) operations, and improve the value added (VA). This VA and NVA concept were derived mainly from TPS. A lean organization understands customer value and focuses its key processes to continuously increase it. The ultimate goal is to provide perfect value to the customer through a perfect value creation process that has zero waste. To make Lean success, level of thinking need to be change in order to focus of management from optimizing separate technologies, assets, and vertical departments to optimizing the flow of products and services through entire value streams that flow horizontally across technologies, assets, and departments to customers (Lean Enterprise Institute, 2009). Eliminating waste along entire value streams, instead of at isolated points, creates processes that need less human effort, less space, less capital, and less time to make products and services at far less costs and with much fewer defects, compared with traditional business systems. Companies are able to respond to changing customer desires with high variety, high quality, low cost, and with very fast throughput times.

According to Anand and Kodali (2008), only in recent times, researchers have emphasized that the theory and principles of lean and its associated tools, techniques, practices and procedures can be extended outside the boundaries of an organization to its supply chains. However, the concept of lean supply chain was proposed in 1994, when the proponents of lean manufacturing, Womack and Jones (1994) envisioned the concept of 'lean enterprise'. The supply chain management concept has evolved with it through the five distinct stages shown in Figure 1 below.



Source: McKee & Ross (2009)

Fig. 1. Evolution of SCM

2.2 The Concepts and importance lean supply chain

Several researchers, such as Lee *et al*. (1997) and Lummus *et al*. (2003), explained that the information transferred from one stage to another in supply chain tends to be distorted and can misguide upstream members in the production decisions, resulting in wastes, thereby affecting the coordination between the different stages of a supply chain. Lean supply chain continuous improvement processes to focus on the elimination of waste or non valued-added functions. These waste and non value-added stops across the supply chain and reduce set of times to allow for the economic production of small quantities. Gordon (2008) came out with his points that strongly support on lean supply chain best practices and performance. Accordingly, there is a research by Accenture, INSEAD and Stanford University show correlation between companies with a successful supply chain strategy and significant financial success. The correlation focuses on four lean supply chain perspectives: How organizations keep goods and services flowing in a smooth, uninterrupted and cost-effectives fashion from suppliers to customer firms end to end. Inventory perspectives; How do we keep minimal, but sufficient inventory in the supply chain pipeline in order to provide good service levels without interruptions. Lean procurement; how can procurement scale and improve its processes to minimize transactions, reduce total cost and work with the best possible suppliers who meet its requirements, Adopting lean within customer and supplier firms; how can business work to eliminate waste while adding value to its customers. Bozdogan (2002) emphasized that the successful of lean supply chain management principles derive from 10 Basic Lean Principles:

- Focus on the supplier network value stream

- Eliminate waste
- Synchronize flow
- Minimize both transaction and production costs
- Establish collaborative relationships while balancing cooperation and competition
- Ensure visibility and transparency
- Develop quick response capability
- Manage uncertainty and risk
- Align core competencies and complementary capabilities
- Foster innovation and knowledge-sharing

Bozdogan (2002) has illustrated the differentiation between conventional versus lean model adapted into lean supply chain management based on 22 characteristics identified. Refer to table 1.

ILLUSTRATIVE CHARACTERISTICS	CONVENTIONAL MODEL	LEAN MODEL
Number & structure	Many; vertical	Fewer; clustered
Procurement personnel	Large	Limited
Outsourcing	Cost-based	Strategic
Nature of interactions	Adversarial; zero-sum	Cooperative, positive-sum
Relationship focus	Transaction-focused	Mutually-beneficial
Selection length	Lowest price	Performance
Contract length	Short-term	Long-term
Pricing practices	Competitive bids	Target costing
Price changes	Upward	Downward
Quality	Inspection-intensive	Designed-in
Delivery	Large quantities	Smaller quantities (JIT)
Inventory buffers	Large	Minimized, eliminated
Communication	Limited; task-related	Extensive; multi-level
Information flow	Directive; one-way	Collaborative; two-way
Role in development	Limited; build-to-print	Substantial
Production flexibility	Low	High
Technology sharing	Very limited; nonexistent	Extensive
Dedicated investments	Minimal-to-some	Substantial
Mutual commitment	Very limited; nonexistent	High
Governance	Market-driven	Self-governing
Future expectations	No Guarantee	Considerable

Source: Bozdogan (2002)

Table 1. The Comparison between Conventional and Lean Model

2.3 The lean supply chain's practices

From the earlier analysis by (APICS, 2004; Manrodt, et al., 2005) and Aberdeen Group (2006), there are significant differences between these two researches. APICS, 2004; Manrodt et al (2005) focused more on lean supply chain level of practices ("Poor Practice", "Inadequate

Practice", "Common Practice", "Good Practice" and "Best Practice") while Aberdeen Group (2006) is focused more on level of adoption ("laggards", "industry norm" and "best in class") of lean supply chain implementations. In conjunction to the objectives of the study, the APICS, 2004; Manrodt et al (2005) research framework on level of lean supply chain practices seems to the perfect match and suitable to be used in order investigate the extent of lean supply chain practices towards performances in Malaysia. If we go back to the research objectives, four objectives related to the lean supply chain practices which are first, to investigate the extent of implementation for lean supply chain practices in Malaysia and second, to examine the effects of lean supply chain practices on the performance of the lean and lean supply chain in Malaysia. Additionally the study is to examine the mediating effect of lean performance. This argument perfectly supported the importance of framework selected.

Generally, from the literature review, there are four significant main practices of lean supply chain such as demand management, standardization, waste management and organizational behavior. The study however, will focus only two lean supply chain key principles that have been identified and being grouped. This is due to the reason that the study is focus on the outbound supply chain rather than inbound. Improving outbound supply chain efficiencies has become a top priority for companies seeking to increase their bottom line (Norek, 2002). The two main areas of improvement mentioned are Demand Management (Demand Management together with Cost Management) and Waste (Waste Management). These two main areas of lean supply chain key principles will be use to investigate the best practices and effects of lean supply chain implementations and practices in Malaysia. For every particular areas of improvement, the continuous of details discussion of the subsequences will be the main agenda of the best practices study. For example, Demand Management will be focused on Demand Signal, Demand Collaboration, Sales and Operation Planning and Inventory Management Practice. Waste will be discussed on waste management and value added activities and environmental issue awareness. The study then will continue to focus on the lean supply chain performance.

2.4 Lean performances

Lean performance is total internal lean optimization process. To develop a lean supply chain, there is need to apply lean to the supply chain as a system (Phelps, 2004). Lean is an approach that identifies the value inherent in specific products, identifies the value stream for each product, supports the flow of value, lets the customer pull value from the producer, and pursues perfection. It is through this holistic, enterprise-wide approach to lean implementation that the theory extends beyond functional strategy to a broader supply chain strategy employed by the company (Goldsby, 2005). The strengths of lean approach are lean's more immediate and practical focus on waste, flow and flexibility (Industry Week, 2010). A lean organization optimizes the flow of products and services to its customers. It delivers customer value by:

- Reducing lead times
- Improving quality
- Eliminating waste
- Reducing the total costs
- Engaging and energizing people (Industry Week, 2010).

Continuous Business Improvement (2010) has introduced 20 keys to world class competitiveness and total workplace improvement which are derived to the lean performances on better quality, faster throughput and cheaper cost.

2.5 Framework and hypotheses

As lean practices will be the core component of organizations business performances, these variables may also significantly influence the lean performance, which need to be focus in this study. Therefore, this theoretical framework (Figure 2) is served to investigate the performances rate of independent variables (lean practices).

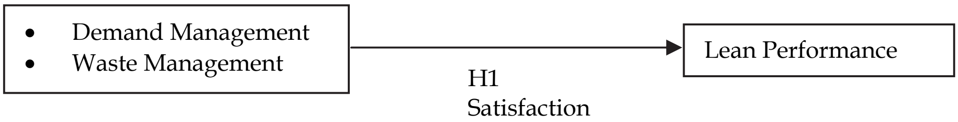


Fig. 2. Proposed Theoretical Framework

2.6 Hypothesis

2.6.1 Lean supply chain practices and lean performance

In term of demand management, it is very important that how well firms manage the demand signal, demand collaboration, sales and operation planning and inventory management is also reflected in how a lean supply chain system view as a system (Phelps, 2004; APICS, 2004; Manrodt et al, 2005). Lean performance is total internal lean optimization process; therefore demand management is vital to play their role to accept the concept of lean performance within their processes subsets. The strengths of lean approach are leanness are more immediate and practical focus on waste, flow and flexibility (Industry Week, 2010), therefore, supply chain partners including the upstream suppliers and downstream customers can work together as a team to provide value to the end-user customer (APICS, 2004; Manrodt et al., 2005). Some internal issuses like "offset" of Bill of Materials (BOMs)'s explosions; can be handle effectively by better understand the "real" demand they are projecting (APICS, 2004; Manrodt et al., 2005) in making used the approaches of lean performances like Reducing lead times, improving quality, eliminating waste, reducing the total costs, engaging and energizing people (Industry Week, 2010).

In the perspectives of waste management, lean performances are important to generate flexibility in order to control organization waste; the focus is to reduce waste; not costs, (APICS, 2004; Manrodt et al 2005). Anything that delays or impedes supply chain's flow must be analyzed as a potential non-value added activity (Craig, 2004). Some of the lean performances initiatives can be taken such as Engaging and energizing people (Industry Week, 2010) and supply chain partners have to work together and individually to eliminate wasteful processes and excess inventory across the chain. This elimination of waste should have a significant by-product: a reduction in cost for the supply chain. Therefore, the following hypothesis is proposed;

> **H1:** Organizations that practice the lean supply chain practices are significantly impact lean performance.

3. Methodology

3.1 Research design

In this study, the units being analyzed which are comprise of electrical, electronics and electronics manufacturing services companies in Malaysia. These manufacturing industries recorded the fastest growth rate in terms of its growth of industry by sub-sectors. Sampling is an option and one of the efficient process that been using by a quantitative research of selecting a sufficient number of data and information from the selected population. By selecting the right sample, it is possible to capture the characteristics of the data or information to the population elements (Sekaran, 2003). The sampling technique used for this research is based on proportionate stratified random sampling. According to FMM, 2010, there are over 1,000 manufacturers and supporting industries in the Electrical & Electronics Industry. 551 companies' related companies have been identified including MNC and SME sectors which are suitable for the test case in order to study and investigate the lean supply chain practices and performances metrics.

The data collection of this study will be carried out by using email, hand distribution and mailing to the respondent. As suggested by Sekaran (2003), the analysis samples should be at least ten times the number of variables in a study. Thus, 40 respondents are targeted in this study, as there are a total of four variables. Roscoe's (1975) rule of thumb suggest samples sizes that are greater than 30 and less than 500 should be appropriate for most research. The minimum sample should be at least 10 times than the number of variables. From the respondents received, 114 out of 551 targeted questionnaires responded.

3.2 Development of questionnaire

In this study, measures of variables were developed based on the literature review in addition to the survey. To date, very few large scale studies were conducted regarding lean supply chain practices, lean performances, and lean supply chain performances(Aberdeen Group (2006); APICS, 2004; Manrodt, Abott &Vitasek, 2005). Therefore, few reliable and validated measures were found in the literature. Accordingly, the study depends on the available that are derived from the issues and questions raised in the literature. The questions were taken directly from the past questionnaires with few modifications made to the model requirements (APICS, 2004; Manrodt, Abott &Vitasek, 2005).

In this study, lean supply chain practices have two dimensions of the independent variables which are: demand management and waste management, mostly following the similar study on lean supply chain practices (e.g., Aberdeen Group (2006); APICS, 2004; Manrodt, Abott &Vitasek, 2005). The study uses a 5-point Likert as point of scales for all dimensions of lean supply chain practices. The scale ranges from 1= low extent to 5= very high extent. In this study demand management is defined as how effectively the lean organizations handle their operations by moving to a pull system (Ducharme and Lucansky (2002), that is, products or services are pulled when requested by the final customer. There are four important facets need to be tested under demand management which are including of demand signal, demand collaboration, sales and operations planning, and inventory management practices (APICS, 2004; Manrodt, Abott &Vitasek, 2005).

In this study waste management is defined as to eliminate activities that do not add value (waste) in the manufacturing processes and increase the value-added activities which are those contribute to the highest level of efficiency in placing the final product at the customer In addition, it is about identifying and eliminating waste; as measured in time, inventory and cost across the complete lean supply chain. This requires continuous effort and improvement (Craig, 2004; Ilyas, Shankar & Banwet, 2008). There are two important facets need to be tested under waste management which are including of demand signal, demand collaboration, sales and operations planning, and inventory management practices (APICS, 2004; Manrodt, Abott &Vitasek, 2005).

Lean performances communicate through strengths of lean approaches, which are lean's more immediate and practical focus on waste, flow and flexibility (Industry Week, 2010). In this study, base on (Continuous Business Improvement, 2010) 20 keys to world class competitiveness and total workplace improvement frameworks suggested that the total performances comes from three important facets; which are better quality, faster throughput and cheaper cost.

4. Analysis

4.1 Profile of organizations

The profile data has been surveyed into four major sectors which are variables, categories, frequency of profiling attempts and percentage. For the number of full time employees data, the range of > 150 employees shows the highest (82%) and follow by 5-50 employees (9.6%) and the lowest is < 5 employees which is 10(8.8%). Most of the companies best categorized fully owned by foreign company (63%), is a large type of size (68%). Data shows that Penang state contributed the highest data (33%) and Pahang (1.8%) contributed as the lowest for state profile. Here, we can conclude that Penang is the most state with the Electrical &Electronics and Electronics Manufacturing Services companies on most of manufacturing kind of operations in Malaysia. The highest age of firm is 11 years – 15 years (33%) operating in Malaysia and the newest which are < 5 years is the lowest, contribute to 9.6% on profile rate.

The profile data mostly covers all general data of the gender, age, race and marital status. The interesting is to know the level of educations and positions profile among respondents to see whether the survey is suitable to be focused to the target segments. For the highest academic qualification, bachelor degree contributed the highest score which is 47.4%, follows by master degree which is 42.1%. The lowest is diploma holder with 10.5%. For positions in the current organizations, the highest score is Middle Management (Manager, Senior Engineer /Executive) with the score of 71.9% and follows by Lower Management (Executive, Engineer, and Supervisor), 21.9% and the lowest is Top Management equivalent to 6.1%.

4.2 Regression for demand management

To test the hypotheses generated from the tested variables, a multiple regression analysis was used. The results are presented in Table 2. The R^2 was 0.15 indicating that 15 percent of the variation of better quality can be explained by the demand management and the F-value of 4.568 was significant at the 0.01 level. Demand collaboration ($\beta = 0.237; p<0.05$) and sales and operations planning ($\beta = 0.262; p<0.01$) were positive and significantly related to better quality. However, the demand signal ($\beta = -.033; p>0.05$) and inventory management practice ($\beta = -.030; p>0.05$) were found no relationship with better quality.The R^2 was 0.27 indicating that 27 percent of the variation of faster throughput can be explained by the demand management and the F-value of 9.990 was significant at the 0.001 level. Sales and operations planning ($\beta = 0.394; p<0.001$) and inventory management practice ($\beta = 0.325; p<0.001$) were positive and significantly related to faster throughput. Demand signal ($\beta = 0.057; p>0.05$) and demand collaboration ($\beta = -.038; p>0.05$) were found no relationship with faster throughput. The R^2 was 0.44 indicating that 44 percent of the variation of faster throughput can be explained by the demand management and the F-value of 21.055 was significant at the 0.001 level. Demand collaboration ($\beta = 0.462; p<0.001$) and sales and operations planning (β = 0.302; p<0.001) were positive and significantly related to cheaper cost. Demand signal (β = 0.109; p>0.05) and inventory management practice (β = 0.036; p>0.05) were found no relationship with cheaper cost.

Variables	*Better Quality*	*Faster Throughput*	*Cheaper Cost*
	β	**β**	**β**
Demand Signal	-0.033	0.057	0.109
Demand Collaboration	.237*	-0.038	.462***
Sales & Operations Planning	.262**	.394***	.302***
Inventory Management Practice	-0.03	.325***	0.036
R^2	0.146	0.272	0.44
Adjusted R^2	0.114	0.245	0.42
F	4.568**	9.990***	21.055***

Note: *p<0.05; **p<0.01; ***p<0.001

Table 2. Regression analysis between Demand Management and Lean Performance

4.3 Regression for waste management

The results are presented in Table 3. The R^2 was 0.272 indicating that 27 percent of the variation of lean performance can be explained by the waste management and the F-value of 4.226 was significant at the 0.001 level. Waste (β = 0.639; p<0.01) and value added activities (β = 0.444; p<0.05) were positive and significantly related to lean performance.

Variables	*Better Quality*	*Faster Throughput*	*Cheaper Cost*
	β	**β**	**β**
Waste	0.169	.242**	.639***
Value Added Activities	0.156	.444***	-0.086
R^2	0.071	0.331	0.377
Adjusted R^2	0.054	0.319	0.365
F	4.226*	27.191***	32.616***

Note: *p<0.05, **p<0.01, ***p<0.001

Table 3. Regression Analysis between Waste Management and Lean Performance

5. Discussions

This study has shown that demand collaboration, sales and operation planning, inventory management practices, waste and value added activities are the most influence lean supply chain practices for lean performances, regardless of the demand signal, which has no influence data survey limitation. Hence, this information can be utilized to promote the acceptance and implementation of lean supply chain practices. Related government bodies for manufacturing and operation such as FFM, SMIDEC and MPC can therefore focus on these factors for further research development of lean supply chain practices and performances. These organizations can organize more training and seminars to smaller manufacturing companies to expose the concept of lean supply chain upfront, as the concept

can consider new, limits to off resources. From an organization point of view, attention should be given to improve employee participation and quality department should play a proactive role in practicing the lean supply chain as a strategic tool.
One of the limitations of this study is that the conclusion drawn from the survey was principally due to the variety of interpretations of what the term and concepts of "lean supply chain performances" actually means. Since, this is a newly concept that need to adapt, it's possible that the lean practitioners should have a solid knowledge before implement it. It's a waste of multiple of resources if doing it wrongly. From the data interpretation, it is resulting that the survey has a good trend of lean supply chain practices towards performances. New hypotheses able to generate which are more specific in term of sub variables interpretations. Even though, there is a concept of mediating being implement in the research, the study able to show up with an excellence result compare to Malaysian geographical area and small scope of manufacturing operations. The sample size of this study is rather small. Although the survey shows consistency of reliability, validity has proven that improvements like supplier engagement and collaboration is not surely clear. To be significant, it is always better to subject the model to a larger sample size. Other alternative like to carry out an external validity by checking with other set of samples in order to strengthen the arguments. The findings of this study have shown that there is a relationship between industry and lean supply chain practices and performances. It's also shows some of the lean supply chain concept is extents, therefore, it is recommended to extend the framework to a more distinguished like standardization of the process and organizational issues handling lean (Aberdeen Group (2006), APICS (2004). Furthermore, the scope of the study can be extended into clustered at certain geographical areas as a result from the critical mass. There will be wider, and the characteristics and practices business unit under test might vary owing to business environment differences.

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2

Service Supply Chain: How Does It Effects to the Logistics Service Effectiveness?

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1. Introduction

In 2009, Malaysia's International Trade and Industry Minister Tan Sri Muhyiddin Yassin quoted services sector in Malaysia is expected to have a significant impact on the growth of Malaysia's economy and targeted to contribute 70% of the gross domestic product (GDP) by 2020 and the services sector currently contributing about 55% to Malaysia's GDP (17th March 2009, BERNAMA). Importance of services industry seem to be acknowledged well by, Ellram et al. (2004) through the article entitled "Understanding and Managing the Services Supply Chain" and this author have popularized the term service supply chain. Sengupta et al., (2006) have taken a next step by differentiating between service supply chain and manufacturing supply chain. They argued that human labor forms a significant component of the value delivery process in service supply chain and while physical handling of a product leads to standardized and centralized procedures and controls in manufacturing supply chains.

With regards to the performance of service sector in Malaysia, the transport sub-sector registering the highest growth of 4.5%, followed by trade, finance and utilities sub-sectors. Services sector achieved total factor productivity utilization of capital and labor. The sector is expected to grow by 2.8% in 2009 supported by broad-based expansion in all services sub-sectors (Productivity Report, 2008). From this data, it shows clearly that the transport sector which comes under logistics industry plan plays an important role in the development of services industry in Malaysia.The present trend of logistics industry in Malaysia is about outsourcing and this has increase the growth of third party logistics (3PL). This is supported by Sohail and Sohal (2006) in their study, in which they found that 67.7% companies in Malaysia use the contract logistics services, with a primary focus on domestic operations. The significance growth logistics industry is offically recognized and underlined under the third industrial master plan (IMP3). According to Ali, Jaafar and Mohamad (2008), Malaysian government has set targets to achieve a growth of 8.6% and the GDP contribution is estimated to be 12.1% by the year 2020 under the Third Industrial Master Plan. The government has decided to increase the total marine cargo by three fold, air cargo by more than two fold and railway freight by more than fourfold by 2020. It is estimated that currently, there are about 22,000 companies in the logistics industry in Malaysia undertaking various areas of activities. Therefore, this study is interested to study about service supply chain management in the context of Malaysian logistics industry.

2. Literature review

A. Service Supply Chain

Baltacioglu et al. (2007) defines service supply chain (SSC) as a network of suppliers, service providers, consumers and other supporting units that performs the function of transaction of resources required to produce service followed by transformation of these resources into supporting and core services and finally delivery these services to customers. Lin et al. (2009) provided the similar explanation with Baltacioglu et al. (2007) but focuses on services as well as servitised products. Lin et al. (2009); Zhang et al. (2009) explains the key members in service supply chain are, service provider, service integrator and customers. The ultimate and most important member would be service provider. They serve as the core unit of service supply chain and service provider plays similar role as the focal company in a traditional manufacturing supply chain. The second key member in service supply chain would be service integrators and they play the role of coordinator in between service and for customers. When a customer places an order, service integrator will react to the customer request by breakdown the service request to service providers in the service chain and deliver back the required services to customer.

B. Service Supply Chain Practices

The service model that was proposed by Ellram et al. (2004) identifies the key practices that need a careful management to ensure a effective service supply chain. Service supply chain scholars have defined service supply chain based on the nature of the service they examine, which means the key definition of service supply chain will be similar to all service sectors, but nature of the definition varies accordingly based on the service sector they have chosen to study. Ellram et al. (2004), studied about professional services and it is a transfer of the service by utilizing the supplier's service assets and staff. However, Ellram et al. (2004) modified the definition to suit professional services by defining service supply chain as the management of information, process, capacity, service performance and funds from the earliest supplier to the ultimate customer.

Baltacioglu et al. (2007) studied about healthcare services and defined service supply chain as the delivery of core services to customer and the core service will be delivered with support of supporting service industry. In healthcare the core service is treatment of illness to the patient and supporting services would be surgical facilities, doctor's examination and laboratory tests. This study will focus on how service supply chain practices will lead to logistics service effectiveness. The following section will discuss about service supply chain practices undertaken in the study. The service supply chain practices proposed by Ellram et al. (2004) and Lin et al. (2009) will be the independent measures for this research. These independent variables will be tested at logistics industry focusing on logistic service providers. But in the context of SSC, they are the key members who are known as service providers and service integrators. The practices such as information flow, knowledge management, capacity and skills management and cash flow management are considered as strategically resources to the logistics service provider (Wong & Karia, 2009).These independent variables will be tested at logistics industry focusing on logistic service providers. But in the context of SSC, they are the key members who are known as service providers and service integrators.

C. Logistics Service Effectiveness

There are various definitions for logistics effectiveness but for this study, the definition from Mentzer & Konrad (1991) is adapted and defines as the extent to which the logistics functions goals are accomplished to achieve high performance. Logistics services are a series of management activities provided by logistics service provider in order to fulfill customer's requirement whereas logistics service effectiveness is referring to the logistics process that can create value added benefits for customer and customer satisfaction. According to Panayides (2007), logistics service effectiveness is defined as of extend of service delivery the logistics service provider can provide to the customer. With reference to past literature, the term logistics service effectiveness can be referred as logistics service delivery or logistics performance and literature related to these two topics can be used to explain about logistics service effectiveness (Bienstock, Mentzer, & Bird 1997; Panayides, 2007).

D. Hypothesis Development

Olavarrieta and Ellinger (1997) discussed that resources are related to ''having'' while capabilities are related to ''doing'', making them more invisible. Therefore capabilities and resources should be treated as independent (Grant, 1991; Amit &Schoemaker, 1993; Yang et al., 2009). Therefore, information flow is process of linking all the members in a supply chain through information. It involves the process of collecting and transmitting and processing data to create information to support all the other management processes (Johnson & Mena, 2008). Information resources help to integrate the downstream and upstream of logistics service provider (Wong & Karia, 2009). Capacity can be referred as firm existing resources to support the customer demand. Armistead and Clark (1994) explained that capacity management from the service perspective as their ability to balance demand request from customers and how capable the firms service delivery system in order to fulfill this customer demand. Cash flow management is activities such as invoicing customer, payment for supplier and transfer of funds in the supply chain. Therefore, a second hypothesis is proposed:

H1: Service supply chain practices have positive effect on logistics service effectiveness.
H1a Information Flow has positive effect on Logistics Service Effectiveness.
H1b: Knowledge Management has positive effect on Logistics Service Effectiveness.
H1c: Capacity and Skill Management has positive effect on Logistics Service Effectiveness.
H1d: Cash Flow Management has positive effect on Logistics Service Effectiveness.

3. Methodology

A. Unit of Analysis

The units being analyzed for this study are the firms. The term firm here refers to companies as well as individual units or sites within companies. Specifically they are the logistics service providers in Penang region which comprises transport service providers, and logistics service providers. The transport service providers include transport operators of air, sea, road, and rail; multimodal operators; and terminal operators. The logistics service providers consist of facilitation services (such as freight forwarders, customs brokers, ship brokers, shipping agents, consolidators, and non-vessel operating common carriers), distribution services (warehousing and transportation, inventory management, and domestic and regional distribution and courier companies), and integrated logistics services (third party logistics providers and lead logistics providers / fourth party logistics providers (Penang Economic Monthly Report, Seri 2007).

The population frame for this study is obtained from the Malaysian Logistics Directory 2009/2010. The list of all population was prepared so that samples can be selected randomly from the identified population. From the Malaysian Logistics directory, there are 250 logistics service providers in Penang Region. However, given the small sampling frame of the study and the likelihood of low response from mail survey (Sekaran, 2003), all the 250 logistics service providers were selected as sample for this study from the Penang region including mainland. Since the population is used as the sample in the study, therefore, the sampling technique employed in this study is census. Questionnaire was distributed to each and every respondent, by mail, by hand and by online respond via goggle group. In deciding the appropriate sample size for this study, Roscoe's (1975) rule of thumb suggests that the minimum sample should be at least 10 times the number of variables (120 in this study). However, given the small sampling frame of the study and the likelihood of low response from mail survey (Sekaran, 2003), the entire 250 logistics service provider firm was included in the study.

B. Development of the Survey Instrument

The questionnaire were developed from the question and issues highlighted in previous literature which was referred as the base for this study. The questionnaire divided into 5 sections as described above with difference type of choices provided to respondent to provide their information. Five point likert-type scale ranging from 1- 5 which refer as "strongly disagree" for 1, "disagree" for 2, "neutral" for 3, 'agree' for 4 and 'strongly agree" for 5 is used on issues such as implementation of service supply chain practices and the effectiveness of logistic service to customers. Five point likert-type scale ranging from 1-5 which refer as "very low extent" for 1, 'low extent' for 2, 'moderate' for 3, 'high extent' for 4 and 'very high extent' for 5 (Lai, 2004) is used to measure the extent to which the logistics service provider perceived their companies are capable of performing each of the logistics service items and the assessment on logistics service effectiveness of the researched firm.

C. Survey Items

Information flow is defined by Zhou and Benton (2007), as the fundamental for integration in the strategic alliance and describes information flow by three characteristics: level of information sharing, information quality and IT supply chain applications. The dimensions undertaken for the study for information flow are information sharing and level of information quality. These measurement items are adapted from Shang and Marlow (2005), Sengupta et al., (2006), and Li et al., (2006). Knowledge management is a set of processes transferring data and information into valuable knowledge (Yang et al, 2009). Hung and Chou, (2005), knowledge management framework generally consists of knowledge management processes and knowledge management enablers. For the purpose of this study, dimension for knowledge management was taken based on knowledge management enablers and the measurements were adapted from (Yang et al, 2009). Panayides (2007), logistics service effectiveness is defined as of extend of service delivery the logistics service provider can provide to the customer. The dimension was captured based on operational performance of the logistics service providers.

4. Data analysis

A. Descriptive Analysis

The overall response rate for the study is 38% from 110 out of 293 questionnaire distributed. However, among 110 questionnaires collected, only 106 sets could be proceed to the data analyses because remaining 4 sets of questionnaire were incomplete. The high response rate obtained from this study is mainly due to the fact that the study applied different methods for the data collection such as by hand and through postage. It is believed that this response rate is considered very good given the low response expected from mail survey and generally low response rate for this type of correlational study in Malaysia.

The respondent firm is mainly focus on Logistics Service Company (27.4%), Container Shipping Company (16.0%), Freight Forwarders (13.2%) and the remaining firms are namely from Forwarding Company, Warehousing, Transportation, Container Shipping Agency, 3rd Party Logistics and others. In this study, we have included railway service, courier service and postal service under the Other category. Whereas, for the number of employee in the firm, the data shows, firms with less than 20 employees (41.5%), 21 to 50 employees (15.1%), 51 to 100 employees (16.0%), 101 to 500 employees (13.2%) and 14.2% for firm which has more than 500 employees. Majority of the firm surveyed in this study have been involved in this industry for more than 15 years (51.9%), while those firms involved for less than 5 years is 11.3%. Those firms established for 5 to 10 years (21.7%) and 15.1% of the firms are between 11 to 15 years involvement in the industry.

B. Hypotheses Testing

To test the hypotheses generated a multiple regression analysis was used. The results are presented in Table 1. The R^2 was 0.454 indicating that 45.4 percent of the variation of logistic service effectiveness can be explained by the four service supply chain variables and the F-value of 21.031 was significant at the 0.001 level. Thus, information flow (β = .371; $p<0.001$), knowledge management (β = .195; $p<0.05$), and cash flow management (β = .417; $p<0.001$) were positive and significantly related to logistic service effectiveness. Nevertheless, capacity and skill management (β = -.018; $p>0.05$), was found have no relationship with logistic service effectiveness. Table 1 shows that cash flow management was counted have greater beta and dominance factor in predicted logistic service effectiveness. Figure 1 visualizes the relationships.

Description	Standardized Coefficients (β)
Information Flow	.371***
Knowledge Management	.195*
Capacity and Skill Management	-.018
Cash Flow Management	.417***
R^2	.454
Adjusted R^2	.433
F	21.031***

Note: *p<0.05; **p<0.01; ***p<0.001

Table 1. Predictors of Logistics Service Effectiveness

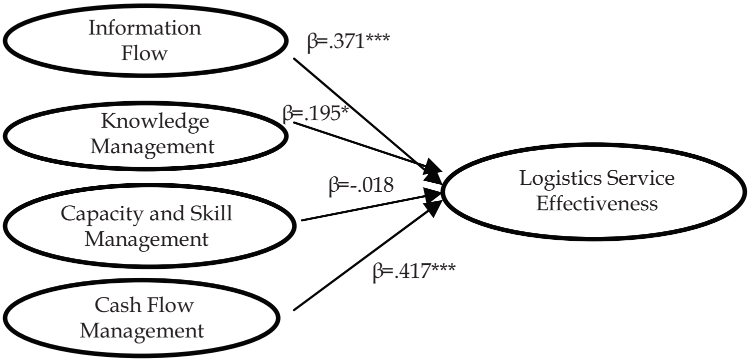

Fig. 1. Predictors of Logistic Service Effectiveness

4. Discussions

A. Service Supply Chain Practices and Logistics Service Effectiveness

Service supply chain practices have a partially significant effect on logistics service effectiveness. As expected, there is a positive relationship between service supply chain practices and logistics service effectiveness. This result is in line with Baltacioglu et al. (2007) commented that effective supply chain management is critical for service companies in order to gain competitive advantage. Baltacioglu et al. (2007) commented that service industry are becoming more complex to manage and a proper service supply chain practices are indeed a tool to cope with challenges in the service industry. Ellram et al. (2004) suggested that understanding and practicing proper service supply chain will improve the outcomes and positively impact the performance of service companies. The evidence provided by this research further strengthens the positive link between service supply chain and logistics service effectiveness. The result of the study indicates that logistics service providers in Penang region do have service supply chain practices in order to delivery effective logistics services to their customer.

The results for the study also shows that information flow, knowledge management and cash flow management are positively significant with logistics service effectiveness. The study shows the dimensions for independent variables which are that information flow, knowledge management and cash flow management are positively significant with logistics service effectiveness. But capacity and skill management has a no positive significant relationship with logistics service effectiveness. The results from the study shows that logistics service provider in Penang region have information flow as a part of their supply chain practices in order to achieve logistics service effectiveness. This results is supported with Ellram et al. (2004) comments, as this scholar point out that the service sector has less flexibility to deal with uncertain demand thus, information flows in the supply chain – including information-sharing and feedback are very important in services for managing this uncertainty. Baltacioglu et al. (2007) consider information flow and technology management as essential for the successful coordination of all key functions in the service supply chain. In an empirical study, Sengupta et al. (2006) find support at the company level for a positive relationship between information-sharing and operational performance in service supply chains.

According to Lee et al (2004) and Yang et al. (2009), organizations often have a competitive advantage or able to exhibit superior performance compared to those organizations that do not implement knowledge management. The results from the study shows that logistics service provider in Penang region have knowledge management as a part of their supply chain practices in order to achieve logistics service effectiveness. Yang et al. (2009) studied about knowledge management and the relation with firm performance in the context of liner shipping. The study showed that organizational structure and knowledge management culture were positively related to organizational performance. The results for this study is similar with Yang et al. (2009) thus further strengthen the empirical result of positive relationship between knowledge management and firms operational performance. The knowledge management practices in this study imply that top management of the logistics service providers firms are very supportive in knowledge management practice in their firms. The logistics service firms provide various programs to encourage employees to create and share knowledge.

There is a no significant relationship between capacity and skill management with logistics service effectiveness. It shows that logistics service provider do not belief proper practice of capacity and skill management can lead to logistics service effectiveness. However the negative relationship supports the justification by Ellram et al.(2004) that capacity and skill management are difficult to measure in the service context hence, organization have a high possibility to misrepresent the quality level of staff providing the service to customer. Capacity and skill management is closely connected to the demands management of the organization and availability of the resources to meet the demand (Baltacioglu et al., 2007). Rao et al. (2009) stated that capacity is important criteria for obtaining and continuing new service request and skill management helps to assign the right people with the right skill level to fulfill the logistics customer request. Hence, the result implies that capacity and skill management is less important in ensuring logistics service effectiveness among the logistics service providers.

The findings shows that logistics service provider in Penang region have a proper practice of cash flow management and according to Ellram et al., (2004), cash flow management usually have lack of proper control for services firms and commented that in service firms the transaction that occurs is only a two-way match which involves the invoice and summarizing the services delivered to customer on the purchase document. Therefore, if the service is not delivered based on the quality defined by customer it is difficult to be tracked and controlled. As of this study, logistics service providers are well aware of the cash flow management and have a proper tracking over the service provided to their customer. Lin et al., (2009) highlighted that cash flow management practice helps to ensure the transfer of fund between the service provider and customer takes places without any issue.

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3

Supply Chain Quality Management

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1. Introduction

In today's economy, it is no longer business versus business, but rather supply chain versus supply chain. To compete, supply chain members must learn to seamlessly integrate, grow, and develop business functions. Traditional quality management practices have been and will continue to be used to address many of these supply chain integration issues. With this in mind, current managerial thinking is advancing the notion of supply chain quality management. Supply chain quality management is a systems-based approach to performance improvement that integrates supply chain partners and leverages opportunities created by upstream and downstream linkages with a focus on creating value and achieving satisfaction of intermediate and final customers (Foster, 2008; Robinson & Malhotra, 2005). The intent of the chapter is to (1) review the positive impact of quality management on supply chain management, (2) present cases of supply chain improvements through quality management with a focus on the processes of design, production, delivery, support, and supplier-customer relationships, and (3) discuss the best practice recommendations, relationship between total quality management factors and transition to supply chain quality management that follow from these results.

2. Positive relationship between quality management and supply chain management

Although there are several definitions of quality, simply put, quality can be defined as meeting or exceeding customer expectations (Evans & Lindsay, 2002). According to the American Society for Quality, the definition of quality is "A subjective term for which each person or sector has its own definition. In technical usage, quality can have two meanings: 1. the characteristics of a product or service that bear on its ability to satisfy stated or implied needs; 2. a product or service free of deficiencies. According to Joseph Juran, quality means “fitness for use;” according to Philip Crosby, it means “conformance to requirements.” (American Society for Quality Online Glossary, 2011) Quality tools exist and include, but are not limited to: cause analysis (cause-and-effect diagrams, pareto charts, and scatter diagram), evaluation and decision-making tools (decision matrix and multi-voting), process analysis (flowchart, failure modes and effects analysis, mistake-proofing, and spaghetti diagrams), data collection and analysis (box and whisker plot, check sheet, control chart, design of experiments, histogram, scatter diagram, stratification, and surveys), idea creation (affinity diagram, benchmarking, brainstorming, and nominal group technique), an improvement project (Gantt chart and Plan-Do-Study-Act continuous improvement model), and management tools (relations diagram, tree diagram, matrix diagram, L-shaped matrix, arrow diagram, and process decision program chart) (Tague, 2004).

Total quality management is a set of quality practices that seek to continuously improve quality in processes. The eight key principles of total quality include (Monczka et al., 2009):

1. Define quality in terms of customers and their requirements.
2. Pursue quality at the source.
3. Stress objective rather than subjective analysis.
4. Emphasize prevention rather than detection of defects.
5. Focus on process rather than output.
6. Strive for zero defects.
7. Establish continuous improvement as a way of life.
8. Make quality everyone's responsibility.

Supply chain management is an approach to integrating suppliers, manufacturers, distributors and retailers, such that products are produced and distributed at the right quantities, to the right location, at the right time, with the mutual goals of minimizing system wide costs and satisfying customer service requirements (Simchi-Levi et al., 2008). In other words, supply chain management synchronizes a firm's processes with its suppliers and customers with the goal of matching the materials, services and information with customer demand (Krajewski et al., 2010). Critical supply chain processes include product design, production, delivery, support, and supplier-customer relationships. To succeed in today's environment, managers need to integrate their goals effectively to compete in the dynamic, global economy and focus on the final customer as the driver for improvements. Supply chains compete based upon cost, quality, time and responsiveness. Supply chain improvement tools include, but are not limited to process improvement tools of flow charting, flow diagrams, service blueprints, process analysis, process re-engineering, link charts, multi-activity analysis, backward chaining, and Gantt charts.

Quality is one of the most important factors for companies in their relationship between suppliers and customers. In fact, quality is so critical that today's executives question whether their companies should be participating in global sourcing as many global suppliers are not able to meet quality requirements (Brockwell, 2011). Positive relationships between quality management and supply chain management exist. To begin, quality management improvements in reducing process variation directly impact on several supply chain performance measures. With continuous quality management improvement, defects - and therefore, process and production variation, are reduced. In turn, as consistency in the supply chain improves due to the variation reduction, cycle times are reduced (the time between two successive replenishments) and on-time delivery improves (Flynn & Flynn, 2005).

Quality management practices, such as design for manufacturability, whereby product and process decisions are developing in new products simultaneously, and effective product designs geared toward the final customer requirements result in less product and process variation. While variance reduction in the processes obviously leads to quality improvements, consideration to the processes used during design enables management to switch from one product to another quicker. Therefore, design for manufacturability leads to quicker setup times between products (Flynn & Flynn, 2005). Quicker setup times allows companies to reduce lot sizes as less cycle (inventory needed between two successive replenishments) and safety stock (the amount of inventory required to protect against deviations from average demand during lead time) is required (Simchi-Levi et al, 2008).

As fewer defects are created, the amount of inventory in the supply chain is reduced. Supply chain members move only 'good' units, and not 'defective' units through the supply chain. Quality management practices reduce process variance, which has a direct impact on supply chain performance measures, such as inventory and time measures (Flynn & Flynn, 2005). As process variation is reduced, leading to more quality units and fewer defective unit moving through the supply chain, the cycle time will also improve. With fewer defective units moving through the supply chain, delivery dependability improves. Similarly, cycle time improvements result in less inventory 'in the way' of supply chain movement as there is less need for safety and cycle stock inventory, and fewer defective units need to be scrapped or replaced (Simchi-Levi et al., 2008).

Quality efforts to reduce variation have many positive results, including pipeline inventory reduction (Flynn & Flynn, 2005). Pipeline inventory (the amount of inventory between members of the supply channel including work in process inventories between manufacturing operations) is held as a function of manufacturing, supply and delivery cycle times. Through quality management, as the number of defects in the supply chain decreases and cycle times are shortened, simultaneously the total and pipeline inventory are reduced (Simchi-Levi et al, 2008). As already noted, pipeline inventory is also improved through variance reduction.

A quality improvement leading to a reduction in defective units, and therefore a reduction in rework, has a positive impact upon the supply chain as cycle times are reduced, schedules are met and customer response times improve (Flynn et al., 1995; Mefford, 1989). Fewer defective units in the system allow the remaining units to move through the supply chain faster, which is noted by improved cycle times. As companies are able to move product faster through the supply chain, schedules and the customers' demands can be met faster. This allows an improved synchronization and integration across the entire supply chain (Ferdows et al., 2004).

The adage 'garbage in, garbage out' advocates strong relationships between suppliers and buyers with respect to quality. Supplier certification programs and registration systems, such as ISO9000, assist companies to obtain quality items at the source. Prompt and reasonable supplier feedback also assists with providing quality inputs to the system. Utilizing statistical process controls throughout the supply chain aids in variation reduction, ensures quality inputs and reduces work-in-process in the supply chain system. Quality at the source, feedback and process controls ensure quality throughput in the system and therefore, reduces inspection time for raw materials, in-process inventory, and finished goods (Flynn & Flynn, 2005). The end result of supplier certification programs is less time is needed to stop the product and inspect for 'quality', which in turn, reduces cycle and transportation times (Heiko, 1990).

Constantly changing suppliers merely due to price, increases the variation in the materials and time elements for the supply chain. Product variation and information accuracy is negatively impacted. Certified suppliers and long-term relationships can positively impact on both quality and supply chain initiatives (Heiko, 1990; Kaynak & Hartley, 2008; Trent & Monczka, 1999). In these relationships, suppliers and buyers reap joint improvement driven by mutual interdependence, open and complete exchange of information, and win-win shared rewards. In these relationships, due to improved and increased exchange of information, supplier's product design changes are minimized, visibility to future purchase volume requirements is increased, and access and visibility to new product requirements is improved. Suppliers gain from a reduction in new product development time, production lead time, ethical treatment, and accurate, timely payment of invoices.

To summarize, quality management practices are associated with supply chain performance improvements. Therefore, quality management and supply chain management strategic goals and initiatives need to be pursued simultaneously as customers drive supply chain management and quality initiatives.

3. Quality and supply chain improvement

As discussed, there is a positive and direct relationship between quality and supply chain management. While the quality management movement started in the United States in the 1970's, the supply chain management movement is much 'younger', gaining momentum with the turn of the 21st century. Within a supply chain, important business processes affect customer satisfaction: design, production, delivery, support, and supplier-customer relationship processes. What quality techniques and tools are available to drive supply chain management improvements?

3.1 Design

We continue with a discussion of several cases whereby quality methods were instrumental in supply chain management improvements, starting with the design process. The design process, which is critical for company and supply chain survival, includes all activities that translate customer requirements, new technology and past learning into functional specifications for a product, process, or service. With supply chains growing to include global partners, time elements squeezing the quality attributes of items and development speed increasing, it is not surprising that the design process has received considerable attention in the past decade. It is imperative that the products and processes to deliver the item to the final customer are jointly designed. A wide variety of quality methods can be used to improve supply chains during the design phase including concurrent engineering, design for assembly, value engineering, and quality function deployment.

Simultaneous, or concurrent, design of products and processes within companies, under the umbrella of concurrent engineering has been successful in product design at Intel and Microsoft. Concurrent engineering, which brings together various functional specialists, is a process to bridge the gap between design and manufacturing with the goal of shortening time to market and improving quality. As supply chain management competition increases, a current design trend is to draw upstream suppliers into the new product development processes (which we will address in greater depth shortly). Due to technological and innovation demands, supply chain concurrent engineering, for products such as electric cars, required suppliers further up the supply chain (beyond Tier 1 suppliers) to participate in the design process to increase competitiveness, reduce time to market and increase quality (Pilkington & Dyerson, 2002). As supply chains increase participation of all members in design efforts, it is imperative that hidden costs of new product development acceleration, such as the form of skipping steps - particularly information communication and allocation of resources toward non-profitable, trivial innovation that drives out more profitable ones, be carefully monitored. Also, it is imperative that during the design phase, splitting design and production of coupled processes should be avoided.

Design for manufacturability provides a method for designing parts that are easy to manufacture and assemble, with cost and cycle time reduction and quality improvements as a result. Continuing in this vein of simultaneous activity, an emphasis on synchronizing product design decisions with supply chain management decisions, extends the concept of design for assembly to 'design for supply chain' (Hulta & Swan, 2003; Joglekar & Rosenthal, 2003; Lee & Sasser, 1995) and 'design for logistics' (Simchi-Levi et al., 2008). Design for supply chain addresses the simultaneous design for materials across the different supply chain levels, while design for logistics emphasizes consideration during design to the processes used to move the items through the supply chain, such as packaging, transportation, timing of value-added processes and standardization. Using design for manufacturability, the automotive industry analyzed the make/buy decision with a focus on supply chain processes which resulted in product and production capability optimization, concluded that simpler products should be outsourced while complex designs remain in-house, and supported the strategic importance of the product in the make/buy decision (Novak & Eppinger, 2001).

Value engineering, a disciplined approach to eliminating waste from products and processes (APICS, 2002), can positively impact upon both supplier and buyer’s bottom-line as demonstrated by the automotive industry where sharing information strengthened the relationship, reduced time to market, improved product quality and reduced costs (Blaney, 2005). Correspondingly, due to the lack of information sharing and value engineering practices, a 'cut-throat attitude' continues to penetrate the construction industry (Blaney, 2005). Extending value engineering to the supply chain should include evaluating all supply chain processes and not just a single process. As an example, Schneider Electric, a global electrical equipment manufacturer, jointly partners with their suppliers to achieve beneficial product results as well as significant supply chain cost, quality and time improvements (Avery, 2002). Joint value engineering efforts resulted in a material change for the component, resulting in cost savings for both members and a quality improvement.

Quality Function Deployment, a methodology to match the customer’s needs with technological capabilities, has proven to be beneficial in designing products such as the 1992 Cadillac, and for companies such as Ford, General Motors, Motorola, and AT&T (Evans & Lindsay, 2002). Extension to the supply chain involves using Quality Function Deployment across supplier-customer boundaries to capture the final customer’s voice and integrate it with supply chain processes. Japanese managers also indicate that the Quality Function Deployment process itself can be utilized to improve supply chain quality, technology management, and supply chain operating initiatives (Chu-Hua et al., 2002).

As previously noted, while supplier-customer integration across the supply chain for all processes is a major trend, integration in the design process can lead to cost reduction, supply chain competitiveness and improvements in quality, product safety, resource planning and materials management. John Deere and Motorola's highly successful new product development are well-known cases in this area. At John Deere, through the supplier development engineering program, a significant cost reduction resulted; however, suppliers and John Deere noted that all members must share technology, risk and accountability. Similarly at Motorola, the need for design resources and a focus on costs were emphasized. Integration typically involves organizational changes including cross-functional integration of multifunctional teams and supplier advisory councils. While a trend in supply chain management is toward strategic sourcing, the question of when to incorporate suppliers into new product development is still debatable. Early supplier design involvement is a concurrent engineering approach between suppliers and buyers that takes advantage of the supplier's design capabilities. Suncor Energy utilized internal personnel, contractors and suppliers to develop a unified strategy to address all phases of the product life cycle. Results indicate a cost reduction, planning and cycle time reduction, and a significant success rate in wells drilled (Monczka et al., 2009). The results highlight the need to develop a unified, joint strategy and importance of communication.

3.2 Production/ delivery, and support processes

We continue our discussion by highlighting the integration of quality and supply chain management improvements during the production, delivery and support processes. The production process is responsible for manufacturing the product from inputs through processes to outputs, while delivery processes are responsible for delivery of the product to the customer. Support process, although they do not add direct value to the product, provide an infrastructure for the core processes. Useful quality management tools in production, delivery and support processes include (but are not limited to) process improvement techniques, Six Sigma quality, performance measurement, Kaizen, benchmarking, value stream mapping, value analysis, and re-engineering.

A quality management survey used in northern Italian businesses uncovered several problems including information communication issues, excessive repetition of technical activities and production configuration errors, that negatively impacted upon the company and the supply chain members (Salvador & Forza, 2004). As a results, the order acquisition and fulfillment processes were changed. Recently, Target Corporation used supply management teams to develop a world-class supply base, reduce costs, improve cycle times and accelerate time to market (Murphy, 2010). The team utilized various quality tools to evaluate value creation in the supply chain activities.

A Six Sigma Quality Program, credited to Motorola, indicates that a process is in control to within tolerance limits of +/- 6 standard deviations from the centerline in control charting, which given natural process variation relates to 3.4 defects per million opportunities. Six Sigma programs have been effectively utilized in services, manufacturing, education and government. For example, Starwood Hotels utilized a Guest Satisfaction Index survey under its Six Sigma program to improve quality, reduce costs, increase speed and customer responsiveness, and efficiency (Monczka et al., 2009). Similarly a printed circuit board company's six sigma project to identify the root causes, key points and critical outputs resulted in changes to the production processes (Lee et al., 2009).

Value analysis and value engineering are useful methods to improve the product, processes or both during new product development to ensure that the product or service fulfills its intended function at the lowest total cost. Value analysis and value engineering was successfully used in several industries, including the U.S. Department of Defense. At the U.S. Department of Defense, life cycle costs are reduced through value engineering processes focused on low-cost systems for equipment, procedures, and supplies that are safe, reliable, and maintainable (Benstin et al., 2011). Value analysis and value engineering were successful used in the chemical, plastic, electronic, transportation and packaging industries to improve production performance, product quality, safety, and customer service while reducing transaction costs and inventory costs.

Benchmarking, whether informal or formal, is an effective method to improve quality, decrease costs, decrease lead time, improve dependability, and reduce shortages. Benchmarked firms improved their supply chains significantly on various measures over firms that chose not to benchmark (Heizer & Render, 2006). Twenty-five years after the growth of benchmarking, a recent multinational survey of benchmarking practices indicates that benchmarking is still an effective improvement tool (Adebanjo et al., 2010). A benchmarking study of supply chain processes from different industries that used dependency analysis and data envelopment analysis favored efficient supply chains as higher financial performers (Reiner & Hofmann, 2006).

3.3 Supplier-customer relationship management

Since purchased components account for over 55% of the cost of goods and suppliers are responsible for over 50% of a firm's product quality problems, the relationship between the supplier and buyer is critical. Quality is the most important factor for companies in their relationship between suppliers and customers (Sila et al., 2006). Therefore, supplier and customer relationship management processes can enhance or inhibit competition. Critical processes to this relationship include communication, mutual assistance on new product development, and training. Strong relationships develop win-win relationships, trust, openness and honesty. However, this is easier said than done. As recently as the turn of the century at Whirlpool, little integration between supply chain members existed as different levels of the supply chain had different quality standards and goals (Roethlein et al., 2000). In fact, raw material providers did not understand where their products would finally end up, let alone the quality goals of members further down the chain.

Supplier certification programs incorporate quality and delivery factors into the vendor selection process, which improves quality and delivery while reducing costs. Similarly, when applied to supply chain processes, a certification process assists with supplier selection and supply base optimization, a process to find the optimal number and mix of suppliers. At Alcoa, a world leader in aluminum and related products production, a comprehensive supplier certification program jointly improves quality and reduces costs for Alcoa and their suppliers (Monczka et al., 2009). As a follow-up to supplier selection, supplier performance rating systems assist with developing a stronger linkage between supplier and buyer through developing a win-win relationship for both partners, and assist with standardizing and homogenizing quality goals throughout the supply chain. Process improvements also assist with communication improvements to communicate quality requirements with suppliers, and using performance measurement systems, supplier improvement programs can be developed.

Improvements to the supplier-customer relationship management exist in the eight key principles of Total Quality Management. To begin, communication of quality requirements from the buyer in term of final customers is critical. Supplier certification processes assist with pursuing quality at the source, while statistical quality controls can monitor and control product and process issues. Objective (measured) instead of subjective (opinion-based) facts should be shared between supply chain members. A system to monitor and correct defects throughout the supply chain, without pointing blame is imperative. Performance data should guide quality and supply chain improvements. With respect to sourcing, supply managers can use data to develop preferred supplier lists, provide feedback to current suppliers, and monitor and improve relationships, products and processes. Total Quality Management programs between suppliers and buyers should focus on prevention of defects, and product and process variance reduction through programs such as supplier certification programs. Monitoring should shift from product monitoring to process monitoring for consistency and reducing variation. A working supplier evaluation and selection system, benchmarking, reduction of duplicated processes, and knowledge transfer between functional units and across member boundaries can assist with the shift to process evaluation. ISO9000, the Malcolm Baldrige National Quality Award, and similar awards are critical factors to consider in the selection system. Another critical aspect in this relationship is developing a viable measure and understanding by supply chain members for process capability. Supplier evaluation and supply base rationalization processes can assist with improving supply chain quality throughout the system as variation between suppliers is reduced and product quality can be improved. As previously discussed, value analysis and value engineering can assist in developing a culture of continuous improvement throughout the supply chain. Similarly including - and rewarding, suppliers for participation in improvement programs can enhance the relationship and reap benefits for both members. The supplier-buyer relationship between supply chain members requires that quality start at the top. That is, it is imperative that company visions, goals and strategies be aligned for the betterment of both companies. Joint projects, shared technology, buyer-supplier councils, and collaborative relationships can enhance the relationship. The end result is a culture of continuous improvement throughout the supply chain, and as a result, a highly effective, competitive one.

In recent years, supplier-buyer linkages, whose main purpose was to procure materials, have been extended into design, information exchange, special services, distribution and marketing. Co-makership is a process whereby suppliers and buyers work to establish a strong partnership with a few suppliers based upon information sharing and trust (Flynn & Flynn, 2005). Co-makership efforts can reduce cycle time, increase inventory turnover and a higher on-time delivery rate. Co-makership encourages quality management practice utilization and supply chain improvements through supplier evaluation, supply base reduction to facilitate long-term relationships, collaboration on product design activities, and proactively managing quality and delivery of parts (Flynn & Flynn, 2005).

3.4 Summary of quality and supply chain management

A recent study highlighted the similarities and differences between supply chain and operations managers as to quality integration (Foster & Ogden, 2008). Supply chain managers emphasized using benchmarking, complaint resolution, design for the environment, Enterprise Resource Planning, supplier development, change management, focus groups and supply chain process improvement more than operations managers. While both supply chain and operations managers realize the value of ISO9000, operations managers emphasize this system slightly more than supply chain managers. Supply chain management is focused on improving future performance, while operations managers are process-oriented. Supply chain management must move beyond its transactions cost-based perspective focused on the buyer-supplier relationship. Since customers drive supply chain management and quality management, integration of quality and supply chain goals will develop a more competitive organization. Integration difficulties arise due to a lack of structure, organizational culture, reward system, and amount or lack of communication across functions (Pagell, 2004).

Our review highlights the various tools used in the key supply chain processes of design, production, delivery, support and supplier-customer relationship management, and reveals that traditional quality management practices applied to process management hold the key to addressing supply chain management issues. While in the past supply chain managers and operations managers approached quality differently, in order to be competitive, today's practices must be inter-organizational, quality and supply chain oriented. There is a need to advance current thinking from traditional firm-centric and a product-based mindset to an inter-organizational supply chain involving customers, suppliers, and partners. Therefore, quality and supply chain management need to be integrated and incorporated into managers decision-making as Supply Chain Quality Management. Supply Chain Quality Management is a systems-based approach to performance improvement that integrates supply chain partners and leverages opportunities created by upstream and downstream linkages with a focus on creating value and achieving satisfaction of intermediate and final customers (Foster, 2008; Robinson & Malhotra, 2005). We continue with a discussion of supply chain quality management.

4. Supply chain quality management

4.1 Total quality management factors & supply chain quality management

In Supply Chain Quality Management, the six Total Quality Management factors that are related to supply chain performance are leadership, strategic planning, human resources management, supplier quality management, customer focus, and process management (Azar et al., 2010).

With respect to leadership and in keeping with W. Edwards Deming, it is top management's responsibility to provide support, commitment and accept responsibility for quality. Similarly, Juran noted that top management is responsible for quality delivery, but he related its impact to the financial impact. As companies move toward supply chain quality management, leadership is essential in order to direct processes, overcome cultural issues, and manage human resources that differ between companies along the supply chain. Leadership has a critical role in Supply Chain Quality Management to guide and direct individual planning and supplier management, build supply chain linkages toward improving quality and performance, and encourage and promote supply chain quality management through collaboration, communication and integration.

Strategic planning involves developing a clear mission, long-term strategy, and long and short-term goals. With respect to supply chain quality management, top management is responsible for developing the supply chain linkages that will positively impact upon quality, and for bridging the gap between the various organizational levels with respect to their quality expectations. To improve quality and supply chain performance, strategic plans are currently focused on supplier evaluation and supply base rationalization. Supply chain partners need to jointly create missions, strategies and goals as well as share values. Perceptual differences need to be resolved to encourage a reliable, trusting supply chain network.

Organizational and cultural differences between supply chain members creates a significant challenge for achieving supply chain and quality goals. Communication, collaboration and integration must be effectively addressed through human resource management. Within supply chain quality management, human resource management focuses on using quality tools and techniques by cross-functional teams, such as quality and sourcing teams. Best supply chain quality management practices indicate a cooperative culture between buyers and suppliers, close internal communication, and teamwork are essential. Training and empowerment programs are likely to increase in importance in the future. Employee training programs focused on customers, while not directly improving customer service measures, will have a positive impact through the indirect relationship with employee relations. Effective people skills are a necessity to manage relationships and partnerships in supply chain quality management.

The current trend with respect to supplier quality management is a supplier selection and evaluation process that encourages long-term relations with a few qualified suppliers capable of achieving necessary quality requirements (Monczka et al., 2009). Through performance reviews which include relevant quality measures, buyers should provide suppliers any necessary education and technical assistance. Best practices in supply chain quality management includes Strategic Supply Management which entails quality management, encourages continuous improvement throughout the supply chain, and includes suppliers in new product development and process development (Azar et al, 2010). Through Strategic Supply Management, suppliers assist in providing low defect levels in incoming materials, and as we noted earlier, this improves downstream quality and positively affects inventory management as safety and pipeline inventories are reduced, and in turn, positively impacts upon supply chain costs and cycle times. Strategic Supply Management can be seen as a simultaneous, bilateral effort between buyer and supplier firms to improve procurement, supply, and distribution processes. Strategic Supply Management initiatives that positively impact upon quality and performance include:

- Reducing supply bases and establishing closer relationships with their suppliers,
- Buyers working closely with suppliers and potentially launching joint strategic projects,
- Earlier supplier involvement and joint problem-solving efforts, leading to the early discovery of quality problems,
- Inter-firm production scheduling breaks down barriers between organizations, resulting in shorter production runs, and
- Developing a favorable quality culture based upon top-management commitment to improving beyond organizational boundaries.

Customer focus represents a commitment to customers through performance evaluation that includes customer satisfaction and customer involvement in design and feedback processes. Product design quality is significantly impacted upon by the positive or negative relationship between buyers and suppliers. Companies that focus on ensuring quality and building close supplier relationships while integrating key suppliers into product and service design will be extremely competitive in the marketplace (Azar et al., 2010).

Process management can be enhanced through incorporating sound quality management practices, such as statistical process control, fool-proofing process design, empowering employees with quality and process training, and sound product designs focused on the customer, and a collaborative design process. Best supply chain quality management practices encourage establishing an effective data collection system for customer feedback and requirements in order to improve product and service design, process management, and performance. Suppliers with effective, operating quality control systems will be positive partners in collaborative new product development efforts.

Best practices in product and process design in supply chain quality management can be found through incorporating Design for Manufacturing, concurrent engineering, Quality Function Deployment, and value engineering, and include:

- Translating customer requirements into product and service design requirements early, linking design and production, and taking supplier capabilities into account.
- Building quality into products and services through using appropriate engineering and quantitative tools during new product development across company boundaries.

- Cross-functional communication across company boundaries, reducing new product development time and using practices to "design it right the first time".
- Building trust between supply chain members so that customer requirements can be designed into the product and associated service.
- Linking design and production across company boundaries by incorporating supplier capabilities into design parameters.

Several issues during design for companies to address include how to build trust, how to improve communication, how to share hidden costs associated with concurrent engineering, how to share new technologies that are mutually developed, material and component issues, whether to utilize suppliers further up the supply chain in new product development, and product complexity issues. Quality tools and techniques can assist managers in answering these questions.

To improve production, delivery and support processes, a supply chain should build upon the basic business best practices by:

- Documenting, managing and controlling value-added production, delivery and support processes within and across the supply chain.
- Using systematic methods to identify significant variations in process performance and output quality, determining root causes, taking corrective actions and verifying results with a focus on the final customer.
- Continuously improving processes to achieve improved cycle times, better quality, and overall operational performance for all supply chain members.
- Innovating to achieve breakthrough performance for the entire supply chain system.

Quality management practices, such as Six Sigma, performance measurement, Kaizen, benchmarking, value stream mapping, value analysis, and re-engineering have proven and will continue to prove to be beneficial to achieving these best practices during production, delivery and support. Specific supply chain management issues with extending the basic best practices include developing a joint total costing approach, sharing data – specifically costs and potentially proprietary information, developing mutually beneficial methods, and developing logistics and inventory management systems beneficial to all members. Again, traditional quality tools can assist managers with these issues.

Issues surrounding building trust, defining performance measures, and developing a system that is mutually beneficial, highlight the difficulties faced in supplier-customer relationship management. Quality techniques such as supplier certification systems, training, and communication top the list on ways to improve this process. These systems take advantage of traditional quality management techniques to manage and lead teams and people. The best practice for a supply chain merely involves extending a company's best practice to include all upstream and downstream partners, as in:

- Defining, monitoring and controlling supplier performance requirements while developing partnering relationships within the entire supply chain from raw materials through the final customer.

Perhaps, this is the most difficult best practice to achieve as people relationships, particularly across company and cultural boundaries, are the most difficult to manage. Various issues on how to develop mutually beneficial work practices, quality practices, and performance across different global supply chain cultures and technology levels, and what organizational structures should be used, exist. Again, quality management practices offer methods to develop solutions.

4.2 Relationships between total quality management factors in supply chain management

Since Supply Chain Quality Management requires the six Total Quality Management factors (leadership, strategic planning, human resource management, supplier quality management, customer focus, and process management). We continue with a discussion of the relationships between each of these factors (Foster, Walin & Ogden, 2011; Kaynak & Hartley, 2008; Kuei et al., 2008; Yeung, 2008). Leadership has a direct impact upon Supply Chain Quality Management through human resource management, strategic planning, customer focus, and supplier quality management, which in turn each impact upon process management, and ultimately, supply chain performance. Additionally, strategic planning has a direct impact upon human resource and customer focus.

Leadership is a critical component of Supply Chain Quality Management as top management directs and manages the resources of a supply chain. With this in mind, leadership directly impacts upon the cultural, process management, supply management, and human resources management issues within the supply chain. In developing competitive supply chains, it is imperative that management integrate quality processes with suppliers and customers to enhance the product's quality performance. Top management support of quality improvements in the organization extend to strategic integration with suppliers as over 50% of a company's quality problems can be attributed to suppliers. Therefore, top management strongly supports quality initiatives with suppliers through teamwork, close internal communication, and developing a cooperative culture that fosters trust and collaboration. Interestingly, these same strategic views are not always shared by middle managers, and many companies fail to address the gap that exists between top and middle management with regard to supplier-buyer integration. Interestingly, supply chain and operations managers approach quality from different perspectives as supply chain managers approach it from a supplier-buyer perspective, which promotes collaboration, supplier development and complaint resolution, while operations managers focus on processes and procedures. With respect to quality initiatives, both types of managers use data analysis, job training, project management, surveys and customer relationship management to foster continuous improvement.

Continuing our discussion of the relationships between the six Total Quality Management factors within Supply Chain Management, human resource management requires a different skill set to manage the supplier-buyer relationship than in the past. Today's strategic sourcing managers need relevant training and empowerment to develop strategic relationships with key supply chain partners. However, top management needs to realize that while training does not directly impact upon a company's customer focus, there is an indirect and valuable experience between training and customer focus through improved employee relations. Clearly, effective people management practices and skills are a critical supply chain management practices as relationships and partnerships must be effectively managed. Quality intensive firms assist in supplier-buyer relationships as teamwork, communication and a cooperative culture is advocated, which also supports trust and collaboration between two companies. A quality focus by both buyers and suppliers also demonstrates a common shared value system that resonates throughout the supply chain and enables value-added products and services to be distributed to the final customer.

With the average manufacturing firm spending more than half of its sales dollars on purchased components and services, it is easy to see why supplier management is critical to developing competitive supply chains. Top and middle managers consider supplier-buyer quality as the number one issue to focus on in improving quality. Supplier quality management has a direct and positive relationship with product and service design, inventory management, process management and performance throughout the supply chain. These relationships support the concept that quality management practices are interdependent in the supply chain and the need to analyze quality improvements through a systems approach. Strategic supply management efforts, such as creating long-term buyer-supplier relationships, reduction of the supply base, formal supplier measurement systems, and strategic supply management integration, have a direct, significant impact upon time-based and cost-related operational efficiency of a supply chain. Time-based improvements in delivery speed, reliability and inventory turnover, and reduction of production cycle time, and cost-related improvement through total and unit cost reduction, and ease of modification to engineering changes, can be attributed to strategic supply management. In turn, time-based and cost-related improvements impact upon on-time shipments and cost of quality, which then leads to improvement in customer satisfaction as customer complaints are reduced, product reliability and customer relations improve. Ultimately, these efforts result in superior supply chain performance as market share, sales volume and profitability increase. Strategic supply management efforts are not constrained by the industry, type of processes, firms size, or markets, and should be pursued through each linkage in a supply chain.

Through involvement in product and service design, suppliers can more effectively meet the buyer's requirements, and therefore, positively impact upon quality. The supplier-buyer relationship impacts upon product design quality as the buyer must balance supplier development to ensure quality with building closer relationships and integration efforts. Failure to balance these efforts may lead to poor quality components or future quality issues between the members. There is a positive relationship between a supplier's quality system and the level of supplier involvement in product design as suppliers with effective quality control systems are more likely to be constructive partners in new product development efforts and less likely to be a hindrance. Positive supplier involvement in new product development is also related to project team effectiveness, and therefore, human resource issues between members.

Firms with comprehensive and operating quality management system have a culture of continuous improvement engrained in them. Therefore, supply chain members will find that companies with operating quality management systems more readily adapt to supply chain integration. Therefore, to create competitive supply chains, it is in the purchasing functions best interests to seek relationships with companies that have operating, quality management systems - even if slightly different approaches to quality management exist. In general, quality management systems represent a comprehensive effort to continuously improve - and adapt to changing conditions.

In competitive supply chains, inventory is exchanged for information as the ease of information exchange facilitates flexibility and responsiveness, reduces costs and improves quality throughout the supply chain. Therefore, an effective information system and associated processes to gather and distribute information forward - and backward, in a supply chain is a requirement. Information accuracy is critical to improving product and service design, processes and supply chain performance. Due to different cultures, organizational structures, information systems, and personnel, a 'one-size' fits all strategic approach will not be appropriate to manage the relationships, transition and information requirements with all suppliers and buyers in a supply chain.

4.3 Transition to supply chain quality management

Today, organizations need to transition from the traditional supply chain model where quality is built through quality in purchasing and processes through a paradigm shift to an integrative, competent supply chain quality management model that leads through design and management of an innovative, quality supply chain. This process requires managers to navigate four distinctive stages to eliminate gaps: 1) emphasis on supply chain strengths by all members; 2) critical success factors need to be identified to develop competencies; 3) emphasis by members on infrastructure and supply chain climate; and 4) continuous improvement through supply chain quality practices (Kuei et al., 2008). To bridge these gaps, four drivers of supply chain quality are identified: supply chain competence, critical success factors, strategic components, and supply chain quality practices (Kuei et al., 2008). Supply chain competence, which is the collective learning of all supply chain members, is represented by organizational, managerial, technical and strategic capabilities and skills within or across the supply chain over time. Supply chain competence is the knowledge that allows the supply chain to compete and competitors have difficulty emulating. Dimensions to competence include product quality, delivery reliability, supplier/buyer trust, operational efficiency, and delivering value/innovation to the customer. Critical success factors include the ability of a supply chain to respond to different customer requirements through a customer focus, supplier relationships, quality of information technology systems, externally focused process integration, and supply chain quality leadership. Supply chain quality management should focus on the elements of quality management, culture, technology management, supplier participation, supply chain configuration design and strategic planning, into the core strategic processes of manufacturing, product development, technology management, international sourcing and customer engagement. Supply chain quality practices, such as supplier-buyer quality meetings, quality data and reporting, supply chain quality office, and supply chain optimization and policy deployment, promote a customer-focused supply chain that achieves supply chain deliverables.

Best practice recommendations to assist with the transition include the following (Kuei et al., 2008):

- Identifying areas of potential joint cooperation between supply chain members with a focus on delivering value and innovation to the end customer.
- Training for all supply chain members in supply chain quality management.
- Developing an ongoing, learning culture.
- Developing a collaborative information system to manage and monitor supply chain processes.
- Utilizing innovative technologies.
- Developing supply chain relationship characterized by trust, flexibility, communication and cooperation through quality management, cultural management, technology management, supplier participation, supply chain design and strategic planning.
- Regular, planned supplier-buyer meetings to review material flows, current and future product development, and supplier performance on quality, cost, and time.
- Developing a supplier quality measurement and evaluation process.

The ultimate goal of these efforts is to create and sustain supply chain quality and excellence through effective utilization of human, physical and intangible resources.

5. Conclusion

This chapter has highlighted four key points:

1. Quality management and supply chain management are positively related.
2. Embedded within this relationship is a process management perspective.
3. Best practices in supply chain quality management can be found within the principles of Total Quality Management.
4. The transition to supply chain quality management requires knowledge in all three areas: processes, quality and supply chain management.

Since the quality movement began, improvements in one area enhance results in the other as quality management and supply chain management are clearly interdependent. Continuous quality improvements impact positively upon inventory levels, product and process variation, cycle times, responsiveness, flexibility, and ultimately, final customer satisfaction. As a result, quality management and supply chain management should be pursued simultaneously as a 'complete' integrated system. Clearly managers realize this relationship exists as we cited several examples of quality tools and techniques impacting upon supply chain processes. Specifically, in the design process, positive results occur through using concurrent engineering, design for manufacturability, value engineering, quality function deployment, and supplier-customer integration. Production, delivery and support processes can be improved through using surveys, six sigma programs, value analysis, value engineering, and benchmarking. Since components account for over 55% of the cost of goods, supplier-customer relationships are critical to providing the right good, in the right quantity, at the right price, at the right place, at the right time to the customer. Incorporating supplier certification programs, and in particular, the eight key principles of Total Quality Management, into these relationships can reap tremendous rewards for all members. Of course, critical to this relationship development is the underlying trust and information sharing that occurs through co-makership. Hence, current managerial thinking needs to shift from traditional firm-centric and product-based mindset to an inter-organizational supply chain system. Supply chain quality management, which is strategic, tactical and operational approach, is required to bring about this change to an inter-organizational process that involves customers, suppliers and partners, and effectively compete in today's business environment. The key Total Quality Management practices in leadership, strategic planning, human resources management, supplier quality management, customer focus and process management are the foundation for supply chain quality management best practices. The transition to supply chain quality management will require a cultural change which will not happen overnight. It requires long-term thinking, evaluation of each member's strengths and weaknesses, improvements in communication and transportation infrastructures, and a culture of continuous improvement. In the future, companies that will excel in the global marketplace will incorporate supply chain quality management to bridge the gaps that exist in design, production, delivery, support, and supplier-customer relationship processes.

6. References

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4

Collaborative Quality Management

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1. Introduction

The challenges within the new business dynamics put higher expectations on visibility, velocity, accessibility and connectivity on supply chain partners (Akyuz & Gürsoy, 2010; Zsidisin & Ritchie, 2009). Nowadays, business organizations are facing with a global economic environment in which quick responses should be made to rapidly- changing customer requirements and the market environment (Yan et al., 2010, p.319), with an increasing levels of technological innovation and shrinkage of buying points in many markets (Williams et al., 2006, p.1273). Such a need for flexibility has brought together independent enterprises and increased the importance of supply chains to provide products or services in a more effective and flexible manner. Since these enterprises originate from various geographical locations, belonging to organizations with different interests, the coordination and integration of business processes involving all these independent enterprises becomes increasingly crucial to improve product and service quality to satisfy customers (Yan et al., 2010).

As competition moves beyond a single firm to the supply chain, QM (Quality Management) in the context of supply chain has started to attract more and more attention from researchers. As the focus is shifting from internal practices to the integration and assurance of processes spanning customers and suppliers, the integration of QM and supply chain topics has received additional importance for future competitiveness (Flynn & Flynn, 2005; Foster & Ogden, 2008; Kaynak & Hartley, 2008; Matthews, 2006; Robinson & Malhotra, 2005; Soltani et al., 2011). In this respect, the need for closer cooperation both internally (between functions) and externally (among partners), as well as new longer-term relationships have been considered as the key features in modern quality management by Williams et al., (2006).

Many literature items highlighted by Kuei et al., (2008) indicate that quality management practices are closely associated with improvements in supply chain performance as well as cumulative capabilities. Also, Flynn & Flynn (2005) have empirically supported the need for integration of quality management practices with supply chain management and emphasised that organizations pursuing quality and supply chain goals simultaneously can achieve a competitive advantage that is difficult to imitate by other enterprises. They have provided clear support for the idea that organizations with stronger quality management practices achieve better supply chain performance. Kaynak & Hartley (2008) also provide empirical support for the relationships among QM practices and performance measures, basing their premises on the confirmed relationships by Kaynak (2003) among the following constructs:

- Supplier quality management
- Process management
- Quality performance
- Quality data and reporting
- Financial and market performance
- Management leadership
- Employee relations
- Training
- Product service design
- Inventory management performance

As the idea of "enterprise" evolves into the idea of "extended enterprise", traditional improvements within the enterprise proved to be insufficient in meet the challenges of the new era (Shao et al., 2006). In this context, information-sharing on product and processes quality within the supply chain framework is becoming a critical factor for quality improvement and competitiveness. In their review of literature for quality management and SCM, Robinson & Malhotra (2005) clearly argue that quality practice should advance from traditional firm-centric, product-based mindset to an inter-organisational supply chain orientation involving customers, suppliers and other partners, while considering internal QM implementation as the prerequisite to supply chain quality. According to Yan et al., (2010, p.319) "satisfying customers can only take place when product quality, service and value are coupled at every node in the supply chain" and "quality management functions and activities should be taken beyond enterprise boundaries" . Similar ideas have also been mentioned by Flynn & Flynn (2005); Lee et al., (2006); and Wiliams et al., (2006); clearly indicating that the new concept of quality needs to be broad, supply-centric and encompassing.

In line with these ideas, Rodrigues (2007) has developed the "quality organisation" framework and defined the "interdependant" behaviours of a quality organisation having the following main characteristics:

- responds to customer needs
- continually gathers and disseminates information
- cooperates and collaborates with internal and external units
- utilises participation, empowerment and a flat organisational structure
- implements on-going training and development

This definition also adds emphasis on the need for and the importance of dependancy, cooperation, collaboration and commitment among partners, and as such it is totally compatible with the "extended" view of the enterprise.

All of the forementioned arguments showed a need for new approaches and tools for quality management of today and of the future (Shao et al., 2006). Compounded with all the opportunities offered by the advances in IT and the increasing importance of the concepts of visibility and connectivity, the idea of "collaborative quality management" has been proposed in the literature as an extension of former philosophies of quality (Shao et al., 2006). Table 1 provided below is a clear depiction of this historical evolution in quality concepts on the way to collaborative quality management.

According to the table, four distinct stages stand out along this historical development. The first stage is characterised by a totally inspection-oriented approach with a focus on the production line. The second stage has a facility focus, with the use of Statistical Quality

Stage	Date	Scope	Focus	Main tools
Quality inspection	Before 1920' s	Product line	Inspection	Measuring devices
Statistical Quality control	1930-1960' s	Facility	Prevention	Control charts, Ishikawa diagram, pareto analysis
Total Quality Management	1970-1990' s	Enterprise	Customer focus, Design for quality, Process control	Doe (Design of Experiments), QFD(Quality Function Deployment), ISO 9000, Six Sigma
Collaborative Quality Management	2000's-future	Global	Process cooperation, Systems Integration, Product lifecycle Management	The Internet, Information Technologies, Enterprise Application Systems

Table 1. Evolution of Collaborative Quality Management (Based on Shao et al., 2006)

Control techniques as its main characteristic. Enterprise-wide, systemic coverage of all the processes, customer-focus and the transition from "control" to "assurance" take place at stage three. Along with the ideas of "design for quality" and "excellence", use of the tools "DOE (Design of Experiments)", "QFD (Quality Function Deployment", "Six Sigma" and "Enterprise-wide Quality Management Systems (ISO 9000), correspond to this stage.

Globalisation, advances in IT and increased importance of process oriented, supply chain-centric approach bring us to the era of "collaborative quality management". Shao et al. (2006) emphasise the following in this regard:

- The need for coordinating the activities of quality management to deal with quality problems in real- time.
- The need for integrating the QM into business processess involving all supply chain partners to measure, analyse and continually improve products, services and processes to achieve the satisfaction of both internal and external customers.

Recently, Unherkal et al., (2010) have provided clear definitions for three significant quality dimensions required in collaborative quality management systems: the management, the assurance and the control aspects of quality. The main characteristics of each dimension are described below:

- Quality Management (QM) provides the strategic basis for quality for the transition towards a collaborative business, starting from the planning stages of the overall transition, and involving both the technical and managerial aspects of quality.
- Quality assurance (QA) specifically focuses on collaborative processes, their modeling, the quality of the models themselves, and ensuring error-prevention from a technical viewpoint.
- Quality control (QC) deals with the functions of actual data gathering and controlling, as well as the testing of the collaborative system, and as such it becomes both operational and tactical in nature.

Shao et al., (2006) also emphasise that partners can collaborate throughout all the quality management processes, including quality control, assurance, improvement and auditting. This broad understanding covers collaboration at transactional (operational), tactical and strategic levels, including continuous, systemic, joint monitoring of the systems of supply chain partners to achieve overall improvements.

In line with this, Section 2 discusses the efforts to change towards such a collaborative quality management system, covering the existing efforts from both Quality Management and Supply Chain perspectives. Section 3 focuses on more recent efforts in developing new collaborative quality models.

2. Inadequacies of the existing approaches and efforts to change

There have been many discussions upto now as to the pitfalls and shortcomings of the available models.

Since the end of 1980s, the ISO 9000 norms have been increasingly recognised and accepted as a reference model for quality assurance (Romano 2002, p.981), being a systematic and process driven approach to quality assurance. However, there have been various critisisms in the related literature regarding the ISO 9000 standards, the most important ones of which are the perceived weakness in its ability to deliver real benefits, continued overemphasis on bureaucratic processes and documentation, as well as misapplications (Sroufe & Curkovic, 2008). The literature also contains evidence supporting that no direct positive performance improvement can obtained by ISO registration as quoted by Sroufe & Curkovic (2008, p.507) based on Johnson (2002) and Terziovsky et al., (2007). It is even argued that "ISO by itself does not provide competitive advantage" (Sroufe & Curkovic, 2008, p.517).

The ISO systems are also critisised for not being supply-chain centric. ISO 9000:2000 revision definitely puts more emphasis on business results, customer relationship management, customer satisfaction, and long-term, mutually-beneficial supplier relationships, indicating efforts to look beyond the enterprise. However, it has been observed that most work on the ISO 9000 found throughout the literature are mainly centered around individual conpanies. Some of these works considered either the upstream side of the supply chain (supplier network) or the downstream one (demand network), while no study has been found concerning the impact of ISO 9000 on the supply chain as a whole (Romano, 2002). The idea of merging the views of upstream and downstream processes is also mentioned in Foster (2008). Soltani et al., (2011) have mentioned the qualitative investigations of the dynamics of supply chain quality management interventions to be rare, as well.

In this line of direction, Romano (2002) made an effort to analyse the impact of ISO 9000 adopting a supply chain perspective, clearly emphasising that there does not emerge any general agreement in the literature concerning the impact of ISO 9000 certification on the supply chain as a whole. The proposed framework of research takes into account the internal quality systems of the focal firms, suppliers and customers, as well as the relationship among these quality systems. This framework also ties up the quality systems of these different partners to the quality, cost, time, and volume flexibility performances of the focal firm.

Naturally, the need for the extension of current reference models to provide a supply-centric, broader and results-oriented view becomes evident. Nevertheless, it appears that efforts to integrate quality systems and supply chain are not yet complete.

Various quality excellence models, as well as performance measurement systems and quality award criteria are also critisised in the literature as "not being chain centric".

Current excellence models definitely attach special importance to result orientation, customer focus, and partnership development. However, they tend to regard the inter-company interactions to be still at partnership level, and not yet at a level of web-based, full process collaboration among supply chain partners.

Kanji & Wong (1999) and Kanji (2001) have already supported this idea, highlighting the need for the creation of a "cooperative quality culture", "managing all processes other than logistics","leadership" and "continunuous improvement" across the whole supply chain. In this direction, an "extended quality excellence model" for supply chain management is proposed, complying with the extended enterprise concept. Kanji's model is similar to EFQM (European Foundation for Quality Management) and emphasises the need for "extended TQM (Total Qality Management)".

Building upon on Kanji's Excellence Model, Wong (2003) developed a supply chain management excellence model, in which the concept of excellence is treated along the supply chain, and special importance is attached to the cooperative relationships. The ideas of customer focus, management by fact, continuous improvement and excellence are all treated across the supply chain partners, not merely for a single enterprise. The diagram provided in Figure 1 combines the ideas proposed by Kanji & Wong (1999), Kanji (2001) and Wong (2003):

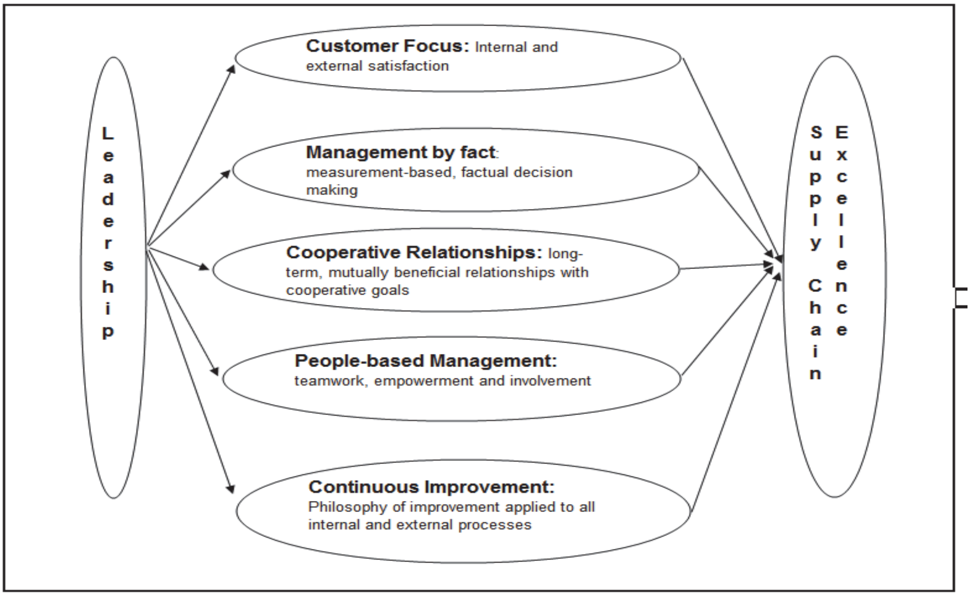

Fig. 1. Supply Chain Excellence Model, based on (Kanji & Wong 1999), Kanji(2001) and Wong (2003)

In line with these ideas, Lee et al., (2006) also highlight the need for modernisation and changes in quality award criteria towards a more holistic and knowledge management-oriented perspective. It should be noted here that this critisism is despite the fact that ISO 9000:2000 revision incorporated several principles underlying the Malcolm Balridge National Quality Award criteria into the standard.

Dror (2008) compares the BSC (Balanced Scorecard approach) against the existing quality award models, MBNQA (Malcolm Balridge National Quality award) and EFQM (European Foundation for Quality Management) based on high-level objectives, long-term programs, processes, targets and performance measures and feedback. The differences and limitations among these three models in Dror (2008)'s work are addressed in detail, and a fundamental difference among these structures is emphasised to be: "while the Balanced Scorecard, although implying a causal system hierarchy, is solely performance-oriented, MBNQA and EFQM emphasise cultural changes in the management of an enterprise (new leadership as a driver), using input variables in terms of system constructs and output variables in terms of operational and business results" (Dror 2008, p.592). Of the three frameworks, the Balanced Scorecard has been pointed out to have important advantages, such as having sequential objectives, the ability to support long-term programs, the potential to select relevant performance measures based on real data, and two feedback levels. Nevertheless, some essential limitations of the Balanced Scorecard have also been referred to, such as focusing on learning as the only source for causality, lack of basic guidelines for selecting performance measures, having no method for setting targets to measures, complexity of feedback from the financial perspective to the customer and the internal processes perspectives, and having no consideration of the time lag between the causes and their effects (Dror 2008, p.592). The difficulties and limitations of the Balanced Scored approach are also mentioned by Berry et al., (2009) and Bhagwat & Sharma (2007) as follows:

- failure to include specific long-term objectives
- failure to relate key measures to performance drivers by means of cause-and effect relationships
- failure to communicate the contents of, and the rationale for, the balanced SCM scorecard
- inaccurate and subjective measures
- lack of participation
- lack of attention to informal controls and organisational context

As such, Balanced Scorecard approach has its own significant limitations, making it difficult to become the foundation for performance measurement and quality excellence.

It is evident from the discussion thus far that currently-proven quality assurance systems, excellence models and award criteria fundamentally suffer from focusing on the enterprise but not the whole supply chain, and not having a holistic, collaboration-centric orientation. Therefore, it is evident that there is a need for change in the quality domain, appearing as extensions, modifications and modernisation efforts for the current assurance and quality excellence ideas, as well as the awarding criteria. For this reason, ideas like extended TQM and modified awards criteria have been in the spotlight for a while.

Additionally, critisism has been put forward towards major supply chain collaboration models, frameworks and initiatives in various aspects. Initial approaches - such as QR (quick response), ECR (efficient consumer response), CRP (continuous replenishment policy), and VMI (vendor-managed inventory) - which lead to CPFR (collaborative planning, forecasting and replenishment) appear as too much material management and logistics oriented (Akyuz& Gürsoy, 2010). CPFR model by Voluntary Interindustry Commerce Solutions (www.vics.org) contains the concept of collaborative exception management, yet it still does not possess the Quality orientation. The major supply chain framework SCOR (Supply Chain Operations Reference Model by Supply Chain Council (www.supply-chain.org), which provides a strong structural foundation for supply chain standardization, communication and collaboration has its drawbacks too. Although it integrates BPR (business process re-engineering), performance measurement and logistics, it has been criticized due to the following aspects, as pointed out by Akyuz & Gürsoy (2010) and Wang et al., (2010):

- it is silent in the areas of human resources, training, and quality assurance
- it has proved to be impractical as a benchmarking tool and in handling the intangible problems such as cultural conflicts
- it is limited to the representation of one single supply chain, and as such cannot handle multiple channels
- order modification, activities of the collaborative design and CRM are not addressed.

Henceforth, major approaches and initiatives from the supply chain domain appear to be lacking the quality assurance and excellence focus.

None of these efforts- neither from the Quality Management nor the Supply Chain Management points of view- appear to provide a coherent and complete collaborative quality management model with an extended, collaborative focus that allows the supply chain partners in different locations to collectively work on quality tasks at all levels via the Internet. Such a model definitely requires the use of state-of-the-art IT architecture and capabilities to overcome the problems of information islands and to provide application integration among supply chain partners, enabling collaboration and joint quality assurance. This leads one to various more recent efforts of collaborative quality model development seen in the literature, which is to be discussed in the upcoming section.

3. Further efforts to develop new collaborative quality models

This section will discuss more recent efforts in the literature to define and develop a supply-centric, collaborative quality platform utilising the current IT technologies.

The conceptual model suggested by Shao et al., (2006) emphasises that partners can collaborate throughout all quality management activities, utilising a web-based, centralised database to provide the backbone and consistency for information- sharing along the entire product lifecycle. The process model developed on top of this conceptual model is supported by a layered, web services-based architecture centered around ERP (Enterprise Resources Planning), CRM (Custumer Relationship Management) and SRM (Supplier Relationship Management) databases. The model also utilises the multi-agent technology, whose main structure is based on 4 main types of collaboration as provided below:

- Quality System Collaboration
- Supplier Collaboration
- Manufacturing Collaboration
- Service Collaboration

The model treats quality functions along the dimensions that cover:

- Quality auditting
- Quality improvement
- Quality assurance
- Quality control

Systemic functions deal with quality system maintenance, quality data reporting, quality planning, quality cost control, continuous improvement and customer satisfaction. Customer-centric functions such as customer service management, after-sales management, and supplier-centric functions such as supplier evaluation and selection, are also included in this model.

This approach is in total compliance with the following notions:

- The critical role of a fully integrated enterprise information system, enabling real time data exchange, synchronisation, visibility and sophisticated level of information integration. This idea is fully supported by numerous literature items with regards to ERP, IT-supply chain interaction and enterprise application integration. It is also fully in line with the extended enterprise view, using internal integrity and ERP implementations as the backbone and proceeding with add-ons like CRM and SRM (Akyuz and Rehan, 2009; Xu, 2011).
- The relevance and importance of the use of Web Services and Service Oriented Architectures (SOA) within the supply chain domain, as the most prominent technological enabler of platform-independant, seamless integration of different partner's heterogeneous databases (Rehan & Akyuz, 2010; Xu, 2011). SOA provides an opportunity to architect new processes enabling multi- organizational collaboration providing platform-independance and web-based integrity (Akyuz, 2008; Rehan & Akyuz, 2010; Unherkal et al., 2010).

Another more recent collaborative model proposed by Guo et al., (2010) defines the collaborative environment as "the quality chain" and use three layers as basic, technical, and operating environment, highlighting the need for the integration of information, standards and organisation with business requirements, society and culture. Based on this definition, they proceed to develop a multi-dimensional collaborative quality control model for a manufacturing environment with the following characteristics:

- Process quality control in the product lifecycle
- Network organisation management with quality collaboration orientation
- Quality information integration and implementation platform.

An internal quality information integration model is suggested on top of this structure, defining the subsystems and the critical data and information. Note that this model involves integration at every step of the operation, again taking ERP systems as the core and providing the integrity for the following items:

- Design information via CAD/CAPP (Computer aided design/Computer Aided Production Planning) and PDM(Product Data Management) modules
- Production planning and control related information via ERP/MRPII
- Manufacturing and shop floor integrity using MES (Manufacturing Execution Systems)
- Quality-related data from IQS (Internal Quality System)
- Project consolidation and project management-related data and information from the PM (project management) system
- Finance and cost-related information from FM (Finance Management) system
- External customer-related information via CRM.

In this model, the quality-related data, information and knowledge are exchanged to support the needs at operational, tactical and strategic levels. On top of integrity at the master data level (such as drawings and bills of material), the flow of critical information at planning and reporting level (such as market development plans, production plans and schedules, quality plans and financial plans) are exchanged. Also established at this stage are the necessary monitoring and feedback mechanisms. With all these features, the model serves the needs for control, management and assurance dimensions of quality. Once again, ERP integrity stands out as the backbone of the platform, with clear definitions for critical data and information flows.

Ho et al., (2009) suggest a co-operative distributed process mining system for quality assurance, highlighting the role and importance of distributed mining as a critical element in the structure. They put forward an XML- based (Extended Mark-up Language) structure including a PME (process mining engine) and a dynamic rule refinement engine. The framework for PME consists of:

- a measurement module, having the practicality of the OLAP (on-line analytical processing) approach,
- a prediction module to perform proactive quality-related predictions based on real-time data utilising a trained artificial neural network, and
- an improvement module, having a knowledge base for business rules.

This structure is consistent with the business intelligence and data warehousing approaches used in a majority of the ERP platforms, utilising ERP as the single-version-of-truth. Together with the use of OLAP, this structure goes further by enabling prediction and improvement capabilities.

It should be noted here that the recently developed models discussed in this section are quality collaboration platforms focusing on the technological viewpoints, basing on the idea of enterprise application integrity and utilising solid ERP foundations and modular, Web-based layered stuctures. However, these representations still lack the business process reengineering and workflow management viewpoints, and do not contain generic process definitions or clear workflows. Alignment of intra- and inter-company processes and workflows with the underlying technological infrastructure is also essential in establishing collaborating business processes. It should also be noted that the ideas of company culture, benchmarking, excellence and awards- concepts that are essential in quality- do not appear to receive the required attension in this group of models.

4. Discussion

In the light of all the inadequecies addressed in section two, the modernisation and extension efforts of total quality management, assurance, excellence and awarding ideas from the Quality domain do not seem to meet the needs of the new supply chain era, even though these efforts did broaden the perspectives on the topic and highlight the importance of supply chain quality. Also, major initiatives and collaborative models from the Supply Chain domain (such as CPFR and SCOR) do not seem to cover the quality management dimension, due to their focus on material management and logistics orientation. Current performance measurement approaches, such as the Balanced Scorecard have been proven to possess their own deficiencies as well, to meet the needs for today's supply chain performance management.

More recent efforts discussed in section three highlight the importance of structural foundation, web services and the layered structures, yet they still lack the ideas of quality excellence and quality systems documentation management. Therefore, it appears that current literature is still in need of further integration of the ideas of collaboration, quality assurance, supply chain, quality system documentation, quality awards&excellence and supply chain performance measurement using a sound infrastructure based on current IT technologies to obtain a coherent, supply-centric, performance- and excellence-oriented collaborative quality model.

In this study, it became evident that such a collaborative quality model should meet the needs of both control, assurance and management aspects of quality. Although these aspects have been defined clearly, there does not seem to be comprehensive, generic process definitions as well as data, information and knowledge requirements to be shared along these dimensions.

The need for and the importance of a sound, jointly used document and knowledge management system appears to be neglected. Similar critisism can also be raised for the human-related, soft aspects, which are always indispensible to quality and collaboration. These soft aspects (such as culture, mutual trust and organisation behaviour) do not appear to receive the attention they have deserved.

In the light of all these ideas, the following can be regarded as the characteristics for an integrative, collaborative quality management model:

- A strong architectural foundation of the partners, with an integrity beyond standard ERP functionality, to cover design, MES, CRM and SRM modules, on top of which quality-related data and information flows can be established.
- Support for operational, tactical and strategic time frames as well as control, assurance and management dimensions of quality.
- Support for collaborative business reengineering tools, allowing continuous improvement, alignment and restructuring among partners' business processes and workflows.
- Critical use of the IT technologies (the Internet, Web services, SOA and mobile services) to assure enterprise application integration among partners.
- Managerial decision support, requiring various data mining, data warehousing and business intelligence techniques layered on top of the integrated systems architecture, aimed at joint managerial decision making and continuous improvement among partners. This also covers the inclusion of predictive and adoptive abilities into the system, requiring the integration of additional tools and techniques, such as artificial intelligence and neural networks.
- Support for a document and knowledge management system to satisfy the requirements regarding the system documentation of multiple quality management systems. This support should naturally handle the requirements such as process documentation, document control and archiving the quality records for multiple quality systems.
- Support for performance measurement and benchmarking among partners. This requires the integration of current the supply chain performance measurement efforts with the literature on quality excellence, including the development of joint measurement & evaluation processes and development of an extended set of metrics. This would serve for the concerns of supply chain performance measurement literature- as highlighted and comprehensively discussed by Akyuz & Erkan (2010) and the need to modernise the quality excellence criteria in a supply-centric manner simultaneously.

5. Conclusion

This study intended to provide a broad view on collaborative quality management.

Starting with the changing business pressures and environments, the evolutionary path of Quality Management is discussed in detail. From historical perspective, this evolutionary path indicated a clear transition from an inspection-orientation approach to a collaborative quality management, and definitely revealed the need for a supply centric viewpoint.

In this perspective, inadequecies of the current approaches from both quality management and supply chain domains are addressed. Extension and modernisation efforts witnessed in the quality management domain, as well as the deficiencies and drawbacks of the major approaches from the supply chain domain are discussed in detail, emphasising the need for a supply-centric, collaboration oriented quality understanding. More recent efforts for collaborative quality modelling towards this end highlighted the importance of web-based architectures and strong information system backbones.

In the light of the commonalities and common characteristics observed, a set of requirements for a collaborative, web-enabled, supply-centric quality management model has been gathered.

This study clearly reveals that modelling efforts to obtain a supply-centric, collaboration-oriented quality management model are still in progress. Multi-dimensional nature of the problem is already evident, involving both hard and soft aspects, together with a complex set of requirements. The need for further integration of the supply chain and quality management domains is also evident. In this regard, the current literature does not seem to provide a totally comprehensive model as yet. Therefore, collaborative quality management still appears as a promising area of research in terms of the following:

- Conceptual model development
- Identification and standardisation of extended processes & information flows
- Development of joint "quality excellence" metrics

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5

Supply Chain Quality Management by Contract Design

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1. Introduction

Along with the competition intensity globally, quality management activities should go across the firms' boundaries and be pursued in supply chain environment (Flynn and Flynn 2005; Kaynak and Hartley 2008; Schweinberg 2009; Yeung 2008). Supply chain quality management (SCQM) is the interdisciplinary field between Quality Management (QM) and Supply Chain Management (SCM). SCQM is different from the traditional QM methods such as Statistical Quality Control (SQC), Total Quality Management (TQM) and Quality Management Systems (QMSs), which focus on the implementation of QM in single firm environment. Since one of the QM activities' characteristics in supply chain situation is that each member makes its QM decisions independently, SCQM is the formal coordination and integration of business processes involving all partner organizations in order to create value and achieve satisfaction of intermediate and final customers (Foster 2008; Kaynak and Hartley 2008; Robinson and Malhotra 2005). SCQM emphasizes the coordination of all members' QM activities which are driven by all members' self-interests. In short, SCQM is the effective integration of firms' internal QM activities.

There are many coordination mechanisms to carry out SCQM such as supply chain contracts, information technology, information sharing, and joint decision-making (Corbett et al. 2004; Lee et al. 1997; Robinson and Malhotra 2005). In this chapter we focus on the method of contract design since the implementation of supply chain contracts have the advantages of small cost and convenient operations. It is known that the process of contract design should pay significant attention to all members' self-interest QM activities and the various supply chain environments. Fortunately, game theory is the natural tool to investigate contract design in various situations of SCQM.

We study contract design for SCQM about behavior observability and external failure sharing in a supplier-manufacturer supply chain. In manufacturing supply chains, members' behavior observability and influencing factors to cost sharing of external failure are two main aspects to influence SCQM implementation (Arshinder et al. 2008; Malchi 2003; Reyniers and Tapiero 1995a, b; Sower 2004). The influencing factors to external failure sharing include the verifiability of external failure, the separability of final product architecture, and the member's relationship (Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Bhattacharyya and Lafontaine 1995; Sila et al. 2006). If some behavior of one member is unobservable to other parties, the member will use this condition as a strategic weapon to improve its own profit. The result of this case may damage other parties as well as the whole supply chain's profit. On the other hand, external failure sharing has directly impact on supply chain's risk sharing. The occurrence of external failure will cause lots of extra cost to the buyers. This kind of cost should be shared by all the members involved in a supply chain. Otherwise, the supply chain is not coordinated and the competitive advantage is ruined.

In this chapter, we employ contract design to pursue SCQM implementation in a manufacturing supply chain. A supplier sells intermediate products to a manufacturer, and the manufacturer inspects the products and processes the "qualified" to be final product. The supplier's production behavior is unobservable to the manufacturer. The analysis is in the view of the manufacturer (the buyer of the supply chain). An external failure sharing mechanism is employed to presents the three influencing factors to external failure sharing which are interactive. Then the circumstance of the supply chain is determined by the observabilities of the manufacturer's inspection and processing, the verifiability of external failure sharing, the separability of final product architecture, and the relationship of two parties. The contracts are designed to guarantee SCQM in different circumstances. The objective of SCQM is to achieve supply chain coordination in this chapter.

The analysis is taken into two steps. In the first step, the first-best achievement is examined in four circumstances characterized only by the observabilities of the manufacturer's inspection and processing. In the second step, contracts for supply chain coordination are designed in circumstances characterized by all of the observability of the manufacturer's inspection and processing and the three influencing factors of external failure sharing. Thirty-two circumstances are divided into two groups based on the two parties' relationship whether the two parties are friends. In this case, the interactions of the three factors of external failure sharing can be illustrated as a tree structure.

Here are the main findings. In the first step, necessary and sufficient conditions in which the first-best solution can be attained are derived in each of the four circumstances. Moreover, it is shown that the observability of the manufacturer's inspection and processing can be investigated separately in the examination of first-best achievement. The unobservable of the manufacturer's inspection is corresponding with the conditions (1) the supplier is not responsible for the external failure caused by the manufacturer's defect, and (2) the supplier's product price and the proportion of customer dissatisfaction that the supplier is responsible for satisfy $\pi / \alpha = ds / (1-s)$ (d is customer satisfaction cost and s is the proportion in which the supplier is responsible for the external failure caused by its own defect). The unobservable of the manufacturer's processing is corresponding with the condition that the final product architecture is separable-but-not-totally.

In the second step, it is concluded that there are five kinds of contracts which guarantee the first-best achievement in the thirty-two circumstances. When the two parties are friends, there are ten circumstances in which contracts are needed to guarantee the first-best achievement; and when the two parties are not friends, there are eight circumstances in which contracts are needed. The relation between circumstances and corresponding contracts is not a one-to-one mapping. Moreover, some contracts are robust to some characteristics of the circumstances. For example, the contract that the manufacturer's inspection quality level is stipulated to the corresponding first-best is robust to the verifiability of external failure, the separability of final product architecture, and the relationship of two parties. Meanwhile, the above contract is a panacea to the eight circumstances in which the first-best solution cannot be achieved without extra contracts when the two parties are not friends. Furthermore, it is shown whether the first-best can be attained based upon the manufacturer's inspection or processing information system installation and how contracts are designed to guarantee the first-best achievement in case that the first-best solution cannot be achieved when some installation is established. Besides, we make a comparison between the results in the literature and in this chapter.

The remainder is organized as follows. Section 2 is literature review. Section 3 is model description. Section 4 is first-best examination of the manufacturer's unobservable inspection and processing. Section 5 is contract design for first-best achievement in circumstances characterized by the manufacturer's behavior observability and the three influencing factors of external failure sharing. The last section is the concluding remarks.

2. Literature review

Competition has extended from firm level to supply chain level. The focus of QM is being transferred to external QM, which is referred to SCQM (Foster 2008; Haynak and Haytley 2008; Liker and Choi 2004). SCQM emphasizes the coordination and integration of each party's businesses to increase the whole supply chain's profit as well as each member's profit (Robinson and Malhotra 2005). However, the coordination of SCQM will not be derived naturally. Buyer's unobservable behaviors and external failure sharing are two aspects which significantly influence the coordination in manufacturing supply chains (Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Hwang et al. 2006; Reyniers and Tapiero 1995a, b; Swinney and Netessine 2009).

The observabilities of a buyer's inspection and processing behaviors have been investigated in two kinds of supply chains. Firstly, Reyniers and Tapiero (1995a, b) consider the unobservable of a buyer's inspection, but the buyer does not process the "qualified" product further. Reyniers and Tapiero (1995b) give the conditions for the first-best achievement. Secondly, Baiman et al. (2000, 2001), Balachandran and Radhakrishnan (2005) and Hwang (2006) consider supply chain in which a buyer inspects a supplier's product and further processes the inspection-qualified product to be final product. These papers only involve the unobservable of the buyer's processing but not the unobservable of the buyer's inspection. Baiman et al. (2000, 2001) give the conditions for the first-best achievement when a supplier has the sole authority in contract design, and Balachandran and Radhakrishnan (2005) and Hwang (2006) give the contract design for the first-best achievement when a buyer has the sole authority. However, the unobservable of a buyer's inspection has not been studied in the case that the buyer processes inspection-qualified product further. On the other hand, the relation between the observabilities of a buyer's inspection and processing has not been investigated in contract design. Maybe there are some interactions between them. In addition, the behavior observability in contract design should be considered in various supply chain environments.

The external failure sharing is influenced by three interactive factors, which are the verifiability of external failure, the separability of final product architecture and the relationship of two parties. In literatures, the three factors are investigated separately. The external failure of a buyer has been studied by modeling in Baiman et al. (2000). In the event of external failure, if the external failure is verifiable, the penalty paid by a supplier to a buyer is based on the external failure caused by the supplier's defect; otherwise, the penalty is based on all external failure. The separability of final product architecture has been investigated by modeling in Baiman et al. (2001). If final product architecture is totally-separable (i.e. the product architecture is modular), the supplier will be responsible for the external failure caused by the supplier; if final product architecture is non-separable (i.e. the product architecture is integrated), the supplier will not be responsible for the external failure (Baiman et al. 2001; Ulrich 1995). Although discussed separately, it is known that the verifiability of external failure and the separability of final product architecture are connected in the proportion of external failure that a supplier is responsible for. Furthermore, the relationship of the two parties of supply chain, which has not been discussed in quality-based supply chain, also connects with the proportion of external failure that a supplier is responsible for. In addition, the above three characteristics of supply chain environment are interacted in contract design. For example, the consideration of the three characteristics has priority, i.e. the contractibility of external failure should be considered firstly. Because the separability of final product architecture and the relationship of the two parties will not influence the proportion of external failure that the supplier is responsible for if the external failure is unverifiable. In this chapter, an external failure-sharing mechanism is employed to connect the three influencing factors and the interactions among the three factors are taken serious in contract design.

In addition, it is worthwhile to note that the observability and the contractibility are different (Tirole 1999). In economic literature, the contractibility is considered as two levels, i.e. observability and verifiability (Tirole 1999; Maskin and Tirole 1999). Since a contractible event must be verified and enforced by a court, an uncontractible event may be observable but not verifiable. However, in the literature of contract design in quality-based supply chain, the unobservable and the uncontractible are always assumed to be the same (Reyniers and Tapiero 1995a, b; Baiman et al. 2000, 2001; Balachandran and Radhakrishnan 2005; Hwang 2006). In this chapter, the observability and verifiability are considered separately if the contractibility is involved. Since the event of external failure is common and observable in the buyer's after-sale of supply chain, the uncontractible of external failure is due to unverifiable. So we take this uncontractible event as "unverifiable".

3. Model description

We consider a supply chain with a risk-neutral supplier and a risk-neutral manufacturer. The supplier provides one unit product for the manufacturer. The supplier's production quality level q_S is the probability that the production fulfills or exceeds the expectation of final customers ($q_S \in [q_S^0, 1)$ and $q_S^0 > 0$), and the supplier's investment $S(q_S)$ satisfies $S(1) = \infty$, $S'(q_S) > 0$, and $S''(q_S) > 0$. The manufacturer will inspect the product once it is received. If the product is defective, the manufacturer can inspect to be "unqualified" with probability δ ($\delta \in [0, \delta^1]$ and $\delta^1 < 1$), and the inspection cost $I(\delta)$ satisfies $I(1) = \infty$, $I'(\delta) > 0$, and $I''(\delta) > 0$. The inspection-unqualified product will be delivered back to the supplier. Otherwise, the manufacturer will process the product into final product and sell to customers. The manufacturer's processing quality level q_M is the probability that the processing fulfills or exceeds the expectation of final customers ($q_M \in [q_M^0, 1)$ and $q_M^0 > 0$), and the processing cost $M(q_M)$ satisfies $M(1) = \infty$, $M'(q_M) > 0$, and $M''(q_M) > 0$. Since the manufacturer's inspection is imprecise, the external failure will occur. The cost of external failure not only includes the final product price, but also customer dissatisfaction (Heagy 1991; Ittner et al. 1999; Kumar et al. 1998; Sower 2004). The supplier is responsible for α

percent of customer dissatisfaction cost d. In addition, supplier's product price is π, the final product price is Π. Without loss of generality, the price of the supplier's raw material is 0 (Balachandran and Radhakrishnan 2005; Hwang et al. 2006).
From the description, the probability of an external failure is $E=(1-q_S)(1-\delta)+(1-q_M)q_S$, where $(1-q_S)(1-\delta)$ is due to the supplier's poor production and the manufacturer's incorrect inspection and $(1-q_M)q_S$ is due to the manufacturer's poor processing. In this chapter, we employ an external failure-sharing mechanism to decide the supplier's share, which wholly represents the verifiabibity of external failure, the separability of the final product architecture, and the relationship of the two parties. Specifically, the supplier's share of the external failure is $E_S=s(1-\delta)(1-q_S)+m(1-q_M)q_S$, where s ($0\le s\le 1$) be the proportion that the supplier takes the responsibility of $(1-q_S)(1-\delta)$, and m ($0\le m\le 1$) be the proportion that the supplier takes the responsibility of $(1-q_M)q_S$. The parameter s, which is related with the verifiability of external failure and the separability of the final product architecture, is determined by an objective judgment machine. The parameter m, which is related with the verifiability of external failure and the relationship of the two parties, is determined by the agreement of the two parties. If the external failure is unverifiable, the supplier will not be responsible for the external failure ($s=0$ and $m=0$); otherwise, the supplier will be responsible for. In case that the external failure is verifiable, the supplier's share of external failure depends on two factors: the final product architecture and the two parties' relationship. For the parameter s, if the architecture is totally-separable, $s=1$; if the architecture is non-separable, $s=0$; if the architecture is separable-but-not-totally, $0<s<1$. For the parameter m, if the two parties are not friends or if the two parties are friends and the final product architecture is totally-separable, $m=0$; if the two parties are friends and if the final product architecture is not-totally-separable, $0<m\le 1$.

4. First-best examinations about manufacturer's unobservable behaviors

First of all, we give the first-best outcome. According to model description, the manufacturer's profit is

$$P^M(q_S,q_M,\delta,\pi,m,\alpha)=(\Pi-\pi)[1-\delta(1-q_S)]-(\Pi+d)E+(\pi+\alpha d)E_S-I(\delta)-M(q_M),$$

the supplier's profit is

$$P^S(q_S,q_M,\delta,\pi,m,\alpha)=\pi[1-\delta(1-q_S)]-(\pi+\alpha d)E_S-S(q_S),$$

and the whole profit of the supply chain is

$$P(q_S,q_M,\delta,\pi,m,\alpha)=\Pi[1-\delta(1-q_S)]-(\Pi+d)E-I(\delta)-S(q_S)-M(q_M).$$

The problem of First-Best of supply chain is $\underset{0<q_S,q_M,\delta<1}{Maximize}\quad P(q_S,q_M,\delta)$. Suppose that $(\Pi+d)q_S^0>M'(q_M^0)$ and $\Pi q_S^0-d(1-q_M^0)>S'(q_S^0)$, there is an interior solution $\{q_S^*,q_M^*,\delta^*\}$ satisfies

$$P_{q_M} = (\Pi + d)q_S - M'(q_M) = 0 \,, \tag{1}$$

$$P_{\delta} = d(1 - q_S) - I'(\delta) = 0 \,, \tag{2}$$

$$P_{q_S} = -d\delta + (\Pi + d)q_M - S'(q_S) = 0 \,. \tag{3}$$

(Referred on Balachandran and Radhakrishnan 2005).
There are four circumstances characterized by the observability of the manufacturer's behaviors, which depend on the observability of the inspection or the processing. The decision-making processes of the circumstances can be considered in two stages by game-theoretical thinking (Rasmusen 1989; Fudenberg and Tirole 1991; Wei 2001). In the first stage, the manufacturer makes an offer of contract to the supplier. If the supplier takes the offer, the processes go into the next stage in which the two parties optimize their profits by manipulating the variables $\{q_S, q_M, \delta\}$ respectively.

The first-best solution can be attained if the supply chain is integrated, i.e. the optimal value $\{\hat{q}_S, \hat{q}_M, \hat{\delta}\}$ of decentralized supply chain is coincident with the first-best $\{q_S^*, q_M^*, \delta^*\}$.

Circumstance 1 The manufacturer's inspection and processing are both unobservable to the supplier. In the second stage, the manufacturer decides the inspection level δ and the processing quality level q_M, and the supplier decides the production quality level q_S simultaneously and independently. Therefore, the manufacturer's optimization problem is

$$\underset{0<q_S, q_M, \delta<1; \pi, \alpha>0}{Maximize} \quad P^M(q_S, q_M, \delta, \pi, \alpha) \tag{A}$$

subject to

$$P^M_{q_M}(q_S, q_M, \delta, \pi, \alpha) = 0 \,, \tag{B}$$

$$P^M_{\delta}(q_S, q_M, \delta, \pi, \alpha) = 0 \,, \tag{C}$$

$$P^S_{q_S}(q_S, q_M, \delta, \pi, \alpha) = 0 \,, \tag{D}$$

$$P^S(q_S, q_M, \delta, \pi, \alpha) \geq v \,. \tag{E}$$

Equations (B) and (C) are incentive-compatible constraints since the supplier does not observe the manufacturer's q_M and δ. Equation (D) is an incentive-compatible constraint since the manufacturer does not observe the supplier's q_S. Equation (E) is a participation constraint ensuring a minimum profit v for the supplier. We have the following result. (All proofs are provided in the appendix.)

Proposition 1 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if and only if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect i.e. $m = 0$; (b) the final product architecture is separable-but-not-totally, i.e. $0 < s < 1$; and (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1 - s)$.

The conditions (a) and (c) can be achieved by contract design, while the condition (b) is objective one of supply chain. Based on condition (a), the manufacturer should not make the supplier hold responsible for the external failure caused by the supplier's own defect. Based on condition (c), the manufacturer should not fiercely reduce the supplier's product price, which will damage the total interest of supply chain. Specifically, (1) the more the Proposition of customer dissatisfaction the supplier is responsible for, (2) the more customer dissatisfaction, or (3) the more the final product's architecture is separable, the higher the supplier's product price.

Circumstance 2 The manufacturer's inspection is unobservable to the supplier while the processing is observable. The second stage is divided into two steps: firstly, the manufacturer decides the processing quality level q_M which the supplier observes; secondly, the manufacturer and the supplier simultaneously move to decide the inspection level δ and the production quality level q_S. Therefore the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P_{\delta}^M(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{C}$$

$$P_{q_S}^S(q_S,q_M,\delta,\pi,\alpha)=0\,, \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\geq v\,. \tag{E}$$

Note that the incentive-compatible constraint (B) is not included in contrast to Circumstance 1, which is because the supplier will utilize the decision about q_M to maximize its profit. The following Proposition holds.

Proposition 2 Suppose that the manufacturer's processing is observable to the supplier while the inspection is unobservable. The first-best solution can be attained if and only if (b) the final product architecture is separable-but-not-totally, i.e. $0<s<1$; and (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi/\alpha=ds/(1-s)$.

According to Proposition 1 and 2, we have the following corollary.

Corollary 1 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (b) the final product architecture is separable-but-not-totally, i.e. $0<s<1$; (c) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi/\alpha=ds/(1-s)$; and (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^* in the contract.

Circumstance 3 The manufacturer's inspection is observable to the supplier while the processing is unobservable. The second stage is: firstly, the manufacturer decides the inspection level δ which the supplier observes; secondly, the manufacturer and the supplier decide the processing quality level q_M and the production quality level q_S simultaneously and independently. Therefore, the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P^M_{q_M}(q_S,q_M,\delta,\pi,\alpha)=0\ , \tag{B}$$

$$P^S_{q_S}(q_S,q_M,\delta,\pi,\alpha)=0\ , \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\geq v\ . \tag{E}$$

Note that the incentive-compatible constraint (C) is not included in contrast to CIRCUMSTANCE 1 and the argument is similar to the one in CIRCUMSTANCE 2. The first-best achievement in Circumstance 3 is characterized by the following Proposition. (Balachandran and Radhakrishnan (2005) derives the same result when $0<s\leq 1$.)

Proposition 3 Suppose that the manufacturer's inspection is observable to the supplier while the processing is unobservable. The first-best solution can be attained if and only if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect, i.e. $m=0$.

According to Proposition 1 and 3 we have

Corollary 2 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (a) the supplier is not responsible for the manufacturer's external failure caused by the manufacturer's defect, i.e. $m=0$; and (e) the manufacturer's inspection quality q_S is stipulated to be the first-best δ^* in the contract.

Circumstance 4 The manufacturer's inspection and processing are both observable to the supplier. The second stage is: firstly, the manufacturer decides the inspection level δ and processing quality level q_M, which the supplier observes; secondly, the supplier decides the production quality level q_S. Therefore the manufacturer's optimization problem is

$$\underset{0<q_S,q_M,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S,q_M,\delta,\pi,\alpha) \tag{A}$$

subject to

$$P^S_{q_S}(q_S,q_M,\delta,\pi,\alpha)=0\ , \tag{D}$$

$$P^S(q_S,q_M,\delta,\pi,\alpha)\geq v\ . \tag{E}$$

Note that the two incentive-compatible constraints (B) and (C) are not included in contrast to Circumstance 1. We have the following Proposition. (Balachandran and Radhakrishnan (2005) derives the same result when $0<s\leq 1$.)

Proposition 4 Suppose that the manufacturer's inspection and processing are both observable to the supplier. The first-best solution can be attained without extra condition.

From Proposition 1, 2, 3, and 4, we have

Corollary 3 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. The first-best solution can be attained if (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^*, and (e) the manufacturer's inspection quality level δ is stipulated to be the first-best δ^* in the contract.

Corollary 4 Suppose that the manufacturer's processing is observable to the supplier while her inspection is unobservable. The first-best solution can be attained if (e) the manufacturer's inspection quality level δ is stipulated to be the first-best δ^* in the contract.

Corollary 5 Suppose that the manufacturer's inspection is observable to the supplier while her processing is unobservable. The first-best solution can be attained if (d) the manufacturer's processing quality level q_M is stipulated to be the first-best q_M^* in the contract.

From Proposition 1, 2, 3 and 4, it is found that the observability of the manufacturer's inspection and processing can be investigated separately. Specifically, we have the following observation.

Observation 1 The observabilities of the manufacturer's inspection and processing can be investigated separately in analyses of the first-best achievement. If the manufacturer's processing is unobservable, the condition (b) should be considered in contract design, if necessary. If the manufacturer's inspection is unobservable, the conditions (a) and (c) should be considered in contract design, if necessary.

5. Contract design in circumstances characterized by influencing factors

In this section, contract design is pursued in circumstances characterized by the combinations of the manufacturer's behavior (including inspection and processing) observability and the three influencing factors of external failure sharing, i.e., the verifiability of the manufacturer's external failure, the separability of the final product architecture, and the relationship of the two parties.

Before contract design, some issues should be illustrated. Firstly, the verifiability of external failure should be considered prior to the separablility of the final product architecture and the relationship of the two parties. Only if the external failure is verifiable, the other two factors will be taken into account. Secondly, the separablility of the final product architecture and the relationship of the two parties are interactive and do not have priority. Thirdly, the observabilities of the manufacturer's behaviors are independent of the three characteristics of supply chain environment. Fourthly, from Observation 1, the observabilities of the inspection and the processing are separable in supply chain quality management.

We divide the circumstances into two groups to discuss: friends or not-friends. In each group, there are four factors influencing contract design, i.e. the observability of the manufacturer's inspection, the observability of the manufacturer's processing, the verifiability of the external failure, and the separability of the final product architecture. It is important that there are only two relations between the four factors – independent and hierarchical. In this case, the braches of the four factors are depicted in Figure 1. The manufacturer's inspection has two nodes: MI_O^N (unobservable) and MI_O (observable). The manufacturer's processing has two nodes: MP_O^N (unobservable) and MP_O (observable). The combination of the verifiability of the manufacturer's external failure and the separability of the final product architecture has three end-nodes: $ME_V + A_{T+N}$ (the manufacturer's external failure is verifiable and the final product architecture is totally separable or non-separable, i.e. $s = 1$ or $s = 0$), $ME_V + A_{S-T}$ (the manufacturer's external failure is verifiable and the final product architecture is separable-but-not-totally, i.e. $0 < s < 1$) and ME_V^N (the manufacturer's external failure is unverifiable, i.e. $E_S = 0$).

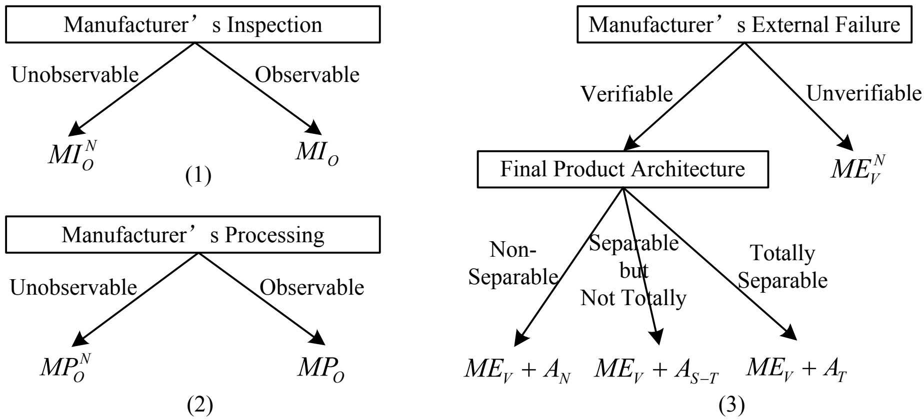

Fig. 1. The branches of the observability of the manufacturer's inspection, the observability of the manufacturer's processing, the verifiability of external failure, and the separability of the final product architecture

There are sixteen different circumstances characterized by the combinations of end-notes in Figure 1. According to Proposition 1-4 and Corollary 1-4, contracts by stipulating which the first-best solution is achieved in different circumstances are exhibited in Table 1. The items of contracts are:

1. The external failure which is caused by the manufacturer's defect but the supplier is responsible for is zero, i.e. $m = 0$.
2. The supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1 - s)$.
3. The manufacturer's inspection quality level δ is the first-best δ^*.
4. The manufacturer's processing quality level q_M is the first-best q_M^*.

For example, if the supply chain in Circumstance 1 of Table 1, Contract [2+4] guarantees first-best achievement according to Proposition 1. Note that the contracts listed in Table 1 are the ones which encompass the least items. Otherwise there are much more satisfied contracts. For instance, Contract [3+4] is suitable for every circumstance according to Proposition 4.

There are five kinds of contracts, i.e. contracts [2], [3], [4], [2+4] and [3+4], to guarantee first-best achievement. When the two parties are friends, there are ten circumstances in which first-best solution is achieved by extra contracts; and when the two parties are not friends, there are eight circumstances. The relation of the circumstances and the contracts is not a one-to-one mapping. When the two parties are friends, the reasons that the first-best can be attained without contract in the other four circumstances are (a) the manufacturer's inspection is observable to the supplier, the external failure is verifiable, and the final product architecture is totally separable (Circumstances 11 and 15); (b) the manufacturer's inspection is observable and the manufacturer's external failure is unverifiable (Circumstance 12 and 16); or (c) the manufacturer's inspection and processing are both

CIRCUMSTANCES	CONTRACTS	
	Friends	Not-Friends
1. $MI_O^N + MP_O^N + ME_V + A_N$	[3+4]	[3]
2. $MI_O^N + MP_O^N + ME_V + A_{S-T}$	[2+4], [3+4]	[2], [3]
3. $MI_O^N + MP_O^N + ME_V + A_T$	[3]	[3]
4. $MI_O^N + MP_O^N + ME_V^N$	[3]	[3]
5. $MI_O^N + MP_O + ME_V + A_N$	[3]	[3]
6. $MI_O^N + MP_O + ME_V + A_{S-T}$	[2], [3]	[2], [3]
7. $MI_O^N + MP_O + ME_V + A_T$	[3]	[3]
8. $MI_O^N + MP_O + ME_V^N$	[3]	[3]
9. $MI_O + MP_O^N + ME_V + A_N$	[4]	–
10. $MI_O + MP_O^N + ME_V + A_{S-T}$	[4]	–
11. $MI_O + MP_O^N + ME_V + A_T$	–	–
12. $MI_O + MP_O^N + ME_V^N$	–	–
13. $MI_O + MP_O + ME_V + A_N$	–	–
14. $MI_O + MP_O + ME_V + A_{S-T}$	–	–
15. $MI_O + MP_O + ME_V + A_T$	–	–
16. $MI_O + MP_O + ME_V^N$	–	–

Table 1. The circumstances and the corresponding contracts when the two parties are friends or not friends

observable to the supplier (Circumstance 13-15). When the two parties are not friends, there is only one reason to guarantee first-best achievement without contract. The reason is that the manufacturer's inspection is observable to the supplier.

Some contracts are robust to the changes of some of three circumstance characteristics. When the two parties are friends, Contract [3+4] is robust to the separability of the final product architecture in circumstances that the manufacturer's inspection and processing are both unobservable to the supplier and the final product architecture is not totally separable (Circumstance 1 and 2); Contract [3] is robust to the verifiability of the manufacturer's external failure and the separability of the final product architecture in circumstances that only the manufacturer's inspection is unobservable to the supplier (Circumstance 4-8); Contract [3] is robust between the verifiable external failure and totally separable final product architecture (Circumstance 3) and the unverifiable external failure (Circumstance 3); and Contract [4] is robust between the nonseparable and separable-but-not-totally final product architectures in circumstances that only the manufacturer's inspection is observable to the supplier and the external failure is verifiable (Circumstance 9 and 10). When the two parties are not friends, contract [3] is robust to the observability of the processing, the verifiability of the external failure, and the separability of the final product architecture in

circumstances except the ones that The first-best can be attained without contract. Contract [3] is used much more times than other contracts. When the two parties are not friends Contract [3] is a panacea to achieve the first-best solution. meanwhile, contract [3] is robust to the verifiability of external failure, the separability of the final product architecture, and the relationship of the two parties in circumstances that only the inspection is unobservable, and robust between between the verifiable external failure and totally separable final product architecture and the unverifiable external failure and between the friend and not-friend relations in circumstances that the inspection and processing are both unobservable.
Compared with the group in which the two parties are friends, there are several changes in groups that the two parties are not friends. Circumstances 9 and 10 guarantee first-best achievement without contracts. Meanwhile, it is plausible that the difference between the two groups is that item [4] is not included in the contract when the two parties are not friends in the same circumstances (Circumstances 1, 2, 9, and 10). However, that the item [4] is stipulated in the contract is not directly related with the situation that the two parties are friends. The reason of this phenomenon is: when the two parties are not friends ($m = 0$) the first-best can be attained by contract [1+2] (Circumstance 2), contract [1+3] (Circumstances 1), and contract [1] (Circumstance 9 and 10), and the circumstances 1, 2, 9, and 10 all guarantee item [1].

5.1 Information system installation

IT and supply chain contracts are two key approaches to supply chain management (Arshinder et al. 2008; Li and Wang 2007; Saraf et al. 2007). The derived results can give further comments on information system installation in supply chain. The circumstances that the manufacturer's inspection and processing are both unobservable to the supplier are always the original type of supply chains. The firms should make tradeoffs between information system installation and contract design to implement supply chain management. The circumstances that the inspection or the processing is observable refer to the situations that one of the information systems is installed. In Table 1, if the manufacturer's inspection and processing systems are both installed in the supply chain, the first-best solution can be attained without contract; otherwise, the first-best solution cannot be attain without contract. To conclude, we have the following proposition.
Proposition 5 Suppose that the manufacturer's inspection and processing are both unobservable to the supplier. If installing an inspection information system in circumstances that the two parties are friends, The first-best can be attained without contract when the external failure is unverifiable or when the external failure is verifiable and the final product architecture is totally separable; contract [4] is needed to guarantee the first-best achievement when the external failure is verifiable and the final product architecture is not totally separable. If installing an inspection information system in circumstances that the two parties are not friends, supply chain can be achieved without contract in any circumstance. If installing a processing information system, supply chain can be achieved by contract [3] in any circumstance and by contract [2] only in circumstance [6].
Therefore, information system installation should be accomplished by contract design, and the managers of supply chain management should pay more attention to relation between information technology and SC coordination. Otherwise, the objective of information system installation will not be achieved and the firm's enthusiasm will be turned down.

5.2 Result comparison with other studies

In the following, we make a specific comparison with the result in Baiman et al. (2000, 2001), which also involve the observability of the buyer's inspection, the verifiability of external failure, and the separability of the final product architecture separately.

When the manufacturer's processing is observable and the external failure is verifiable, Baiman et al. (2000) show that the first-best solution is achieved (Proposition 2a); however, Table 1 shows that the first-best solution is achieved with extra contracts if the manufacturer's inspection is unobservable (Circumstances 5-7) or without extra contract if the inspection is observable (Circumstances 13-15).

When the manufacturer's processing is unobservable, the manufacturer's inspection is observable, and external failure is verifiable, Proposition 3 in Baiman et al. (2000) and Proposition 4 in Baiman et al. (2001) show that the first-best solution is achieved; however, Table 1 shows that the first-best solution is achieved without extra contract if the two parties are not friends (Circumstances 9-16 in Not-Friends group) or if the two parties are friends and the final product architecture is totally-separable (Circumstance 11 in Friends Group), or with extra contract if the two parties are friends and the final product architecture is not-totally-separable (Circumstances 9 and 10 in Friends group).

When the final product architecture is non-separable, Proposition in Baiman et al. (2001) shows that the first-best solution cannot be achieved, but Table 1 shows that the first-best solution can be attained without extra contract if the manufacturer's inspection is observable and with extra contract if the inspection is unobservable.

It is worthwhile to note that the above comparisons are just arguments by modeling approaches to SCC. The results are based on different assumptions of the quality-based supply chain.

6. Concluding remarks

Contract design for SCQM is discussed in a manufacturing supply chain. It is shown that supplier and manufacturer in some circumstances must stipulate some items in contract to guarantee coordination in SCQM, while other circumstances guarantee coordination without extra contract. Furthermore, information system installation is an alternative approach to coordination in those circumstances that need extra contracts to guarantee coordination. The exact information system should be chosen based on characteristics of the circumstances.

Two issues are highlighted in the manufacturing supply chain. The observability of the buyer's inspection is highlighted in supply chains such that the buyer further processes the supplier's product to be final product. The result is different from the case that the buyer does not further process the supplier's product. If the buyer's inspection is unobservable, the supplier will be exposed to moral hazard. Moreover, the extra conditions in which the first-best solution is achieved are different from the ones in supply chains such that the buyer does not process the supplier's product further. In this chapter, the situation that the manufacturer's inspection is unobservable is corresponding with two extra conditions: (1) the supplier is not responsible for the external failure caused by the manufacturer's defect, and (2) the supplier's product price and the proportion of customer dissatisfaction the supplier is responsible for satisfy $\pi / \alpha = ds / (1-s)$.

The interactions between the external failure's verifiability, the final product architecture's separability, and the two parties' relationship are also highlighted. The three factors do not independently influence the contract design. Only if the external failure is verifiable, the other two factors will be taken into account. The final product architecture's separability and the two parties' relationship have the same hierarchy and have interactive influences. In this chapter, an external failure-sharing mechanism is employed to connect the three factors.

7. Acknowledgment

This study was supported by the National Natural Science Foundation of China under Grant No.70872091 and No.70672056.

8. Appendix

This Proof of Proposition 1: It is only to prove that the solution of maximization problem coincides with the first-best solution if and only if the conditions are satisfied in the circumstance.

The Lagrangian for the maximization problem in Circumstance 1 of Section 4 is $L = P^M + \lambda_1 P^M_{q_M} + \lambda_2 P^M_{\delta} + \lambda_3 P^S_{q_S} + \mu(P^S - v)$ with λ_1, λ_2, λ_3 and μ as Lagrange multipliers on constraints (B), (C), (D), and (E). The first-order conditions of the Lagrangian are

$$L_{q_M} = (\Pi + d)q_S - (\pi + \alpha d)mq_S - M'(q_M) - \lambda_1 M''(q_M) + \lambda_3 m(\pi + \alpha d) + \mu m q_S(\pi + \alpha d) = 0\,, \quad \text{(A1)}$$

$$L_{\delta} = [\pi(1-s) + d(1-\alpha s)](1-q_S) - I'(\delta) - \lambda_2 I''(\delta) + [\lambda_3 - (1-q_S)\mu][\pi - s(\pi + \alpha d)] = 0\,, \quad \text{(A2)}$$

$$\begin{aligned} L_{q_S} &= (\Pi - \pi)\delta - (\Pi + d)(\delta - q_M) + (\pi + \alpha d)[m(1-q_M) - s(1-\delta)] + \lambda_1[\Pi + d - m(\pi + \alpha d)] \\ &-\lambda_2[\pi(1-s) + d(1-\alpha s)] - \lambda_3 S''(q_S) + \mu\{\pi\delta + (\pi + \alpha d)[s(1-\delta) - m(1-q_M)] - S'(q_S)\} = 0 \end{aligned}\,, \quad \text{(A3)}$$

$$\begin{aligned} L_{\pi} &= [(\mu - 1)(1-q_S) - \lambda_3](1-s)(1-\delta) + [(\mu-1)q_S + \lambda_3][1 - m(1-q_M)] \\ &-\lambda_1 m q_S + \lambda_2(1-s)(1-q_S) = 0 \end{aligned} \quad \text{(A4)}$$

$$L_{\alpha} = [(\mu - 1)(1-q_S) - \lambda_3]s(1-\delta) + [(\mu-1)q_S + \lambda_3]m(1-q_M) + \lambda_1 m q_S + \lambda_2 s(1-q_S) = 0\,. \quad \text{(A5)}$$

Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem.

On the one hand, if the first-best solution is achieved, $\hat{q}_S$, $\hat{q}_M$ and $\hat{\delta}$ must satisfy (B0), (C0), and (D0). Comparing (B), (C) with (B0), (C0), we have $\pi = (\pi + \alpha d)s$ and $m(\pi + \alpha d) = 0$. Since $\pi > 0$, then $m = 0$, $0 < s < 1$, and $\pi / \alpha = ds/(1-s)$.

On the other hand, the only thing we have to prove is that if $m = 0$, $0 < s < 1$, and $\pi / \alpha = ds/(1-s)$ then $\lambda_1, \lambda_2, \lambda_3 = 0$ and $\mu = 1$. Because if $\lambda_1, \lambda_2, \lambda_3 = 0$ and $\mu = 1$ exist $L = P - v$ and the first-best solution is derived. Firstly Plugging $m = 0$ into (A1) and comparing with (B) we have $\lambda_1 = 0$ since $M''(q_M) > 0$, and plugging $\pi / \alpha = ds/(1-s)$ into (A2) and comparing with (C), we have $\lambda_2 = 0$ since $I''(\delta) > 0$. Secondly, plugging (D), (D0), and $\lambda_1, \lambda_2 = 0$ into (A3) we have $\lambda_3 = 0$ since $S''(q_S) > 0$. Finally, plugging $m = 0$ and $\lambda_1, \lambda_2, \lambda_3 = 0$ into (A4) we have $\mu = 1$ since $0 < s < 1$. At this moment, (A3) is also satisfied.

Proof of Proposition 2: The Lagrangian for the maximization problem in Circumstance 2 of Subsection 4.1 is $L = P^M + \lambda_2 P_\delta^M + \lambda_3 P_{q_S}^S + \mu(P^S - v)$ with λ_2, λ_3, and μ as Lagrange multipliers on constraints (C), (D), and (E). The first-order conditions of the Lagrangian are

$$L_{q_M} = (\Pi + d)q_S - (\pi + \alpha d)mq_S - M'(q_M) + \lambda_3 m(\pi + \alpha d) + \mu m q_S(\pi + \alpha d) = 0\,, \quad \text{(A6)}$$

$$L_\delta = [\pi(1-s) + d(1-\alpha s)](1-q_S) - I'(\delta) - \lambda_2 I''(\delta) + [\lambda_3 - (1-q_S)\mu][\pi - s(\pi + \alpha d)] = 0\,, \quad \text{(A7)}$$

$$\begin{aligned} L_{q_S} &= (\Pi - \pi)\delta - (\pi + d)(\delta - q_M) + (\pi + \alpha d)[m(1-q_M) - s(1-\delta)] - \lambda_2[\pi(1-s) + d(1-\alpha s)] \\ &\quad -\lambda_3 S''(q_S) + \mu\{\pi\delta + (\pi + \alpha d)[s(1-\delta) - m(1-q_M)] - S'(q_S)\} = 0, \end{aligned} \quad \text{(A8)}$$

$$L_\pi = [(\mu - 1)(1-q_S) - \lambda_3](1-s)(1-\delta) + [(\mu-1)q_S + \lambda_3][1 - m(1-q_M)] + \lambda_2(1-s)(1-q_S) = 0 \quad \text{(A9)}$$

$$L_\alpha = [(\mu-1)(1-q_S) - \lambda_3]s(1-\delta) + [(\mu-1)q_S + \lambda_3]m(1-q_M) + \lambda_2 s(1-q_S) = 0\,. \quad \text{(A10)}$$

Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem.
We only prove that if $0 < s < 1$ and $\pi / \alpha = ds / (1-s)$ then $\lambda_2, \lambda_3 = 0$ and $\mu = 1$. Firstly, plugging $\pi / \alpha = ds / (1-s)$ into (A7) and comparing with (C) we have $\lambda_2 = 0$. Secondly, plugging (D), (D0) and $\lambda_2 = 0$ into (A8) we have $\lambda_3 = 0$. Finally, plugging $\lambda_2, \lambda_3 = 0$ into (A9) and (A10) we have $(\mu-1)(1-q_S)(1-s)(1-\delta) + (\mu-1)q_S[1 - m(1-q_M)] = 0$ and $(\mu-1)(1-q_S)s(1-\delta) + (\mu-1)q_S m(1-q_M) = 0$. The two equations imply $(\mu-1)[(1-q_S)(1-\delta) + q_S] = 0$. Then $\mu = 1$, since $0 < q_S < 1$ and $\delta < 1$.
Proof of Corollary 1: The process of proof is tantamount to solve two maximization problems

$$\underset{0<q_S,\delta<1;\pi,\alpha>0}{Maximize} \quad P^M(q_S, q_M^*, \delta, \pi, \alpha) \quad \text{(A)}$$

subject to

$$P_\delta^M(q_S, q_M^*, \delta, \pi, \alpha) = 0\,, \quad \text{(C)}$$

$$P_{q_S}^S(q_S, q_M^*, \delta, \pi, \alpha) = 0\,, \quad \text{(D)}$$

$$P^S(q_S, q_M^*, \delta, \pi, \alpha) \geq v\,. \quad \text{(E)}$$

According to the proof of Proposition 3, the solution of the above problem coincides with the first-best solution.
Proof of Proposition 3: The Lagrangian for the maximization problem in Circumstance 3 is $L = P^M + \lambda_1 P_{q_M}^M + \lambda_3 P_{q_S}^S + \mu(P^S - v)$ with λ_1, λ_3, and μ as Lagrange multipliers on constraints (B), (D), and (E). Let $\{\hat{q}_M, \hat{q}_S, \hat{\delta}, \hat{\alpha}, \hat{\pi}\}$ be the solution of the maximization problem. We only prove that if $m = 0$ then $\lambda_2, \lambda_3 = 0$ and $\mu = 1$.
Following the similar steps we have that if $m = 0$ then $\lambda_1, \lambda_3 = 0$. It leaves to prove that $\mu = 1$. From the first-order conditions of the Lagrangian we have

$$L_\pi = (\mu - 1)[(1 - q_S)(1 - s)(1 - \delta) + q_S] = 0 \,, \tag{A11}$$

$$L_\alpha = (\mu - 1)(1 - q_S)s(1 - \delta) = 0 \,. \tag{A12}$$

If $s = 0$ we have $(\mu - 1)[(1 - q_S)(1 - \delta) + q_S] = 0$ from (A11), while if $s = 1$ we have $L_\alpha = (\mu - 1)(1 - q_S)(1 - \delta) = 0$ from (A12). Hence it holds that $\mu = 1$.

Proof of Proposition 4: The Lagrangian for the maximization problem in Circumstance 4 is $L = P^M + \lambda_3 P^S_{q_s} + \mu(P^S - v)$ with λ_3 and μ as Lagrange multipliers on constraints (D) and (E). By following the similar track as in the proof of proposition 3 we are able to obtain $\lambda_3 = 0$ and $\mu = 1$.

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6

Supply Chain Flexibility: Managerial Implications

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1. Introduction

Today's companies are forced into functioning in a challenging business world with extensive uncertainties. Frontrunners turn out to be those companies that are able to foresee the market swings and react swiftly with minimal adjustment costs and effective response strategies. Hence, developing flexibility in adapting to sudden changes in global markets, resource availabilities, and outbreaks of financial and political crises becomes an integral part of effective management strategy. Supply chain management presents an especially important domain where such flexibility is critical to achieving a consistently successful performance.

Earlier research on flexibility in supply chains has focused primarily on manufacturing (e.g., Barad & Nof, 1997; De Toni & Tonchia, 1998; Gupta & Goyal, 1989; Kaighobadi & Venkatesh, 1994; Koste & Malhotra, 1999; Mascarenhas, 1981; Parker & Wirth, 1999; Sethi & Sethi, 1990). In contrast, recent studies have tended to examine a proliferation of different dimensions like volume, launch, and target market flexibilities (Vickery, Calantone & Drőge, 1999); logistics flexibility potentially including flexibilities in postponement, routing, delivery and trans-shipment (Barad & Sapir, 2003; Das & Nagendra, 1997); order quantity and delivery lead time flexibilities (Wang, 2008); sourcing flexibility (Narasimhan & Das, 2000); launch flexibility and access flexibility (Sánchez and Pérez, 2005). Firm performance has presented another core theme in recent work, with results pointing to the importance of customer-supplier flexibility capabilities to improve competitiveness (Merschmann & Thonemann, in press; Sánchez and Pérez, 2005). Duclos, Vokurka & Lummus (2003) argue for the importance of organizational flexibility and information systems flexibility (in addition to operations system, market, logistics, and supply flexibility) so that the supply chains can function in a seamless succession of efficient processes; while More & Babu (2009) claim that supply chain flexibility is a new strategic tool for management.

In thinking about the managerial implications of supply chain flexibility, it is useful to distinguish among 'flexible competencies' (internal flexibility issues from the supplier perspective) versus 'flexible capabilities' (customer perceptions on external flexibility issues) (Zhang, Vonderembse & Lim, 2003). It is important in this regard to tease out the relevant factors for suppliers and customers using procedures like Delphi (Lummus, Vokurka & Duclos, 2005), where the different attributes could be identified and unified metrics could be developed to enable communication across different perspectives (Gunasekaran, Patel &

McGaughey, 2004). This is a complicated issue with performance measurement being a multi-dimensional construct that needs to target operational parameters like efficiency in addition to the stakeholder exposure factors like control and accountability (Parmigiani, Klassen & Russo, 2011).

Supply chain risks and disruptions can be caused by natural disasters, unexpected accidents, operational difficulties, terrorist incidents, and industrial or direct action. In any case, supply chains need to be flexible enough to recover from any disruptions at the earliest possible time. Moreover, it is possible to consider two different types of flexibility within the supply chain context; volume/capacity flexibility that allows to decrease or increase production according to the observed demand and delivery flexibility that allows to make changes to the deliveries, e.g. adapting new delivery amounts or delivery dates. In line with these ideas, Schutz and Tomasgard (2009) analyse volume, delivery, storage and operational decision flexibilities in a supply chain under uncertain demand and arrive at a trade-off between volume and delivery flexibility and operational decision and storage flexibility.

A recent survey on supply chain flexibility by More and Babu (2009) provides a comprehensive definition of flexibility within the context of supply chain, summarizes the methods used to model supply chain flexibility, and concludes with interesting future research avenues. Although there is no general agreement on how to define supply chain flexibility, the area has tremendous potential for researchers providing opportunities for modelling and application of flexibility to the supply chain, interrelationships and trade-offs between different types of flexibilities, industry-specific or business function-specific impact of flexibility, and/or potential barriers to the implementation of flexibility.

In this chapter, we aim to focus on the synergies between supply chain flexibility and forecasting, risk management, and decision making as the influential factors affecting performance and management of supply chains. In light of the scarcity of studies investigating supply chain flexibility and the pressing need for future work in this area, we aim to (1) provide a review of extant literature, (2) highlight emerging research directions, and (3) discuss managerial repercussions. In so doing, this chapter will emphasize three areas that collectively play a critical role in determining the effectiveness of flexible supply chains: forecasting, risk management, and decision making.

2. Forecasting and supply chain flexibility

Forecasts represent main inputs into planning and decision making processes in supply chains. Predictions of future demands, resource requirements and consumer needs present some areas where collaborative forecasting may play a significant role in contributing to flexible supply chain performance. In fact, the quality of decisions and the resulting outcomes may be argued to depend on the extent of information sharing and forecast communication in flexible supply chains.

Planning and decision making processes in supply chains heavily rely on forecasts. Accordingly, forecasting accuracy is a core factor that influences the performance of a supply chain (Zhao, Xie & Leung, 2002). Bullwhip effect is a prime example of how predictive inaccuracy can easily intensify through the supply chain (Chang & Lin, 2010), crippling the affected partners. Predictions of future demands, resource requirements and consumer needs present some areas where collaborative forecasting may play a significant role in contributing to flexible supply chain performance.

While flexibility is argued to provide a way for eluding forecasting uncertainties (Bish, Muriel & Biller, 2001), it may also be viewed as a means for benefitting from the informational advantages and forecasting expertise of supply chain partners (Småros, 2003). This may be especially critical given the strong influence of the organizational roles in guiding the individual and group forecasts (Önkal, Lawrence & Sayım, 2011). Additionally, biases such as overconfidence and optimism are found to have significant effects on supply chain forecasts (Fildes et al, 2009), thus challenging predictive accuracy and synchronized information flow among the decision makers. All these factors make collaborative forecasting an indispensable tool for flexibility and responsive decision making in supply chains (Caridi, Cigolini & de Marco, 2005; Derrouiche, Neubert & Bouras, 2008), as well as for improving efficiency and competitiveness (Aviv, 2001; Helms, Ettkin &Chapman, 2000).

Supply chain flexibility requires extensive information and forecast sharing, and thus is vulnerable to a variety of motivational factors that can potentially lead to significant distortions (e.g., Mishra, Raghunathan & Yue, 2007). Various studies have clearly demonstrated the impact of such forecasting errors and distortions on supply chain performance (e.g., Zhao & Xie, 2002; Zhu, Mukhopadhyay &Yue, 2011). In this regard, the role of trust in collaborative forecasting presents an extremely promising research area. Supply chain relationships are acknowledged to rely on trust, with its role investigated mainly in the context of information sharing and information quality (e.g., Chen, Yen, Rajkumar & Tomochko, 2010). This can easily be extended to studies that focus on how trust among partners could reduce individual and organizational biases (Oliva & Watson, 2009), leading to forecast sharing and improved predictive accuracy for the whole supply chain.

In summary, collaborative forecasting and forecast sharing constitute vital areas for enhanced decision making in flexible supply chains. Further research in this domain is likely to face serious challenges emanating from behavioral factors and organizational dynamics, but the rewards to flexible supply chain management will surely be worth the effort.

3. Risk management and supply chain flexibility

Uncertainties in the operating environment of firms reduce the reliability in terms of delivering at the right time, at the right amount and quality. Uncertainty requires firms to quickly respond to changing environments. Operating in a flexible supply chain helps the firms to accomplish this rapid adaptation. On the other hand, increasing flexibility brings along additional risks for the firms to undertake. Alignment, adaptability and agility (flexibility) are fundamental elements for supply chain risk management. It is accepted that flexibility increases supply chain resilience; however, firms are reluctant to invest in flexibility when it is not clear how much flexibility is required. The higher the flexibility, the riskier is the chain. However, there are some methods and models which help to mitigate the level of risk associated with the level of flexibility. This section analyses the relationship between supply chain flexibility and supply network risk management.

An interesting study focusing on risk management in a supply chain that is subject to weather-related demand uncertainty is provided by Chen and Yano (2010). These researchers focus on a manufacturer-retailer dyad of a seasonal product with weather sensitive demand to examine weather-linked rebate for improving the expected profits. This is an extension of rebate contracts which have several advantages over other contract types such as no required verification of leftover inventory and/or markdown amounts, and no adverse effect on sales effort by the retailer. The paper reports interesting results on how the weather-linked rebate can take many different forms, and how this flexibility allows the supplier to design contracts that are Pareto improving and limit the reciprocal risks of offering and accepting the contract. The structural results can be extended to allow the two parties to limit their risk under the increased flexibility.

Table 1 lists a sample of relatively recent events that have affected the respective supply chains which would have turned out having very different outcomes if the supply chains had higher levels of flexibility and appropriate risk management practices.

Event	Outcome	Reference
September 1999: Taiwan earthquake	Huge losses for many electronic firms that use Taiwanese manufacturers as suppliers.	Sheffi, 2005
March 2000: Fire at the Philips microchip plant in Albuquerque, NM.	Nokia and Ericsson were affected. Nokia resumed production in three days whereas Ericsson shut down production with $400 million loss.	Latour, 2001
April – June 2003: SARS outbreak	It is estimated that transportation industry lost 38 billion RMB, wholesale and retail trade industries lost 12 billion RMB and manufacturing industry lost 27 billion RMB.	Ji and Zhu, 2008
Summer 2004: Below-average temperature decreased the demand for certain products	Cadbury Schweppes' drinks business was hit by soggy summer weather. Coca-Cola and Unilever pointed the weather for low sales of soft drink and ice cream products. Nestle reported decreased demand for ice-cream and bottled water due to poor weather.	Kleiderman, 2004
May 2008: earthquakes in Sichuan, China	Severe damage to infrastructure network.	Qiang and Nagurney, 2010
March 2011: Japanese earthquake	Large negative impact on the economy of Japan and major disruptions to global and local supply chains.	Nanto et al., 2011

Table 1. Key events and outcomes underlining the importance of risk management in supply chain

The list can easily be extended to include high profile events like natural disasters and terrorism attacks in different regions. All these occurrences have dramatic effects on the supply chains, whether these are humanitarian supply chains involving health aid or basic food supply chains. Further research into embedding emergency flexibilities in these chains via best case risk management practices will be extremely valuable for both the practitioners and the academics aiming to improve supply chain management performance under extremely demanding circumstances.

4. Decision making and supply chain flexibility

Existing literature defines supply chain flexibility as a reactive means to cope with uncertainty. Networked companies in a dynamic and complex environment require coordination of their multiple plants, suppliers, distribution centres, and retailers. There are numerous decision making models (linear, non-linear, and multi-objective) which aim for coordination of the supply network players and hence increase the overall flexibility of the chain.

Schutz and Tomasgard (2009) employ a stochastic programming model to balance supply and demand in a supply chain from the Norwegian meat industry. The authors find that a deterministic model of the supply chain produces as good results as does the stochastic model given a certain level of flexibility in the chain. The level of extra capacity required to obtain volume flexibility, number of products to achieve mix flexibility, or the level of procurement flexibility stand as important decisions in the supply chain to improve market responsiveness and resolve uncertainty-related problems. Das (2011) proposes a mixed integer programming model for supply chain to address demand and supply uncertainty along with market responsiveness. A scenario-based stochastic approach is utilized to model the demand behaviour where they test the supply chain flexibility based on a pool of suppliers. The proposed mixed integer programming model is tested to aid supply chain managers in setting supplier flexibility, capacity flexibility, product flexibility and customer service level flexibility.

On the other hand, Wadhwa and Saxena (2007) propose a decision knowledge sharing model to improve collaboration in flexible supply chains. The main benefit of the model is to facilitate sourcing and distribution decisions. Empirical results demonstrate that full decision-sharing in a flexible supply chain leads to decreased total costs.

Given the abundance of decision models that may be employed to adopt or increase supply chain flexibility, further work on comparative analysis of such models in different contexts with systematic variations in levels of uncertainty appears to be highly promising.

5. Interconnectedness of forecasting, risk management and decision making

The three areas of analysis are not mutually exclusive. There is a definite need for studies to focus on and explore the intersections of forecasting, risk management and decision making in the context of supply chain flexibility. We will discuss these interactions next.

5.1 Decision making / risk management for supply chain flexibility

Risk management and decision making are inherently intertwined. Their interactions gain a special significance for the plethora of managerial issues faced in efforts to introduce flexibility to different aspects of supply chains. Yu et al. (2009) focuses on a two-stage supply chain where the buying firm faces a non-stationary, price-sensitive demand of a critical component and where two suppliers (primary and secondary) are available. The authors suggest a mathematical model as a decision aid to choose the most profitable sourcing strategies in the presence of supply chain disruption risks. It should be noted that the demand model used in this study is fairly simple and the supplier's capacity is assumed to be infinite. One critical limitation of this study is that it considers only the buyer's profit instead of examining the sourcing decisions from both parties' point of view.

Giannikis and Louis (2001) develop a framework for designing a multi-agent decision support system to aid the management of disruptions and mitigation of risks in manufacturing supply chains. The agents responsible for communication, coordination, and disruption management are built to simulate the supply chain which is occasionally subject to abnormal events (e.g. an unusual fluctuation in the manufacturing process). Effective disruptions management is assumed under collaborative behavior of supply chain partners by learning from previous corrective actions for future decisions, suggesting risk mitigation at operational and tactical levels. The most important result of this analysis may be that risk management cannot be perceived as an individual process of each partner.

5.2 Forecasting / risk management for supply chain flexibility

Forecasts may be utilized as critical tools for risk management, and this gains a special significance for managing flexible supply chains. Introducing successful mechanisms for operational flexibilities throughout the supply chain requires effective integration of forecasts into risk management strategies. This is a vital and yet challenging process for supply chain management. Future work directed at exploring the role of forecasting – risk management interactions for the performance of supply chains and their flexibility concerns will prove especially useful in various contexts ranging from waste management to quality control.

5.3 Forecasting / decision making for supply chain flexibility

As far as the uncertainty in demand and supply processes is concerned, flexibility improves the performance of supply chains in terms of cost efficiencies and market response. The close interplay between forecasting and decision making plays a vital role in managing such uncertainties to expand the supply chain capabilities, resulting in enhanced system performance throughout. Management of flexible supply chains necessitates planning for alternative forecast scenarios and building efficient response strategies to tackle possibilities of disruptions/crises/alterations for a variety of factors. Strong coordination mechanisms among supply chain partners will be needed for information sharing, forecast adjustment/synchronization, and group decision making.

6. Conclusion and directions for future research

Integrating flexibility into supply chains requires building efficient response mechanisms for adapting to changes in a host of internal and external factors. In today's competitive and complex markets, supply chain management has to function along a dynamic interplay of forecasting, risk management and decision making challenges (Wadhwa, Saxena & Chan, 2008). Developing effective supply chain strategies will need to involve a complicated mixture of incentive alignment, information sharing, decision synchronization and collaborative planning and forecasting (Cao & Zhang, 2011; Derrouiche, Neubert & Bouras, 2008; Simatupang & Sridharan, 2005). Enhancing information visibility (Wang and Wei, 2007), improving communication among supply chain partners, and developing effective collaborative forecasting and decision support tools will prove immensely valuable in attaining the desired strategic goals. The next decade of supply chain management research may be expected to start providing answers to the multi-disciplinary challenges associated with improving the global value and performance of flexible supply chains.

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7

Bullwhip-Effect and Flexibility in Supply Chain Management

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1. Introduction

One of the most relevant characteristics of inventory management methods is the amplification phenomenon called the "bullwhip-effect", defined as the upstream increasing of production variability, caused by a supply chain's demand variability at the retail level. This effect has been extensively studied, both from industrial and theoretical points of view (Takahashi et al., 1994). Among the multiple reasons mentioned in literature (Lee et al., 2000; Takahashi et al., 1994; Warburton, 2004; Wu and Meixell, 1998), four features are frequently reported at the origin of this phenomenon (Lee et al., 1997): demand signal processing, strategic ordering behavior, ordering batching and price variations.

Geary et al. (2006) pointed out ten common causes of bullwhip-effect and the subsequent re-engineering principles to eliminate or prevent amplification. Among them, the *time compression principle* suggests that the most relevant principle to achieve this goal is the existence of an optimal minimum lead time. Takahashi and Myreshka (2004) extensively studied sources of bullwhip-effect and proposed several counter-measures for the demand, ordering process and supply sides. Some of these counter-measures are: sharing information about inventory and production levels among stages along the chain, controlling inventory replenishment by a single method, reducing the lead-time, designing appropriate forecasting methods (or eliminating forecasting practices) and implementing pull or hybrid methods.

It has been argued that the lack of flexibility in a supply chain is a consequence of the bullwhip-effect. In order to analyze this argument, Pereira (1999) developed general expressions for the amplification measure in the case of three ordering methods: push, pull and hybrid. In a further contribution, Pereira and Paulre (2001) introduced the *adjustment degree* of production to demand rate, a flexibility measure evaluating the distance between the demand and production signals on each supply chain stage. Considering the ordering methods above, an AR(1) demand process and a non-capacity-restricted supply chain model, it was found that the adjustment degree behaves as a bullwhip-effect, especially in push systems. More importantly, it was found that the bullwhip-effect is structurally due to the upstream propagation of the demand forecasting. Chen et al. (2000) also studied the increments of variability in a generic supply chain structure, for the specific case of a stationary AR(1) process, finding that the demand forecasting importantly impacts the amplification level in the supply chain. However, they did not explain how it is produced by forecasting methods.

In a recent work Pereira et al. (2009) have shown that for an AR(1) demand stochastic process, flexibility on each stage of the supply chain strongly depends on the *manager's belief* about the downstream forecasting processes. Beliefs affect the decision rules in ordering methods, structurally defining the adaptation capability in the supply chain. Then, flexibility could be used as a strategy to keep amplification under control. In this chapter we present some analytical results that explore this insight, considering the modeled supply chain and demand process. Moreover, an introductory analysis of inventory amplification is presented, in order to inspect the effect of manager's belief on it. We propose that belief-based regulation may improve the amplification levels both in production and inventory sides. But, it strongly depends on the adopted forecasting method and the assumed demand process.
The remainder of this chapter is organized as follows. In section 2.1, the supply chain model and ordering equations are presented. In section 2.2, the flexibility framework is introduced and relevant preliminary results on adjustment degree for the modeled supply chain are presented for push, pull and hybrid methods. In section 3, we introduce one of the amplification acceptability criteria proposed in literature, which indicates the requirements for control of the bullwhip effect. Further, the mathematical relation between the adjustment degree and the amplification is presented, which allows us to express the amplification acceptability criteria in terms of flexibility conditions. In section 3.3, a fading variable, representing the manager's belief on estimates, is analyzed in terms of its impact both on production and inventory amplification measures. Conclusions are presented in section 4.

2. Preliminaries

2.1 The supply chain model

Consider a multi-echelon, single-item, supply chain composed by production stages $\mathbf{P}_i \quad (i = 1, \ldots, n)$, stock sites $\mathbf{B}_i \quad (i = 0, \ldots, n)$, and a supplier stage "Supplier", as shown in Fig. 1. This will be called the *reference model* $\mathbf{M}$ (Pereira and Paulre, 2001).
Let us consider a periodic ordering method managing the production levels on each stage of the supply chain (Takahashi and Myreshka, 2004). Then, the i-th production stage periodically receives an order $\mathbf{O}_i$, which defines how many units of the item stocked in $\mathbf{B}_i$ need to be processed and further stocked in $\mathbf{B}_{i-1}$. The elapsed time between the instant when an order is calculated and the moment where the ordered units are ready to be delivered (i.e., the lead time) is considered an exogenous variable, identical in all stages: $L^i = L \quad (i = 1, \ldots, n)$. A period is defined here as a unitary interval of time. Thus, $t \in \mathbb{Z}$ starts the t-th period; $t + 1$ starts the $(t + 1)$-th, and so forth.

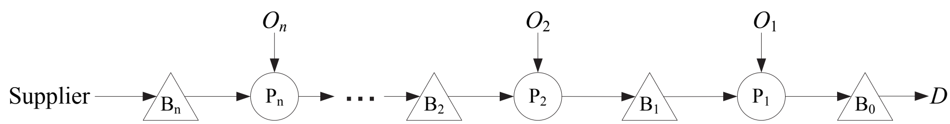


Fig. 1. Serial configuration of production stages

The following variables are defined in the model $\mathbf{M}$:
Furthermore, the production rate at stage $\mathbf{P}_i$ is given by

$$P_t^i = O_{t-L}^i, \quad (i = 1, \ldots, n), \tag{1}$$

which means that the manufacturing lead time between stages $\mathbf{P}_i$ and $\mathbf{P}_1$ can be written as $LT^{(i)} = iL$.

D_t : demand rate on stock site $\mathbf{B}_0$, during period t,
$\hat{D}^i_{t,t+j}$: $t+j$ demand forecast, estimated at the end of t, for the stage $\mathbf{P}_i$,
$\triangle\hat{D}^i_t$: marginal change of the sum of the demand forecast, calculated at the end of t, for the stage P_i,
O^i_t : production order on the stage $\mathbf{P}_i$, calculated at the end of t,
P^i_t : production rate on stage $\mathbf{P}_i$, during t, placed on stock $\mathbf{B}_{i-1}$ at the beginning of $t+1$,
L^i : lead time on stage i. We assume $L^i = L \quad \forall i$.

Inventory management systems differ in the way the production order on each stage is defined. In the case of push, hybrid and pull management methods, the ordering equation any stage i is expressed as (Pereira and Paulre, 2001):

$$\text{Push}: \quad O^i_t = D_{t-(i-1)L} + \sum_{j=1}^{i} \Delta\hat{D}^j_{t-(i-j)L}, \tag{2}$$

$$\text{Hybrid}: \quad O^i_t = D_{t-(i-1)L} + \Delta\hat{D}^1_{t-(i-1)L}, \tag{3}$$

$$\text{Pull}: \quad O^i_t = D_{t-(i-1)L}. \tag{4}$$

Notice that (3) characterizes a system where only the first stage operates in push.

2.2 Evaluating flexibility in the supply chain

A system is said *flexible* whenever it has the capability to self-adjust in response to changes in its environment. The design of a flexible system implies control of three dimensions (Pereira and Paulre, 2001): degree, effort and time of adjustment. More precisely, let a system and its environment be characterized by the trajectories they take in the state spaces $\mathscr{S}$ and $\mathscr{E}$, respectively. In addition, let us assume an observer is able to recognize the environment and the system states $e_t \in \mathscr{E}$ and $s_t \in \mathscr{S}$, at time t; she/he also identifies a logic $\mathscr{L}$ such that

$$\mathscr{L}(e_{t-l_t}, s_t) = (s^*_t, \|s^*_t - s_t\|). \tag{5}$$

This means that, given e_{t-l_t} and s_t, $\mathscr{L}$ allows the observer to define an expected state $s^*_t \in \mathscr{S}$ and its distance to the current state s_t. Thus, the system responsiveness remains characterized by $l_t \geq 0$, indicating that the expected state depends on information provided to $\mathscr{L}$ in t, but occurring in $t - l_t$. The considered system is said to be in *partial equilibrium* when $\mathscr{L}(e_{t-l_t}, s_t) = (s^*_t, 0)$. Whenever $\|s^*_t - s_t\| \neq 0$, flexibility is the property that tends to realize the partial equilibrium in the system. In order to do this, the system must expend a specific effort and time. Thus, in given times $t_1, t_2, \ldots, t_n$, we assume that a flexible system dynamically adjusts to *demanded* changes defined in a succesion of states $\mathscr{D} = s^*_1, \ldots, s^*_n$.

Stage	Push	Hybrid	Pull
$i=1$	G	G	0
$i>1$	$\vartheta^{i-1} + H_i$	ϑ^{i-1}	0

Table 1. Adjustment degree ϑ^i for the three management methods

Now, we argue that the flexibility analysis provides a convenient framework to study the supply chain bullwhip-effect. In fact, let us consider that $\mathscr{D}$ may be represented by the demand process D_t and the system states, on each stage, by P_t. Then, given a stage i, a deviation variable is defined as $\theta_t^i = P_t^i - D_{t-iL}$, which means that a demand signal received by the stage i at time $t-(i+1)L$ has a response at $t-iL$, i.e. within a leadtime L. This delay may be considered the responsiveness capability (adjustment time) of this stage. The adjustment degree on i is expressed as follows,

$$\vartheta^i = \frac{V\left[\theta_t^i\right]}{V\left[D_{t-iL}\right]} \quad \forall i \geq 1, \tag{6}$$

where $V[\cdot]$ denotes the variance of the argument. Notice that, as ϑ^i decreases, the stage-i's adjustment of the production level to the delayed demand signal improves. Thus, the optimal adjustment is reached when $\vartheta^i = 0, \forall i$.

It has been shown that, when the model **M** is considered, ϑ^i, as measured for pull, push and hybrid management methods, has the structure presented in Table 1 (Pereira and Paulre, 2001), where G and H_i depend on the demand forecasting strategy (see section 3.2). This result reveals that push-type stages propagate adjustment variability upstream in the supply chain, scaling up or down the adjustment degree, in a very similar way to the bullwhip-effect behavior.

3. Flexibility and amplification

3.1 The amplification of production

The bullwhip-effect in a supply chain is usually evaluated by an *amplification* measure, defined as follows (Muramatsu et al., 1985),

$$Amp^i = \frac{V\left[P_t^i\right]}{V\left[D_t\right]}. \tag{7}$$

This metric may be interpreted as the scaling effect of demand variability, from the first to upstream stages. It has been proposed that an adequate ordering method should satisfy the following inequality (Muramatsu et al., 1985), called here the *Muramatsu Amplification Condition* (MAC):

$$1 \geqslant Amp^1 \geqslant Amp^2 \geqslant \ldots \geqslant Amp^n. \tag{8}$$

Hereinafter, let us see the relation between the amplification and the adjustment degree measures. Indeed, expanding the expression for (6), it follows that

$$\begin{aligned}\frac{V\left[P_t^i - D_{t-iL}\right]}{V\left[D_t\right]} = & \frac{V\left[P_t^i\right]}{V\left[D_t\right]} + \frac{V\left[D_{t-iL}\right]}{V\left[D_t\right]} \\ & - \frac{2}{V\left[D_t\right]} \operatorname{cov}\left[P_t^i, D_{t-iL}\right].\end{aligned} \tag{9}$$

Stationarity assumption allows us to write

$$\vartheta^i = Amp^i + 1 - \frac{2}{V\left[D_t\right]} \operatorname{cov}\left[P_t^i, D_{t-iL}\right]. \tag{10}$$

Defining $\gamma^i = \frac{2}{V[D_t]} \operatorname{cov}\left[P_t^i, D_{t-iL}\right]$, we have

$$Amp^i = \vartheta^i + \gamma^i - 1. \tag{11}$$

In consequence, the MAC inequality may be written in terms of the adjustment degree of production as follows:

$$1 \geqslant \vartheta^1 + \gamma^1 - 1 \geqslant \vartheta^2 + \gamma^2 - 1 \geqslant \ldots \geqslant \vartheta^n + \gamma^n - 1. \quad (12)$$

This is an interesting result because, since Amp^i measures the bullwhip-effect of a given management system, when faced to a specific demand behavior, it suggests that monitoring of ϑ^i yields a more adequate feedback to the supply chain manager. In fact, it furnishes her/him with a control variable in the supply chain. In the next section, this idea is explored for the three ordering methods.

3.2 Flexibility conditions for an AR(1) demand process

A simple observation of Table 1 exposes the way that the adjustment behavior propagates upstream in the supply chain. Inspecting the expression (12), a manager could rapidly establish a control condition, when implementing a particular method. For instance, it is easy to see that a hybrid method satisfies

$$2 \geqslant \vartheta^1 + \gamma^1 \geqslant \vartheta^1 + \gamma^2 \geqslant \ldots \geqslant \vartheta^1 + \gamma^n, \quad (13)$$

whilst in a pull method with $\vartheta^i = 0\ (\forall i)$, we have

$$2 \geqslant \gamma^1 \geqslant \gamma^2 \geqslant \ldots \geqslant \gamma^n. \quad (14)$$

However, for a push method this condition needs to be found for every specific demand process. Therefore, for sake of analysis, let us assume that the demand rate can be accurately modeled by an i.i.d stationary AR(1) stochastic process with mean μ, variance σ^2 and autocorrelation coefficient $\lambda \in (-1, 1)$.
When a pull ordering method is adopted, using (1) and (4), we have $P_t^i = D_{t-iL}$. Hence, for a stationary stochastic demand process it follows,

$$\begin{aligned} \gamma^i &= \frac{2}{V[D_t]} \left(E\left[(D_{t-iL})^2 \right] - (E\left[D_{t-iL}\right])^2 \right) \\ &= 2. \end{aligned} \quad (15)$$

Thus, the relation between ϑ^i and Amp^i is

$$Amp^i = \vartheta^i + 1. \quad (16)$$

But $\vartheta^i = 0, \forall i$ (see Table 1), which implies $Amp^i = 1$. In consequence, a pull inventory management simultaneously minimizes ϑ^i and accomplishes the MAC criteria. Differently, when a push ordering method is considered, using (1) and (2), we have

$$\begin{aligned} P_t^i &= D_{t-iL} + \sum_{j=1}^{i} \Delta \hat{D}^j_{(i+1-j)L} \\ &= D_{t-iL} + \theta_t^i. \end{aligned} \quad (17)$$

Therefore,

$$\gamma^i = \frac{2}{V\left[D_t\right]}\left\{V\left[D_t\right]\right.$$
$$+E\left[D_{t-iL}\left(\sum_{j=1}^{i}\Delta\hat{D}^j_{t-(i+1-j)L}\right)\right]$$
$$\left.-E\left[D_t\right]E\left[\sum_{j=1}^{i}\Delta\hat{D}^j_{t-(i+1-j)L}\right]\right\}, \tag{18}$$

This equation shows that in the push method, the relation between ϑ^i and Amp^i depends on the first and second order statistics of the demand stochastic process able to describe the requested units. A closed expression can be found for some specific demand stochastic processes. In particular, given an AR(1) stochastic demand process, a straightforward analysis shows that

$$\triangle\hat{D}^i_t = (D_t - D_{t-1})\sum_{j=1}^{L+1}\lambda^{LT^{(i-1)}+j}$$
$$= (D_t - D_{t-1})\lambda^{LT^{(i-1)}}\phi. \tag{19}$$

where $\phi = \lambda\frac{\lambda^{L+1}-1}{\lambda-1}, \lambda \neq 1$. Knowing that $E\left[D_{t-k}D_{t-j}\right] = \lambda^{k-j}\sigma^2 + \mu^2, \quad \forall k > j$, we find an expression for γ^i, expressed as

$$\gamma^i = 2 + 2(\lambda - 1)\phi\sum_{j=1}^{i}\lambda^{LT^{(j-1)}-(1-j)L-1}$$
$$= 2 + 2\left(\lambda^{L+1} - 1\right)\frac{1-\lambda^{2Li}}{1-\lambda^{2L}}. \tag{20}$$

From this equation, $\gamma^i - \gamma^{i-1} \leq 0$. In addition, (11) and Table 1 imply $\vartheta^i = Amp^{i-1} - \gamma^{i-1} - 1$ and $\vartheta^i = \vartheta^{i-1} + H_i$, respectively. Then

$$Amp^i = Amp^{i-1} + \gamma^i - \gamma^{i-1} + H_i. \tag{21}$$

Now, let us restrict ϑ^i such that

$$\vartheta^1 \geqslant \vartheta^2 \geqslant \ldots \geqslant \vartheta^n, \tag{22}$$

meaning that $H_i \leq 0, \forall i$. In such case, (21) implies $Amp^{i-1} \geq Amp^i, \forall i$, and the MAC condition would be satisfied. Unfortunately, in a previous publication we have shown that $H_i \leq 0$ is rarely satisfied and for most of λ values we have $\vartheta^i \geq \vartheta^{i-1}$ (Pereira and Paulre, 2001). For this reason, a different strategy needs to be explored. Actually, given that the MAC condition is immediately satisfied by a pull method, it could be interesting to know how amplification is reduced when a push or hybrid method moves closer to the pull case. In the next section such idea is analyzed, introducing a *fading variable* which models the manager's belief on demand forecasting.

3.3 The manager's belief effect

In Pereira et al. (2009) we proposed an alternative to control the bullwhip-effect, using a learning variable representing the manager's belief on the forecasted demand change. This learning was modeled by a factor α, included in the ordering equation as $O_t^i = P_t^{i-1} + \alpha \triangle \hat{D}_t^i$, which conveys $\theta_t^i = \alpha \triangle \hat{D}_t^i$. Applying the same procedure yielding the results on Table 1 (Pereira and Paulre, 2001), it is straightforward to prove that the amplification value on stage i, Amp_α^i, is expressed as follows,

$$Amp_\alpha^i = \begin{cases} 1 + A_\alpha & i = 1, \\ Amp_\alpha^{i-1} + F_\alpha^i & i > 1. \end{cases} \tag{23}$$

In particular, when the AR(1) process is considered, we find

$$A_\alpha = 2\alpha\phi(1-\lambda)(\alpha\phi + 1), \tag{24}$$

$$F_\alpha^i = 2\alpha\phi(1-\lambda)\lambda^{2(i-1)L}\{\alpha\phi - \frac{1}{\lambda} - \phi\frac{1-\lambda}{\lambda}(i-1)\} \quad (i = 2, \ldots, n). \tag{25}$$

In Fig. 2 amplification for $\alpha \in [0,1]$, $L = 1$, $\lambda \in (-1,1)$ and $i \in \{2,8\}$ is presented. Notice that for $i = 2$ and the region $\lambda \geq 0$, the more α increases the more the bullwhip-effect is important, but the greatest amplification value is not reached as λ approaches 1. On the other hand, results for $i = 8$ (Fig. 2(b)) are not intuitive and suggest that the improvement strategy consisting on the progressive reduction of the adjustment degree, by decreasing α, does not necessarily reduce the bullwhip-effect. Even though, one may conclude that in push or hybrid methods, the bullwhip-effect is robustly reduced when stages approaches a pull-type ordering method. In other words, a manager is not necessarily enforced to abandon the push strategy to obtain acceptable amplification levels, but she/he should make a careful analysis in order to appreciate the consequences of his beliefs about the demand behavior and estimates.
Now, it is interesting to know how the inventory amplification level is shaped by the demand process. In particular, the way that the belief variable influences such level. Therefore, let us define $Iamp^{(i-1)} (i = 1, \ldots, n)$ as the inventory amplification of the stock site $\mathbf{B}_{i-1}$, that is

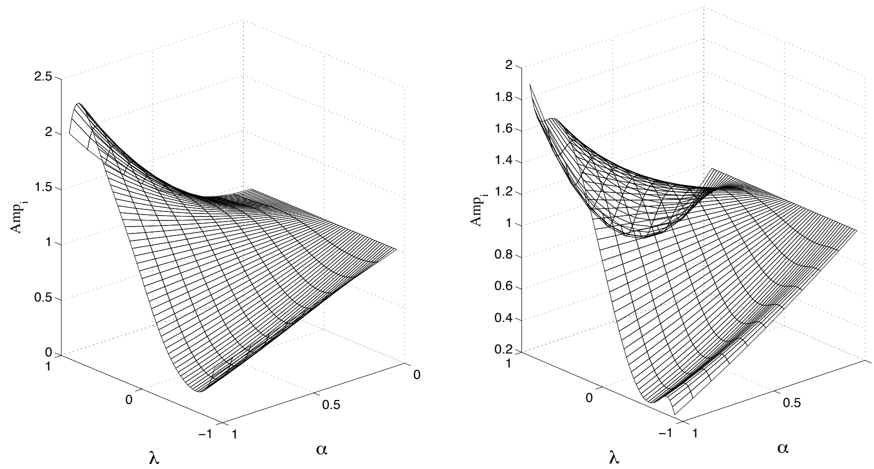
$$Iamp^{(i-1)} = \frac{V(B_t^{(i-1)})}{V(D_t)}. \tag{26}$$

It has been demonstrated that the production amplification impacts the inventory fluctuation, in the way depicted in Table 2 (Pereira, 1995). In general, ψ^i and ν^i $(i = 1, \ldots, n)$ are complex expressions depending on the forecasted and real demand processes. Instead, let us consider the expression (27), which represents the amplification level of the marginal inventory change,

$$Amp^{\triangle B^{i-1}} = \frac{V(B_t^{(i-1)} - B_{t-1}^{(i-1)})}{V(D_t)}. \tag{27}$$

Stage	Push	Hybrid	Pull
$i = 1$	$Amp^1 + \psi^1$	$Amp^1 + \psi^1$	$Amp^1 + \nu^1$
$i > 1$	$Amp^i + \psi^i$	$Amp^i + \nu^i$	$Amp^i + \nu^i$

Table 2. Amplification of inventory $InvAmp^{(i-1)}$ for the three management methods



(a) $i = 2$ (b) $i = 8$

Fig. 2. Amplification when $\alpha \in [0,1]$, $L = 1$ and $i = 2, 8$ (Pereira et al. , 2009).

This variable measures how sensitive the inventory is to the demand process. Intuitively, the more sensitive it is, the less smooth the inventory signal, when faced to the demand process. Restricting ourselves to the case $i = 1$ and given that $B_t^0 = B_{t-1}^0 + P_{t-1}^1 - D_t$, a straightforward analysis reveals that, when the learning variable α is included in the model, the following expression is obtained

$$\begin{aligned} Amp_\alpha^{\triangle B^0} &= Amp_\alpha^1 + 1 - 2\left[\lambda^{L+1} + \alpha\phi(\lambda^{L+1} - \lambda^{L+2})\right] \\ &= 2\left[1 + \alpha\phi\left((1-\lambda)(\alpha\phi + 1) - \lambda^{L+1} + \lambda^{L+2}\right) - \lambda^{L+1}\right]. \end{aligned} \tag{28}$$

Figure 3 shows $Amp_\alpha^{\triangle B^0}$ for $\alpha \in [0,1]$ and $\lambda \in (-1,1)$, when $L = 1$. This indicates that the inventory on stock site $\mathbf{B}_0$ is actually sensitive to the belief variable meaning that a smoothing effect should be expected if α is decreased for a given λ value. As qualitatively observed, effectiveness of α is low for negative values of autocorrelation. Notice that the same kind of phenomenon is observed in Figure 2: the more α decreases, the less the amplification improves.

We may conclude that a fading action, implemented via the manager's belief variable, may be a sound strategy for reduction of the bullwhip effect, both on the production and inventory sides, but only for specific values of autocorrelation. In particular, this kind of management should be surely applied for low positive values of λ.

4. Conclusions

In a previous paper we proposed that flexibility aids in reduction of the bullwhip-effect in a multi-echelon, single-item, supply chain model. In this chapter we have found a flexibility condition that guarantees the control of the bullwhip-effect in the supply chain (expression

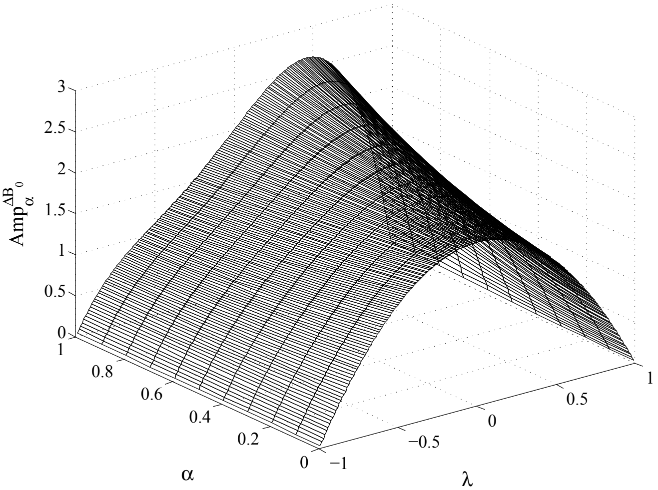


Fig. 3. Marginal inventory change amplification on stock site $\mathbf{B}_0$, when $\alpha \in [0, 1]$.

(22)). This is an interesting result because it asks the manager for an ordering strategy that synchronizes the flexibility among stages in the chain. However, such condition being difficult to fulfill when an AR(1) demand process is considered, a different strategy has been explored. Control of a learning variable, representing the manager's belief on demand forecasting, has been proposed here as an alternative strategy to regulate the bullwhip-effect. We have seen that, although this strategy does not necessarily assure fulfillment of the MAC condition, it may be an effective way to smooth production and inventory fluctuation. Our results indicate that, under the model assumptions, the pull ordering method is highly robust, in the sense of reduction of the amplification effect. Thus, the fading strategy suggested invites the supply chain manager to improve synchronization among stages in the supply chain, becoming closer to the pull method. Nevertheless, a manager is not necessarily enforced to abandon the push strategy in order to obtain acceptable amplification levels, but she/he should make a careful analysis assessing the consequences of his beliefs about the demand and estimates behavior.
Results presented in this chapter open to new ideas about the way that different fading strategies impact the bullwhip-effect behavior. Even if an early study was proposed by Pereira et al. (2009), the focus was rather mathematical and no framework was suggested as a specific analytical grid. In consequence, future research concerns the hypothesis that decision makers evidence limited rationality bias when facing an ordering method. Although this idea has been already analyzed (Oliva and Gonçalves , 2005), we think that the availability heuristic proposed by Tversky and Kahneman (1974), in our case concerning the overreaction to the downstream information, could be successfully explored using our supply chain model.

5. Acknowledgment

This publication has been fully supported by the Universidad Diego Portales Grant VRA 132/2010.

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8

A Fuzzy Goal Programming Approach for Collaborative Supply Chain Master Planning

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1. Introduction

Supply chain management (SCM) can be defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain (SC), for the purposes of improving the long term performance of the individual companies and the SC as a whole (Mentzer et al. 2001). One important way to achieve coordination in an inter-organizational SC is the alignment of the future activities of SC members, hence the coordination of plans. It is often proposed that operations planning in supply chains can be organized in terms of a hierarchical planning system (Dudek & Stadtler 2005). This approach assumes a single decision maker with total visibility of system details who makes centralized decisions for the entire SC. However, if partners are reluctant to reveal all of their information or it is too costly to keep the information of the entire supply chain up-to-date, the hierarchical planning approach is unsuitable or infeasible (Stadtler 2005). Hence, the question arises of how to link, coordinate and optimize production planning of independent partners in the SC without intruding their decision authorities and private information (Nie et al. 2006).

Stadtler (2009) defines collaborative planning (CP) as a joint decision making process for aligning plans of individual SC members with the aim of achieving coordination in light of information asymmetry. Then, to generate a good production-distribution plan in a SC, it is necessary to resolve conflicts between several decentralised functional units, because each unit tries to locally optimise its own objectives, rather than the overall SC objectives. Because of this, in the last few years, the visions that cover a CP process such as a distributed decision-making process are getting more important (Hernández et al. 2009).

Selim et al. (2008) assert that fuzzy goal programming (FGP) approaches can effectively be used in handling the collaborative production and distribution planning problems in both centralized and decentralized SC structures. The reasons of using FGP approaches in this type of problems are explained by Selim et al. (2008) as follows:

1. Collaborative planning is the more preferred mode of operation by today's companies operated in SCs. These companies may consent to sacrifice the aspiration levels for their goals to some extent in the short run to provide the loyalty of their partners or to strengthen their partners' competitive position in the long term. In this way, they can facilitate providing a long-term collaboration with their partners and subsequently gaining a sustainable competitive advantage.

2. Due to the impreciseness of the decision makers' aspiration levels associated with each goal, conventional deterministic goal programming (GP) approach cannot fully reflect such complexity.
3. Collaborative planning problems in SCs are complex and mostly multiple objective problems, and often include incommensurable goals. Incommensurability problem in goal programming occurs when deviational variables measured in different units are summed up directly. In goal programming technique, a normalization constant is needed to overcome this difficulty. However, in FGP, incommensurable goals can be treated in a reasonable and practical way.

Therefore, it may be appropriate to use FGP approaches in production and distribution planning problems existing in real-world supply chains.

We arrange the rest of this work as follows. Section 2 presents a literature review about integrated production and distribution planning models, as well as collaborative. Section 3 describes the FGP approaches to deal with supply chain planning problem in centralized and decentralized SC structures. Section 4 presents a multi-objective, multi-product and multi-period model for the master planning problem in a ceramic tile SC. Then, in Section 5, the solution methodology and the FGP approaches for different SC structures (i.e. centralized and decentralized) are described. Section 6 validates and evaluates our proposal by using an example based on a real-world problem. Finally, Section 7 provides conclusions and directions for further research.

2. Literature review

The considered ceramic supply chain master planning (CSCMP) problem deals with a medium term production and distribution planning problem in a four-echelon ceramic tile supply chain involving one manufacturer, multiple warehouses, multiple logistic centres and multiple shops. The integration of production and distribution planning decisions is crucial to ensure the overall performance of the SC, and has attracted attention both from practitioners and academics for many years (Vidal & Goetschalckx 1997; Erengüç et al. 1999; Bilgen & I. Ozkarahan 2004; Mula et al. 2010). According to Liang & Cheng (2009), in production and distribution planning problems, the decision maker (DM) attempts to: (1) set overall production levels for each product category for each source (manufacturer) to meet fluctuating or uncertain demand for various destinations (distributors) over the intermediate planning horizon and (2) make suitable strategies regarding regular and overtime production, subcontracting, inventory, and distribution levels, and thus determining appropriate resources to be used.

On supply chain planning, most prior studies have concentrated on formulating a sophisticated supply chain planning model and devising an efficient algorithm to solve it under a centralized supply chain environment where all supply chain participants are grouped as one organization or company and all functions of a supply chain are fully integrated by an independent planning department or supervisor (Jung et al. 2008). According to Mula et al. (2010), the vast majority of works that deal with the production and distribution integration opt for the linear-programming based approach, particulary mixed integer linear programming models. Chen & Wang (1997) proposed a linear programming model to solve integrated supply, production and distribution planning in a supply chain of the steel sector. McDonald & Karimi (1997) presented a mixed deterministic integer linear programming model to solve a production and transport planning problem in the chemical industry in a multi-plant, multi-product and multi-period environment. Timpe & Kallrath (2000) and Kallrath (2002) presented a couple of models for production, distribution and sales planning with different time scales for business and production aspects. Dhaenens-Flipo & Finke (2001) modelled a multi-facility, multi-item, multi-period production and distribution model in the form of a network flow. Park (2005) suggested an integrated transport and production planning model in a multi-site, multi-retailer, multi-product and multi-period environment. Likewise, the author also presented a production planning submodel whose outputs act as the input in another submodel with a transport planning purpose and an overall objective of maximizing overall profits with the same technique. Ekş{}ioğ{}lu et al. (2006) showed an integrated transport and production planning model in a multi-period, multi-site, monoproduct environment as a flow or graph network to which the authors added a mixed integer linear programming formulation. Later, Ekşioğlu et al. (2007) extended this model to become a multi-product model solved by Lagrangian decomposition. Ouhimmou et al. (2008) developed a mixed integer linear programming (MIP) model for tactical planning in a furniture supply chain related to production and logistics decisions. Fahimnia et al. (2009) proposed a model for the optimization of the complex two-echelon supply networks based on the integration of aggregate production plan and distribution plan.

According to Dudek & Stadtler (2005) the relevant literature on linking and coordinating the planning process in a decentralized manner, distinguishes three main approaches: coordination by contracts, multi-agent systems and mathematical programming models. The largest number of references reviewed in Stadtler (2009) employs mathematical decomposition (exact mathematical decomposition, heuristic mathematic decomposition and meta-heuristics). Originally developed for solving large-scale linear programming, mathematical decomposition methods seem to be an attractive alternative for solving distributed decision-making problems. Barbarosoglu & Özgür (1999) developed a model which is solved by Lagrangian and heuristic relaxation techniques to become a decentralized two-stage model: one for production planning and another for transport planning. It generates a final plan level by level, where one stage determines both its own plan and supply requirements and passes the requirements to the next stage. Luh et al. (2003) presented a framework combining mathematical optimization and the contract communication protocol for make-to-order supply network coordination based in this relaxation method. Nie et al. (2006) developed a collaborative planning framework combining the Lagrangian relaxation method and genetic algorithms to coordinate and optimize the production planning of the independent partners linked by material flows in multiple tier supply chains. Moreover, Walther et al. (2008) applied a relaxation approach for distributed planning in a product recovery network.

However, these examples require the presence of a central coordinator with a complete control over the entire supply chain, otherwise there is no guarantee for convergence of the final solution without extra modification procedure or acceptance functions because of the duality gap or the oscillation of mathematical decomposition methods (Jung et al. 2008). In this context, FGP can be a valid alternative to the previous drawbacks.

Fuzzy mathematical programming, especially the fuzzy goal programming (FGP) method, has widely been applied for solving various multi-objective supply chain planning problems. Among them, Kumar et al. (2004) and Lee et al. (2009) presented FGP approaches for supplier selection problems with multiple objectives. Liang (2006) presented a FGP approach for solving integrated production and distribution planning problems with fuzzy multiple goals in uncertain environments. The proposed model aims to simultaneously minimize the total distribution and production costs, the total number of rejected items, and the total delivery time. Torabi & Hassini (2009) proposed a multi-objective, multi-site production planning FGP model integrating procurement and distribution plans in a multi-echelon automotive supply chain network.

3. Modelling approaches for centralized and decentralized planning in SC structures

3.1 Planning in centralized supply chain structure

According to their basic structures, SCs can be categorized as centralized and decentralized. A supply chain is called centralized if a single dominant firm has all the information and tries to, in the short run, simply optimize its own operational decisions regardless of the impact of such decisions on the other stages of the chain (Erengüç et al. 1999). According to Selim et al. (2008), FGP approaches can be used in handling collaborative master planning problems in both centralized and decentralized SC structures. In order to handle the problem in centralized SC, Selim et al. (2008) propose to use Tiwari et al. (1987) weighted additive approach defined as follows:

$$\begin{aligned} &\textit{Maximize} \sum_k w_k \mu_k(x) \\ &\textit{subject to } \mu_k \in [0,1] \quad \forall k \\ &\qquad x \geq 0 \end{aligned} \tag{1}$$

In this approach, w_k and μ_k denotes the weight and the satisfaction degree of the kth goal respectively. Therefore, the weighted additive approach allows the dominant partner in the SC to assign different weights to the individual goals in the simple additive fuzzy achievement function to reflect their relative importance levels.

3.2 Planning in decentralized supply chain structure

A SC is called decentralized when various decisions are made in different companies that try to optimize their own objectives. Selim et al. (2008) state that the methods that take account of min operator are suitable in modelling the collaborative planning problems in decentralized SC structures. Among these methods, Selim et al. (2008) propose to use Werners (1988) fuzzy and operator to address the SC collaborative planning problems in decentralized SC structures. By adopting min operator into Werners' approach the following linear programming problem can be obtained:

$$\begin{aligned} &\textit{Maximize } \ \gamma\lambda + (1-\gamma)(1/K)\sum_k \lambda_k \\ &\textit{subject to } \ \mu_k(x) \geq \lambda + \lambda_k \quad \forall k \in K, \forall x \in X \\ &\qquad \lambda, \lambda_k, \gamma \in [0,1] \end{aligned} \tag{2}$$

where K is the total number of objectives, μ_k is the membership function of goal k, and γ is the coefficient of compensation defined within the interval [0,1]. In this approach, the coefficient of compensation can be treated as the degree of willingness of the SC partners to sacrifice the aspiration levels for their goals to some extent in the short run to provide the loyalty of their partners and/or to strengthen their competitive position in the long run.

To explore the viability of the proposed fuzzy modelling approaches for the collaborative SC planning in centralized and decentralized SC structures, we consider a supply chain master planning problem related to a ceramic tile supply chain in the next section.

4. Model formulation

We adopt the ceramic supply chain master planning problem presented in Alemany et al. (2010). Figure 1 shows the structure of a typical SC of the ceramic sector. The authors describe the peculiarities related to these SCs and consider several assumptions. First, the flow of parts, components, raw materials (RMs) and finished goods (FGs) that might circulate between the nodes is known beforehand. The existence of several production plants situated in various geographical locations is also assumed. These production plants are supplied with various RMs provided by different suppliers with a limited supply capacity.

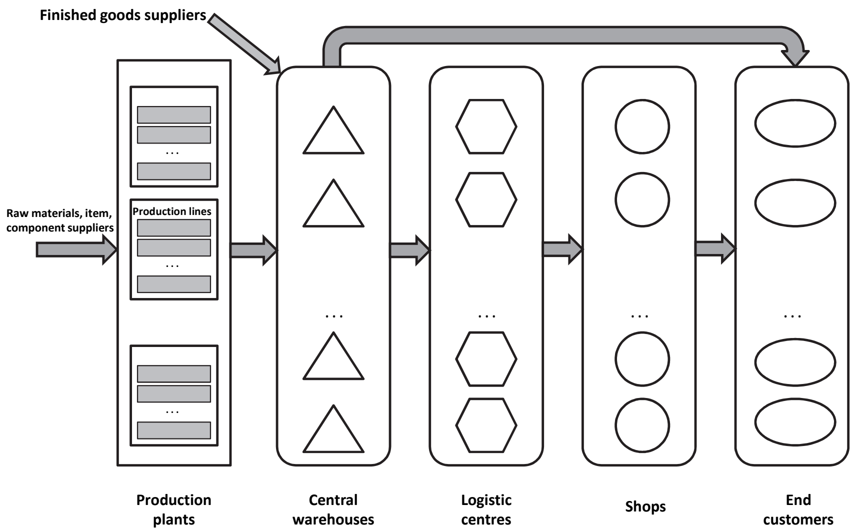

Fig. 1. Ceramic tile SC considered in Alemany et al. (2010)

In the SC under study, each production plant has one or several parallel production lines, which process different FGs, with a limited capacity. Moreover, there are FGs with high added values that are manufactured only in production plants; others may be partly subcontracted, while some may be totally subcontracted to external suppliers. FGs are grouped into product families to minimize setup times and costs. A product family is defined as a group of FGs with identical physical characteristics and whose preparation on product lines is similar. Given the important setup times between product families on production lines, minimum run lengths for product families are specified. Item setups among the products belonging to the same product family also exist. Because of technological factors involved in the production process itself, each product should be produced in an equal or greater amount than the minimum lot size defined, when it's manufactured on a specific line.

The distribution of FGs from production plants to end customers is carried out in various stages by different types of distribution centres, such as central warehouses, logistic centres and shops. Neither manufactured nor subcontracted FGs can be stored in manufacturing plants. They are sent to the first distribution level which is composed of several central warehouses with a limited storage capacity. The demand of end customers and logistics centres is covered by the outgoing FGs from central warehouses. Besides, logistics centres only supply FGs to shops that have been previously assigned to them. Finally, shops only attend end costumers' demand. Although a maximum service level is pursued in this SC, limited backorders are permitted in both central warehouses and shops.

4.1 Nomenclature

The nomenclature defines the indices, sets of indices, parameters and decision variables (Table 1).

Indices			
c	RMs, items, and components (*c*=1…*C*)	*q*	Logistic centres (q=1…*Q*)
i	FGs (*i*=1…*I*)	*w*	Shops (*w*=1…*W*)
f	Product families (f=1…*F*)	*r*	Suppliers of RMs, items, and components (r=1…*R*)
l	Production lines (*l*=1…*L*)		
p	Production plants (p=1…*P*)	*b*	Suppliers of finished products (b=1…*B*)
a	Warehouses (*a*=1…*A*)	*t*	Periods of time (*t*=1…*T*)
Sets of Indices			
Il(l)	Set of FGs that can be manufactured on manufacturing line *l*	*Lp(p)*	Set of manufacturing lines that belong to production plant *p*
Fl(l)	Set of product families that can be manufactured on manufacturing line *l*	*Pa(a)*	Set of production plants that can send FGs to warehouse *a*
If(f)	Set of FGs that belong to product family *f*	*Aq(q)*	Set of warehouses that can supply logistics centre *q*
Ip(p)	Set of FGs that can be produced in production plant *p*	*Rc(c)*	Set of suppliers that can supply RM *c*
Ia(a)	Set of FGs that can be stored in warehouse *a*	*Rp(p)*	Set of suppliers of RMs that can supply production plant *p*
Ic(c)	Set of FGs of that RM *c* form part	*Cr(r)*	Set of RMs that can be supplied by supplier *r*
PFNS	Set of FGs that cannot be subcontracted	*Qa(a)*	Set of logistics centres that can be supplied by warehouse *a*
PFSP	Set of FGs that can be subcontracted either partially or completely	*Wq(q)*	Set of shops that can be supplied by logistics centres *q*

PFST	Set of FGs that are compulsorily subcontracted completely	*Qw(w)*	Set of logistics centres capable of supplying shop *w*
Iq(q)	Set of FGs that can be sent to logistics centre *q*	*Bi(i)*	Set of suppliers of FGs *i* to which the FG may be subcontracted
Iw(w)	Set of FGs that can be sent to shop *w*	*Ba(a)*	Set of suppliers of FGs that can supply warehouse *a*
Lf(f)	Set of manufacturing lines that may produce product family *f*	*Ab(b)*	Set of warehouses that can be supplied by the supplier *b* of FGs

Model Parameters

ca_{crt}	Capacity (units) of supplying RM *c* of supplier *r* in period *t*	*M1,M2*	Very large integers
$costtp_{crp}$	Cost of purchase and transport of one unit of RM *c* from supplier *r* to production plant *p*	$capal_a$	Storage capacity (m^2) in warehouse *a*
caf_{lpt}	Production capacity available (time) of production line *l* at plant *p* during time period *t*	$costtcl_{iaq}$	Cost of transporting one m^2 of FG *i* from warehouse *a* to logistics centre *q*
cm_i	Loss ratio of FG *i*. It represents the percentage of faulty m^2 obtained due to the intrinsic characteristics of the production process in the ceramics sector.	$costina_{ia}$	Cost of making an inventory of one m^2 of FG *i* in the warehouse during a time period
cq_i	First quality coefficient of FG *i*. It represents the percentage of m^2 that can be sold as first quality.	$costdifa_{ia}$	Cost of backordering one m^2 of demand of FG *i* in warehouse *a* in a time period
$costta_{ipa}$	Cost of transporting one m^2 of FG *i* from production plant *p* to warehouse *a*	pa_{ia}	Sales value of one m^2 of FG *i* in warehouse *a*
$costp_{ilp}$	Cost of producing one m^2 of FG *i* on production line *l* of production plant *p*	da_{iat}	External demand (m^2) of FG *i* at the warehouse *a* in period *t*
$costsetupf_{flp}$	Setup costs for product family *f* on production line *l* of production plant *p*	ssa_{ia}	Safety stock (m^2) of FG *i* at warehouse *a*
$costsetup_{ilp}$	Setup costs for FG *i* on production line *l* of production plant *p*	$\alpha 1$	Maximum backorder quantity permitted in a period in warehouses expressed as a percentage of the demand of that period
$tfab_{ilp}$	Time to process one m^2 of FG *i* on production line *l* of production plant *p*	$costsc_{ib}$	Cost of subcontracting one m^2 of FG *i* to FG supplier *b*

$tsetupf_{flp}$	Setup time for product family *f* on production line *l* of production plant *p*	$minsc_{ib}$	Minimum amount (m^2) of FG *i* to be subcontracted to FG supplier *b*
$tsetupi_{ilp}$	Setup time for article *i* on production line *l* of production plant *p*	$costttk_{iqw}$	Cost to transport one m^2 of FG *i* from logistics centre *q* to shop *w*
lmi_{ilp}	Minimum lot size (m^2) of FG *i* on production line *l* of production plant *p*	$costdiftk_{iw}$	Cost to backorder one m^2 of the demand of FG *i* in a time period at shop *w*
tmf_{flp}	Minimum run length (expressed as multiples of the time period used) of product family *f* on production line *l* of production plant *p*	pw_{iw}	Sales price of one m^2 of FG *i* in shop *w*
v_{ic}	Units of RM *c* needed to produce one m^2 of FG *i*	dtk_{iwt}	External demand (m^2) of FG *i* in shop *w* during the time period *t*
ssc_{cp}	Safety stock of RM *c* in production plant *p*	$\alpha 2$	Maximum backorder quantity permitted in a period in shops expressed as a percentage of the demand of that period
		$casc_{ibt}$	Supply capacity (m^2) of FG *i* of supplier *b* in time period *t*
Decision Variables			
CTP_{crpt}	Amount of RM *c* to be purchased and transported from supplier *r* to production plant *p* in time period *t*	INA_{iat}	Inventory (m^2) of FG *i* in warehouse *a* in time period *t*
INC_{cpt}	Inventory of the RM *c* at plant *p* at the end of time period *t*	CSC_{ibat}	Amount (m^2) of FG *i* subcontracted to supplier *b* for warehouse *a* in time period *t*
MPF_{flpt}	Amount (m^2) of product family *f* manufactured on production line *l* of production plant *p* in time period *t*	S_{ibt}	Binary variable with a value of 1 if FG *i* is subcontracted to supplier *b* in time period *t*
MP_{ilpt}	Amount (m^2) of FG *i* manufactured on production line *l* of production plant *p* in time period *t*	VEA_{iat}	Amount (m^2) of FG *i* sold in warehouse *a* during time period *t*
X_{ilpt}	Binary variable with a value of 1 if FG *i* is manufactured on production line *l* of production plant *p* in time period *t*, and with a value of 0 otherwise	$DIFA_{iat}$	Backorder quantity (m^2) of FG *i* in warehouse *a* during time period *t*

Y_{flpt}	Binary variable with a value of 1 if product family *f* is manufactured on production line *l* of production plant *p* in time period *t*, and with a value 0 otherwise	$CTCL_{iaqt}$	Amount (m²) of FG *i* transported from warehouse *a* to logistics centre *q* in time period *t*
ZI_{ilpt}	Binary variable with a value of 1 if a setup takes place of product *i* on production line *l* of production plant *p* in time period *t*, and with a value of 0 otherwise	$CTTK_{iqwt}$	Amount (m²) of FG *i* transported from logistics centre *q* to shop *w* in time period *t*
ZF_{flpt}	Binary variable with a value of 1 if a setup takes place of product family *f* on production line *l* of production plant *p* in time period *t*, and with a value of 0 otherwise	$VETK_{iwt}$	Amount (m²) of FG *i* sold in shop *w* during time period *t*
CTA_{ipat}	Amount (m²) of FG *i* to be transported from production plant *p* to warehouse *a* in time period *t*	$DIFTK_{iwt}$	Backorder quantity (m²) of FG *i* in shop *w* during time period *t*

Table 1. Nomenclature.

The formulation of the model is as follows.

4.2 Objective functions

Formulations of the objective functions of the ceramic supply chain master planning model are presented in the following.

- Manufacturer's cost function (COSTM)

COSTM = Total procurement cost + Total manufacturing cost + Total transportation to warehouses cost

$$Minimize \left\{ \begin{array}{l} \sum_t \sum_p \sum_{r \in Rp(p)} \sum_{c \in Cr(r)} \cos ttp_{crp} * CTP_{crpt} + \sum_t \sum_p \sum_{l \in Lp(p)} \sum_{i \in Il(l)} \cos tp_{ilp} * MP_{ilpt} \\ + \sum_t \sum_p \sum_{l \in Lp(p)} \sum_{f \in Fl(l)} \cos tsetupf_{flp} * ZF_{flpt} + \sum_t \sum_p \sum_{l \in Lp(p)} \sum_{i \in Il(l)} \cos tsetupi_{ilp} * ZI_{ilpt} \\ + \sum_t \sum_a \sum_{p \in Pa(a)} \sum_{i \in Ip(p)} \cos tta_{ipa} * CTA_{ipat} \end{array} \right\} \quad (3)$$

- Profit function of warehouse *a* (WaPROFIT)

WaPROFIT = Sales revenue – Total inventory cost – Total subcontracting cost – Total transportation to logistic centres cost – Total backorder cost

$$Maximize \left\{ \begin{array}{l} \sum_t \sum_i pa_{ia} * VEA_{iat} - \sum_t \sum_{i \in Ia(a)} \cos tina_{ia} * INA_{iat} - \sum_t \sum_i \sum_{b \in Bi(i)} \cos tsc_{ib} * CSC_{ibat} \\ - \sum_t \sum_{q \in Qa(a)} \sum_{i \in Iq(q)} \cos ttcl_{iaq} * CTCL_{iaqt} - \sum_t \sum_{i \in Ia(a)} DIFA_{iat} \end{array} \right\} \quad (4)$$

- Cost function of logistic centre *q* (LCqCOST)

$LCqCOST$ = Total transportation to shops cost

$$Minimize\left\{\sum_{t}\sum_{w\in Wq(q)}\sum_{i\in Iw(w)}\cos tttk_{iqw} * CTTK_{iqwt}\right\} \tag{5}$$

- Profit function of shop w (SwPROFIT)

$SwPROFIT$ = Sales revenue - Total backorder cost

$$Maximize\left\{\sum_{t}\sum_{i} pw_{iw} * VETK_{iwt} - \sum_{t}\sum_{i\in Iw(w)} DIFTK_{iwt}\right\} \tag{6}$$

4.3 Constraints

The constraints originally proposed by Alemany et al. (2010) are briefly reviewed as follows: Constraint (7) is the inventory balance equation for RMs.

$$INC_{cpt} = INC_{cpt-1} + \sum_{r\in Rc(c)} CTP_{crpt} - \sum_{i\in Ic(c)} (v_{ic} * \sum_{l\in Lp(p)} MP_{ilpt}) \qquad \forall c,p,t \tag{7}$$

Constraint (8) establishes safety stocks for RMs.

$$INC_{cpt} \geq ssc_{cp} \qquad \forall c,p,t \tag{8}$$

Constraint (9) defines the available capacity of supply for RMs suppliers.

$$\sum_{p} CTP_{crpt} \leq ca_{crt} \qquad \forall c, r\in Rc(c), t \tag{9}$$

Constraint (10) establishes the available capacity for production lines.

$$\sum_{f\in Fl(l)} tsetupf_{flp} * ZF_{flpt} + \sum_{i\in Il(l)} \left(tsetupi_{ilp} * ZI_{ilpt} + tfab_{ilp} * MP_{ilpt}\right) \leq caf_{lpt} \qquad \forall p, l\in Lp(p), t \tag{10}$$

Constraint (11) is related to the product families to be produced in each line.

$$MPF_{flpt} = \sum_{i\in If(f)} MP_{ilpt} \qquad \forall p, l\in Lp(p), f\in Fl(l), t \tag{11}$$

Constraint (12) establishes minimum lot sizes for FGs' production.

$$MP_{ilpt} \geq lmi_{ilp} * X_{ilpt} \qquad \forall p, l\in Lp(p), i\in Il(l), t \tag{12}$$

Constraints (13) and (14) allocate products and product families to each line. Parameters M1 and M2 are large enough integer numbers.

$$MP_{ilpt} \leq M1 * X_{ilpt} \qquad \forall p, l\in Lp(p), i\in Il(l), t \tag{13}$$

$$MPF_{flpt} \leq M2 * Y_{flpt} \qquad \forall p, l\in Lp(p), f\in Fl(l), t \tag{14}$$

Constraints (15)-(18) guarantee the control of the setup of FGs and product families.

$$ZI_{ilpt} \geq X_{ilpt} - X_{ilpt-1} \qquad \forall p, l \in Lp(p), i \in Il(l), t \tag{15}$$

$$\sum_i ZI_{ilpt} \geq \sum_i X_{ilpt} - 1 \qquad \forall p, l \in Lp(p), t \tag{16}$$

$$ZF_{flpt} \geq Y_{flpt} - Y_{flpt-1} \qquad \forall p, l \in Lp(p), f \in Fl(l), t \tag{17}$$

$$\sum_f ZF_{flpt} \geq \sum_f Y_{flpt} - 1 \qquad \forall p, l \in Lp(p), t \tag{18}$$

Constraint (19) ensures the accomplishment of the family run lenght

$$\sum_{t=t'}^{t'+tmf_{flp}-1} ZF_{flpt} \leq 1 \qquad \forall p, l \in Lp(p), f \in Fl(l), t' = 1,..,T - tmf_{flp} + 1 \tag{19}$$

Constraint (20) ensures that only first quality FGs are transported to the central warehouses.

$$\sum_{l \in Lp(p)} (1 - cm_i) * cq_i * MP_{ilpt} = \sum_{a \in Ap(p)} CTA_{ipat} \qquad \forall p, i \in Ip(p), t \tag{20}$$

Constraints (21)-(24) are related to subcontracting decisions. These constraints also ensure that the amount of FGs subcontracted is transported to warehouses.

$$\sum_{a \in Ab(b)} CSC_{ibat} \geq \min sc_{ib} * S_{ibt} \qquad \forall i \in PFSP, b \in Bi(i), t \tag{21}$$

$$\sum_{a \in Ab(b)} CSC_{ibat} \geq \min sc_{ib} * S_{ibt} \qquad \forall i \in PFST, b \in Bi(i), t \tag{22}$$

$$\sum_{a \in Ab(b)} CSC_{ibat} \leq casc_{ibt} * S_{ibt} \qquad \forall i \in PFSP, b \in Bi(i), t \tag{23}$$

$$\sum_{a \in Ab(b)} CSC_{ibat} \leq casc_{ibt} * S_{ibt} \qquad \forall i \in PFST, b \in Bi(i), t \tag{24}$$

Constraint (25) establishes safety stocks for FGs.

$$INA_{iat} \geq ssa_{ia} \qquad \forall a, i \in Ia(a), t \tag{25}$$

Constraint (26) fixes the capacity of the warehouses.

$$\sum_{i \in Ia(a)} INA_{iat} \leq capal_a \qquad \forall a, t \tag{26}$$

Constraints (27)-(28) are inventory balance equations for FGs in warehouses.

$$INA_{iat} = INA_{iat-1} + \sum_{p \in Pa(a)} CTA_{ipat} - VEA_{iat} - \sum_{q \in Qa(a)} CTCL_{iaqt} \qquad \forall i \in PFNS, a, t \tag{27}$$

$$INA_{iat} = INA_{iat-1} + \sum_{p \in Pa(a)} CTA_{ipat} + \sum_{b \in Ba(a) \wedge b \in Bi(i)} CSC_{ibat} - VEA_{iat} - \sum_{q \in Qa(a)} CTCL_{iaqt}$$

$$\forall i \in PFSP, a, t \quad (28)$$

Constraint (29) is similar to (27)-(28) but also ensures the subcontracted FGs only comes from FG suppliers.

$$INA_{iat} = INA_{iat-1} + \sum_{b \in Ba(a) \wedge b \in Bi(i)} CSC_{ibat} - VEA_{iat} - \sum_{q \in Qa(a)} CTCL_{iaqt} \quad \forall i \in PFST, a, t \quad (29)$$

Backorder quantities in warehouses are calculated using Constraint (30).

$$VEA_{iat} + DIFA_{iat} - DIFA_{iat-1} = da_{iat} \quad \forall a, i \in Ia(a), t \quad (30)$$

Constraint (31) limits the backorder quantities in warehouses.

$$DIFA_{iat} \leq \alpha 1 * da_{iat} \quad \forall a, i \in Ia(a), t \quad (31)$$

Constraints (32) and (33) are the inflows and outflows of FGs through each logistic centre and shop, respectively.

$$\sum_{a \in Aq(q)} CTCL_{iaqt} = \sum_{w \in Wq(q)} CTTK_{iqwt} \quad \forall q, i \in Iq(q), t \quad (32)$$

$$CTTK_{iqwt} = VETK_{iwt} \quad \forall w, q \in Qw(w), i \in Iw(w), t \quad (33)$$

Constraint (34) determines backorder quantities in shops.

$$VETK_{iwt} + DIFTK_{iwt} - DIFTK_{iwt-1} = dtk_{iwt} \quad \forall w, i \in Iw(w), t \quad (34)$$

Constraint (35) limits the backorder quantities in shops.

$$DIFTK_{iwt} \leq \alpha 2 * dtk_{iwt} \quad \forall w, i \in Iw(w), t \quad (35)$$

The model also contemplates non-negativity constraints and the definition of binary variables (36).

$$MPF_{flpt}, MP_{ilpt}, CTP_{crpt}, CTA_{ipat}, INA_{iat}, INC_{cpt}, CTCL_{iaqt}, CTTK_{iqwt}, VEA_{iat}, DIFA_{iat},$$

$$VETKiwt, DIFTK_{iwt}, CSC_{ibat} \geq 0 \text{ and, } X_{ilpt}, Y_{flpt}, ZF_{flpt}, ZI_{ilpt}, S_{ibt} \in \{0,1\} \quad (36)$$

$$\forall f \in F, \forall i \in I, \forall c \in C, \forall l \in L, \forall p \in P, \forall a \in A, \forall q \in Q, \forall w \in W, \forall r \in R, \forall b \in B, \forall t \in T$$

Finally, some decision variables can be defined as integers, but it could change depending on the real-world problem where the model is applied.

5. Solution methodology

In order to reach a preferred solution for the ceramic master planning problem in centralized and decentralized SC structures the Tiwari et al. (1987) and Werners (1988) approaches are adopted to transform the multi-objective FGP model to a mixed integer linear programming (MILP) one.

5.1 Defining the membership functions

There are many possible forms for a membership function to represent the fuzzy objective functions: linear, exponential, hyperbolic, hyperbolic inverse, piece-wise linear, etc. (see Peidro & Vasant (2009) for a comparison of the main types of membership functions). Among the various types of membership functions, the most feasible for constructing a membership function for solving fuzzy mathematical programming problems is the linear form, although there may be preferences for other patterns with some applications (Zimmermann 1975; Zimmermann 1978; Tanaka et al. 1984). Moreover, the main advantage of the linear membership functions is that they generate equivalent, efficient and computationally linear models.

We formulate the corresponding non increasing continuous linear membership functions for objective function as follows (Bellman & Zadeh 1970):

$$\mu_m = \begin{cases} 1 & z_m < z_m^l \\ \dfrac{z_m^u - z_m}{z_m^u - z_m^l} & z_m^l < z_m < z_m^u \\ 0 & z_m > z_m^u \end{cases} \tag{37}$$

$$\mu_M = \begin{cases} 1 & z_M > z_M^u \\ \dfrac{z_M - z_M^l}{z_M^u - z_M^l} & z_M^l < z_M < z_M^u \\ 0 & z_M < z_M^l \end{cases} \tag{38}$$

where μ_m is the membership function of a minimization objetive z_m and μ_M is the membership function of a maximization objetive z_M. Moreover, z_m^l, z_M^l and z_m^u, z_M^u are the lower and upper bounds of the objective functions. We can determine each membership function by asking the decision maker to specify the fuzzy objective value interval (37)-(38). Besides, we can obtain these bounds from the optimisation values of each objective function.

5.2 Transforming the multi-objective FGP model into an MILP model for centralized SC structures

According to Selim et al. (2008), the Tiwari et al. (1987) weighted additive approach can be used to handle the collaborative ceramic master planning problem in a centralized SC structure. By adopting this approach, the problem can be formulated as follows:

$$\left.\begin{array}{ll} \textit{Maximize} & w_1\mu_{COSTM} + w_2\sum_a \mu_{W_a PROFIT} + w_3\sum_q \mu_{LC_q COST} + w_4\sum_w \mu_{S_w PROFIT} \\ \textit{subject to} & \mu_{COSTM}, \mu_{W_a PROFIT}, \mu_{LC_q COST}, \mu_{S_w PROFIT} \in [0,1] \end{array}\right\} \tag{39}$$

This model also considers Constraints (7) to (36).

w_1, w_2, w_3 and w_4 denotes the weights of manufacturer's, warehouses', logistic centres' and shops' objectives, respectively.

5.3 Transforming the multi-objective FGP model into an MILP model for decentralized SC structures

To deal with the collaborative ceramic master planning problem in a decentralized SC, according to Selim et al. (2008), the Werners (1988) approach can be adopted. By using the Werners' fuzzy and operator, the problem under study can be formulated as follows:

$$\left.\begin{array}{ll} \textit{Maximize} & \gamma\lambda + (1-\gamma)\left(\dfrac{1}{1+A+Q+W}\right)\left[\lambda_1 + \sum_a \lambda_a + \sum_q \lambda_q + \sum_w \lambda_w\right] \\ \textit{subject to} & \mu_{COSTM} \ge \lambda + \lambda_1 \\ & \mu_{W_aPROFIT} \ge \lambda + \lambda_a \qquad \forall a \\ & \mu_{LC_qCOST} \ge \lambda + \lambda_q \qquad \forall q \\ & \mu_{S_wPROFIT} \ge \lambda + \lambda_w \qquad \forall w \\ & \mu_{COSTM}, \mu_{W_aPROFIT}, \mu_{LC_qCOST}, \mu_{S_wPROFIT}, \lambda, \lambda_1, \lambda_a, \lambda_q, \lambda_w, \gamma \in [0,1] \end{array}\right\} \tag{40}$$

This model also considers Constraints (7) to (36).
A, Q and W are the total number of warehouses, logistic centres and shops in the SC.

6. Application to a ceramic tile supply chain

This section uses the example provided by Alemany et al. (2010) to validate and evaluate the results of our proposal. It is a representative SC of the ceramic tile sector. There are 3 production plants, which produce 4 FGs grouped into 3 product families which rates, minimum run lengths and fixed costs are provided. Each plant contains two production lines. All the product families may be manufactured on the production lines at the various plants. Moreover, there are 2 warehouses, 3 logistics centres and 6 shops. They are considered six weeks periods in the planning horizon. Also, they are provided the following information: bill of materials, transportation costs, setup costs, initial inventory, available production and storage capacities, raw material costs, safety stocks, inventory costs, setup times, production costs, sale prices, subcontracting costs, backorder costs, production run times, minimum lot sizes and demand. Details on this data used can be found in Alemany et al. (2010).

6.1 Implementation and resolution

The proposed models have been developed with the modelling language MPL and solved by the CPLEX 12 solver in an Intel Xeon, at 2.93 GHz, with 48 GB of RAM. The input data and the model solution values have been processed with the Microsoft SQL Server Database (2008).
We define each membership function by obtaining upper and lower bounds of each objective function. The upper and lower bounds obtained by maximizing and minimizing each objective function separately are presented in Table 2.

6.2 Evaluation of results

As stated previously, we adopt the weighted additive approach proposed by Tiwari et al. (1987) to deal with the collaborative CSCMP problem in a centralized SC structure. To explore the influence of different weight structures on the results of the problem several problem instances are generated. Solution results of the model obtained by Tiwari et al. (1987) weighted additive approach are presented in Table 3. It is clear that determination of the weights requires expert opinion so that they can reflect accurately the relations between the different partners of a SC. In Table 3, w_1, w_2, w_3 and w_4 denotes the weights of manufacturer's, warehouses', logistic centres' and shops' objectives for each instance. On the other hand, Table 3 adds the degree of satisfaction of the objective functions for the proposed method.

Objectives	Upper bound	Lower bound
COSTM	785545	543825
W_1PROFIT	302078	171296
W_2PROFIT	332787	198072
LC_1COST	1359	1329
LC_2COST	1187	1162
LC_3COST	1227	1199
S_1PROFIT	66552	64784
S_2PROFIT	65825	64154
S_3PROFIT	68787	67044
S_4PROFIT	66448	64727
S_5PROFIT	68486	66643
S_6PROFIT	59838	58288

Table 2. Upper and lower bounds of the objectives.

	Problem instances								
	1	2	3	4	5	6	7	8	9
$w1$	0.25	0.4	0.3	0.3	0.4	0.2	0.3	0.3	0.3
$w2$	0.25	0.2	0.2	0.2	0.1	0.2	0.4	0.2	0.1
$w3$	0.25	0.2	0.2	0.1	0.1	0.3	0.2	0.4	0.1
$w4$	0.25	0.2	0.3	0.4	0.4	0.3	0.1	0.1	0.5
μ_{COSTM}	0.7666	0.7707	0.7655	0.7655	0.9834	0.7672	0.7747	0.7760	0.9536
$\mu_{W1PROFIT}$	1.0000	1.0000	1.0000	1.0000	0.9507	1.0000	1.0000	1.0000	0.9956
$\mu_{W2PROFIT}$	0.5738	0.5670	0.5681	0.5681	0.1153	0.5738	0.5779	0.5780	0.1726
$\mu_{LC1COST}$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4662	0.5629	0.0000
$\mu_{LC2COST}$	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000
$\mu_{LC3COST}$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000
$\mu_{S1PROFIT}$	0.8335	0.8335	1.0000	1.0000	1.0000	0.8335	0.4694	0.3224	1.0000
$\mu_{S2PROFIT}$	0.6118	0.6118	0.9506	0.9506	0.9506	0.6118	0.6118	0.3830	0.9506
$\mu_{S3PROFIT}$	0.9187	0.9187	1.0000	1.0000	1.0000	0.9187	0.5965	0.5965	1.0000
$\mu_{S4PROFIT}$	0.9175	0.9175	1.0000	1.0000	1.0000	0.9175	0.5477	0.5477	1.0000
$\mu_{S5PROFIT}$	0.8919	0.8919	1.0000	1.0000	1.0000	0.8919	0.4653	0.4653	1.0000
$\mu_{S6PROFIT}$	0.8651	0.8651	1.0000	1.0000	1.0000	0.8651	0.5752	0.5752	1.0000

Table 3. Solution results obtained by Tiwari et al. (1987) approach.

Table 4 shows the degree of satisfaction of each objective function obtained by Werners (1988) approach with different values of the coefficient of compensation (γ). It is observed from Fig. 2 that the range of the achievement levels of the objectives increases with the decrease of the coefficient of compensation, taking the maximum possible value in the interval 0.5-0. That is, the higher the compensation coefficient γ values, the lower the difference between the degrees of satisfaction of each partner of the decentralized SC. So, for high values of γ, we can obtain compromise solutions for the all members of the SC, rather than solutions that only satisfy the objectives of a small group of these partners. Table 4 shows in general terms, the reduction of the degree of satisfaction of logistics centres 1 and 3 and shop 2, at the expense of substantially increasing the degree of satisfaction of the logistic center 2 and the rest of shops. Also, the degree of satisfaction related to warehouse 1 increases while reducing the degree of satisfaction associated to warehouse 2.

	ϒ									
	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0
μ_{COSTM}	0.7728	0.7722	0.7733	0.7723	0.7672	0.7672	0.7672	0.7672	0.7666	0.7672
$\mu_{W1PROFIT}$	0.929	0.9262	0.9274	0.9317	1,0000	0.9762	0.9622	0.9622	1,0000	0.9622
$\mu_{W2PROFIT}$	0.6405	0.6468	0.6442	0.6416	0.5736	0.5967	0.6099	0.6093	0.5732	0.6093
$\mu_{LC1COST}$	0.6405	0.6405	0.6405	0.6405	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
$\mu_{LC2COST}$	0.6405	0.6405	0.6405	0.6405	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
$\mu_{LC3COST}$	0.6405	0.6405	0.6405	0.6405	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
$\mu_{S1PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.8335	0.8335	0.8335	0.8335	0.8335	0.8335
$\mu_{S2PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.6118	0.6118	0.6118	0.6118	0.6118	0.6118
$\mu_{S3PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.9187	0.9187	0.9187	0.9187	0.9187	0.9187
$\mu_{S4PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.9175	0.9175	0.9175	0.9175	0.9175	0.9175
$\mu_{S5PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.8919	0.8919	0.8919	0.8919	0.8919	0.8919
$\mu_{S6PROFIT}$	0.6405	0.6405	0.6405	0.6405	0.8651	0.8651	0.8651	0.8651	0.8651	0.8651

Table 4. Solution results obtained by Werners (1988) approach.

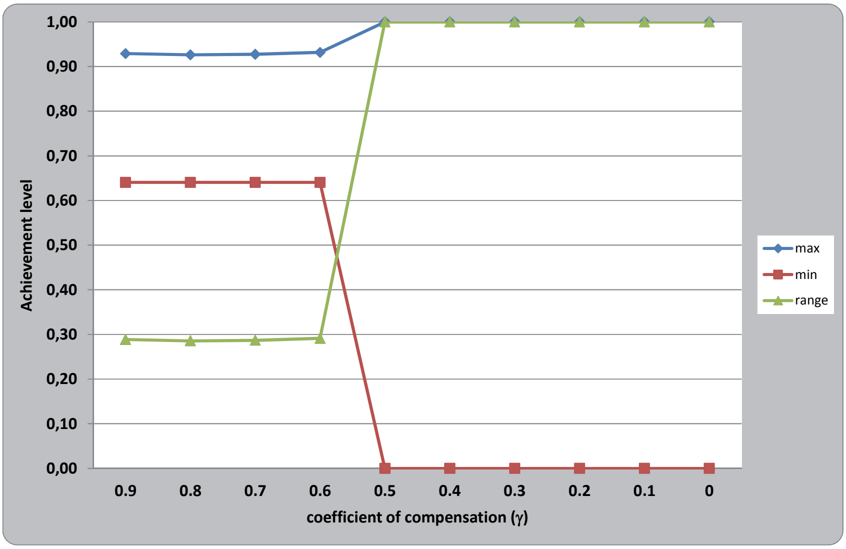

Fig. 2. Range of the achievement levels of the objectives.

7. Conclusion

In recent years, the CP in SC environments is acquiring an increasing interest. In general terms, the CP implies a distributed decision-making process involving several decision-makers that interact in order to reach a certain balance condition between their particular objectives and those for the rest of the SC. This work deals with the collaborative supply chain master planning problem in a ceramic tile SC and has proposes two FGP models for the collaborative CSCMP problem based on the previous work of Alemany et al. (2010). FGP allows incorporate into the models decision maker's imprecise aspiration levels. Besides, to explore the viability of different FGP approaches for the CSCMP problem in different SC structures (i.e. centralized and decentralized) a real-world industrial problem with several computational experiments has been provided. The numerical results show that collaborative issues related to SC master planning problems can be considered in a feasible manner by using fuzzy mathematical approaches.

The complex nature and dynamics of the relationships among the different actors in a SC imply an important degree of uncertainty in SC planning decisions. In SC planning decision processes, uncertainty is a main factor that may influence the effectiveness of the configuration and coordination of SCs (Davis 1993; Minegishi and Thiel 2000; Jung et al. 2004), and tends to propagate up and down the SC, affecting performance considerably (Bhatnagar and Sohal 2005). Future studies may consider uncertainty in parameters such as demand, production capacity, selling prices, etc. using fuzzy modelling approaches.

Although the linear membership function has been proved to provide qualified solutions for many applications (Liu & Sahinidis 1997), the main limitation of the proposed approaches is the assumption of the linearity of the membership function to represent the decision maker's imprecise aspiration levels. This work assumes that the linear membership functions for related imprecise numbers are reasonably given. In real-world situations, however, the decision maker should generate suitable membership functions based on subjective judgment and/or historical resources. Future studies may apply related non-linear membership functions (exponential, hyperbolic, modified s-curve, etc.) to solve the CSCMP problem. Besides, the resolution times of the FGP models may be quite long in large-scale CSCMP problems. For this reason, future studies may apply the use of evolutionary algorithms and metaheuristics to solve CSCMP problems more efficiently.

8. Acknowledgments

This work has been funded by the Spanish Ministry of Science and Technology project: 'Production technology based on the feedback from production, transport and unload planning and the redesign of warehouses decisions in the supply chain (Ref. DPI2010-19977).

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Information Sharing: a Quantitative Approach to a Class of Integrated Supply Chain

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1. Introduction

The literature on the incorporating information on multi-echelon inventory systems is relatively recent. Milgrom & Roberts (1990) identified the information as a substitute for inventory systems from economical points of view. Lee & Whang (1998) discuss the use of information sharing in supply chains in practice, relate it to academic research and outline the challenges facing the area. Cheung & Lee (1998) examine the impact of information availability in order coordination and allocation in a Vendor Managed Inventory (VMI) environment. Cachon & Fisher (2000) consider an inventory system with one supplier and N identical retailers. Inventories are monitored periodically and the supplier has information about the inventory position of all the retailers. All locations follow an (R, nQ) ordering policy with the supplier's batch size being an integer multiple of that of the retailers. Cachon and Fisher (2000) show how the supplier can use such information to allocate the stocks to the retailers more efficiently.

Xiaobo and Minmin (2007) consider four different information sharing scenarios in a two-stage supply chain composed of a supplier and a retailer. They analyse the system costs for the various information sharing scenarios to show their impact on the supply chain performance.

Information sharing is regarded to be one of the key approaches to tame the bullwhip effect (Kelepouris et. al, 2008). Kelepouris et. al (2008) examine the operational aspect of the bullwhip effect, studying both the impact of replenishment parameters on bullwhip effect and the use of point-of-sale (POS) data sharing to tame the effect. They simulate a real situation in their model and study the impact of smoothing and safety factors on bullwhip effect and product fill rates. Also they demonstrate how the use of sharing POS data by the upper stages of a supply chain can decrease their orders' oscillations and inventory levels held.

Gavirneni (2002) illustrates how information flows in supply chains can be better utilized by appropriately changing the operating policies in the supply chain. The author considers a supply chain containing a capacitated supplier and a retailer facing independent and identically distributed demands. In his setting two models were considered. (1) the retailer is using the optimal (*s*, S) policy and providing the supplier information about her inventory levels; and (2) the retailer, still sharing information on her inventory levels, orders in a period only if by the previous period the cumulative end-customer demand since she last ordered was greater than a specified value. In model 1, information sharing is used to supplement existing policies, while in model 2; operating policies were redefined to make better use of the information flows.

Hsiao & Shieh (2006) consider a two-echelon supply chain, which contains one supplier and one retailer. They investigate the quantification of the bullwhip effect and the value of information sharing between the supplier and the retailer under an autoregressive integrated moving average (ARIMA) demand of $(0,1,q)$. Their results show that with an increasing value of q, bullwhip effects will be more obvious, no matter whether there is information sharing or not. They show when the information sharing policy exists, the value of the bullwhip effect is greater than it is without information sharing. With an increasing value of q, the gap between the values of the bullwhip effect in the two cases will be larger.

Poisson models with one-for-one ordering policies can be solved very efficiently. Sherbrooke (1968) and Graves (1985) present different approximate methods. Seifbarghi & Akbari (2006) investigate the total cost for a two-echelon inventory system where the unfilled demands are lost and hence the demand is approximately a Poisson process. Axsäter (1990a) provides exact solutions for the Poisson models with one-for-one ordering policies. For special cases of (R, Q) policies, various approximate and exact methods have been presented in the literature. Examples of such methods are Deuermeyer & Schwarz (1981), Moinzadeh and Lee (1986), Lee & Moinzadeh (1987a), Lee and Moinzadeh (1987b), Svoronos and Zipkin (1988), (Axsäter, Forsberg, & Zhang, 1994), Axsäter (1990b), Axsäter (1993b) and Forsberg (1996). As a first step, Axsäter (1993b) expressed costs as a weighted mean of costs for one-for-one ordering polices. He exactly evaluated holding and shortage costs for a two-level inventory system with one warehouse and N different retailers. He also expressed the policy costs as a weighted mean of costs for one-for-one ordering policies. Forsberg (1995) considers a two-level inventory system with one warehouse and N retailers. In Forsberg (1995), the retailers face different compound Poisson demands. To calculate the compound Poisson cost, he uses Poisson costs from Axsäter (1990a).

Moinzadeh (2002), considered an inventory system with one supplier and M identical retailers. All the assumptions that we use in this paper are the same as the one he used in his paper, that is the retailer faces independent Poisson demands and applies continuous review (R, Q)-policy. Excess demands are backordered in the retailer. No partial shipment of the order from the supplier to the retailer is allowed. Delayed retailer orders are satisfied on a first-come, first-served basis. The supplier has online information on the inventory status and demand activities of the retailer. He starts with m initial batches (of size Q), and places an order to an outside source immediately after the retailer's inventory position reaches $R+s$, $(0 \leq s \leq Q - 1)$. It is also assumed that outside source has ample capacity.

To evaluate the total cost, using the results in Hadley & Whitin (1963) for one level-one retailer inventory system, Moinzadeh (2002) found the holding and backorder costs at each retailer and the holding cost at the supplier. The holding cost at each retailer is computed by the expected on hand inventory at any time (Hadley & Whitin, 1963). In the above system the lead time of the retailer is a random variable. This lead time is determined not only by the constant transportation time but also by the random delay incurred due to the availability of stock at the supplier. In his derivation Moinzadeh (2002) used the expected value of the retailer's lead time to approximate the lead time demand and pointed out that "the form of the optimal supplier policy in the context of our model is an open question and is possibly a complex function of the different combinations of inventory positions at all the retailers in the system" (Moinzadeh, 2002). As Hadley and Whitin (1963) noted, treating the lead time as a constant equal to the mean lead time, when in actuality the lead time is a random variable, can lead to carrying a safety stock which is much too low. The amount of the error increases as the variance of the lead time distribution increases (Hadley & Whitin, 1963).

In this chapter, we, at first and in model 1, implicitly derive the exact probability distribution of this random variable and obtain the exact system costs as a weighted mean of costs for one-for-one ordering policies, using the Axsäter's (1990a) exact solutions for Poisson models with one-for-one ordering policies. Second, we, in the model 2 define a new policy for sharing information between stages of a three level serial supply chain and derive the exact value of the mean cost rate of the system. Finally, in the model 3, we define a modified ordering policy for a coverage supply chain consisting of two suppliers and one retailer to benefit from the advantage of information sharing. (Sajadifar et. al, 2008)

2. Model 1

In what follows we provide a detailed formulation of the basic problem explained above, and we show how to derive the total cost expression of this inventory system.

2.1 Problem formulation

We use the following notations:

S_0 Supplier inventory position in an inventory system with a one- for-one ordering policy

S_1 Retailer inventory position in an inventory system with a one-for-one ordering policy

L Transportation time from the supplier to the retailer

L_0 Transportation time from the outside source to the supplier (Lead time of the supplier)

λ Demand intensity at the retailer

h Holding cost per unit per unit time at the retailer

h_0 Holding cost per unit per unit time at the supplier

β Shortage cost per unit per unit time at the retailer

t_i Arrival time of the i th customer after time zero

$c(S_0, S_1)$ Expected total holding and shortage costs for a unit demand in an inventory system with a one-for-one ordering policy

R The retailer's reorder point

Q Order quantity at both the retailer and the supplier

m Number of batches (of size Q) initially allocated to the supplier

K Expected total holding and shortage costs for a unit demand

$TC(R,m,s)$ Expected total holding and shortage costs of the system per time unit, when the supplier starts with m initial batches (of size Q), and places an order to an outside source immediately after the retailer's inventory position reaches $R+s$

Also we assume:

1. Transportation time from the outside source to the supplier is constant.
2. Transportation time from the supplier to the retailer is constant.
3. Arrival process of customer demand at the retailer is a Poisson process with a known and constant rate.
4. Each customer demands only one unit of product.

5. Supplier has online information on the inventory position and demand activities of the retailer.

To find K, the expected total holding and shortage costs for a unit demand, we express it as a weighted mean of costs for the one-for-one ordering policies. As we shall see, with this approach we do not need to consider the parameters L, L_0, h, h_0, and β explicitly, but these parameters will, of course, affect the costs implicitly through the one-for-one ordering policy costs. To derive the one-for-one carrying and shortage costs, we suggest the recursive method in (Axsäter, 1990a and 1993b).

2.2 Deriving the model

To find the total cost, first, following the Axsäter's (1990a) idea, we consider an inventory system with one warehouse and one retailer with a one-for-one ordering policy. Also, as in Axsäter (1990a) let S_0 and S_1 indicate the supplier and the retailer inventory positions respectively in this system. When a demand occurs at the retailer, a new unit is immediately ordered from the supplier and the supplier orders a new unit at the same time. If demands occur while the warehouse is empty, shipment to the retailer will be delayed. When units are again available at the warehouse the demands at the retailer are served according to a first come first served policy. In such situation the individual unit is, in fact, already virtually assigned to a demand when it occurs, that is, before it arrives at the warehouse.

For the one-for-one ordering policy as described above, we can say that any unit ordered by the supplier or the retailer is used to fill the S_i^{th} ($i = 0, 1$) demand following this order. In other words, an arbitrary customer consumes S_1^{th} (S_0^{th}) order placed by the retailer (supplier) just before his arrival to the retailer. Axsäter (1990a) obtains the expected total holding and shortage costs for a unit demand, that is, $c(S_0, S_1)$ for the one-for-one ordering policy.

In this paper, based on the one-for-one ordering policy as described above, we will show that the expected holding and shortage costs for the order of the j^{th} customer is exactly equal to the total costs for a unit demand in a base stock system with supplier and retailer's inventory positions $S_0=s+mQ$ and $S_1=R+j$ and so is equal to $c(s+mQ, R+j)$ (A.12). Then, considering Q separate base stock systems in which the inventory positions of the supplier and the retailer for the j^{th} base stock system is $s+mQ$ and $R+j$ respectively, we obtain the exact value of $TC(R, m, s)$, the expected total holding and shortage costs per time unit for an inventory system with the following characteristics:

- The single retailer faces independent Poisson demand and applies continuous review (R, Q)-policy.
- The supplier starts with m initial batches (of size Q) and places an order to an outside source immediately after the retailer's inventory position reaches $R+s$.
- The outside source has ample capacity.

We intend to show that

$$TC(R,m,s) = \frac{\lambda}{Q}.\sum_{j=1}^{Q} c(s+mQ, R+j)$$

Figure 1 shows the inventory position of the retailer and the supplier between the time zero (the time the supplier places the order Q_0) and the time the same order (Q_0) will be sent to the retailer.

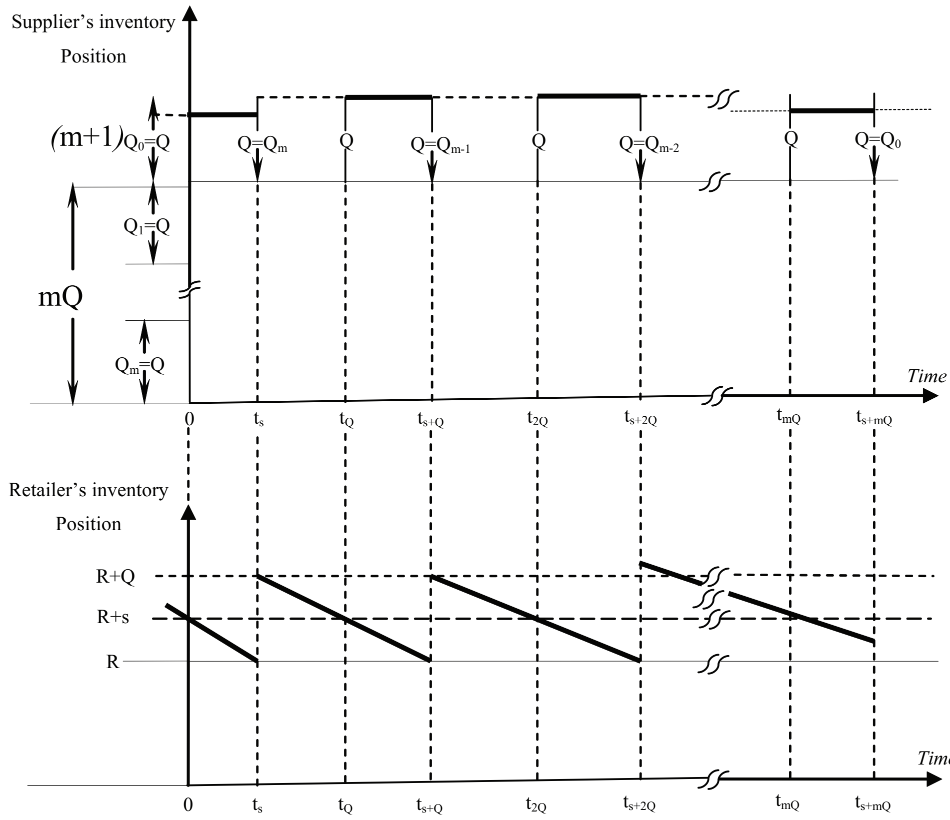


Fig. 1. Inventory position of the supplier and the retailer in $[0,t_{s+mQ}]$

To prove this assertion, let us consider a time at which the supplier places an order to the outside source. We designate this time as time zero. We also denote the batch which the supplier orders at time zero by Q_0. At this time, the retailer's inventory position is exactly $R+s$ and the supplier's inventory position will just reach$(m+1)Q$. Thus the batch Q_0 will fill the $(m+1)^{\text{th}}$ demand for the retailer batch at the warehouse. We denote the arrival times of customers who arrive after time zero by t_1, t_2, ... At time t_s when the s^{th} customer arrives, the retailer will order one batch of size Q, and the supplier's inventory position will drop to mQ. We note that after time zero, at the arrival time of $(s+mQ)^{th}$ customer, i.e., at time t_{s+mQ} , the retailer will order a batch of size Q. This retailer's order will be fulfilled by the (same) batch Q_0 that was ordered by the supplier at time zero. This means that the batch Q_0 is released from the warehouse when $(s+mQ)^{th}$ system demand has occurred after this order, *i.e.* after time zero.

The first unit in the batch Q_0 will be used in the same way to fill the $(R+1)^{th}$ retailer demand after the retailer order. Then the first unit in the batch Q_0 will have the same expected retailer and warehouse costs as a unit in a base stock system with $S_0=s+mQ$ and $S_1=R+1$.(the first base stock system) Therefore the corresponding expected holding and shortage costs will be equal to $c(s+mQ\ , R+1)$ (A(12)).

In the same way it can be seen that the j^{th} unit in the batch Q_0 will be used to fill the $(R+j)^{th}$ retailer demand after the retailer order. Then the j^{th} unit in the batch Q_0 will have the same expected retailer and warehouse costs as a unit in a base stock system with $S_0=s+mQ$ and $S_1=R+j$.(j^{th} base stock system) Therefore the expected holding and shortage costs for the j^{th} unit in the batch Q_0 will be equal to $c(s+mQ\ ,\ R+j)$, $j=1,\ldots,Q$ (A(12)).
It should be noted that each customer, demands only one unit of a batch of size Q. If we number the customers who use all Q units of this batch from 1 to Q, then the demand of any customer will be filled randomly by one of these Q units. That is, each unit of a batch of size Q will be consumed by the j^{th} ($j=1,2,\ldots,Q$) customer according to a discrete uniform distribution on $1,2,\ldots,Q$. In other words, the probability that the i^{th} ($i=1,2,\ldots,Q$) unit of a batch of size Q is used by the j^{th} ($j=1,2,\ldots,Q$) customer is equal to $1/Q$. Therefore we can now express the expected total cost for a unit demand as:

$$K=\frac{1}{Q}.\sum_{j=1}^{Q}c(s+mQ,R+j) \tag{1}$$

Since the average demand per unit of time is equal to λ, the total cost of the system per unit time can then be written as:

$$\begin{aligned} TC(R,m,s) &= \lambda.K \\ &= \frac{\lambda}{Q}.\sum_{j=1}^{Q}c(s+mQ,R+j) \end{aligned} \tag{2}$$

which proves our assertion.

3. Model 2

In this section, we consider a three-echelon inventory system with two warehouses (suppliers) and one retailer, as shown in Fig 2. This system usually called three-echelon serial inventory system. We want to find the expected total holding and shortage costs for a unit demand in three-echelon inventory system with two warehouses (suppliers) and one retailer.

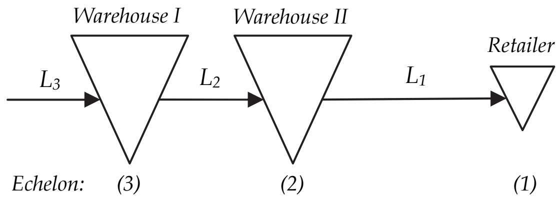


Fig. 2. Three-echelon Serial Inventory System

In this inventory system, transportation times from an outside source to the warehouse I, between warehouses, and also from the warehouse II to the retailers are constant. We assume that the retailer faces Poisson demand. Unfilled demand is backordered and the shortage cost is a linear function of time until delivery, or equivalently, a time average of the net inventory when it is negative. Each echelon follows a base stock, or (S-1, S), or one-for-one replenishment policies. This means essentially that we assume that ordering costs are low and can be disregarded.

The assumptions can be organized and presented as follows:

1. Transportation times between all locations are constant.
2. Arrival process of customer demand at the retailer is a Poisson process with a known and constant rate.
3. Each customer demands only one unit of product.
4. There are linear holding costs at all locations and shortage cost in the retailer.
5. Replenishment policies are one-for-one.
6. Unfilled demand is backordered and the shortage cost is a linear function of time until delivery.
7. Delayed retailer orders are satisfied on a first-come, first-served basis.
8. The outside source has ample capacity.

We fix the retailer, the warehouse II, and the warehouse I, to echelon one, two and three respectively as shown in Fig. 2. In order to derive the cost function, the following notations are used for serial inventory system:

S_i Inventory position at echelon i in an inventory system with a one-for-one ordering policy

L_1 Transportation time from the Warehouse *II* to the retailer

L_2 Transportation time from the Warehouse *I* to the Warehouse *II*

L_3 Transportation time from the outside source to the Warehouse *I* (Lead time of the Warehouse I)

T_i Random delay incurred due to the shortage of stock at the echelon i (i=2,3)

λ Demand intensity at each echelon

h_i Holding cost per unit per unit time at echelon i(i=$1,2,3$)

β Shortage cost per unit per unit time at the retailer

We characterizes our one-for-one replenishment policy by the (S_3, S_2, S_1) of order-up-to inventory positions which S_3, S_2, S_1 are the inventory position at warehouse *I* (echelon 3), the inventory position at warehouse *II* (echelon 2), and the inventory position at retailer (echelon 1), respectively. So we consider a one-for-one replenishment rule with (S_3, S_2, S_1) as the vector of order-up-to levels.

When a demand occurs at a retailer with a demand density, λ, a new unit is immediately ordered from the warehouse *II* to warehouse *I* and also warehouse I immediately orders a new unit at the same time, that is, each echelon faces the same demand intensity (λ). For the one-for-one ordering policy as described above, any unit ordered by the retailer is used to fill the $S_1{}^{th}$ demand following this order, hereafter, referred to as its demand. It means that, an arbitrary customer consumes $S_1{}^{th}$ order placed by the retailer just before his arrival to the retailer and we can also say that the customer consumes $S_2{}^{th}$ ($S_3{}^{th}$) order placed by the warehouse *II* (warehouse *I*) just before his arrival to the retailer. If the ordered unit arrives prior to its (assigned) demand, it is kept in stock and incurs carrying cost; if it arrives after its assigned demand, this customer demand is backlogged and shortage costs are incurred until the order arrives. This is an immediate consequence of the ordering policy and of our assumption that delayed demands and orders are filled on a first come, first served basis. We confine ourselves to the case where all $S_1 \geq 0$.

To find the total cost, following the Axsäter's (1990a) idea, let $g_i^{S_i}(.)$ (i=1, 2, 3) denote the density function of Erlang (λ, S_i) distribution of the time elapsed between the placement of an order and the occurrence of its assigned demand unit:

$$g_i^{S_i}(t) = \frac{\lambda^{S_i} t^{S_i - 1}}{(S_i - 1)!} e^{-\lambda t} \quad (3)$$

The corresponding cumulative distribution function $G_i^{S_i}(t)$ is:

$$G_i^{S_i}(t) = \sum_{k=S_i}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} \quad (4)$$

An order placed by the retailer, arrives after L_1+T_2 time units, and an order placed by warehouse II, arrives after L_2+T_3 time units, where T_i *(i=2,3)* is the random delay encountered at echelon *i* in case the echelon *i* is out of stock.
Let $\pi_1^{S_1}(t_2)$ denotes the expected retailer carrying and shortage costs incurred to fill a unit of demand at retailer when inventory position at retailer is S_1. We evaluate this quantity by conditioning on $T_2 = t_2$. Note that the conditional expected cost is independent of S_2 and S_3, and is given by:

$$\pi_1^{S_1}(t_2) = \beta \int_0^{L_1+t_2} (L_1 + t_2 - s) g_1^{S_1}(s) ds + h_1 \int_{L_1+t_2}^{\infty} (s - L_1 - t_2) g_1^{S_1}(s) ds, S_1 > 0; \quad (5)$$

The conditional distribution of T_2, on condition that T_3=t_3, obtained from:

$$P\langle T_2 = 0 | T_3 = t_3 \rangle = \sum_{k=0}^{S_2-1} \frac{\lambda^k (L_2 + t_3)^k}{k!} e^{-\lambda(L_2+t_3)} = 1 - G_2^{S_2}(L_2 + t_3) \cdot \quad (7)$$

Also the conditional density function $f(T_2)$ for $0 \le T_2 \le L_2 + t_3$ is given by:

$$f\langle T_2 = t_2 | T_3 = t_3 \rangle = g_2^{S_2}(L_2 + t_3 - t_2) = \frac{\lambda^{S_2}(L_2 + t_3 - t_2)^{S_2-1}}{(S_2 - 1)!} e^{-\lambda(L_2+t_3-t_2)} \quad (8)$$

The expression (6) shows the probability of time of receiving S_2^{th} demand; that is after receiving $(S_2\text{-}1)^{th}$ demand, S_2^{th} demand occurs at the time of L_2+t_3-t_2. On the other view, we can say the time distance between receiving S_2^{th} demand and receiving the order from warehouse *I* (L_2+t_3) is t_2 and we call it the delay time that occurred in warehouse *II*. As we mentioned earlier the warehouses face a Poisson demand process with rate λ. Therefore we use the expression (5) in third echelon as follows:

$$P(T_3 = 0) = \sum_{k=0}^{S_3-1} \frac{\lambda^k (L_3)^k}{k!} e^{-\lambda L_3} = 1 - G_3^{S_3}(L_3) \quad (9)$$

The density function f(t_3) for $0 \le t_3 \le L_3$,because we assume that inventory positrons at all facilities in this system are equal or greater that zero, is given by:

$$f(t_3) = g_3^{S_3}(L_3 - t_3) = \frac{\lambda^{S_3}(L_3 - t_3)^{S_3-1}}{(S_3 - 1)!} e^{-\lambda (L_3-t_3)} \quad (10)$$

Let $\Pi_1^{S_1}(S_3, S_2)$ denotes the expected retailer carrying and shortage costs incurred to fill a unit of demand at retailer when S_3, S_2, and S_1 are the inventory position at warehouse *I*, warehouse *II* and the retailer, respectively. Considering both states that we have delay time or have not in both warehouses, we obtain the cost that incurred to fill a unit of demand at retailer, as follows:

$$\Pi_1^{S_1}(S_3,S_2)=(1-G_3^{S_3}(L_3))\left(\int_0^{L_2} g_2^{S_2}(L_2-t_2)\pi_1^{S_1}(t_2)dt_2+(1-G_2^{S_2}(L_2))\pi_1^{S_1}(0)\right)$$
$$+\int_0^{L_3} g_3^{S_3}(L_3-t_3)\left(\int_0^{L_2+t_3} g_2^{S_2}(L_2+t_3-t_2)\pi_1^{S_1}(t_2)dt_2+(1-G_2^{S_2}(L_2+t_3)\pi_1^{S_1}(0))\right)dt_3. \quad (11)$$

The long-run average shortage and retailer carrying costs is clearly given by $\lambda\Pi_1^{S_1}(S_3,S_2)$.
The conditional expected warehouse *II* holding cost, $\pi_2^{S_2}(t_3)$, on condition that $T_3=t_3$, is independent of S_3 and given by:

$$\pi_2^{S_2}(t_3)=h_2\int_{L_2+t_3}^{\infty}(s-L_2-t_3)g_2^{S_2}(s)ds, S_2>0; \quad (12)$$

Therefore we find the average warehouse holding cost per unit for warehouse II when the inventory position at warehouse *I* is S_3 as follows:

$$\Pi_2^{S_2}(S_3)=\int_0^{L_3} g_3^{S_3}(L_3-t_3)\pi_2^{S_2}(t_3)dt_3+(1-G_3^{S_3}(L_3))\pi_2^{S_2}(0). \quad (13)$$

Also the average warehouse *I* holding costs per unit $\eta(S_3)$, which depends only on the inventory position S_3 is:

$$\eta(S_3)=h_3\int_{L_3}^{\infty} g_3^{S_3}(s)(s-L_3)ds \quad (14)$$

and $\eta(0)=0$.
We conclude that the long-run system-wide cost for the three-echelon serial inventory system by adding the costs which occurred in each echelon and is given by:

$$C(S_3,S_2,S_1)=\lambda(\Pi_1^{S_1}(S_3,S_2)+\Pi_2^{S_2}(S_3)+\eta(S_3)) \quad (15)$$

3.1 Determination the economical policy of a three-echelon inventory system with (*R,Q*) ordering policy and information sharing

In this section, we consider a three-echelon serial inventory system with two warehouses (suppliers) and one retailer with information exchange. The retailer applies continuous review (*R,Q*) policy. The warehouses have online information on the inventory position and demand activities of the retailer. The warehouse *I* and *II*, start with m_1 and m_2 initial batches of the same order size of the retailer, respectively. The warehouse *I* places an order to an outside source immediately after the retailer's inventory position reaches an amount equal to the retailer's order point plus a fixed value s_1, and The warehouse *II* places an order to

The warehouse *I* immediately after the retailer's inventory position reaches an amount equal to the retailer's order point plus a fixed value s_2. Transportation times are constant and the retailer faces independent Poisson demand. The lead times of the retailer and the warehouse *II*, are determined not only by the constant transportation time but also by the random delay incurred due to the availability of stock at the warehouses.

In order to find the total cost function for a unit demand in three echelon inventory system with (R,Q) ordering policy, first of all, we would present an (R,Q) ordering policy for a system with two warehouses and one retailer as showed in Fig. 2.

In this section, we want to obtain this cost function by using the cost function presented by the section 3, Hajiaghaei-keshteli and Sajadifar (2010), for the same system with one-for-one ordering policy.

We use the following notations:

S_i Echelon i inventory position in an inventory system with a one-for-one ordering policy

L_1 Transportation time from the Warehouse *II* to the retailer

L_2 Transportation time from the Warehouse *I* to the Warehouse *II*

L_3 Transportation time from the outside source to the Warehouse I (Lead time of the Warehouse I)

λ Demand intensity at all echelons

h_i Holding cost per unit per unit time at echelon *i*

β Shortage cost per unit per time at the retailer

$c(S_3,S_2,S_1)$ Expected total holding and shortage costs for a unit demand in an inventory system with a one-for-one ordering policy

R The retailer's reorder point

Q Order quantity at all locations

m_2 Number of batches (of size Q) initially allocated to the warehouse *II*

m_1 Number of batches (of size Q) initially allocated to the warehouse *I*

K Expected total holding and shortage costs for a unit demand

$TC(R,m_1,m_2,s_1,s_2)$ Expected total holding and shortage costs of the system per time unit, when the warehouse I and warehouse *II*, start with m_1 and m_2 initial batches (of size Q), and place an order in a batch of size Q to upper source immediately after the retailer's inventory position reaches $R+s_1$ and $R+s_2$ respectively.

As we shall see, with this approach we do not need to consider the parameters L_i, h_i, and β explicitly, but these parameters will, of course, affect the costs implicitly through the one-for-one ordering policy costs.

When a demand occurs at the retailer, a new unit is immediately ordered from the warehouse *II* to the warehouse *I* and also the warehouse I immediately orders a new unit at the same time.

If demands occur while the warehouses are empty, shipments are delayed. When units are again available at the warehouses, delivered according to a first come, first served policy.

In such situation the individual unit is, in fact, already virtually assigned to a demand when it occurs, that is, before it arrives at the warehouses. For the one-for-one ordering policy, an arbitrary customer consumes $(S_1+S_2+S_3)^{th}$, $(S_1+S_2)^{th}$ and $S_1{}^{th}$, order placed by the warehouse I, warehouse II, and the retailer, respectively, just before his arrival to the retailer.

If the ordered unit arrives prior to its (assigned) demand, it is kept in stock and incurs carrying cost; if it arrives after its assigned demand, this customer demand is backlogged and shortage costs are incurred until the order arrives. This is an immediate consequence of the ordering policy and of our assumption that delayed demands and orders are filled on a first come, first served basis.

To obtain $TC(R,m_1,m_2,s_1,s_2)$, we assume the warehouse *I* and *II* start with m_1 and m_2 initial batches (of size Q) respectively. The warehouse *I* places an order to an outside source immediately after the retailer 's inventory position reaches $R+s_1$, and warehouse *II* places an order to warehouse I immediately after the retailer's inventory position reaches $R+s_2$, while s_1 is equal or greater than s_2.

Let us consider a time that the warehouse *I* places an order to the outside source. We set this time equal to "A". We also denote the batch which the warehouse *I* orders at time "A" by Q_A. At this time, the retailer's inventory position is just $R+s_1$ and the warehouse *I*'s inventory position will just reach $(m_1+1)Q$.

After time "A", when the retailer's inventory position reaches $R+s_2$, warehouse *II* places an order to the warehouse *I* and her inventory position will just reach $(m_2+1)Q$ and warehouse *I* 's inventory position will reach m_1Q. We set this time to "B".

After time "B", when s_2^{th} customer demand arrives, that is, the retailer inventory position reaches R, the retailer will order one batch (of size Q), and the warehouse *II*'s inventory position will reach m_2Q.

We note that after time "A", at the arrival time of $(m_1Q + s_1 - s_2)^{th}$ customer demand, the warehouse *II* will order a batch (of size Q). This warehouse *II*'s order will be fulfilled by the (same) batch Q_A, that was ordered by the warehouse *I* at time "A", and after time "A´", at the arrival time of $(m_2Q + s_2)^{th}$ customer demand, the retailer will order a batch (of size Q). This warehouse *II*'s order will be fulfilled by the (same) batch Q_B that was ordered by the warehouse *II* at time "B".

Besides after time "A", At the arrival time of $(m_1Q + m_2Q + s_1)^{th}$ customer, the retailer will order a batch of size Q, this retailer's order will be fulfilled by the same batch Q_A that was ordered by the warehouse *I* at time "A". Figure 3 shows the inventory position of the retailer and the warehouses, as we detailed.

Furthermore, the $(R+1)^{th}$ customer who arrives after this retailer's order, will use the first unit of this batch; this customer is $(m_1Q+m_2Q+s_1+R+1)^{th}$ customer who arrives after time "A". This customer will incur a cost equal to $c(m_1Q+s_1-s_2, m_2Q+s_2, R+1)$, similar to $c(S_3,S_2,S_1)$, see equation (A.8), in which S_3, S_2, and S_1 are replaced by $m_1Q+s_1-s_2$, m_2Q+s_2, and $R+1$, respectively.

The j^{th} unit ($j=1,2, \ldots, Q$) in the batch will have to wait for the $(R+j)^{th}$ customer who arrives after this retailer's order and it will incur a cost equal to $c(m_1Q+s_1-s_2, m_2Q+s_2,R+j)$, similar to (A.8), in which S_3, S_2, and S_1 are replaced by $m_1Q+s_1-s_2$, m_2Q+s_2, and $R+j$, respectively.

It should be noted that each customer demands only one unit of a batch of size Q. if we number the customer who use all Q units of this batch from 1 to Q, then the demand of any customer will be filled randomly by one of these Q units. That is, each unit of a batch of size Q will be consumed by the j^{th} ($j=1,2,\ldots,Q$) customer according to a discrete uniform distribution between$[1,Q]$. In other words, the probability that the i^{th} unit of a batch of size Q is used by j^{th} ($j=1,2,\ldots,Q$) customer is equal to $1/Q$.

Therefore we can now express the expected total cost for a unit demand as:

$$K = \frac{1}{Q}\sum_{j=1}^{Q} c(m_1Q + s_1 - s_2, m_2Q + s_2, R + j) \tag{16}$$

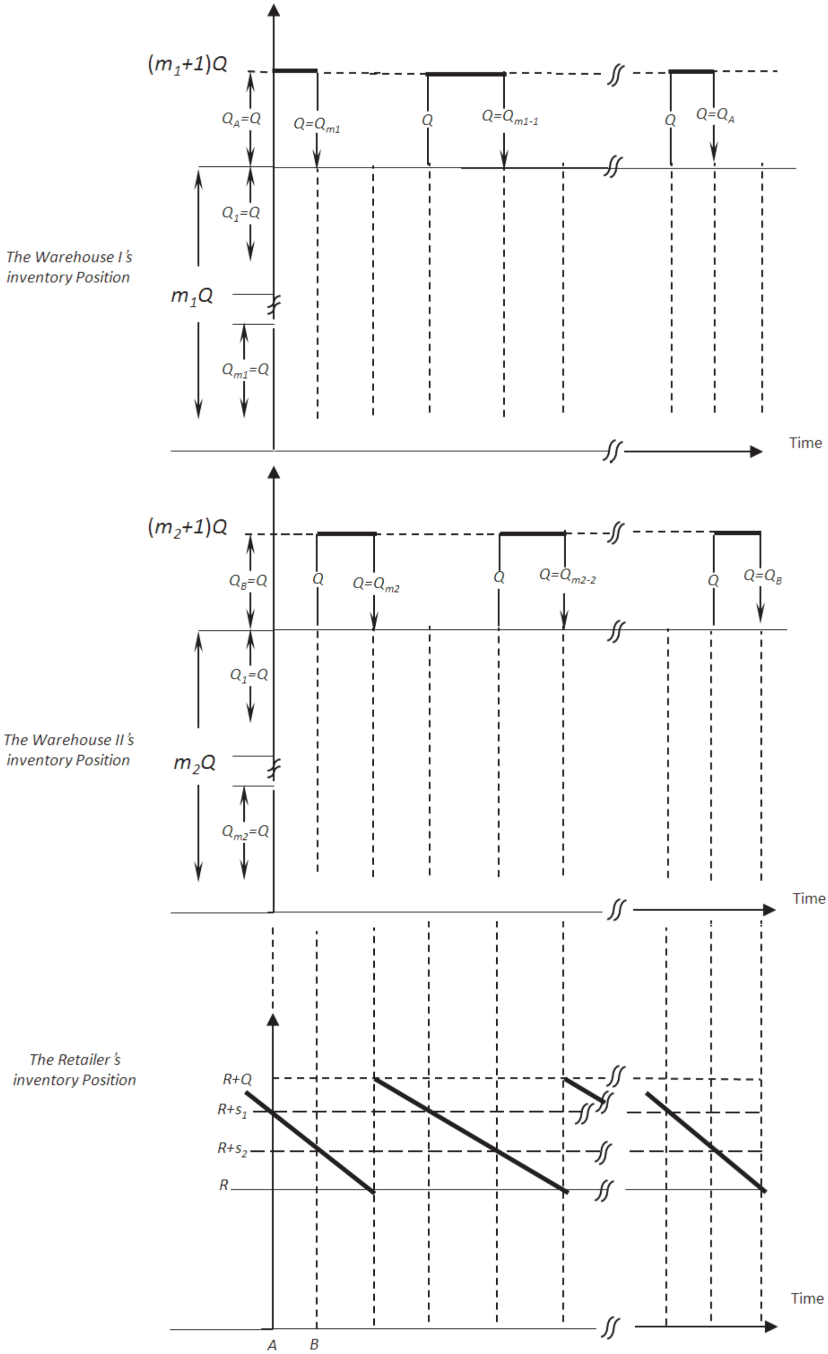


Fig. 3. Inventory position of the supplier and the warehouses

Since the average demand per unit of time is equal to λ, the total cost of the system per unit time can then be written as:

$$\mathrm{TC}(\mathrm{R},\mathrm{m}_1,\mathrm{m}_2,\mathrm{s}_1,\mathrm{s}_2) = \lambda.K = \frac{\lambda}{Q}\sum_{j=1}^{Q} c(m_1Q + s_1 - s_2, m_2Q + s_2, R + j) \tag{17}$$

4. Model 3

In this section, we consider a single item, two-level inventory system which consisting of two suppliers and one retailer, as shown in Fig 4. Transportation times are constant. The retailer faces Poisson demands and applies continuous (R, Q) policy. Each supplier starts with m initial batches of size $Q/2$ and places an order in a batch of size $Q/2$ to an outside source immediately after the retailer's inventory position reaches $R+s$. (Sajadifar et. al, 2008)

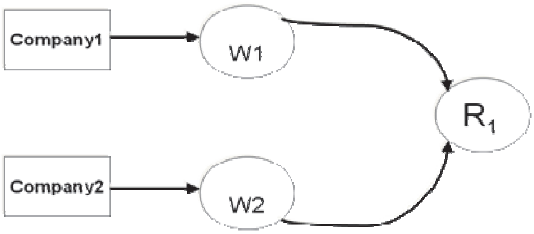


Fig. 4. A convergent two-level inventory system

4.1 Problem formulation

The following notations are used for this system:

S_0 Suppliers inventory position in an inventory system with a one- for-one ordering policy
S_1 Retailer inventory position in an inventory system with a one-for-one ordering policy
L_i Transportation times from the supplier i to the retailer
L_0^i Transportation times from the outside source to the supplier i (Lead time of the supplier)
λ Demand intensity at the retailer
h Holding cost per unit per unit time at the retailer
h_0^i Holding cost per unit per unit time at the supplier i
β Shortage cost per unit per unit time at the retailer
t_k Arrival time of the k^{th} customer after time zero
ω_i Random delay incurred due to the shortage of stock at the supplier i
X_i Lead time of the retailer when she receives a bath from the path i
P_{ij} The probability that path i is shorter than path j.
$g^n(t)$ Density function of the Erlang (λ, n)
$G^n(t)$ Cumulative distribution function of $g^n(t)$
c_i (S_0, S_1) Expected total holding and shortage costs for a unit demand in an inventory system with a one-for-one ordering policy in path i.
R The retailer's reorder point
Q Order quantity at the retailer
m Number of batches (of size$Q/2$) initially allocated to the suppliers
K Expected total holding and shortage costs for a unit demand

TC(*R*,*m*,*s*)Expected total holding and shortage costs of the system per time unit, when the suppliers starts with *m* initial batches (of size *Q*/2), and places an order in a batch of size *Q*/2 to outside sources immediately after the retailer's inventory position reaches *R*+*s*.
It can be seen that $X_i = L_i + \omega_i$. To find *K*, we express it as a weighted mean of costs for the one-for-one ordering policies. As we shall see, with this approach we do not need to consider the parameters L_i ,L_0^i , *h*, h_0^i , β and λ explicitly, but these parameters will, of course, affect the costs implicitly through the one-for-one ordering policy costs. To derive the one-for-one carrying and shortage costs, we suggest the recursive method in (Axsäter,1990a).
Also, we consider the following assumptions:

1. Orders do not cross, *i.e.* all orders/portions have arrived when the reorder point is reached and new orders are placed.
2. Each customer demands only one unit of product.
3. Each path that starts from outside source of the supplier i and end to the retailer is named by the path i. In other words the retailer receives each batch that shipped by the supplier *i* from the path *i* (*i*=1, 2).
4. Delayed retailer orders are satisfied on a first-come, first-served basis.

4.2 Deriving model

In this section, we use the method that (Haji and Sajadifar ,2008) introduced for evaluating the exact expected total costs of the inventory system, i.e., the exact expected total holding and shortage costs per time unit, *TC(R,m,s)*. To obtain *TC(R,m,s)*, using the (Axsäter,1990a) exact solutions for Poisson models with one-for-one ordering policies they show that the expected holding and shortage costs for the order of the j^{th} customer is exactly equal to the total costs for a unit demand in a base stock system with suppliers and retailer's inventory positions $S_0=s+mQ$ and $S_1=R+j$ and so is equal to $c(s+mQ, R+j)$.(A.12)
Figure 5 shows the inventory position of the retailer and the each supplier between the time zero (the time the each supplier places the order $Q_0/2$) and the time the same order ($Q_0/2$) will be sent to the retailer.
Let us consider a time that inventory position of the retailer reaches to '*R*+*s*'. We designate this time as time zero. At this time, the suppliers immediately place an order equal to *Q*/2 to the outside sources. We denote this batch by $Q_0/2$. At this time, the retailer's inventory position is exactly *R*+*s* and the suppliers' inventory positions will just reach $(m+1)Q/2$. Since we assume that the orders do not cross, the $(m+1)^{th}$ order at the retailer will release the orders $Q_0/2$ at the suppliers. It can be easily seen that the $(s+mQ)^{th}$ customer at the retailer will be caused to an order placement at the retailer and the one which has been already assigned to this order at the suppliers are the batches $Q_0/2$. This means that the batch $Q_0/2$ at each suppliers, is released from the warehouse when $(s+mQ)^{th}$ system demand has occurred after time zero i.e. at t_{s+mQ}.
The batch $Q_0/2$ will be received from the path *i* earlier than the batch $Q_0/2$ from the path *j* with the probability P_{ij}. Therefore, the first unit in the batch $Q_0/2$ (which will be received from path *i*) will be used in the same way to fill the $(R+1)^{th}$ retailer demand after the retailer order. Then the first unit in the batch $Q_0/2$ will have the same expected retailer and warehouse costs as a unit in a base stock system with $S_0=s+mQ$ and $S_1=R+1$ (Haji and Sajadifar 2008). Hence the corresponding expected holding and shortage costs will be equal to $c_i(s+mQ\ , R+1)$ (A(12)).

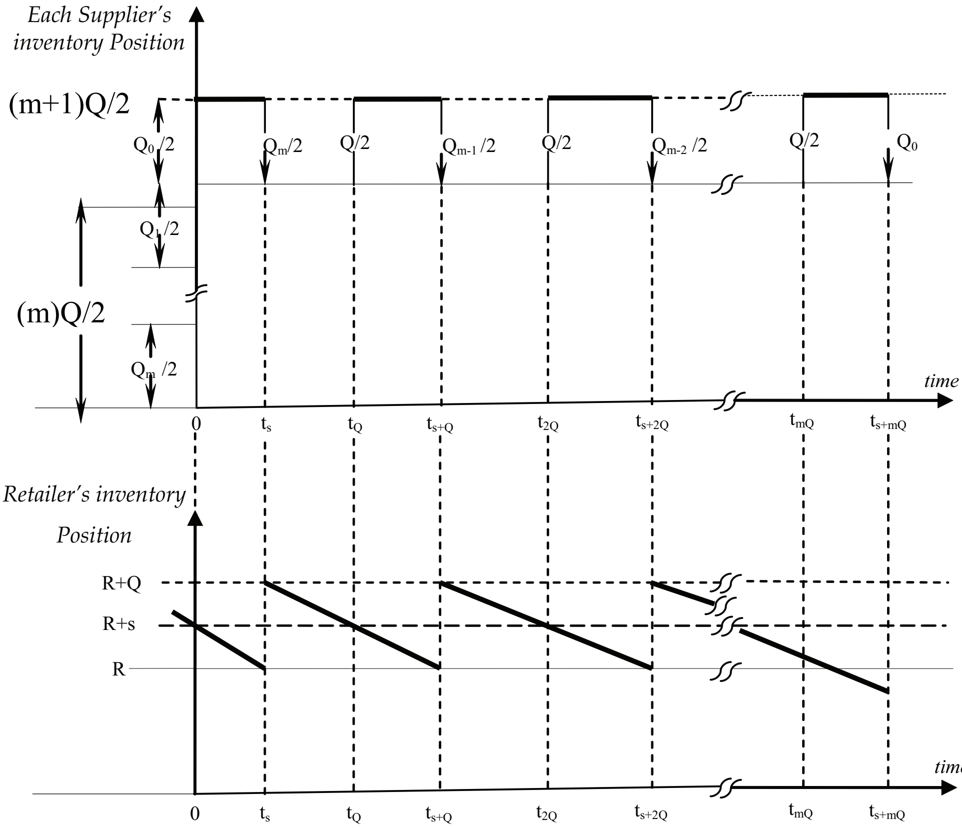


Fig. 5. Inventory position of the each supplier and the retailer in $[0, t_s + mQ]$

In the same way it can be seen that the j^{th} unit in the batch $Q_0/2$ (which will be received from the path i), will be used to fill the $(R+j)^{th}$ retailer demand after the retailer order. Then the j^{th} unit in the batch $Q_0/2$ will have the same expected retailer and warehouse costs as a unit in a base stock system with $S_0=s+mQ$ and $S_1=R+j$. Therefore the expected holding and shortage costs for the j^{th} unit in the batch $Q_0/2$ will be equal to $c_i(s+mQ, R+j)$, $j=1,\dots, Q/2$ (A(12)).
Similarly, one can easily see that the j^{th} unit in the batch $Q_0/2$ (which will be received from the path j), will be used to fill the $(R+Q/2+j)^{th}$ retailer demand after the retailer order. Then this unit will have the same expected retailer and warehouse costs as a unit in a base stock system with $S_0=s+mQ$ and $S_1=R+Q/2+j$ and the expected holding and shortage costs for this unit will be equal to $c_j(s+mQ , R+Q/2+j)$, $j=1,\dots,Q/2$ (A(12)).
It should be noted that each customer, demands only one unit of a batch. If we number the customers who use all Q units of these batches from 1 to Q, then the demand of any customer will be filled randomly by one of these Q units. That is, each unit of two batches of (total)size Q will be consumed by the j^{th} ($j=1,2,\dots,Q$) customer according to a discrete uniform distribution on $1,2,\dots,Q$. In other words, the probability that the i^{th} ($i=1,2,\dots,Q$) unit of two batches of (total)size Q is used by the j^{th} ($j=1,2,\dots,Q$) customer is equal to $1/Q$.
Therefore we can now express the expected total cost for a unit demand as:

$$k = \frac{1}{Q}\left[P_{12}.(\sum_{i=1}^{Q/2} c_1(s + mQ, R + i) + \sum_{i=(Q/2)+1}^{Q} c_2(s + mQ, R + i)) \right] + \frac{1}{Q}\left[P_{21}.(\sum_{i=1}^{Q/2} c_2(s + mQ, R + i) + \sum_{i=(Q/2)+1}^{Q} c_1(s + mQ, R + i)) \right] \tag{17}$$

Since the average demand per unit of time is equal to λ, the total cost of the system per unit time can then be written as:

$$TC(R, m, s) = \lambda.k = \frac{\lambda}{Q}\left[P_{12}.(\sum_{i=1}^{Q/2} c_1(s + mQ, R + i) + \sum_{i=(Q/2)+1}^{Q} c_2(s + mQ, R + i)) \right] + \frac{\lambda}{Q}\left[P_{21}.(\sum_{i=1}^{Q/2} c_2(s + mQ, R + i) + \sum_{i=(Q/2)+1}^{Q} c_1(s + mQ, R + i)) \right] \tag{18}$$

Corollary: the probabilities P_{ij}, are computed as follows: ($i, j = 1, 2$, and $P_{ij} + P_{ji} = 1$)
1: If $L_1 > L_2$ and $L_0^1 > L_0^2$, then $P_{12} = 0$.
2: If $L_1 < L_2$ and $L_0^1 < L_0^2$, then $P_{12} = 1$.
3: If $L_1 > L_2$, $L_0^1 < L_0^2$, and $L_1 + L_0^1 < L_2 + L_0^2$, then $P_{12} = G^{s+mQ}(L_2 + L_0^2 - L_1)$, (B.1).
4: If $L_1 > L_2$, $L_0^1 < L_0^2$, and $L_1 + L_0^1 > L_2 + L_0^2$, then $P_{12} = 0$.
5: If $L_1 < L_2$, $L_0^1 > L_0^2$, and $L_1 + L_0^1 > L_2 + L_0^2$, then $P_{12} = G^{s+mQ}(L_1 + L_0^1 – L_2)$.
6: If $L_1 < L_2$, $L_0^1 > L_0^2$, and $L_1 + L_0^1 < L_2 + L_0^2$, then $P_{12} = 1$.
One can find the idea of the proofs in appendix B and more information about this section in (Sajadifar et. al, 2008).

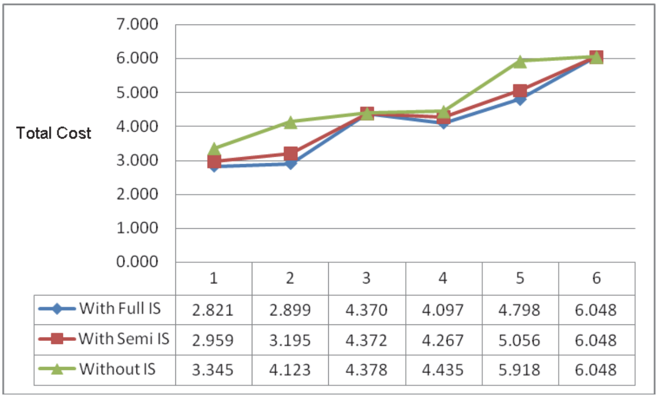
5. Discussion

We, in model 1, derived the exact value of the total cost of the basic dyadic supply chain. In model 2.1 and 2.2 we, using the idea introduced in model 1, obtained the exact value of the expected total cost of the proposed inventory system. For demonstrating the effect of information sharing, we define three different types of scenarios each of which derives the benefits of sharing information between each echelon. Scenario 1: With Full information sharing, scenario 2: With semi information sharing and scenario 3: Without information sharing. For the first scenario, each echelon shares its online information to the upper echelon, that is, s_1 and s_2 are both positive integer. With semi information sharing, just echelon 1 shares its inventory position with echelon 2, then, only echelon 2 has online information about the retailer's inventory position, that is, s_1 is a positive integer and s_2 is zero. And for the last kind of relation between echelons, we assume in third scenario, that no echelon shares its online information about inventory position *that is* the both value of s_1 and s_2 are zero. It means that we have no s_i in this kind of relation. Numerical examples show that the total inventory system cost reduces when the information sharing is on effect. Table 1 consists of 6 pre-defined problems to show the IS effects.
Fig.6 shows the total cost of the inventory system for each problem and on each scenario. As one can easily find, the more the information would be shared between echelons, the less the total cost would be offered. Of course, from managerial point of view, the cost of

establishing information system must be considered for making any decision about sharing information. The model presented in subsection 2.2 can enhance one to derive and determine the exact value of shared information between each echelon.

Prob. No.	Q	λ	β	h_i	L_i
1	*3*	*2*	*10*	*0.5*	*1*
2	*4*	*2*	*10*	*0.5*	*1*
3	*3*	*5*	*10*	*0.5*	*1*
4	*3*	*2*	*100*	*0.5*	*1*
5	*3*	*2*	*10*	*1*	*1*
6	*3*	*2*	*10*	*0.5*	*5*

Table 1. Six Pre-Defined problems to show capability of three kinds of information sharing policy in cost reduction



	1	2	3	4	5	6
With Full IS	2.821	2.899	4.370	4.097	4.798	6.048
With Semi IS	2.959	3.195	4.372	4.267	5.056	6.048
Without IS	3.345	4.123	4.378	4.435	5.918	6.048

Fig. 6. Changing the TC^* in each scenario and in each problem.

In model 3, we expressed our findings as %deviation between average total cost rates between the two systems, in which:

$$\%deviation = \frac{TC_{\text{Without Information}} - TC_{\text{With Information}}}{TC_{\text{With Information}}} \times 100$$

For this purpose we fix all the parameters except λ, L_1, L_2 and Q. These problems were constructed by taking all possible combinations of the following values of the parameters Q, λ, L_1, and L_2: Q=2,6,10, 20; λ=2,5 ; L_1, L_2=0, 0.5, 1, 1.5 and 2. We have assumed that the value of the parameters, L_0^1 ,L_0^2 ,h , h_0^1, h_0^2 and β are constant and for instance are as: 1,1 ,1 ,0.1 ,0.1 and 10 respectively.
These numerical examples show that the savings resulting from our policy will decrease as the maximum possible lead time for an order increases. The value of information sharing will be minimal when Q is small or large. The most value of the shared information is 13% saving in total cost for λ=2, Q=10 and $\sum L_i / \sum (L_i + L_0^i) = 0.2$.

6. Conclusions

We, in this chapter, showed how to obtain the exact value of the total holding and shortage costs for a class of integrated two-level inventory system with information exchange. Three different models were introduced which incorporated the benefits of information sharing and we, using the idea of the one-for-one ordering policy, obtained the exact value of the expected total cost function for the inventory system in all of them. Resorting to some numerical examples generated by model 2.2, we demonstrated that increasing the information sharing between echelons of a serial supply chain can decrease the total integrated system costs. Also, analyzing the findings of model 3, we showed that the savings resulting from our policy decrease as the maximum possible lead time for an order increase, and the value of information sharing will be maximal when the order size is neither large nor small.

7. Appendix A

This Appendix is a summary of Axsäter, S. (1990a). For more details one can see Axsäter, S. (1990a)'s paper. We define (as in Axsäter, S. (1990a) for one retailer) the following notations:

$$g^{S_0}(t) = \text{Density function of the Erlang } (\lambda, S_0)$$

and,

$$G^{S_0}(t) = \text{Cumulative distribution function of } g^{S_0}(t).$$

Thus,

$$g^{S_0}(t) = \frac{\lambda^{S_0} t^{S_0 - 1}}{(S_0 - 1)!} e^{-\lambda t}, \tag{A.1}$$

And,

$$G^{S_0}(t) = \sum_{k=S_0}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} \tag{A.2}$$

The average warehouse holding costs per unit is:

$$\gamma(S_0) = \frac{h_0^i S_0}{\lambda}(1 - G^{S_0+1}(L_0^i)) - h_0^i L_0^i (1 - G^{S_0}(L_0^i)), \quad S_0 > 0 \tag{A.3}$$

And

$$\text{for } S_0 = 0 \text{ , } \gamma(0) = 0. \tag{A.4}$$

Given that the value of the random delay at the warehouse is equal to *t*, the conditional expected costs per unit at the retailer is:

$$\pi^{S_1}(t) = e^{-\lambda(L_i+t)} \frac{h+\beta}{\lambda} \sum_{k=0}^{S_1-1} \frac{(S_1 - k)}{k!} (L_i + t)^k \lambda^k + \beta(L_i + t - \frac{S_1}{\lambda}) \tag{A.5}$$

(0!=1 By definition),
The expected retailer's inventory carrying and shortage cost to fill a unit of demand is:

$$\Pi^{S_1}(S_0) = \int_0^{L_0^i} g_0^{S_0}(L_0^i - t)\pi^{S_1}(t)dt + (1 - G_0^{S_0}(L_0^i))\pi^{S_1}(0) \tag{A.6}$$

and,

$$\Pi^{S_1}(0) = \pi^{S_1}(L_0^i) \tag{A.7}$$

Furthermore, for large value of S_0, we have

$$\Pi^{S_1}(S_0) \approx \pi^{S_1}(0) \tag{A.8}$$

The procedure starts by determining $\overline{S}_0$ such that

$$G^{\overline{S}_0}(L_0) < \varepsilon \tag{A.9}$$

Where ε is a small positive number.
The recursive computational procedure is:

$$\Pi^{S_1}(S_0 - 1) = \Pi^{S_1 - 1}(S_0) + (1 - G^{S_0}(L_0^i)) \times (\pi^{S_1}(0) - \pi^{S_1 - 1}(0)), \tag{A.10}$$

$$\Pi^0(S_0) = G^{S_0}(L_0^i)\beta L_0^i - G^{S_0 + 1}(L_0^i)\beta \frac{S_0}{\lambda} + \beta L_i \tag{A.11}$$

and, The expected total holding and shortage costs for a unit demand in an inventory system with a one-for-one ordering policy is:

$$c_i(S_0, S_1) = \Pi^{S_1}(S_0) + \gamma(S_0) \tag{A.12}$$

8. Appendix B

We will present the proof of the corollary 3 as follows:

$$X_i = L_i + \omega_i ,$$

and

$$\omega_i = \max\{0, L_0^i - t_{s+mQ}\} ,$$

then

$$\begin{aligned} P_{12} = P(X_1 < X_2) &= P(t_{s+mQ} < L_0^1).P(X_1 < X_2 \mid t_{s+mQ} < L_0^1) \\ &+ P(L_0^1 < t_{s+mQ} < L_0^2).P(X_1 < X_2 \mid L_0^1 < t_{s+mQ} < L_0^2) \\ &+ P(t_{s+mQ} > L_0^2).P(X_1 < X_2 \mid t_{s+mQ} > L_0^2) \end{aligned}$$

$$P_{12} = P(X_1 < X_2) = G^{s+mQ}(L_0^1) + G^{s+mQ}(L_2 + L_0^2 - L_1) - G^{s+mQ}(L_0^1) \qquad \text{(B.1)}$$
$$P_{12} = G^{s+mQ}(L_2 + L_0^2 - L_1)$$

All of the other corollaries can be proved easily in the same way.

9. References

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10

Production and Delivery Policies for Improved Supply Chain Performance

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1. Introduction

The research on supply chain management evolved from two separate paths: (1) purchasing and supply perspective of the manufacturers, and (2) transportation and logistics perspective of the distributors. The former is the same as supplier base integration, which deals with traditional purchasing and supply management focusing on inventory and cycle time reduction. The latter concentrates on the logistics system for effective delivery of goods from supplier to customer. Supply chain management focuses on matching supply with demand to improve customer service without increasing inventory by eliminating inefficiencies and hidden operating costs throughout the whole process of materials flow. An essential concept of supply chain management is thus the coordination of all the activities from the material suppliers through manufacturer and distributors to the final customers. Recently, many researchers (for example, Weng, 1997, Lee and Whang, 1999, Cachon and Lariviere, 2005, Gerchak and Wang, 2004, Davis and Spekman, 2004, Yao and Chiou, 2004, Chang et al., 2008 among others) have examined theoretical, as well as practical, issues involving buyer-supplier coordination. The research findings claim that well coordinated supply chains have the potential for companies competing in a global market to gain a competitive advantage, especially in situations involving outsourcing, which is becoming increasingly common.

The current chapter discusses, from the perspective of supplier base integration, supply chain coordination for a make-to-order environment in which manufacturing (or assembly) and shipping capacity is ready. The managers have purchase orders in hand and the choice of flexible production and delivery policies in filling the order. For the benefits of operational efficiency, the supplier adopts the policy of frequent shipments of manufactured parts and products in small lots. In the case of standard-size container shipping, each container has limited space, and the manufacturer should split the orders into multiple containers over time. This can be extended to the situation where the manufacturer may have to use multiple companies (different trucks) to ship the entire orders. For the buyer, it is important to work closely with the supplier to facilitate frequent delivery schedules so that the supplier is able to meet the buyer's requirements while still remaining economically viable. Obviously, this collaboration is an example of vendor managed inventory (VMI) system that requires well-managed cooperation between buyer and supplier in terms of sharing information on demand and inventory. While using the multiple delivery models, it is assumed that the vendor has the flexibility to select its own production policy. It can produce all units in a single setup or multiple setups to respond to a buyer's order. The existing literature, however, has not focused on comparisons between single-setup-multiple-delivery (SSMD) and multiple-setup-multiple-delivery (MSMD) policies. Although the SSMD policy is well accepted and gaining popularity, the MSMD policy has been largely disregarded due to the likelihood of high setup costs. However, when we factor in setup reduction through learning and the reduction of necessary inventory space, the MSMD may be just as viable, or even the better option in certain situations. For example, suppose in a make-to-order environment that the supplier receives customer orders frequently through the Internet and has cost/time efficient setup operation, then it is natural for the supplier to choose the MSMD policy over the SSMD policy, since the MSMD policy would help the company keep a low inventory and provide fast delivery to its customers, obviously enhancing the supplier's competitive advantage. This advantage will be apparent especially for the companies in high tech industries, where the product's life cycle tends to be shorter. This is also true of companies in the food industry, where the demand is always for fresh products. See David Blanchard, 2007 for more examples.

In this study, we extend the models that focused on the supplier's production policy (See Kim et al., 2008, and Kim and Ha, 2003). Kim et al., 2008 assumed in their MSMD model that the setup reduction through learning is restricted to one single lot and the learning starts anew for the next lot. In our first extension, however, we relax that assumption and allow that the setup reduction through learning is continued and accumulated throughout the subsequent production lots. The second extension of the model is that the MSMD model is allowed to have unequal setups and deliveries, while retaining the assumption of the MSMD model that the learning on setup reduction is confined to each lot alone and does not continue across lots. In other words, the model allows the number of setups to be unequal to the number of deliveries in each lot. This model may provide greater flexibility to the supplier in determining the production policy compared to the MSMD model or the SSMD model. Numerical examples are presented for illustration.

Although our goal is to elaborate on the entire supply chain synchronization, our discussion is limited to a relatively simple situation, i.e., single buyer and single supplier, under deterministic conditions for a single product that may account for a significant portion of the firm's inventory expenses. It is hoped that the result can be extended to a supply chain where multiple products and multiple parties are involved. In the following sections, the chapter discusses the supply chain coordination issue, from the perspective of supplier base integration, for a make-to-order environment in which manufacturing (or assembly) and shipping capacity is ready. The supplier has the flexibility to select its own production policy, producing all units of demand in either a single setup or multiple setups to respond to a buyer's order, and also to choose a shipping policy of single or multiple deliveries for a given lot. Not much research in the existing literature has focused on comparisons between single-setup-multiple-delivery (SSMD) and multiple-setup-multiple-delivery (MSMD) policies. This study compares the SSMD and the MSMD policies, where frequent setups give rise to learning in the supplier's setup operation. A multiple delivery policy shows a strong and consistent cost-reducing effect on both the buyer and the supplier, in comparison to the traditional lot-for-lot approach. This paper extends the MSMD model in two directions: (1) Modified MSMD Model (I): multiple-setup-multiple-delivery with allowance for unequal number of setups and deliveries, and (2) Modified MSMD Model (II): multiple-setup-multiple-delivery with allowance for cumulative learning on setups over the subsequent production cycles. Numerical illustrations are provided to compare the performance of the proposed models. The concluding section summarizes and discusses the implications of the results obtained.

2. Assumptions of the models and notation

When the buyer orders a quantity, Q, the supplier in response can pursue one of the following three policies: (1) Lot for Lot, i.e., single-setup-single-delivery (SSSD), (2) SSMD, or (3) MSMD. In the latter two cases, the order quantity, Q, will be split into a smaller delivery size over multiple deliveries, while the setup frequency for each policy would be different. If the setup cost is relatively high, a less frequent setup may be economically attractive to the supplier. The supplier would prefer to produce the entire order quantity, Q, with one setup, unless it can reduce the setup cost significantly to justify multiple setups. In this SSMD case, the supplier will hold and maintain the buyer's inventory due to the small delivery lot size. And because the supplier has all the necessary information, he often assumes the role of a central decision-maker in a vendor-managed inventory system. The supplier's cost function includes a setup and order handling cost, and a holding cost, while the buyer's relevant costs consist of an ordering cost, a variable holding cost, and a fixed transportation cost. However, it is not unusual for the buyer to pay increased order handling costs because it is incurred as a result of frequent deliveries imposed by the buyer.

If the MSMD policy is chosen, on the other hand, the supplier can meet the buyer's demand with lower inventories than in the case of the SSMD policy. But he will incur higher setup costs due to more frequent setups. Also, there will be opportunity costs for the supplier that account for the capacity foregone by having more frequent setups than with the SSMD policy for a given order quantity. However, the MSMD policy may give rise to learning effects on setup operations, which in turn will reduce setup time and cost. The reduced setup time (and cost) will eventually benefit the supplier in the long run. It is reasonable for the buyer and the supplier to share this opportunity cost, because both the buyer and supplier can benefit from such a policy: the supplier achieves setup reduction via the learning effect on setup operations, and the buyer receives the benefits of multiple deliveries, i.e., lower inventories.

Once a long-term contract between buyer and supplier is agreed upon, both parties work in a cooperative manner to coordinate supply with actual customer demand. Their effective linkage in this manner will eventually make any practice of frequent delivery in small lot sizes beneficial to both parties. In this study, market demand rate, production rate, and delivery time are assumed to be constant and deterministic. It is also assumed that all cost parameters, including unit price, are known and constant, and neither quantity-discount nor backorders are allowed. The following notations are adopted:

A = the ordering cost per order for buyer,

a = a parameter associated with supplier's hourly opportunity cost,

b = a parameter associated with decreasing rate of setup time, $-\ln r / \ln 2$ where r represents the percentage learning rate for the supplier's setup operations,

C = the supplier's hourly setup cost,

D = the annual demand rate for buyer,

F = the fixed transportation cost per delivery trip,

H_B = the holding cost/unit/year for buyer,

H_S = the holding cost/unit/year for supplier, $H_B > H_S$
J = the number of supplier setups per customer lot order, $J = 1, 2, 3, \ldots, N$,
K = the supplier's hourly opportunity cost for the time foregone attributed to the increased number of setups,
N = the number of deliveries per production cycle,
P = the annual production rate for supplier, $P > D$,
Q = the order quantity for buyer,
q = the delivery lot size per trip, $q = Q/N$,
S = the setup time/setup for supplier,
V = the unit variable cost for order handling and receiving,
α = the proportion of the fixed part of the total setup cost,
m = the number of deliveries per setup within a production cycle.

3. Single-Setup-Multiple-Delivery (SSMD) model

In the SSMD model, the order quantity is produced with one setup and shipped through multiple deliveries over time. The multiple deliveries are to be arranged in such a way that each succeeding delivery arrives at the time that all inventories from the previous delivery have just been depleted. As mentioned earlier, the buyer's total cost consists of ordering and holding costs, as well as transportation costs, incurred during the multiple deliveries as:

$$TC(Q,N)_{Buyer} = \frac{D}{Q}A + \frac{Q}{2N}H_B + \frac{DN}{Q}(F + V\frac{Q}{N}) \quad (1)$$

And the supplier's cost function includes a setup and order handling cost, and a holding cost:

$$TC(Q,N)_{Supplier} = \frac{D}{Q}CS + \frac{QH_S}{2N}\left\{(2-N)\frac{D}{P} + N - 1\right\} \quad (2)$$

The aggregate total cost function for both parties is as follows:
Note that $N = 1$ reduces Equations (1) – (3) to the conventional single delivery case, which is a special case of the SSMD

$$TC(Q,N)_{Aggregate} = \frac{D}{Q}(A + CS) + \frac{Q}{2N}\left[H_B + H_S\left\{(2-N)\frac{D}{P} + N - 1\right\}\right] + \frac{DN}{Q}(F + V\frac{Q}{N}) \quad (3)$$

policy. The fact that the second derivatives of Equation (3) (with respect to Q and N) are positive confirms the convexity of the aggregated total cost function. The optimal contract quantity, delivery frequency, and delivery size are as follows:

$$Q^*_{SSMD} = \sqrt{\frac{2D(A+CS)}{H_S(1-\frac{D}{P})}}$$

$$N^* = \sqrt{\frac{(A+CS)\{P(H_B - H_S) + 2DH_S\}}{F(P-D)H_S}}$$

$$q^* = \sqrt{\frac{2DFP}{P(H_B - H_S) + 2DH_S}} \tag{4}$$

The expression for optimal order (contract) quantity for SSMD is almost identical to the supplier's independent Economic Production Quantity (EPQ) model, except that the buyer's ordering cost, A, is added to the supplier's setup cost in the numerator of Equation (4). In the SSMD model, the buyer's holding costs and transportation costs do not affect the contract quantity. In other words, the supplier can determine the contract quantity alone without the knowledge of the buyer's holding and transportation costs information. In fact, the integrated optimal order quantity in Equation (4) is greater than the supplier's independent production quantity by the ratio of $\sqrt{(1+\frac{A}{CS})}$, which is close to 1 when the buyer's order cost, A, is very low compared to the supplier's setup cost, CS, as the case may be in current applications of electronic data interchange (EDI) based ordering systems in JIT environments. This is one of the reasons why the supplier may be willing to take a leading role in establishing such supplier-buyer linkage. The optimal delivery size is obtained by dividing the order quantity by the number of deliveries in Equation (4). Kim and Ha, 2003 claimed that the SSMD policy consistently outperforms the single delivery policy, given that the order quantity is greater than the minimum required level.

4. Multiple-Setup-Multiple-Delivery (MSMD) model

In the SSMD model, as shown in the earlier section, the supplier maintains large inventories and incurs high inventory holding costs due to the small delivery lot sizes over the multiple shipments. If the supplier, however, chooses the MSMD policy to set up the production process more frequently and to produce the exact quantity to be shipped on every setup, it can meet the buyer's demand with lower average inventory than in the case of the SSMD policy. But the supplier in this MSMD case consumes more capacity hours due to frequent setups, which incurs higher setup costs in the long run. However, if the supplier's capacity is greater than the threshold level ($P = 2D$), it is more beneficial for the supplier to implement the MSMD policy, even though he pays more frequent setup costs since the savings in inventory holding costs is greater than the increased setup costs. The supplier who has a tight constraint on capacity, therefore, should not choose the MSMD policy until its capacity is expanded. If the supplier has no constraint on capacity, or the savings earned from the lowered inventories compensate for the opportunity costs of the foregone capacity, the MSMD policy would be a feasible option to implement. One other factor pertaining to the MSMD policy is that the MSMD policy results in an increased opportunity to achieve larger learning effects on setup operations, which, in turn, will reduce the setup time/cost. In the following, we develop the structure of the MSMD policy and compare it with the SSMD policy in order to help the decision maker choose the appropriate policy for a given supply chain environment.

We now assume that the system has no constraint on capacity for setting up N batches to produce the order quantity, i.e., the order quantity, Q, is equally split, manufactured and delivered over N times. Learning effects on setup operations is also assumed to reduce the setup time/cost per setup, as the number of setups increases. The MSMD policy obviously changes the supplier's cost structure significantly, but the buyer's total cost remains intact as in Equation (1). The supplier's total cost consists of the setup cost that reflects learning effects due to multiple setups, the holding cost, and the opportunity cost that accounts for the extra setups in the supplier's capacity. The following equation shows these costs in order:

$$TC(Q,N)_{Supplier} = CS\left\{\alpha\frac{D}{Q}N + (1-\alpha)\sum_{J=1}^{DN/Q} J^{-b}\right\} + \frac{QH_S}{2N}\frac{D}{P} + K\left\{e^{a(N-1)} - 1\right\}S\left\{\alpha\frac{D}{Q}(N-1) + (1-\alpha)\sum_{J=\frac{D}{Q}+1}^{DN/Q} J^{-b}\right\}, \quad N \geq 2. \tag{5}$$

In Equation (5) above, α is the fixed cost portion of the setup cost. The setup cost has two components: fixed (or machine) and variable (or human) setup operation. And the learning effect is applied to the variable setup cost only. Without multiple setups, i.e., if *N=1*, Equation (5) reduces to the conventional single delivery lot-for-lot model. The second term in Equation (5) depicts the holding costs, and the third term represents the opportunity cost for the capacity foregone due to increased setups. Frequent setups are more likely to disrupt the supplier's current production schedule and thus there would be opportunity costs for the capacity foregone by having more frequent setups than an SSMD policy. As the number of setups, *N*, increases, the supplier's current opportunity cost per unit time, *K*, also increases. This increasing pattern can be modeled by one of various possible functions, such as linear or exponential, depending upon the supplier's situation of capacity available. If a vendor operates a tight production schedule, the initial opportunity cost *(K)* and the increasing rate of cost per unit of time will be higher than those of other vendors with a less tight schedule. In this paper, the unit time opportunity cost is assumed to be exponentially increasing as shown in the first part of the last term of Equation (5). The second part of the term, which reflects learning effects, is the amount of the supplier's capacity used up for increased number of setups. The entire term then represents the opportunity cost per unit of time. Note that this opportunity cost term vanishes when *N*=1.

The integrated total cost function for both parties is as shown below:

$$TC(Q,N)_{Aggregate} = \frac{D}{Q}A + CS\left\{\alpha\frac{D}{Q}N + (1-\alpha)\sum_{J=1}^{DN/Q} J^{-b}\right\} + \frac{Q}{2N}\left(H_B + H_S\frac{D}{P}\right) + \frac{DN}{Q}\left(F + V\frac{Q}{N}\right) + K\left\{e^{a(N-1)} - 1\right\}S\left\{\alpha\frac{D}{Q}(N-1) + (1-\alpha)\sum_{J=\frac{D}{Q}+1}^{DN/Q} J^{-b}\right\}, \quad N \geq 2, \tag{6}$$

Since the terms reflecting learning effects in Equation (6) bring step functions into the equation, derivatives with respect to *Q* and *N* do not exist at the boundary points of each *J*. Therefore we approximate Equation (6) by a continuous function, i.e.,

$$TC(Q,N)_{Aggregate} \cong \frac{D}{Q}A + CS\left\{\alpha\frac{D}{Q}N + (1-\alpha)\int_{J=0.5}^{\frac{D}{Q}N+0.5} J^{-b}dJ\right\}$$
$$+\frac{Q}{2N}\left(H_B + H_S\frac{D}{P}\right) + \frac{DN}{Q}\left(F + V\frac{Q}{N}\right) \tag{7}$$
$$+K\left\{e^{a(N-1)} - 1\right\}S\left\{\alpha\frac{D}{Q}(N-1) + (1-\alpha)\int_{J=\frac{D}{Q}+0.5}^{\frac{D}{Q}N+0.5} J^{-b}dJ\right\}, \qquad N \ge 2,$$

Integration for J in Equation (7) leads to

$$TC(Q,N)_{Aggregate} = \frac{D}{Q}A + CS\left[\alpha\frac{D}{Q}N + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}N + 0.5\right)^{1-b} - 0.5^{1-b}\right\}\right]$$
$$+\frac{Q}{2N}\left(H_B + H_S\frac{D}{P}\right) + \frac{DN}{Q}\left(F + V\frac{Q}{N}\right) \tag{8}$$
$$+K\left\{e^{a(N-1)} - 1\right\}S\left[\alpha\frac{D}{Q}(N-1) + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}N + 0.5\right)^{1-b} - \left(\frac{D}{Q} + 0.5\right)^{1-b}\right\}\right].$$

If the MSMD policy is chosen, the supplier can meet the buyer's demand with lower inventories than in the case of the SSMD policy, although more frequent setups will incur higher setup costs. A comparison of the integrated total costs for both SSMD and MSMD policies in Equations (3) and (8) would be sufficient in leading the supplier to an informed decision. However, since it is difficult to make an algebraic comparison of the two total costs due to the complexities of the expressions, Kim et al., 2008 suggested a brief guideline to help the supplier in making a decision about setup and delivery policy: If the supplier's capacity is greater than the threshold level ($P = 2D$), it is more beneficial for the supplier to implement the MSMD policy and to maintain fewer inventories. Even though the supplier pays greater costs for the frequent setups compared to the SSMD policy, the savings in inventory holding costs surpasses the increased setup costs. As the supplier's production capacity increases, MSMD becomes more and more cost effective. On the other hand, the smaller the supplier's production capacity, the more beneficial SSMD becomes. When we take the learning effect on setup operation into our consideration, as the learning rate on setup operation increases, the rate at which MSMD becomes more efficient accelerates. In the next two subsections, we discuss the extensions of the MSMD model.

4.1 Modified MSMD model (I): Unequal number of setups and deliveries

In this section, we develop a modified multiple setup multiple delivery model (modified MSMD Model (I)), which retains the assumption that the setup reduction through learning is confined to each lot alone and does not continue across lots. However, the modified MSMD model (I) proposed in this section allows the number of setups to be unequal to the number of deliveries in each lot. This model may provide greater flexibility to the supplier in determining the production and delivery policy compared to the MSMD model. For certain parameter values, this modified MSMD model (I) will result in lower total cost compared to the MSMD model. In our modified MSMD model (I) with unequal setups and deliveries, the total cost function takes the following form:

$$
\begin{aligned}
TC(Q,m,N)_{Aggregate} &= \frac{D}{Q}A + CS\left[\alpha\frac{D}{Q}\left(\frac{N}{m}\right) + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}\left(\frac{N}{m}\right)+0.5\right)^{1-b} - 0.5^{1-b}\right\}\right] + \frac{Q}{2N}(H_B) \\
&+ \left(\frac{\mathrm{N}}{\mathrm{m}}\right)\frac{Q}{2m}H_S\left\{(2-m)\frac{D}{P}+m-1\right\} + \frac{DN}{Q}\left(F+V\frac{Q}{N}\right) \\
&+ K\left\{e^{a(N/m-1)}-1\right\}S\left[\alpha\frac{D}{Q}\left(\frac{N}{m}-1\right) + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}\left(\frac{N}{m}\right)+0.5\right)^{1-b} - \left(\frac{D}{Q}+0.5\right)^{1-b}\right\}\right].
\end{aligned}
\quad (9)
$$

In this modified MSMD model (I), *m* is the number of deliveries per setup within a production cycle. The aggregate total cost is comprised of the ordering cost, the setup cost, the inventory cost for both the supplier and the buyer, transportation cost, and the opportunity cost owing to additional setups within the production cycle. The frequency of setups within a production cycle is defined in this model as the ratio of the total number of deliveries to the number of deliveries per setup in a production cycle. The model is formulated as a mixed integer nonlinear programming problem with the objective to minimize the total cost and determine the optimal production batch quantity (Q), optimal number of deliveries (*m*) per setup, and optimal number of deliveries (N) per production cycle. The constraints for the model are that all three variables Q, *m*, and N are greater than 0, that N is an integer, and that the number of orders in the finite planning period times the optimal order quantity per batch equals the demand for that finite planning period. The production batch quantity is less than or equal to the demand during the finite planning period, and frequency of setups within a production cycle is greater than 0. The mathematical formulation of the mixed integer nonlinear programming problem for the proposed model is formulated below:
Minimize:

$$
\begin{aligned}
TC(Q,m,N)_{Aggregate} &= \frac{D}{Q}A + CS\left[\alpha\frac{D}{Q}\left(\frac{N}{m}\right) + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}\left(\frac{N}{m}\right)+0.5\right)^{1-b} - 0.5^{1-b}\right\}\right] + \frac{Q}{2N}(H_B) \\
&+ \left(\frac{\mathrm{N}}{\mathrm{m}}\right)\frac{Q}{2m}H_S\left\{(2-m)\frac{D}{P}+m-1\right\} + \frac{DN}{Q}\left(F+V\frac{Q}{N}\right) \\
&+ K\left\{e^{a(N/m-1)}-1\right\}S\left[\alpha\frac{D}{Q}\left(\frac{N}{m}-1\right) + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}\left(\frac{N}{m}\right)+0.5\right)^{1-b} - \left(\frac{D}{Q}+0.5\right)^{1-b}\right\}\right].
\end{aligned}
\quad (10)
$$

Subject to:
Q, m, N > 0,
N and m are integers,
$\left(\frac{D}{Q}\right)Q = D,$
$Q \leq D,$

$$\left(\frac{N}{m}\right) \geq 1.$$

4.2 Modified MSMD model (II): Cumulative learning on setups over production cycles

In this section, we propose another extension of the MSMD model, which allows the learning of setup reduction achieved through earlier operations to accumulate across production cycles throughout the entire planning period. When this is imposed on the modified MSMD model (I), the model becomes modified MSMD model (II), which has the dual properties of both the SSMD and the MSMD models. This model can be applied to the situation where the time interval between consecutive orders is short enough for the supplier not to lose the learning gained from earlier setup operations. The model is thus built along the lines of single setup multiple deliveries with learning on setups over the multiple cycles. The benefits of this model over the MSMD model may be twofold: First, the overall setup cost and, in turn, the total cost is lower compared to the MSMD model. Second, the opportunity cost component incurred owing to additional setups in the MSMD model can be eliminated since the setup times are reduced as the production cycle is repeated. This, in turn, increases the scope for further reduction in the total cost for the same parameter values compared to the MSMD model. The total cost function takes the following form:

$$\begin{aligned} TC(Q,N)_{Aggregate} &= \frac{D}{Q}A + CS\left[\alpha\frac{D}{Q} + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}+0.5\right)^{1-b} - 0.5^{1-b}\right\}\right] \\ &+ \frac{Q}{2N}H_B + \frac{QH_S}{2N}\left((2-N)\frac{D}{P} + N - 1\right) + \frac{DN}{Q}\left(F + V\frac{Q}{N}\right) \end{aligned} \quad (11)$$

In this model, the total cost is comprised, as shown above, of the ordering cost, the setup cost that reduces through learning for subsequent setups during the entire finite planning period, the inventory cost of the buyer and the supplier, and the transportation cost, which is comprised of the fixed and the variable transportation cost components. The model is built along the lines of the single setup multiple delivery models with the addition of the variable N, the number of shipments from the supplier to the buyer in each setup. Owing to multiple shipments during each production lot, the supplier's inventory cost function is similar to the one obtained by Kim and Ha (2003).

The modified MSMD model (II) can be formulated as a mixed integer nonlinear programming problem with the objective to minimize the total cost as shown below:

Minimize:

$$\begin{aligned} TC(Q,N)_{Aggregate} &= \frac{D}{Q}A + CS\left[\alpha\frac{D}{Q} + \frac{(1-\alpha)}{(1-b)}\left\{\left(\frac{D}{Q}+0.5\right)^{1-b} - 0.5^{1-b}\right\}\right] \\ &+ \frac{Q}{2N}H_B + \frac{QH_S}{2N}\left((2-N)\frac{D}{P} + N - 1\right) + \frac{DN}{Q}\left(F + V\frac{Q}{N}\right) \end{aligned} \quad (12)$$

Subject to:

$$\left(\frac{D}{Q}\right)Q = D.$$

The variables to be determined are the production batch quantity Q and the number of shipments N in order to determine the supplier's production and delivery policy at the minimal total cost for the supply chain.

5. Numerical illustration

Suppose a buyer, who is currently using an *EOQ* policy seeking short-term advantage, plans to develop a long-term buyer-vendor relationship for an improved supply chain management. The buyer's annual demand is *D = 4,800 units/year*, ordering cost is *A = $25/order*, and holding cost is H_B = *$5/unit/year*. The fixed cost per trip and unit variable transportation costs are *F = $50.00* and *V = $1.00/unit*, respectively. For our illustration purposes, we consider that the supplier's annual production capacity can be any level of the following: 9,600 units, 19,200 units, 28,800 units, 38,400 units, and 48,000 units. Depending upon the supplier's selected capacity level, the supplier may use from 50% to 10% of its capacity to meet the buyer's demand. The unit holding cost for the supplier, H_S = $4/unit/year. It currently takes 5 workers 6 hours to set up the system, and the hourly labor cost per worker is $20. Thus, the cost per setup is *$600 ($20/hr × 5 worker × 6 hrs.)*. And the fixed cost portion of the setup cost (α) is 0.5. The learning rates (*r*) considered in this example are 90% (*b* = 0.152003), 80% (*b* = 0.321928), and 70% (*b* = 0.514573). The parameter value associated with the supplier's hourly opportunity cost (a) is 0.003. Tables 2 through 16 illustrate 15 different scenarios, in which only the production rate (*P*) and the learning rate (*r*) vary while other parameters remain unchanged. Notice that the parameter (*b*), which is associated with the learning rate, varies as the learning rate varies.

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 9,600 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 90%**
V = $1 per unit	**b = 0.152003**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 2. (P = 9,600, r = 90%, b = 0.152003)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 9,600 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 80%**
V = $1 per unit	**b = 0.321928**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 3. (P = 9,600, r = 80%, b = 0.321928)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 9,600 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 70%**
V = $1 per unit	**b = 0.514573**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 4. (P = 9,600, r = 70%, b = 0.514573)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 19,200 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 90%**
V = $1 per unit	**b = 0.152003**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 5. (P = 19,200, r = 90%, b = 0.152003)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 19,200 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 80%**
V = $1 per unit	**b = 0.321928**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 6. (P = 19,200, r = 80%, b = 0.321928)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 19,200 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 70%**
V = $1 per unit	**b = 0.514573**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 7. (P = 19,200, r = 70%, b = 0.514573)

D = 4,800 units/year	H_S = \$4 per unit per year
A = \$25 per order	**P = 28,800 units/year**
H_B = \$5 per unit per year	a = 0.003
F = \$50 per shipment	**r = 90%**
V = \$1 per unit	**b = 0.152003**
C = \$100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 8. (P = 28,800, r = 90%, b = 0.152003)

D = 4,800 units/year	H_S = \$4 per unit per year
A = \$25 per order	**P = 28,800 units/year**
H_B = \$5 per unit per year	a = 0.003
F = \$50 per shipment	**r = 80%**
V = \$1 per unit	**b = 0.321928**
C = \$100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 9. (P = 28,800, r = 80%, b = 0.321928)

D = 4,800 units/year	H_S = \$4 per unit per year
A = \$25 per order	**P = 28,800 units/year**
H_B = \$5 per unit per year	a = 0.003
F = \$50 per shipment	**r = 70%**
V = \$1 per unit	**b = 0.514573**
C = \$100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 10. (P = 28,800, r = 70%, b = 0.514573)

D = 4,800 units/year	H_S = \$4 per unit per year
A = \$25 per order	**P = 38,400 units/year**
H_B = \$5 per unit per year	a = 0.003
F = \$50 per shipment	**r = 90%**
V = \$1 per unit	**b = 0.152003**
C = \$100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 11. (P = 38,400, r = 90%, b = 0.152003)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 38,400 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 80%**
V = $1 per unit	**b = 0.321928**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 12. (P = 38,400, r = 80%, b = 0.321928)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 38,400 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 70%**
V = $1 per unit	**b = 0.514573**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 13. (P = 38,400, r = 70%, b = 0.514573)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 48,000 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 90%**
V = $1 per unit	**b = 0.152003**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 14. (P = 48,000, r = 90%, b = 0.152003)

D = 4,800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 48,000 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 80%**
V = $1 per unit	**b = 0.321928**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 15. (P = 48,000, r = 80%, b = 0.321928)

D = 4800 units/year	H_S = $4 per unit per year
A = $25 per order	**P = 48000 units/year**
H_B = $5 per unit per year	a = 0.003
F = $50 per shipment	**r = 70%**
V = $1 per unit	**b = 0.514573**
C = $100 per hour	K = 100
S = 6 hours per setup	α = 0.5

Table 16. (P = 48,000, r = 70%, b = 0.514573)

We coded the models as mixed integer nonlinear programming problems in AMPL language and solved them using the MINLP solver on the Neos solver website (http://www.neos-server.org/neos/solvers/minco:MINLP/AMPL.html). Tables 17 through 31 provided are the results obtained for each scenario presented in tables 2 through 16 respectively. For example, Table 17 contains the result of the parameter values in Table 2 for the 5 different models, namely Lot-for-Lot, SSMD, MSMD, Modified MSMD (I), and Modified MSMD (II). The metrics used for each model are aggregate TC per year, *Q**, *N**, *D/Q**, *m**, and *N*/m**. The *D/Q** gives the frequency of orders per year, while *N*/m** gives the frequency of setups per order (when applicable).

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,535.00	$9,816.00	$11,107.00	$9,678.57	$9,678.57
Q*	962	1770.34	853.33	1569.76	1569.76
N*	N/A	6	1	5	5
D/Q*	5	2.71	5.62	3.06	3.06
m*	N/A	N/A	N/A	5	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 17. (Result of Table 2)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,535.00	$9,816.00	$10,633.14	$9,525.09	$9,525.09
Q*	962	1770.34	737.3	1460.36	1460.36
N*	N/A	6	1	5	5
D/Q*	5	2.71	6.51	3.29	3.29
m*	N/A	N/A	N/A	5	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 18. (Result of Table 3)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,535.00	$9,816.00	$10,115.00	$9,333.90	$9,333.90
Q*	962	1770.34	618.08	1221.23	1221.23
N*	N/A	6	1	4	4
D/Q*	5	2.71	7.76	3.93	3.93
m*	N/A	N/A	N/A	4	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 19. (Result of Table 4)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,035.38	$10,249.77	$10,662.91	$10,036.27	$10,036.27
Q*	1039.23	1453.27	926.21	1254.36	1254.36
N*	N/A	4	1	3	3
D/Q*	4.62	3.30	5.18	3.83	3.83
m*	N/A	N/A	N/A	3	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 20. (Result of Table 5)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,035.38	$10,249.77	$10,248.29	$9,796.28	$9,796.28
Q*	1039.23	1453.27	804.82	1138.27	1138.27
N*	N/A	4	1	3	3
D/Q*	4.62	3.30	5.96	4.22	4.22
m*	N/A	N/A	N/A	3	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 21. (Result of Table 6)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$11,035.38	$10,249.77	$9,791.52	$9,521.93	$9,521.93
Q*	1039.23	1453.27	678.657	883.795	883.795
N*	N/A	4	1	2	2
D/Q*	4.62	3.30	7.07	5.43	5.43
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 22. (Result of Table 7)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,859.7	$10,330.52	$10,506.20	$10,105.46	$10,105.46
Q*	1069.36	1345.26	954.78	1236.42	1236.42
N*	N/A	3	1	3	3
D/Q*	4.49	3.57	5.03	3.88	3.88
m*	N/A	N/A	N/A	3	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 23. (Result of Table 8)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,859.70	$10,330.52	$10,111.98	$9,840.35	$9,840.35
Q*	1069.36	1345.26	831.4	1009.21	1009.21
N*	N/A	3	1	2	2
D/Q*	4.49	3.57	5.77	4.76	4.76
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 24. (Result of Table 9)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,859.70	$10,330.52	$9,676.44	$9,521.93	$9,521.93
Q*	1069.36	1345.26	702.62	883.795	883.795
N*	N/A	3	1	2	2
D/Q*	4.49	3.57	6.83	5.43	5.43
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 25. (Result of Table 9)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,771.34	$10,367.18	$10,427.27	$10,132.32	$10,132.32
Q*	1085.18	1336.4	969.8	1130.33	1130.33
N*	N/A	3	1	2	2
D/Q*	4.42	3.59	4.95	4.25	4.25
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 26. (Result of Table 10)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,771.34	$10,367.18	$10,043.21	$9,840.35	$9,840.35
Q*	1085.18	1336.4	845.39	1009.21	1009.21
N*	N/A	3	1	2	2
D/Q*	4.42	3.59	5.68	4.76	4.76
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 27. (Result of Table 11)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,771.34	$10,367.18	$9,618.30	$9,521.93	$9,521.93
Q*	1085.18	1336.4	715.27	883.795	883.795
N*	N/A	3	1	2	2
D/Q*	4.42	3.59	6.71	5.43	5.43
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 28. (Result of Table 12)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,715.40	$10,396.43	$10,377.26	$10,132.32	$10,132.32
Q*	1095.45	1243.65	979.55	1130.33	1130.33
N*	N/A	2	1	2	2
D/Q*	4.38	3.86	4.9	4.25	4.25
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 29. (Result of Table 13)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,715.40	$10,396.43	$9,999.60	$9,840.35	$9,840.35
Q*	1095.45	1243.65	854.49	1009.21	1009.21
N*	N/A	2	1	2	2
D/Q*	4.38	3.86	5.62	4.76	4.76
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 30. (Result of Table 14)

	Lot for Lot	SSMD	MSMD	Modified MSMD (I)	Modified MSMD (II)
TC(Aggregate) $ per year	$10,715.40	$10,396.43	$9,581.39	$9,521.93	$9,521.93
Q*	1095.45	1243.65	723.49	883.795	883.795
N*	N/A	2	1	2	2
D/Q*	4.38	3.86	6.63	5.43	5.43
m*	N/A	N/A	N/A	2	N/A
N*/m*	N/A	N/A	N/A	1	N/A

Table 31. (Result of Table 15)

We compare the results for the 5 models in the context of annual $TC_{Aggregate}$ in Table 1 based on the data obtained from Tables 17 through 31 for the 15 different sets of parameter constants.

Serial #, P, r %	**Lot-4-Lot ($)**	**SSMD ($)**	**MSMD ($)**	**Modified ($) MSMD (I)**	**Modified ($) MSMD (II)**
1. 9600, 90%	$11,535.00	$9,816.00	$11,107.00	$9,678.57	$9,678.57
2. 9600, 80%	11,535.00	9,816.00	10,633.14	9,525.09	9,525.09
3. 9600, 70%	11,535.00	9,816.00	10,115.00	9,333.90	9,333.90
4. 19200, 90%	11,035.38	10,249.77	10,662.91	10,036.27	10,036.27
5. 19200, 80%	11,035.38	10,249.77	10,248.29	9,796.28	9,796.28
6. 19200, 70%	11,035.38	10,249.77	9,791.52	9,521.93	9,521.93
7. 28800, 90%	10,859.70	10,330.52	10,506.20	10,105.46	10,105.46
8. 28800, 80%	10,859.70	10,330.52	10,111.98	9,840.35	9,840.35
9. 28800, 70%	10,859.70	10,330.52	9,676.44	9,521.93	9,521.93
10. 38400, 90%	10,771.34	10,367.18	10,427.27	10,132.32	10,132.32
11. 38400, 80%	10,771.34	10,367.18	10,043.21	9,840.35	9,840.35
12. 38400, 70%	10,771.34	10,367.18	9,618.30	9,521.93	9,521.93
13. 48000, 90%	10,715.40	10,396.43	10,377.26	10,132.32	10,132.32
14. 48000, 80%	10,715.40	10,396.43	9,999.60	9,840.35	9,840.35
15, 48000, 70%	10,715.40	10,396.43	9,581.39	9,521.93	9,521.93

Table 1. Comparison of 5 Models

It is observed that in all 15 cases, the SSMD model yields better (lower) TC compared to the Lot-for-Lot model. It is apparent that, as the supplier's production capacity and learning rate increase, the MSMD policy becomes more and more efficient. For a given production capacity level, the performance of the MSMD policy improves as the system retains more learning on setup operations. In other words, the smaller the supplier's production capacity, the more beneficial the SSMD becomes. Throughout all the 15 cases, both the modified MSMD (I) model and modified MSMD (II) consistently outperform the other three models. Due to the specific parameter values, the ratio of N^*/m^* remains the same for all 15 scenarios and there is no difference in performance for the above example between the modified MSMD (I) model and the MSMD (II) model.

6. Conclusion

An effective linkage between the stages (or parties) that form the supply chain, based on a cooperative strategy that strengthens buyer-supplier relationships, improves the competitive position of the entire chain. Through such integration, both buyer and supplier can obtain benefits in terms of quality, flexibility, costs, and reliability of supply, etc. A key goal of supply chain management is therefore the coordination of all the activities from the material suppliers through manufacturer and distributors to the final customers.

In an effort to improve the supply chain coordination, this study compares the single-setup-multiple-delivery (SSMD) and the multiple-setup-multiple-delivery (MSMD) policies, where frequent setups give rise to learning in the supplier's setup operation. The consistency of our results obtained from the SSMD is also observed in a more complex environment, i.e., multiple setups and multiple deliveries. The learning effects in MSMD policy tend to decrease the capacity loss and opportunity cost that may result from more frequent setups. As the learning rate on setup operation increases, the rate at which MSMD becomes more efficient accelerates. This paper extends the MSMD model in two directions: (1) Modified MSMD Model (I): multiple setup multiple delivery with allowance for unequal number of setups and deliveries, and (2) Modified MSMD Model (II): multiple setup multiple delivery with allowance for cumulative learning on setups over the subsequent production cycles. The modified MSMD models showed improved performance in aggregate total costs over the MSMD model throughout the entire finite planning horizon. Overall, the supply chain coordination strategy facilitating multiple setups and multiple deliveries in small lot sizes show a strong and consistent cost-reducing effect, in comparison with the Lot-for-Lot approach, on both the buyer and the supplier. It is suggested that the surplus benefits are shared by both parties according to the contribution (or sacrifice) each party made to the integration efforts.

As a guideline for the supplier in selecting the policy, this study claims that it is more beneficial for the supplier to implement the multiple setups and multiple deliveries (MSMD) policy if the supplier’s capacity is greater than the threshold level ($P = 2D$), even though he pays more frequent setup costs, since the savings in inventory holding costs is greater than the increased setup costs. If the supplier has no constraint on capacity, or the savings earned from the lowered inventories compensate for the opportunity costs of the foregone capacity, the MSMD policy would be a feasible option to implement.

For future research purposes, the proposed model may be further embellished to address cases involving multiple buyers, suppliers, and products. Finally, the development of stochastic models in this area is likely to result in a more meaningful, albeit more complex, analysis under real world conditions.

7. References

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11

Inter-Organizational Collaboration in Dynamic, Short-Term Supply Chains

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1. Introduction

A new network organizational form, called dispersed manufacturing network or DMN, is emerging among companies' supply chains. The organizational form is both abetted as well as spurred by the increasing globalization of supply chains. This organizational form takes shape in the form of networks of dynamic and flexible supply chains held together by emergent and easily re-configurable short-term collaborative links between partners. Globalization allows more companies to connect and to collaborate with one another irrespective of distance or boundaries. However, globalized business environments are also more turbulent and complex. These give rise to the need for flexible DMN networks that are robust to unpredictable changes. Researchers need to identify and understand the new rules of engagement among companies that inform this novel organizational form. This chapter provides explanations for the emergence of such networks, describes their advantages, and show examples of such supply chains in the field. The chapter's domain covers the following supply chain areas;

- Design of supply chains
- Agility of supply chain
- Decision making in a supply chain
- Supply chain collaboration

2. Background

Agile, dynamic and flexible supply chains have become increasingly necessary to cope with the ever-changing markets, complexity and competition of a globalized world. Globalization denotes not just increased opportunities for companies, but also enhanced risks, including the augmented potential of competitive threats or changes suddenly arising from anywhere in the world (Ghoshal, 1987; Puig et al., 2009; Steenkamp & de Jong, 2010).

Globalization acts as a two-edged sword for many business organizations. On one hand, the prospect of globalization beckons to all companies with attractive vistas of wide new sourcing horizons and fresh market opportunities. Thus with globalization, every company is now in theory able to source from the very best suppliers, and to sell into every potential market. However, the rise of globalization also come attendant with special challenges. For example, all companies are now equally subject to direct competition from global players. Smaller companies may appear to be more disadvantaged due to their lack of resources as compared with large companies. More importantly, all companies that are plugged into global networks of supply and demand are now also exposed to every disturbance or change that takes place in global business environments.

For instance, in 2010, the Canadian company Research in Motion or RIM found its landmark product, the Blackberry, in trouble over new security requirements by governments in the Middle East and in India. These Middle Eastern and Indian governments have lately realized that the tight security as provided by Blackberries may also be taken advantage of by various elements in their societies for subversion. They requested RIM to drastically change the way Blackberries work, on the pain of Blackberries being banned from those markets. Therefore, just because the Blackberry is a global product, RIM has to take into account every requirement or change that comes its way from anywhere (The Economic Times, 2011; WSJ.COM, 2011). Another example is the devastating earthquake and tsunami that stuck northeastern Japan in March, 2011. The destructive effects of the disasters, compounded by the related nuclear crisis that arose from them, severely disrupted the operations of many Japanese parts suppliers. As a result, the global supply chains of many companies are unexpectedly affected by this shortage of parts (Hookway & Poon, 2011).

Companies cannot avoid globalization, because even the basic advantages confer by a globalized strategy such as lower costs and wider markets are simply irresistible. In an increasing number of industries, companies with more parochial business strategies are being outclassed and outmaneuvered by globalized competitors. For instance, companies that are able to implement flexible innovation processes that extend across supply chains are better able to manage and benefit from the effects of increasing globalization (Santos et al., 2004; Reinmoeller & van Baardwijk, 2005). However, becoming a part of globalized economies also mean that companies must be able to cope with more volatile business environments. Consider a company that seeks to be successful in such an environment. High uncertainty in the business environment means that a company cannot readily predict the types of resources it will require going forward into the future. A company could not reliably know what type of, or indeed if any, internal resources should be developed for the future. Similarly, a company may not assume that the resources of its long-standing external supply chain partners will always remain useful and relevant in an unsettled environment.

Research has shown that the higher competition and turbulence of globalized business environments could be mitigated if companies could leverage more on their supply networks (Gulati, 1995; Prashantham & Birkinshaw, 2008; Vachon et al., 2009). Specifically, companies that could build dynamic and flexible supply chains and use them for targeted co-production as and when needed, may more adroitly navigate the unpredictable challenges posed by global competition and markets (Camarinha-Matos & Afsarmanesh, 2005; Noori & Lee, 2006; Jackson, 2007; Katzy & Crowston, 2008; Dekkers, 2009b; Noori & Lee, 2009). An example of companies that rely extensively on agile supply chain partners to better cope with fast-moving environments is the Shanzhai companies found in South China. Shanzhai companies' successes depend largely on their ability to quickly assemble alliances with the right partners to address specific opportunities or threats that may suddenly arise in their environments (Shi, 2009; Noori et al., n.d.). The concept of dynamic and flexible supply chains cannot be easily described or explained in traditional supply chain terms. This chapter will seek to explain this new form of network collaboration, the advantages, the new supply chain formation process, and the new rules of engagement required for such supply chains.

3. Dispersed manufacturing networks explained

The traditional view of collaborative networks has typically considers long-term and stable business relationships among companies in such networks as both desirable and necessary. These types of strong relationships are believed to be critical to prevent opportunism, to foster trust, and to encourage commitment from all involved parties (Feenstra et al., 1999; Campbell & Keys, 2002). An alternative perspective of collaborative networks, the Dispersed Network Manufacturing or DMN paradigm, describes how companies may address highly variable changes to markets and competition by entering into loosely connected networks alliances with other companies to obtain access to more diversified resources. The DMN perspective suggests that the dynamism of the market or competition should be matched by the dynamism of a company's network relationship ties, and that that these ties should be quickly switchable or reconfigurable to meet new requirements (Granovetter, 1973; Zhan et al., 2003; Noori & Lee, 2006; Dekkers, 2009b; Noori & Lee, 2009).

3.1 Dispersed manufacturing networks as a concept

The DMN perspective does not ignore or negate the value and importance of strong ties among companies. Rather, the DMN perspective delineates the difference between short-term business connections and long-term interactive relationships between companies, and shows how companies can leverage on their long-term relations while minimizing the costs of network inertia (Kim et al., 2006). DMN networks can be better understood if they are compared against the characteristics of other collaborative networks such as Third Italy, Japanese keiretsu and Korean chaebol. These comparisons of characteristics are as shown in Table 1. As may be seen, a key distinguishing characteristic of DMN networks is the existence of short-term goal-specific business connections that take place within longer-term network relationships.

Another distinguishing characteristic of DMN networks from other types of collaborations networks is their location along the degrees of ownership integration versus degrees of coordination integration. Though DMN companies are independent and completely autonomous from one another, they are highly coordinated for specific purposes. Figure 1 shows how DMN networks are positioned along those integration axes. The independent nature of DMN companies is especially important because this absolved DMN networks from equity considerations to prop up failing partners, or from corporate pressure to ally with an unsuitable sister company.

In the DMN perspective, a company with agile, dynamic and flexible supply chains is one that is able to quickly locate and collaborate on co-production with appropriate partners to seize some fleeting opportunity, or to defend against a suddenly looming threat. As the opportunity fades or as the threat recedes, to be inevitably replaced by newer prospects or risks, the company will need to be able to quickly re-shuffle its portfolio of partners. In effect, this means that a company's supply chains need to be able to rapidly coalesce, and then to just as speedily split up depending on unpredictable shifts in a business environment. This form of network collaboration works optimally when companies are able to actively seek and dynamically collaborate with partners based on short-term, goal-specific, business connections (Camarinha-Matos & Afsarmanesh, 2005; Katzy & Crowston, 2008; Dekkers, 2009a; Noori & Lee, 2009).

Characteristics	"Third Italy" (Brusco, 1982; Amin, 1999; Hadjimichalis, 2006)	Japanese Keiretsu (Anchordoguy, 1990; Minor et al., 1995; Feenstra et al., 1999)	Korean Chaebol (Chang, 1988; Campbell & Keys, 2002)	DMN Model (Magretta & Fung, 1998; Noori & Lee, 2006; 2009; Shi, 2009; Tse et al., 2009)
Network structure	• Decentralized	• Based around a central bank	• Based around a central company	• Range from decentralized to hub-centric
Equity ownership of partner company	• None	• Partial ownership by the dominant company	• Typically a subsidiary of the dominant company	• None
Public sector support	• Yes • Local level	• Yes • National level	• Yes • National level	• None
Dominant cross-company management link	• Professional ties	• Directorate interlocks	• Family ties	• Professional/ Social ties
Third party intermediation	• No	• No	• No	• Yes • Indirect social links
Territorial concentration	• Yes	• No	• Yes	• No
Sectoral specialization by company	• Yes	• Partial	• Partial	• Yes
Typical business-related duration	• Long-term	• Long-term	• Long-term	• Short-term

Table 1. Characteristics of Collaborative Networks [Adapted from Noori, Tan & Lee (n.d.)]

However, this does not mean that companies are transacting only in one-shot deals with total strangers. On the contrary, the various companies in such a network are typically engaged in long-term relationships with one another. These companies may have already worked with each another numerous times, and even in different supply chain relations, wherever it had suited them to have done so before in the past. Their short-term business connections therefore take place within the context of these long-term relationships. Each company's business reputation, specific talents, resources, performance record are known within their networks, and will affect its chances of being invited to take part in any new network. Therefore, even though a company may transact with other companies only through short-term connections at any time, the company also have to simultaneously take into consideration its long-term future as a member of good-standing in the network. Such a consideration acts to deter the onset of opportunism to seek benefit from making selfish short-term gains, and to encourage good faith in dealing with every partner (Heide & Miner, 1992; Miles et al., 2009).

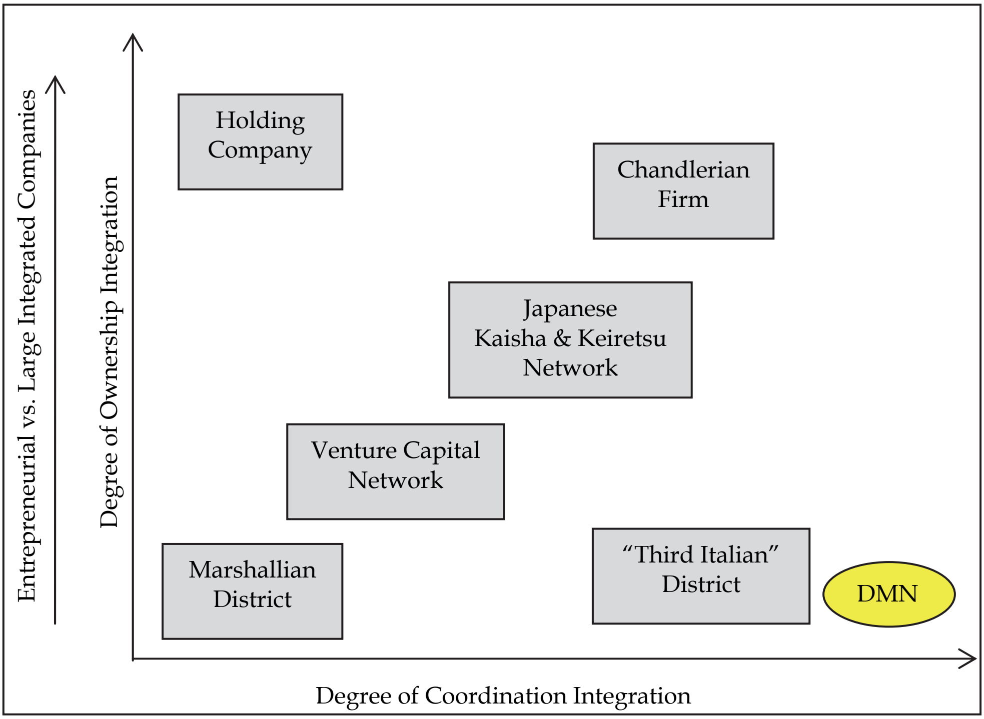
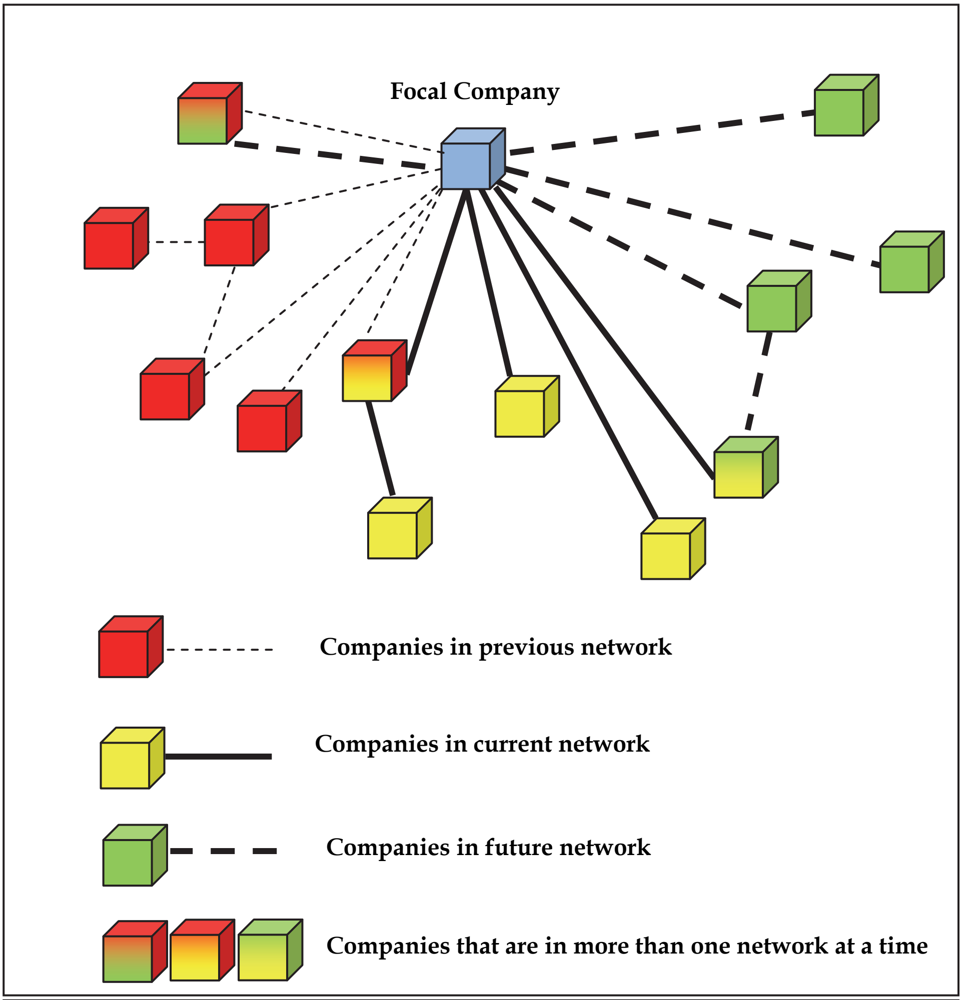


Fig. 1. Location of DMN along Ownership versus Coordination Integration Axes
[Adapted from Robertson & Langlois (1995) and Noori (2009)]

These loose ties allow the companies to easily enter, exit or to shift their positions on the value chain if necessary to achieve more optimal configurations. Like a set of Lego building blocks, companies in a DMN network can easily re-sort themselves into different connections to serve various needs. Each network is temporary, and when they are no longer needed, they are as easily dissolved so that each company need not shoulder the costs of maintaining unproductive alliances. By freeing up their internal resources, companies could then easier seek to join new networks (Saeed et al., 2005; Noori et al., n.d.). The temporary nature of DMN network connections as established within long-term relationships are illustrated in Figure 2.

The prime enablers for such dispersed collaboration are the existence of affordable and pervasively widespread globalized technology that allows easy communication and interconnectivity among disparate businesses, and a shared collaboration understanding and culture among the companies (Noori & Lee, 2006). The use of standardized information technology (IT) systems is recognized as a necessary enabler for efficient collaboration and operations among companies (Upton & McAfee, 1996). Flexible IT systems allow companies to link or to de-link easily from one another without sacrificing prior investments in dedicated collaborative systems. In this respect, recent technological advances that resulted in the creation of cheap and universally available IT systems have made it possible for the first time for many companies in different industries and in different parts of the world to possibly operate as DMN networks.



- Because of flexible and more informal contracting arrangements, a DMN company may rapidly switch supply networks to meet different demands.
- Their partners behave similarly, and all parties understand that any supplier may still be called upon in the future if the need arises.

Fig. 2. Dynamic DMN Network Connections [Adapted from Noori, Tan & Lee (n.d.)]

More importantly, the effects of globalization have made companies very aware of their need for agile and nimble supply chains. Companies increasingly understand that such flexible and more innovative supply networks may only be attainable through short-term connections with other companies drawn from much wider supply networks (Camarinha-Matos & Afsarmanesh, 2005; Katzy & Crowston, 2008; Dekkers, 2009a; Noori & Lee, 2009).

The cultural change that will be necessary for companies to adopt the DMN perspective will necessarily depend on their respective industries or environments. In general, a very stable business environment is less favorable or perhaps makes it less necessary, for DMN networking. Traditional collaborative networks that emphasized long-term and stable business connections may then be more suitable under such conditions. Conversely, more chaotic industries or environments may increase the number of situations where DMN networks are perceived as advantageous by companies, and hence will lead to greater proliferation of such networks.

3.2 Dispersed manufacturing networks advantages

The fundamentally transient nature of DMN processes i.e. the operations of networks that are established for specific co-production or innovation purposes, and then afterwards dispersed, provides certain performance advantages as compared with the more traditional stable collaboration networks. These advantages include higher goal attainments, improved operational efficiency and higher supply chain flexibility.

3.2.1 Higher goal attainments

The custom-build nature of DMN networks that gather together all the relevant capabilities for a particular task at hand will naturally tend to result in higher likelihood of network goal attainments. The concentrated assembly of the appropriate mix of experts, specialists, or customized resources will create the necessary attention and focus to provide the desired solutions (Katzy & Crowston, 2008). One potential danger that may arise from over-reliance on a closed set of such network partners is that it may limit the possible solutions that could be available to the group. However, this risk is itself mitigated by the nature of transitory and open-ended connections as found in DMN networks. Essentially, the dynamic and ever-changing links among DMN networks allow more opportunities for different companies to come into contact with, and to exchange information or knowledge. The objective-specific nature of DMN networks also means that a company will likely belong to different DMN networks at the same time, as to be able to fulfill all of its various objectives. A particular DMN network that is lacking in some critical skill or resource will have such deficiencies recognized by some its more experienced members, and rectified with the inclusion of additional member companies. Therefore, information and resources in DMN networks tend to be more complete for some particular purposes and hence make them more effective for the purpose of targeting joint efforts.

3.2.2 Improved operational efficiency

The dispersed nature of DMN networks also contributes to their operational efficiency. In dispersed co-production, specific manufacturing or distribution resources are employed from various companies only when needed. Unneeded resources are freed up and make available for use by other companies. These can only result in lower cost and better efficiency for the companies in the network as a whole (Noori & Lee, 2006; Dekkers & Bennet, 2009; Noori & Lee, 2009).

Operational efficiency can also be enhanced if member companies adopt beneficial process innovations. In this respect, the turnover or "churn" effect of network members in DMN networks makes them more amendable to the spread and adoption of process innovations in manufacturing and distribution operations. Firstly, the periodic entry of new member companies into networks serves to bring in knowledge of new operational innovations that may arise from time to time. Every member company in the network is exposed to such innovations, and can gain by learning these processes from each other. Secondly, the looser connections in DMN networks that allow easy recruitment of new members also allow for the easy retirement of current member companies that are deemed to be no longer assets to the network. The real threat of getting dropped by partners due to inefficiency acts as a spur to all network companies to quickly adopt process innovations where they are valuable and necessary. A company that is not fast on its feet or that is overly reluctant to invest in new and beneficial process innovations could be easily replaced by more proactive companies. Process innovations that are initially rare will rapidly become commonplace and standard offerings in DMN networks. In due course, the proliferation of such beneficial process innovations in these networks adds up to more efficient and cost-effective operations for DMN companies (Noori et al., n.d.).

3.2.3 Higher supply chain flexibility

The fundamentally dynamic nature of DMN networks also acts to create greater supply chain flexibility. Supply chain flexibility is defined as the ability of firms to adapt or react to change with little penalty to time, effort, cost or performance, and is critical to firms' survival in more turbulent business environments (Upton, 1994; Sanchez & Perez, 2005). For instance, consider the consequences to companies in the event of any major supply chain glitches. The unexpectedness and severity of such disruptions have been known to adversely affect companies' performances, reputations and market values (Hendricks & Singhal, 2003). Supply chain flexibility is viewed as an important ability to mitigate the negative effects of supply chain disruptions (Narasimhan & Talluri, 2009).

DMN companies are not only more willing but also more able to change supply chain partners whenever required. DMN companies are already accustomed to adding, switching or dropping partners as and when necessity may command such actions. In addition to that, because DMN companies are faced with lower hurdles when adjusting networks, they will be more willing to make use of supply chain flexibility as a coping mechanism to address environmental changes.

4. Types of dispersed manufacturing networks

The formation process of collaboration networks among companies has been identified as consisting of three types i.e. emergent, engineered or embedded processes (Ring et al., 2005). In its purest form, a DMN network may be formed and come into being as the result of emergent and spontaneous collaborations that takes place among a group of independent companies which discovered that they share a joint objective. This emergent process occurs when companies are naturally pulled by converging interests to work together as one.

The emergent process of network formation can be likened to the adaptive process whereby companies sense and respond to potential collaborations. An example of such emergent networks is the Shanzhai companies of South China (Shi, 2009; Tse et al., 2009). Essentially, these Shanzhai companies form collaboration networks among themselves without any formal leader. Each Shanzhai company coordinates with only its immediate partners with minimal consideration for the overall network coordination as a whole.

Over time, and with repeated interactions, the formation process of some DMN networks may gradually evolve toward a more engineered process. This happens if certain DMN companies increasingly take on the specialized roles of coordinators in the formation process of DMN networks. The engineered process comes about when these coordinating companies actively seek out to connect potentially collaborators with one another. Finally, when these companies have sufficient prior experience with one another, and have built social structures to support further collaborative efforts among themselves, the embedded process of collaboration may be said to take place (Magretta & Fung, 1998; Noori & Lee, 2006).

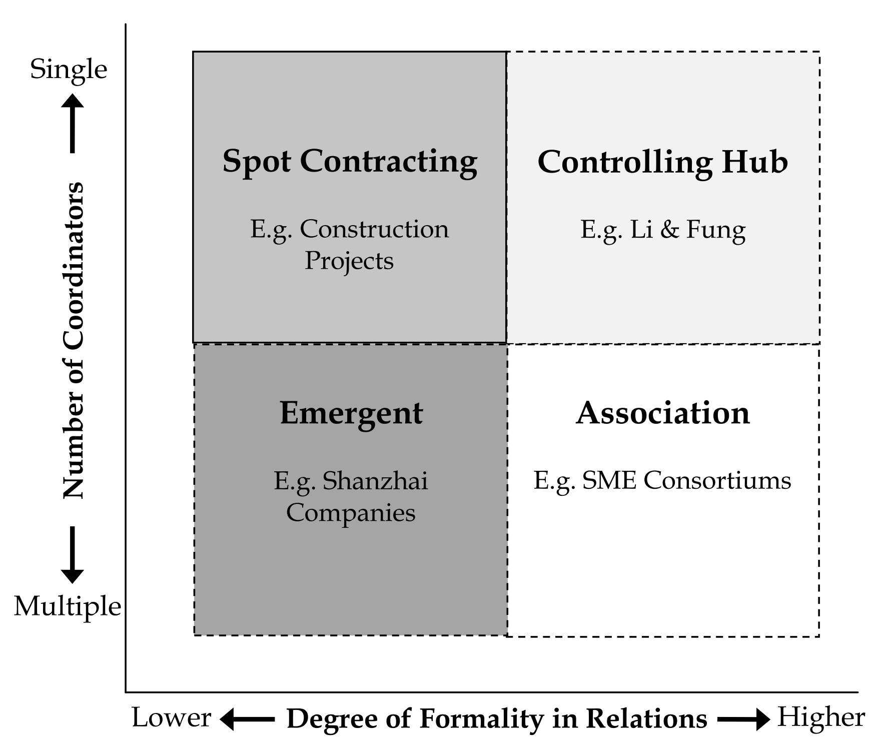
The engineered and embedded processes of network formation may be likened to a learning process whereby a group of companies come to gradually institutionalized collaboration routines to improve their collaborative efficiency. One example of such a coordinated network is managed by the well-known Li & Fung of Hong Kong, China. The main selling point of Li & Fung is their ability to quickly and competitively organize specialized resources from their wide range of suppliers to fulfill any customer order. Li & Fung essentially acts as a clearing house or a central hub to link their customers to their networks of suppliers (Magretta & Fung, 1998).

In addition to the above, the degree of formality in companies' business relationships will also inform their network formation processes. Like all companies, DMN companies engaged with each other through a web of both formal and informal relations. It should be noted that DMN companies are typically far more reliant on the informal social-networking aspect of business relations. Companies often find that having excellent informal relationships with partners are absolutely critical to promote information flows across supply chains (Reagans & McEvily, 2003). The extent and accuracy of supply chain information flow are especially important to companies in fast-moving or fluid business environments. At the same time, power or industry specific issues allows more dominant DMN companies to place an additional layer of formal safeguards in business transactions with partners. By seeking both benefits from informal ties, and safeguards from formal ties, these companies endeavor to obtain more relational rent from their networks (Emerson, 1962; Lavie, 2006). Therefore, the degree of formality in such relationships, which may vary from low to high, can be beneficial to certain companies by providing assurance of commitment or performance. By contrasting these two characteristics of network formation processes in a 2x2 matrix, four DMN networks types labeled as Controlling Hub, Spot Contracting, Emergent and Association are tentatively identified. The positioning of these DMN network types on the Coordination and Formal Relations Axes are shown in Figure 3.

5. Implications of dispersed manufacturing networks

DMN networks have clear advantages over traditional collaborative networks, especially in turbulent business environments. A DMN network can draw from a wider and more diverse pool of resources, with lesser constraint to change partners as required. A group of companies working as a DMN network will be more agile, innovative and efficient than a comparable group of companies working in a more traditional network.

However, this does not mean that a company in a DMN network may assume that it can always be successful. A DMN company will have to work even harder than a traditional company to be successful. Firstly, a DMN company has to invest more effort into relationship management with its peers. Individual companies in DMN networks have to rely on networking to gain access to various critical resources that may be too prohibitively costly for each to develop on its own (Ring et al., 2005; Katzy & Crowston, 2008). Secondly,



- "**Controlling Hub**" - A focal company organizes and coordinates networks of resources within its supply net. Though it may have long-term formal contracts with its partners, it only engages them on a per need short-term basis.
- "**Spot Contracting**" - A focal company organizes and coordinates networks of resources from the open market for specific purposes.
- "**Emergent**" - A group of companies spontaneously come together to form an open network to share or exchange resources for specific purposes.
- "**Association**" - A group of companies self-organize themselves to share or exchange resources. Though they may have long-term contracts with one another, each network among themselves is formed only on a short-term per need basis.

Note: These are "ideal-type" models, and boundaries in real networks may not be as clean-cut as shown here. In addition, some networks may also transit over time from one model type to another to suit shifting business conditions.

Fig. 3. Tentative Range of Dispersed Manufacturing Network Types

DMN companies have to stay competitive in its areas of competency against every other DMN company in the network with the same areas of competency. There are no permanent allies, and hence no permanent enemies in a DMN network, and the onus is on each DMN company to prove its continual worth to its peers. A DMN company that has ceased to be competitive will be unable to easily find partners to pursue new business opportunities or to fend off competitive threats.

Given that it is more difficult to be a DMN company, why should any company ever seek to be one? Simply, the performance advantages of a DMN network will eventually make joining such networks a necessity wherever they are possible. It is anticipated that traditional collaborative networks in industries with more turbulent business environments will gradually transit to become DMN networks. Competition in these industries will always exist, but increasingly, such competition may be fought out only among DMN networks.

For instance, in certain supply chain areas, i.e. in humanitarian supply chains, DMN networks are essentially already the means by which organizations collaborate with one another. Humanitarian supply chains are typically unpredictable, costly, difficult, and needed to be quickly set-up under complicated conditions. They are also usually custom-build and may be required only on a short-term basis for disaster mitigation (Oloruntoba & Gray, 2006; Thomas & Fritz, 2006; Maon et al., 2009). Given these challenges, many relief organizations operate under DMN dispersion rules. For instance, relief organizations may find themselves with limited resources in certain disaster areas. Under such circumstances, they may share resources with each other in order to meet their common goal of disaster relief. Later, these organizations may encounter one another again at a different disaster area, and will collaborate once more, though perhaps in different ways, to provide relief.

The DMN perspective suggests that small companies operating in DMN networks can have a competitive advantage against larger firms (Noori & Lee, 2006; 2009). All else being equal, smaller companies tend to have lesser overheads. Traditionally, their limitation is that they also have lesser access to internal resources enjoyed by larger companies. A DMN network allows small companies better access to all such resources, while still keeping to their advantage of lower overheads. The cost-efficiency, effectiveness, flexibility and innovativeness of a DMN network of a host of small companies can therefore compare very well against the workings of an equivalent-sized large company. An analogy from nature may be to compare swarm entities versus larger entities. In this comparison, consider how a colony of ants working in short-term collaborative clusters may carry out many more different tasks, and perform them all far more efficiently, than a single elephant could do by itself. The DMN perspective of convenient but temporary collaboration among independent entities for shared benefits may yet prove to be a more palatable and realistic form of cooperation that can be possible among different companies.

6. Conclusion

As a relatively new and developing perspective, only time will reveal how DMN concepts will roll out in companies. However, the continuing aggregation and intensification of global markets and competition suggest that the need for a DMN approach by businesses will become more acute over time. In the light of these trends, it is important that DMN should continue to attract both practitioner attention and scholarly research so as to ready the ground to guide current and future business practices. This chapter seeks to bring attention to this phenomenon in order to spur further investigative efforts.

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12

Advanced Supply Chain Planning Systems (APS) Today and Tomorrow

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1. Introduction

The Supply Chain Management (SCM) paradigm is widely discussed today in virtually all industry sectors. This paradigm emerged in the late 1980s, and became widespread in the 1990s as a way to organize a set of concepts, methods and tools for promoting a holistic view of the entire supply chain. Supply chain optimization greatly depends on the planning process (Jespersen & Skjott-Larsen, 2005). This process aims to obtain a balance between supply and demand, from primary suppliers to final customers, to deliver superior goods and services through the optimization of supply chain assets. This is quite a difficult task since it involves simultaneously synchronizing a large quantity of complex decisions, and dealing with other issues that can complicate the process, for instance the existence of conflicting objectives and the presence of stochastic behaviours (Lin et al., 2007; Camarinha-Matos and Afsarmanesh, 2004; Schneeweiss and Zimmer, 2004; Terzi & Cavalieri, 2003; Min and Zhou, 2002; Simchi-Levi et al., 2000).
To cope with the complexity of supply chain planning, a set of information technology (IT) tools can be used directly or indirectly. These systems are used for information integration, inventory management, order fulfilment, delivery planning and coordination, just to mention a few. Among the leading IT tools for Supply Chain Managemet, the Advanced Planning and Scheduling (APS) system is widely discussed today, which may be due to the fact that APS systems focus on a very relevant problem in supply chains, i.e. how to synchronize hundreds of real planning decisions at strategic, tactical and operational levels in a complex environment. This quite challenging objective requires an advanced solution.
Basically, APS are computer supported planning systems that put forward various functions of Supply Chain Management, including procurement, production, distribution and sales, at the strategic, tactical and operational planning levels (Stadtler, 2005). These systems stand for a quantitative model-driven perspective on the use of IT in supporting Supply Chain Management, for exploiting advanced analysis and supply chain optimization methods. In fact, APS systems have represented a natural evolution of planning approaches for the

manufacturing area since the 1970s (Martel & Vieira, 2010). The first system approach was Material Requirements Planning (MRP), which evolved later into Manufacturing Resources Planning (MRP II), Distribution Resources Planning (DRP) and, during the 1990s, into Enterprise Resources Planning (ERP systems). APS systems arose to fill the gap of ERP systems, which are basically transactional systems and not planning systems (Stadtler, 2005). ERP's planning capabilities, although fundamental to the planning process, are limited when not leveraged by an APS system.

Despite many advances in this domain, there are some profound changes taking place in the key supply chain technology. We would like to call attention to some fundamental trends identified by some recent studies (Cecere, 2006; Van Eck, 2003): need to better deal with risk (robustness), agility, responsiveness and focus on multi-tier relationships. They can be divided into two major trends: firstly, trying to expand from an internal to an external supply chain point-of-view, in which relationships with partners and collaborations are considered to a greater extent; and secondly, paying more attention to the stochastic behaviour of the supply chain, managing risks and responding adequately to them.

In this chapter we discuss how APS systems are being used to deliver superior value in the context of complex supply chain problems (APS today). In addition, we explore some limitations and possible avenues of these systems (APS Tomorrow) to address the profound changes taking place in the supply chain technology.

In order to do so, this chapter is organized into two parts:

Part I – APS Today (Section 2): first, we highlight some advantages of APS systems towards obtaining superior supply chain plans, and in this sense, we discuss the capacity of these systems in employing optimization technology and their ability to integrate time frames ranging from long-term strategic periods to short-term operational ones. We also introduce and compare some typical systems in the market and we present some implementation approaches through three case studies in large companies. These case studies portray common situations in the APS area. They demonstrate that by utilizing current technology and modelling approaches, in practice one is mostly trying to implement and integrate the internal supply chains, not the entire supply chain.

Part II – APS Tomorrow (Section 3): we now explore the other side of the coin, i.e. the inherent limitations to model multi-tier supply chains and to perform experiments with large-scale real and complex problems. Two main issues are discussed: the inability of traditional approaches to create sophisticated simulation scenarios and the limitation in modelling distributed contexts to capture important business phenomena, like negotiation and cooperation. In order to overcome these handicaps, we introduce what we call a distributed APS system (d-APS) and we provide some insights from our experience with this kind of system in a Canadian softwood lumber industry, as being performed by the FORAC Research Consortium. Some preliminary and laboratory tests show interesting results in terms of the quality of the solution, planning lead-time and the possibility of creating complex simulation scenarios. We strongly believe that this new generation of APS systems will bring about a revolution in the market in the coming years, contributing to the improvement of the current APS practices.

Finally, Section 4 outlines some final remarks and conclusions.

2. Part I: APS today

2.1 Advanced planning and scheduling (APS) systems

The planning process is at the heart of APS systems. It aims to support decision-making by identifying alternatives for future activities and by selecting good strategies or even the best one (Fleischmann et al., 2004) while considering the decision-maker's objectives and constraints in the company's environment. In the authors' view, the main characteristics of APS are:

- *Integral planning*: planning of the entire supply chain. It can focus on internal supply chain issues (i.e. when a single company has several production sites, or distribution centres) and theoretically it can consider the whole supply chain (i.e. from the company's suppliers to the company's customers).
- *True optimization*: APS systems exploit advanced analysis and supply chain optimization technology (exact ones or heuristics) to carry out planning and scheduling activities. Optimization problems seek solutions where decisions need to be made in a constrained or limited resource context. Most supply chain optimization problems require matching demand and supply when one, the other, or both may be limited (Lapide & Suleski, 1998). The main optimization approaches employed are mathematical programming (largely linear and mixed integer programming), constraint programming, and heuristics (including scheduling methods like the theory of constraints or simulated annealing). Other quantitative approaches are also used, such as forecasting and time series analysis, exhaustive enumeration and scenario planning (what-if analysis and simulations). For a guide on the main optimization and quantitative issues in APS (e.g. how to define optimization problems for strategic, tactical and operational levels and solve them), the reader is referred to Van Eck (2003), Shapiro (2000), and Lapide & Suleski (1998).
- *A hierarchical planning system*: APS are typically hierarchical planning systems (Stadtler and Kilger, 2004; Hax and Meal, 1975).

In order to translate these three characteristics into an implementable APS system, two main aspects of the APS have to be considered: the architecture (how the system is organized, including the 'hierarchy' and 'integral planning') and the engine (how each part of the APS architecture performs its planning activities).

In terms of APS architecture, according to Meyr & Stadtler (2004), a typical system is organized though combinations of a set of building blocks encompassing decisions at three levels: strategic (long-term decisions), tactical (mid-term decisions), and operational (short-term decisions levels). In more specific terms, some typical building blocks are suggested by Meyr & Stadtler (2005):

- *Strategic network planning*: long-term planning normally dedicated to plant allocations and to designing the physical distribution network. In addition, other strategic decisions related to market strategies can be supported, such as determining which products to position in certain markets.
- *Demand planning*: represents sales forecast for long, medium and short terms, based on a set of quantitative and qualitative approaches. This results in expected demand, which acts as an input for several other building blocks.
- *Demand fulfilment & ATP (available-to-promise)*: an interface for the customers in which orders are tracked from order entry to delivery. It includes order promising, due dates settings and shortage planning.
- *Master planning*: aims to balance demand and capacity over a medium-term planning interval, coordinating procurement, production and distribution.
- *Production planning and scheduling*: while master planning coordinates the planning activities between sites, production planning and scheduling is done within each site.

Production planning is dedicated to lot-sizing, and scheduling is dedicated to two planning tasks, machine sequencing and shop floor control.

- *Distribution planning*: deals with materials flows in a more detailed manner than master planning, taking care of transport of goods directly to customers or via warehouses and cross-docking.
- *Transport planning*: aims to sequence customer locations on a vehicle's trip though vehicle routing.
- *Purchasing & material requirement planning*: a step further compared to traditional bill-of-material explosion and ordering of materials done by an ERP. It performs advanced purchase planning using alternative suppliers, quantity discount and lower/upper quantity analysis.

Rodhe (2004) mentions that, in addition to these building blocks, others can be included in an APS, for example, coordinating them with other systems, like OLTP (Online Transaction Processing) (e.g. ERP or legacy systems) or data warehouses.

As a hierarchical planning system, an APS has to coordinate and integrate information between building blocks. Information flows can be horizontal and vertical. Horizontal flows basically orient all building blocks according to customer needs. Examples of these flows include customer orders, sales forecasts, internal orders for warehouse replenishment, and purchasing orders for suppliers. Vertical flows, on the other hand, represent a way to coordinate lower level plans by means of the results of higher level plans (downward flows), or a way to inform upper levels about the performance of the lower level (upward flows) (Fleischmann et al., 2004).

We can understand APS systems as being composed of building blocks. These building blocks are very flexible and can be configured in many ways, or even bought and installed separately. For example, similarly to Meyr & Stadtler (2004), the FORAC Research Consortium employed this idea to represent the possible configuration of APS systems in the forest products industry in Canada. Figure 1 presents an instantiation for the softwood lumber industry, according to Frayret et al. (2004b).

To respect some particularities of this industry sector in Canada, several important adaptations were made with respect to Meyr & Stadtler (2004). For example, the building block labelled 'Synchronized Production-Distribution Lot-Sizing' stands for production planning and scheduling, as well as distribution and transportation planning. In this example, this happens because the loading of machine groups, with their respective lot-sizing, is highly influenced by the sequence of jobs in this industrial sector. In addition, it was decided to include the execution level below the short-term, so that the control becomes explicit. Some of these building-blocks were implemented and tested for the softwood industry, as we will discuss in Part II of the chapter.

Apart from architectural reorganizations, supply chain planning systems are very flexible in terms of the APS engine they employ. By engine we understand the mathematical approach they use, which is basically models and algorithms. The literature provides a diversity of studies in this domain, such as Gaudreault et al. (2007), Chen & Ji (2007), Lee et al. (2002), Kuroda et al. (2002), and Azouzi & Massicotte (2001).

There have been many practical and theoretical developments in terms of APS architecture and engine to date. In the next section, we present the main systems available on the market, according to a study performed by AMR Research.

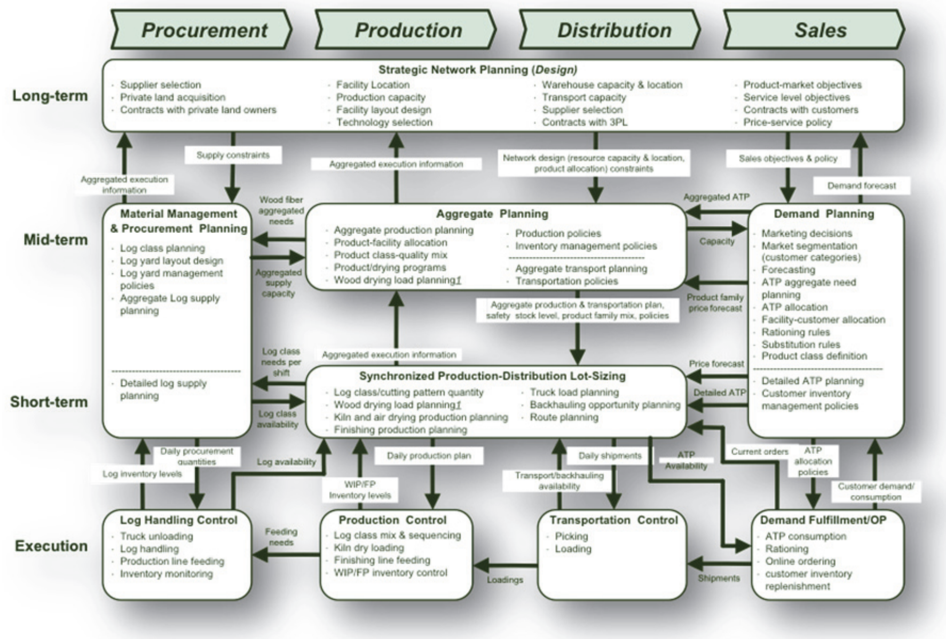

Fig. 1. Supply chain planning for the Forest Products Industry

2.2 Some systems available on the market

Based on AMR's 'The Supply Chain Management Market Sizing Report 2007-2012' (Fontanella et al., 2008), the world's top eight Supply Chain Management vendors that offer APS systems on the market are SAP, Oracle, Manhattan Associates, i2 Technologies, IBS, RedPrairie, Infor and JDA Software. By visiting each vendor's product portfolio we can classify each one into two vendor categories:

- Enterprise suite vendors such as SAP, Oracle, and Infor that in the late 90s started to buy or develop an APS system to add to their product portfolio.
- Best-of-Breed suite vendors such as i2 Technologies, RedPrairie and Manhattan Associates that started as specialized Supply Chain Management solutions vendors.

With a closer look at each solution, it can be noted that all of them offer a similar core functional scope that covers all APS building blocks previously described. The main differences are related to industry focus and presence of functional blocks. For example, SAP does not offer a solution that covers business requirements at the strategic level of planning, leaving it with a partner solution. Another difference is in the industry vertical bias of each software vendor, mainly due to the fact that some of them started their product development in a specific industry such as IBS in the Chemical Industry, JDA (who acquired Manugistics) and RedPrairies in the Retail Industry.

The top two vendors in the list are SAP and Oracle and their APS contributions are those we will analyze. Both are ERP vendors that identified a software revenue potential in the Supply Chain Management market and added supply chain planning solutions to their product portfolio. As biggest rivals, each adopted a different strategy to enhance their solution offering. SAP developed its SAP Supply Chain Management system from scratch and Oracle acquired best-of-breed solutions and packaged them in Oracle's Supply Chain Management Applications suite. These paths resulted in APS solutions with different characteristics in some aspects, such as functional scope and technical architecture.

Building Block	SAP	Oracle
Strategic Network Planning	N/A – Partner Solution	Strategic Network Optimization
Demand Planning	SAP APO: DP - Demand Planning	Demantra Demand Management
Master Planning	SAP APO: SNP - Supply Network Planning	Advanced Supply Chain Planning
Distribution Planning	SAP APO: DPLY - Deployment	Advanced Supply Chain Planning
Production planning and scheduling	SAP APO: PPDS - Production Planning / Detailed Scheduling	Oracle Production Scheduling
Transport Planning	SAP APO: TPVS - Transportation Planning / Vehicle Scheduling	Oracle Transportation Management
Demand Fulfillment & ATP	SAP APO: GATP - Global Available-to-Promise	Global Order Promising
Inventory Planning	SAP APO: Safety Stock Planning	Inventory Optimization
Supply Chain Monitoring	SAP APO: SCC - Supply Chain Cockpit	Advanced Planning Command Center
Collaborative Planning	SAP SNC - Supply Network Collaboration	Collaborative Planning

P = Product / M = Module / F = Functionality

Table 1. Main building blocks for SAP's Supply Chain Management system and Oracle's Supply Chain Management suite

We have had the opportunity to analyze each suite in detail and they seem to be quite similar in many terms (see Table 1). Both cover all aspects of APS system building blocks but the difference appears in a detailed analysis. Oracle's solution is a best of breed acquisition system and presents some advantages especially in the transportation planning area due to the fact that this functionality was a result of a best of breed software acquisition. On the other hand SAP has some advantages regarding technical architecture. Its APS is a single system called SAP Advanced Planning and Optimization (SAP APO) and is divided into five modules. An outside-the-box real-time integration is possible between all planning levels resulting in minimal effort to cascade the plans from strategic to operational levels. Additionally, companies employing SAP ECC (SAP ERP Core Component) as their ERP system will also have an outside-the-box integration between planning and transactional levels, which considerably facilitates integration. However, Oracle's Supply Chain Management suite is a group of about seven different products, each with its own data set, data model and technical design, some of them already with a plug-in that guarantees integration while some are real-time integration and mostly in batch mode.

In brief, it can be stated that, if minimum integration issues are required and for those already having an SAP ERP system, the SAP APO is recommended. If not, either system will provide quite a good functional scope. For those who would like to confront both systems, we recommend a detailed functional analysis so a good decision between Oracle and SAP can be made. However, a functional analysis alone is not enough. There are other important aspects to consider as well, when deciding which system best suits the company's requirements, such as:

- *Experienced consulting ecosystem*: are there consulting companies with enough available consultants that are proficient on the tool? Are there enough success cases of companies that have implemented that particular system?
- *Vendor pricing model*: will the entire solution have to be bought to get the Return On Investment after deploying all functionalities or can we effect a pay by deployed model?
- *Deployment flexibility*: does the solution have technical flexibility that allows a phased implementation or are there so many dependencies that it is better to deploy the whole solution to achieve a reasonable cost/benefit equation?

In the next subsection some typical implementation projects are discussed, from our practical experience.

2.3 A typical implementation project

When desiring to start an APS implementation project, it is a good plan to gather insights and advice in the field. By doing so, companies will gain a more precise idea of what they should not do, because the fact is that there are more unsuccessful APS implementation stories than successful ones. We will explore some reasons for this in the following.

Due to the extensive promotion of ERP implementation in the late 1990s, many companies whose systems had failed to operate properly found themselves trapped, having made a huge investment promising large Returns On Investment that simply did not materialize. At this same time, most software vendors, such as SAP, Oracle, JD Edwards were launching their Supply Chain Management solutions, which turned out to be good timing for positioning these new systems as the solution that would guarantee those promised Returns On Investment. It was commonly believed that implementing all the new advanced planning functionality along with the ERP would surely result in immense benefits. Marketing campaigns employed interesting arguments, such as "boost ERP benefits with an APS" or "use the experience from ERP implementation to guarantee a worry-free APS project".

From a business transformation viewpoint, this can be quite misleading. All typical APS implementation projects are normally executed with a methodological approach that ignores critical transformation aspects for a successful APS implementation. They are:

- Unified *Vision*: are all stakeholders in agreement as to the expected benefits from the APS project? Since a supply chain has intrinsic conflicting objectives, it is quite natural that each area will expect benefits that are at variance to the others. If these expectations inside the company are not aligned frustrations will emerge.
- Clear *Strategy*: is there a detailed roadmap that outlines all the organizational transformations necessary to achieve these benefits? Believing that an APS implementation is like an ERP implementation might lead to some surprises. The methodological approach is very different. Specific organizational changes must occur

in the right order and volume to allow an adequate organizational maturity to capture the return on the APS project investment. How much change the organization can absorb should also be taken into account.

- Structured *Processes*: are considered to be a key dimension, because APS systems demand a coherent and streamlined planning process. They are systems with a high degree of modelling flexibility, meaning that they tend to accept almost anything. If business rules and decision criteria are not explicit and clear for the company, this can become a problem because incoherent rules and criteria can be modelled in the system.
- Aligned *KPIs*: as many firms know, good initiatives in different directions add up to zero. Misaligned indicators can implode all efforts to streamline the supply chain resulting in wasted efforts. Revisiting KPIs is vital to guarantee a coherent incentive structure and it must be built considering intrinsic supply chain trade-offs.
- Aligned *Organizational* Structure: to guarantee that local efforts will result in an overall optimum, knowing exactly what is expected from each is clearly essential. This means that each role and responsibility should be defined and done so considering all supply chain dependencies to eliminate dysfunctional empowerment where one's effort could be undermined by that of another.
- Educated and Prepared *People*: since transformation is ultimately achieved only through individual change, it is critical to involve, educate and train the supply chain team. In contrast to an ERP, users can abandon an APS system and go back to their comfortable spreadsheets with no important consequences, at least in the short term. Underestimating the need of user involvement, persuasion and behavioural orientation to drive an effective change management can be risky.
- The right *Technology*: technology is where most of the business processes will materialize. Specialists like to say that process and technology is the same thing; i.e. one materializes the other. It Obviously, not much thought is required to say that if one does a perfect job in designing processes and chooses the wrong technology all efforts will be lost.

Having explained this framework of seven transformation dimensions, it would be interesting to share some relevant practical lessons. Three typical case studies of APS implementation are presented, from the author's experience.

2.4 Case studies

In this subsection we present three case studies that aptly represent the following situations:

- APS Readiness: a company has no APS solution and has decided to adopt one but is doubtful of being ready for it. The challenge then is to make sure that it can deal with such a transformation process.
- APS Maximization: a company wants to extract much more from their investment in the APS solution. The challenge is to find more benefit areas and achieve quick gains to finance future solution evolution.
- APS Recovery: a company has invested substantially in an APS project and finds itself in a situation where the system has almost shut down, the spreadsheets have come back and are replacing the APS system. The challenge is to recover this investment.

2.4.1 APS readiness

This study was performed in a consumer goods manufacturer with USD 5.35 billion revenue in the fourth quarter of 2008, with 37 product categories, ranging from frozen food to fresh meat and with 11 brands in its product portfolio. Their supply chain comprises 17 plants, 10 distribution centres and 17 sales offices. The company was interested in implementing SAP APO to support its planning processes that had gone through revision. The question here was knowing whether the company was ready for such a technology since there were critical pre-requisites that would put a condition on full value capture of an investment in such a complex supply chain.

The APS Readiness assessment was applied in all seven-transformation dimensions (vision, strategy, processes, organization, KPIs, technology and people). It consisted in confronting subject areas in all dimensions against an ideal situation. Table 2 shows what subject areas were analyzed and with what ideal reference they were confronted.

Dimension	What is Verified?	How?	Ideal Reference.
Vision	Stakeholder Expectation of APS total benefits	C-Level Interviews Management Level Interviews	Alignment among stakeholders
Strategy	Project alignment with corporate strategy	Interviews	Alignment with corporate strategy
Processes	Planning Processes Planning Hierarchies Process Documentation Planning Model Adherence Enabling Processes	Adjusted O.W. Survey Process Analysis Documentation Analysis Interviews System and Process Analysis	O.W. ABCD Checklist/APICS O.W. ABCD Checklist/APICS Consulting experience O.W. ABCD Checklist/APICS
Technology	Technical Readiness Check	Infrastructure Check ERP Configuration Check	APS Quick Sizing Tool APS Best Practices
KPIs	Current KPI Structure KPI Analysis Processes	KPI Hierarchy Analysis Process Analysis	SCORE Model O.W. ABCD Checklist
People	Team Skill Set Check SCM Knowledge	Curriculum Analysis SCM Test	APICS APS Education Curriculum
Organization	Roles & Responsibilities	RACI Matrix Analysis	APICS

N.B.: O.W. stands for Oliver White™; RACI is R (Responsible), A (Accountable), C (communicated), I (Informed) is a matrix to define roles and responsibilities.

Table 2. APS Readiness Assessment Methodology

For each verified subject area a specific methodology was used to collect information from the company's actual situation and then the result was structured and compared to the ideal situation. A rationale was used to give a readiness score. As shown in Table 3, a 100% grade meant full readiness. Different scores from this ideal goal indicated that work had to be done to achieve an acceptable number. The final result was presented in a format demonstrated in Table 3. The company overall weighted average readiness was 64% of 100%.

Dimension	Item Verified	Score	Reference Score	Weight
Vision	Executive Alignment	65%	80%	1
	Expected Benefits Alignment	57%	80%	1
Strategy	Alignment with strategy	80%	80%	1
Process	Adherence to Reference Model	79%	80%	1
	Planning Processes	56%	80%	3
	Planning Hierarchy	49%	80%	2
	Process Documentation	85%	80%	2
	Enabling Processes	68%	80%	3
Technology	Hardware Sizing	100%	80%	1
	ERP Configuration	73%	80%	2
	Process Requirements	50%	80%	2
KPIs	KPI Analysis Process	74%	80%	3
	KPI Structure	89%	80%	1
People	Curriculum Analysis	51%	70%	2
	SCM Test	48%	80%	3
Organization	RACI Matrix Analysis	45%	80%	2
	Average	67%	**80%**	

Table 3. APS Readiness Result

The weight used for each subject area considered the difficulty necessary to elevate the readiness level. It is possible to see that most effort usually went into Planning Process revision, Enabling Process revision, KPI Management revision, and Team Education. The overall score was the company's distance from the ideal readiness situation. Table 4 shows the scale that was used to indicate whether or not they were ready to start an APS implementation project.

Readiness Check	
81-100%	**Ideal for best value capture of APS project**
61-80%	**Adequate together with an improvement plan during APS project**
41-60%	**Inadequate, demanding corrective actions before APS project**
21-40%	**Inadequate, demanding maturing actions before APS project**
0-20%	**Inadequate, demanding revision actions before APS project**

Table 4. APS Readiness Scale

Since 64% was the overall readiness, they embarked on the project but with an improvement plan to address the subject areas that received a low readiness grade. Some of the improvement initiatives were: aligning stakeholders about expected benefits, planning processes revision, planning hierarchy revision, process documentation and team education in Supply Chain Management concepts and APS training.

The final product from this analysis was a roadmap with these initiatives that ranged all seven dimensions to guarantee a full value capture of the APS system.

2.4.2 APS maximization

This study was done in a steel manufacturer with USD 1.26 billion revenue in 2008 with a product line that includes rolled tubes, drawn tubes for automotive applications, industry in general, oil industry and civil construction. They have an integrated mill plant with a 550.000 tons-per-year installed capacity divided into five sub-plants that offer a unique production synchronization challenge.

Initially, the company started a transformation process with a pre-implementation assessment in all seven-transformation dimensions (vision, strategy, processes, organizational structure, KPIs and people) that pointed out the root causes for their supply chain inefficiencies. The root causes identified were:

- Lack of Supply Chain Management concepts in the organization.
- Lack of an adequate product hierarchy across all planning processes.
- Lack of alignment between their KPI structure and their supply chain strategic objectives.
- Lack of planning hierarchy to deploy strategy to execution and a feedback loop.
- Lack of an integrated planning system.
- Their ERP and legacy system did not support integrated supply chain logic.

Based on this, a roadmap was built to eliminate all root causes. Unfortunately, the roadmap was not taken seriously because the implementation was executed by a vendor that had won the bid with a very aggressive proposal that promised an implementation in much less time and effort than originally estimated. The result was a faulty system with some modules almost shutting down. The worst case was the Production Planning & Detailed Scheduling (PPDS) module.

The company therefore decided to make an APS maximization effort. A post-optimization analysis was executed to find out what the issues were for the PPDS sub-utilization. The final result was:

- Bad shop floor information due to the lack of standard procedures and KPIs to enforce good shop floor confirmations.
- Process orders with remaining quantities below minimum tolerance were integrated to the SAP APO system resulting in the need for a time-consuming consistency check before actual production sequencing.
- Lack of a clear sequencing logic between upstream and downstream resources causing a bullwhip effect from downstream resources.
- A business strategy that focused on flexible fulfilment and at the same time shop floor KPIs that oriented production for high capacity utilization.

All of these issues culminated in some major symptoms such as:

- 1000 exception alerts that led to no credibility in the information the system was generating.
- Need for manual sequencing due to so many exceptions and information inconsistencies.
- An hour and a half daily effort for data cleansing and validation and five hours for manual sequencing and result analysis.

Once all issues were identified, a small project was organized to eliminate them. Also, a study was executed to understand exactly what sequencing logic the production scheduler used and when this was understood, a scheduling heuristic was adapted.

Even though the software vendor had declared PPDS was not an adequate tool for sequencing the hot rolling mill, the assessment showed that the logic used was much simpler than expected and PPDS was an adequate system for this purpose, with the condition that all root causes and issues identified be addressed properly.
The lesson learned in this case was that an APS system sub-utilization usually is a symptom and not a root cause, which usually involves another dimension such as unclear operating logic (process), misaligned indicators (KPI), unclear roles and responsibilities (organization) or a lack of knowledge on the system logic or Supply Chain Management logic (people). Certainly there are problems related to the system (technology), but usually they are the easiest to remedy. The challenge is to ensure that all other dimensions are at the same level of maturity to allow maximum system value capture.

2.4.3 APS recovery

This study was performed in an Iron Pellet and Iron Pellet Feed manufacturer with 15% world market share having USD 1.37 billion revenue in 2007. This company has a quite simple supply chain with two manufacturing facilities, two iron ore pipelines, two mines and a port with two berths. Their initial APS system implementation goal was to support the strategic, tactical and operational planning processes. At the tactical level, the main objective was to define optimal product formulation and mix to achieve strategic goals, service level and profitability. At the tactical level the objective was to balance supply with demand, particularly considering port variability that had a high impact in plant production and pipeline flow. On the operational level the goal was to reduce demurrage costs by better synchronization and sequencing of ships' loads.
The SAP APO system had brought minimal benefits and from all implemented functionalities only the ship scheduling solution was being used with many restrictions. The first thing to do was to apply a 'technological diagnosis' to find out what had really gone wrong. It consisted of an analysis in five main areas:

- Technical: identify any problem related to bad hardware sizing, poorly developed programs, or network problems.
- Functional: identify any problem related to poor functional scope offered by the system and gap analysis. In other words, verify whether the system has the proper functionality to support the business process in an adequate way.
- Modelling: identify any problem related to poorly implemented and misused standard functionality. The main objective was to find out if there was anything forcing the system, something it was not meant to do. Another aspect was to find out if the important business variables necessary for quality decision-making were actually modelled in the system.
- Business Process: identify problems related to business process design. There might be a business logic that is wrong according to business needs and best practices. Since typically a system is built based on best practices and proven methods, if the process design contains wrong assumptions something might be expected from the system that it cannot deliver.
- End-user: investigate whether the end-user is properly trained on the tool and educated on the logic behind it.

It was possible to show in a structured way what the system problem actually was. It turned out that the minor problem was technical or functional. The most important ones were end-user knowledge of the system and process design. Together with this analysis it was also possible to conduct a broader and additional assessment in all other six-transformation dimensions (vision, strategy, process, indicators, people, and organization) to bring to light other root causes for supply chain dysfunctions. The main lesson learned from a 'recovery' perspective was that implementing an APS tool without a structured planning process and company maturity in terms of the seven dimensions mentioned might result in a recovery initiative.

Based on this analysis, a three-year roadmap was then built, which was:

- *Phase one – Structure Integrated Planning process and support with SAP APO*: structure a sales & operations planning process and configure the SAP APO using simple heuristics so the results are easy to understand and digest. Align some configurations in the ERP system so as to support the new planning process. Functional scope: Demand Planning and Supply Network Planning modules.
- *Phase two - Structure short term planning processes and extend collaboration with suppliers*: leverage short-term results with stronger planning process integration with suppliers (CPFR - Collaborative Planning, Forecasting, and Replenishment). Functional scope: Supply Network Planning with optimization and Production Planning & Detailed scheduling module.
- *Phase three - Extend planning capabilities*: include real-time supply chain visibility with SAP's Event Manager system and support stronger integration with a collaborative demand planning process with internal sales representatives and clients, and support further collaboration with suppliers in short-term planning with SAP Supply Network Collaboration (supplier managed inventory scenario) and extend the Supply Network Planning module for the mid-term planning (extend procurement plan visibility).

This three-year roadmap revealed an interesting conclusion: apart from phase one, which was successfully implemented and resulted in the company effectively capturing the value of the APS tool with sales & operations planning process and with several what-if simulation capabilities, phases two and three were not actually implemented. Carrying out these two phases means going beyond the company's boundary, which is a complex procedure using the current technology and modelling approaches. This is the main topic of the Part II.

3. Part II: APS tomorrow

In the first part of this chapter we highlighted some advantages of APS systems for obtaining superior supply chain plans. In this sense, we discussed the power of these systems, we introduced and discussed some typical systems on the market and we presented three implementation approaches through case studies in large companies. As can be noted, while the current practice and technology allow for dealing with the internal supply chain, the entire supply chain has not been properly considered so far.

In Part II we now explore inherent limitations of traditional APS systems in modelling distributed contexts to capture important business phenomena, like negotiation and cooperation, as well as in creating sophisticated simulation scenarios. To overcome these drawbacks, we introduce what we call a distributed APS system (d-APS) and we provide some insights about our experience with this kind of system in a Canadian softwood lumber industry.

3.1 Limitations, trends and opportunities

Recent studies in the domain demonstrate that APS is a fruitful field in practice and in academia today. Similarly, it is also a fertile area in the software systems market, with, for example, 44 available software packages having been surveyed by Elliott (2000). More recently, McCrea (2005) claimed that Supply Chain Management software is facing a sustainable growing market with at least 127 global vendors. The top four in revenue were SAP, i2 Technologies (which was incorporated by JDA), Oracle and Peoplesoft. This accounts for the explosion in the market in only five years.

This fast-paced dynamism brings about significant market transformation. For example, Lora Cecere, a former research director for AMR Research, discussed the profound changes taking place in the key supply chain technology (Cecere, 2006). We would like to call attention to some key issues pointed out by this study: need to deal better with risk (robustness), agility, responsiveness, multi-tier and focus on relationships. These can be divided into two major trends: firstly, trying to expand from an internal supply chain point-of-view to an external one, in which relationships with partners and collaborations are considered to a greater extent; and secondly, paying more attention to the stochastic behaviour of the supply chain, managing risks and responding adequately to them.

In terms of the first trend, despite the fact that the Supply Chain Management paradigm preconizes the coordination and integration of operations and processes throughout the supply chain, few APS, such as the one proposed in Dudek & Stadtler (2005), have the ability to cross organizational boundaries to properly address this purpose. As discussed before, APS procedures are normally used for internal supply chains and collaboration is a complex task. In order to cope with this approach, we will later introduce the distributed APS approach.

As for robustness, the software modules of APS are dedicated to deterministic planning (Meyr & Stadtler, 2004), which does not allow for robust planning. In fact, the management of uncertainties is a significant limitation of APS systems (Stadtler, 2005). The deterministic planning algorithms of the APS systems react quickly to changes while on the other hand, uncertainties are coped with through some limited approaches. First, flexibility can be incorporated into the production system and/or even reserved capacity to cope with uncertainty. For example, by being flexible (or having extra capacity), one can absorb non-expected demand from clients. Second, stochastic data is presented by the expected or worst-case value, and then 'what-if' simulations are applied afterwards (Van Eck, 2003).

'What-if' simulation in APS is an attention-grabbing functionality today. It allows for scenario analysis in stochastic and complex contexts. Basically, as explained by Musselman et al. (2002), this kind of simulation is mainly composed of experiments where one or more parameters or data of the APS are changed so that different scenario results can be compared. For example, the demand forecast can be changed manually and the master planning be executed in a 'simulated mode', so that different demand scenarios are generated. Or, for day-to-day activities, if one or more orders are not 'schedulable' because capacity and demand are not balanced in the short term, a set of strategies to temporarily augment the system's capacity can be used (e.g. additional work hours or even an extra shift at the bottleneck, outsourcing etc.). The advantage is in being able to investigate several variants of a system without disrupting its operations. Moreover, some vendors provide complete facilities to compare plans and schedules, allowing for multiple copies of different plans visible for side-by-side comparison. Some vendors also provide the ability to produce cost analyses of various planning options.

The major problem in current commercial APS systems is that the potential of simulation is limited to single runs of deterministic 'what-if' tests of plans, in which only a few exceptions situations can be tested in a a 'copied' version of the APS. This is a reactive approach, and as a consequence this can lead to nervous planning (Van Eck, 2003). These sensitivity analysis-type simulations do not necessarily lead the model towards a robust solution (Genin et al., 2007).

If more sophistication is necessary (e.g. considering the stochastic nature of supply chain), integration with other simulation-dedicated approaches can be required. For example, Landeghem & Vanmaele (2002) developed a tactical planning method embedded with a Monte Carlo simulation approach for allowing the assessment of uncertainties in supply chains. Additionally, the integration of a traditional APS system could be made with some discrete-event simulation approaches, such as the one proposed by Lendermann et al. (2001). Within their simulation framework, APS procedures represent the decision system and a discrete-event simulation approach is used to represent the manufacturing and logistics operations. The simulation models of each supply chain member exchange data with the APS in the same way as real manufacturing or logistics nodes.

A more pro-active approach is needed to discover solutions that are less sensitive to parameters uncertainties. A way of doing so is to include uncertainties in the model itself so that the algorithms can attempt to find a robust solution (Van Eck, 2003). Many efforts have been made to overcome this drawback, like the emergence of APS employing stochastic programming, or a special type of this approach called robust optimization. These techniques combine models for optimum resource allocation under uncertain conditions in order to produce a robust decision-making approach. These are powerful approaches when the uncertainty can be described permitting the evaluation of several scenarios under uncertainties to find the optimum solution.

For exemple, Santoro et al. (2005) present a stochastic programming approach for solving strategic supply chain design problems of realistic scales, where a huge number of scenarios can be computed. However, at the tactical and operational levels, stochastic programming models problem sizes may still be hard to solve, especially in the APS context and in general real-sized problems (Genin et al., 2008). The difficulty is in the growth of the model size when several scenarios are evaluated in a multi-period model. In spite of these drawbacks, stochastic programming is still a promising approach (Stadtler, 2005). Similarly to stochastic programming, some criticisms related to robust programming formulations concern their computational burden (Landeghem & Vanmaele, 2002), but as shown by some recent advances in this domain (e.g. Kazemi et al., 2010), calculation performance is being considered tractable even for realistic cases.

Even if stochastic programming-related approaches live up to their promise, traditional APSs will still be restrained by their inability to deal with supply chain relationships, i.e. they are not conceived to deal with negotiation and collaboration schemas. For example, in the three examples provided in Part I, collaboration was not considered, mainly due to the inability of the modelling approach and technology being employed. These are crucial elements in modern supply chain that companies are striving to catch up with. The first question is how to integrate different supply chain partners in a collaborative APS. There are possibilities of collaborating in two directions, i.e. with customers and with suppliers, spanning multiple planning domains. Kilger & Reuter (2004) propose that the APS systems of different partners can be interconnected, as shown in Figure 2.

Despite the fact that collaborations are a hot topic today and practitioners and academics alike mention their benefits and potential, in actual fact the notion is quite complicated. In theory, one APS for the whole supply chain can be possible, however few companies have

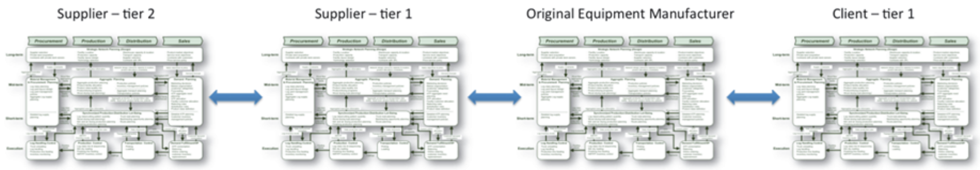

Fig. 2. APS and collaboration

succeeded in implementing one system for diverse partners. Most companies are still having trouble achieving the integration of the internal supply chain, as indicated in Part I of this chapter.

On the other hand, in theoretical terms collaborations between two APS systems seem to be less complicated. Collaborations can be two-tier (e.g. focal company – one key supplier), but they also can span multi-tiers (tier 3 – tier 2 – tier 1 – customer). They can be done in the domains of demand management, inventory management, transportation management, as well as other domains. But, in practice Kilger & Reuter (2004) argue that collaboration in APS is quite complex, and typical challenges are related to master data integration, access to user-specific secure data and the mutual decision-making process.

In today's APS software, part of it can be done manually or by using an exchange platform created for that purpose. Despite this possible collaboration, a real and more profound integration across supply chains through APS systems faces important barriers related to interconnection among business models, which requires sharing strategies, timely information, resources, profits and loss, which can be a quite delicate topic in a very fast and competitive world.

Other gaps exist between APS theory and practice (e.g. see Lin et al., 2007). However an interesting way to improve simulation and collaboration capabilities of APS systems and contribute to overcoming all these discussed limitations is the concept of d-APS (distributed APS) systems. Derived from the artificial intelligence field, this concept encompasses different ways of understanding and modelling supply chain planning systems using an agent-based reasoning. The concept of d-APS will be introduced in the next subsection.

3.2 The emergence of the distributed and agent-based approaches

Distributed advanced planning and scheduling systems (hereafter d-APS) arise from the convergence of two fields of research. On one hand, the first field deals with APS, and it generally proposes a centralized perspective of supply chain planning. On the other hand, the second field concerns agent-based manufacturing technology, which entails the development of distributed software systems to support the management of production and distribution systems.

Before discussing d-APS systems, it is interesting to briefly explain what an agent-based system stands for. The agent-based modelling approach aims to build complex software entities interacting with each other using mechanisms from distributed artificial intelligence, distributed computing, social network theory, cognitive science, and operational research (Tweedale, 2007; Samuelson, 2005). Examples of this mechanism include: *Autonomy*: the capacity to act without the intervention of humans or other systems; *Pro-activeness*: agents do not just act in reaction to their environment, but they are able to show goal-directed behaviour in which they can take initiative; *Social ability*: agents interact with other agents (and perhaps humans beings), and normally they have the ability to engage in social activities (e.g. cooperative problem solving or negotiation) in order to achieve their goals.

This sophisticated social capability is quite interesting in this domain. Examples of these abilities include: *Cooperation capability*: working together to attain a common goal; *Coordination capability*: organizing the problem resolution process in a way that makes it possible to prevent problematic interactions and stimulate exploitation of beneficial interactions; *Negotiation capability*: managing an acceptable agreement for the parts involved, dealing with possible conflicts.

Since the early 1990s, several developments address the context of distributed decision-making across the supply chain using agent technology, but these approaches do not clearly address the integration of advanced planning functions with agents. More recently, d-APS appears to consider these issues explicitly (Santa-Eulalia et al. 2011; Santa-Eulalia et al., 2008). It models the supply chain as a set of semi-autonomous and collaborative entities acting together to coordinate their decentralized plans. By using the agent–based approach, the concept of d-APS goes farther than traditional APS, as it includes extended capabilities, such as the utilization of negotiation and artificial intelligence mechanisms to coordinate, integrate and synchronize supply chain planning decisions. In this sense, d-APS systems may provide more modelling functionalities, thus allowing a higher level of complexity to be captured in comparison to classic APS systems.

As discussed before in Part I of this chapter, traditional systems have a large hierarchical structure for optimizing different areas (procurement, production, distribution, etc.) at diverse decision levels (strategic, tactical and operational). On the other hand, in a d-APS system we have a distributed structure where different agents encapsulate diverse planning functions and work semi-autonomously, interacting with each other following complex social protocols.

In such a model of the supply chain, each agent (i) makes local decisions, using its ability to exploit mathematical models to plan supply chain operations, and (ii) collectively interacts with other agents to coordinate their decisions and reach a compromise. More specifically, an agent's social ability represents some form of heuristic that is used to coordinate the local decision-making tools, allowing complex social behaviours to be performed, such as negotiations and collaboration. In other words, the agents can be seen as a general construct that represents various types of supply chain entities, through which distributed advanced planning tools can be plugged together and collaborate. These entities can be, for example, APS modules for operational planning or for tactical planning (Santa-Eulalia et al., 2008).

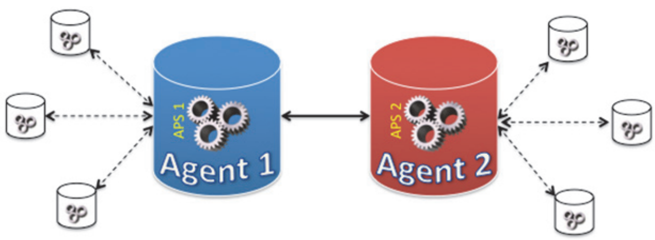

Fig. 3. A general schema for a d-APS (inspired by Santa-Eulalia et al., 2008)

Figure 3 schematizes this concept. Agent 1 encapsulates an APS tool dedicated to a specific planning domain 1 (e.g. a product assembler) while Agent 2 encapsulates specialized APS for the planning domain 2 (e.g. a distributor). Agent 1 interacts with 2, exchanging information or negotiating. Also, the assembler interacts with a set of suppliers and the distributor cooperates with a set of customers. Each agent has its own specialized APS tool, which can provide solutions for its own planning problem. Each planning problem can be quite different from each other to respond to different behaviours of supply chain partners, such as the ones defined by Gattorna (2006): agile, flexible, lean and continuous replenishment behaviours. The entire supply chain planning takes place when all agents interact with one another collaboratively to reconcile their local plans with the global plan for the entire supply chain.

In Figure 3 we do not represent the control structure of these systems. The reader may have the impression that the relationships between different agents in d-APS are sequential. This figure is a mere representation of the encapsulation of diverse APS tools and the consequent multiple coordination process among those entities, but it does not aim to represent their control structure. In reality, the coordination and control structures of d-APS are quite flexible and do not follow a typical hierarchical system, as in traditional APS systems. As mentioned by Frayret et al. (2004a), agent-based manufacturing approaches do not restrict or force the design of specific control architectures. According to the authors, diverse architectures can be found in the literature to define how the responsibilities are distributed across the organization, such as open architectures (Barber et al., 1999), heterarchical (Duffie, 1996), quasiheterarchical (Shen et al., 2000) and others. Due to this diversity of possible control architectures to manage the interdependencies among activities, diverse mechanisms for coordination exist.

Another interesting advantage of d-APS system is related to simulation. Agents are largely used for simulation, since they naturally model the simultaneous operations of multiple agents in an attempt to re-create and predict the actions of complex phenomena. Thus, simulating actions and interactions of autonomous individuals in a supply chain (e.g. vendors, manufacturers, distributors, clients etc.) and with the possibility of assessing their effects on the system as a whole is one interesting property of this system. It can naturally generate stochastic behaviours of supply chains (like orders arrivals, machines breakdown, etc.), such as traditional discrete-event simulation usually modelled through simulation packages like Arena® or Promodel®.

Therefore, to sum-up, we propose the following as the main characteristics of d-APS systems:

- d-APS are agent-based systems for supply chain planning and they incorporate optimization technology such as traditional APS systems, to perform distributed planning activities.
- A d-APS is composed of semi-autonomous APS tools, each dedicated to a specialized modelling domain, which are normally different in nature from one another, and that can act together in a collaborative manner employing sophisticated interaction schemas.
- Despite the fact that APSs are hierarchical systems, d-APS systems can exhibit more complex control structures, where more autonomy can be given to some decision-making entities of the entire planning system.
- As agent societies, these systems have to perform planning decisions considering both local and global objectives as well as constraints.
- Furthermore, these systems employ concepts from discrete-event simulation to perform stochastic and dynamic (time-advancement) experimentations, not only deterministic what-if analysis, as traditional APS do.

- These systems incorporate issues from artificial intelligence, including social and local intelligence related mainly to collaboration and negotiation possibilities, learning abilities, and pro-activity.

This is not an exhaustive list, but is the first step towards a more rigorous definition of what d-APS systems are.

It is important to mention at this point that this d-APS concept is being used successfully mostly in laboratorial research. However, we strongly believe that it is not far from being ready to reach the market, as some recent industrial experiences demonstrate. The FORAC Research Consortium in Canada had the opportunity to develop and test a d-APS system in the softwood lumber industry in Québec, Canada, with interesting success. In this next subsection we quickly present this concept and how it was tested in industry.

3.3 Prototyping in a Canadian lumber industry

The FORAC Research Consortium[1] is a centre of expertise dedicated to Supply Chain Management in the forest products industry in Canada. It has experts from several domains, including forestry engineering, industrial engineering, mechanical engineering, management sciences such as operations management and strategic management. Its efforts are divided into two sectors: research & knowledge and technology transfer activities. FORAC has been working with agent-based systems for supply chain management since 2002. As a result, a d-APS, referred to as the FORAC Experimental Planning Platform (hereafter the FORAC Platform), was developed and experimented with for this specific industry sector.

The platform was conceived based on a general and well-accepted model for supply chain management, the SCOR (Supply-Chain Operations Reference) from the Supply Chain Council (SCC, 2010; Stephens, 2000) in such a way as to guarantee that the d-APS would be able to solve a large number of supply chain planning problems and be easily used by companies. This allows the creation of a general agent shell for the d-APS.

In order to do so, the supply chain was organized into business units, in which the overall problem is split into smaller sub-problems, which allows that each agent models a smaller scale problem employing specialized planning tools. In order to solve the entire supply chain problem, agents make use of sophisticated interaction mechanisms.

Figure 4 presents the basic architecture of the FORAC Platform. Some planning agents have been developed to support a business unit, i.e. an internal supply chain where the same company owns all production units. The following agents are responsible for the operational planning:

- *Deliver* agent: manages all relationships with the business unit's external customers and fulfils all commitments to them;
- *Make* agents: several make agents are responsible for carrying out production planning functions, each one in charge of a part of the overall planning functions by means of specialized planning capabilities. Several make agents can be used inside a planning unit;
- *Source* agent: manages the relationship with all business units' suppliers, forwarding procurement needs to the right suppliers.

[1] www.forac.ulaval.ca

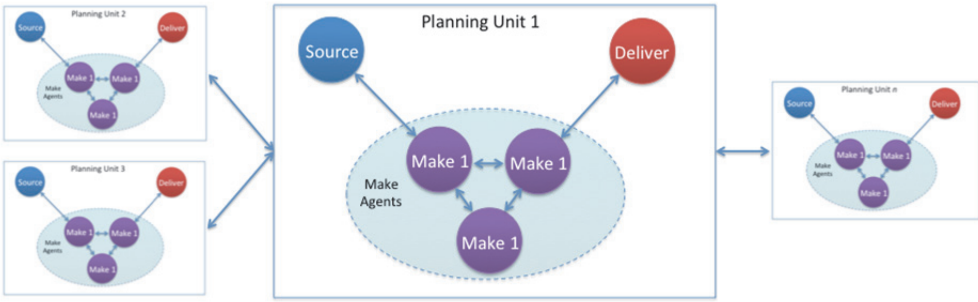

Fig. 4. Overview of the Platform

This architecture can be seen as a general framework that can be applied in diverse fields. For example, the FORAC Platform was implemented in the softwood industry in the province of Québec, Canada. By using dataset from two companies, the research consortium implemented the d-APS schematized in Figure 5.

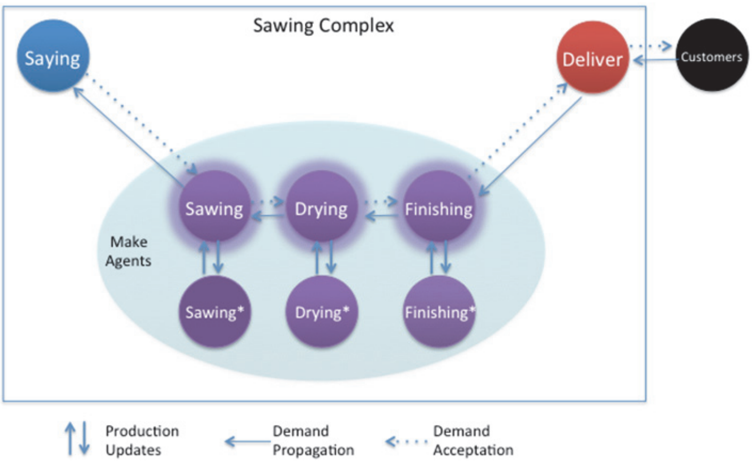

Fig. 5. Specialization in the Softwood Lumber Industry in Québec

The implemented agents are: deliver agent (manages all relationships with the business unit's external customers and fulfils all commitments to them); three make agents (sawing, drying and finishing) responsible for carrying out production planning functions, each one being in charge of a part of the overall planning functions by means of specialized planning capabilities; source agent (manages the relationship with all the business units' suppliers, forwarding procurement needs to the right suppliers), customer agent (generates the demand for products and evaluates supply chain offers). In addition, each agent responsible for production planning has a counterpart agent responsible for executing the production plan (sawing*, drying* and finishing*), referred to as execution agents. This platform can be used for planning a supply chain, or it can be used for performing simulation with stochastic number generation and time advancement.

In what follows, we explain its planning and simulation approach together. Generally speaking, Figure 5 can be understood through its products processing sequence: logs are sawn into green rough lumber, which are then dried, leading to dry rough lumber, the latter finally being transformed into dry planed lumber during the finishing process. Arrows represent the basic planning and control sequence. Essentially, the FORAC Platform functioning is divided into five basic steps:

1. *Production update*: before starting a planning cycle, all planning agents update their inventory level states. Actually, all execution agents (sawing*, drying* and finishing*) receive the last planned inventory for the current period from the planning agents (sawing, drying and finishing). The execution agents perform perturbations on the inventory level to represent the stochastic behaviour of the execution system and send the perturbed information back to their respective planning agents. This perturbation in the execution system can be seen as an aggregated representation of what happens on the shop floor, i.e. a set of uncertainties that cause the manufacturing system to have a stochastic output, which is ultimately reflected in the physical inventory level of the supply chain. It can also be real ERP information from the shop floor.
2. *Demand propagation*: with the planned inventory updated, all agents are ready to perform operations planning. The first planning cycle is called demand propagation because the customer demand is transmitted across the whole supply chain. First, the deliver agent receives customers' orders for finished products (dry planed lumber) and sends this demand to the finishing agent. If no products are available in stock, the finishing agent will perform an infinite capacity planning for this demand and will send its requirements in terms of dry rough lumber to the drying agent. The drying agent now performs its planning operations also using an infinite capacity planning logic, and its requirements in terms of green rough lumber will be sent to the sawing agent. Then, sawing executes an infinite capacity planning process to generate its needs for logs, which are transmitted to the source agent. The source agent will confirm with sawing whether all requirements will be sent on time. Now, the supply propagation starts.
3. *Supply propagation*: based on the supply offer from the source agent, sawing now performs finite capacity planning in a way to respect the demand from drying in terms of green rough lumber (pull planning approach), and respecting its own limitation in terms of production capacity. In addition, sawing tries to identify if it still has some available capacity for performing a push planning approach. If there are resources with available capacity, sawing allocates more production based on a price list to maximize the throughput value, meaning that it makes a complementary plan to occupy the additional capacity with products of high market prices. The sawing plan containing products to answer drying demands and products to occupy the exceeding capacity is finally sent to drying. Drying, in return, uses the same planning logic (first a pull and after a push planning logic) and sends an offer to the finishing agent. Finishing performs the same planning approach and sends an offer to the deliver agent. Deliver send its offer to the customer agent. In summary, the general idea of the supply propagation is to perform finite capacity planning, where part of the capacity can be used to fulfil orders (pull approach) and part of it to push products to customers so as to better occupy capacity.
4. *Demand acceptation*: the customer agent receives offers from deliver and evaluates whether they satisfy all its needs. Part of this offer can be accepted by the customer and part can be rejected, for example, because it will not arrive at the desired time. This information is sent to the deliver agent. Now, as part of the demand is no longer

necessary, deliver will send the adjusted demand for the finishing in the form of a new demand propagation with fewer products. This new demand will be propagated backwards (step 2) to the source agent. Next, from source this demand will be forwarded in the form of a supply propagation (step 3) up to the deliver agent. During the demand propagation, all planning agents will have more available capacity to be occupied with high market price products. The planning cycle finishes here.

5. *Time advancement*: due to the fact that the FORAC Platform uses the rolling horizon approach, after the end of a planning cycle involving these four steps, the simulation time moves ahead for the next planning period. In this case, the next planning period is the next 'replanning date', which is delimited by the control level (replanning frequency). It can vary within any time period, from one day to several months, and it depends on the interest of the supply chain planner. The planning cycle (i.e. the above-mentioned four steps) is repeated at each replanning date until the end of the simulation horizon.

These five steps represent the basic logic of the operations planning. Some mechanisms useful for simulation during these five steps are detailed in the following.

First, for the production update, one has to understand how the perturbation arrives at the beginning of each planning cycle. This is explained in Figure 6.

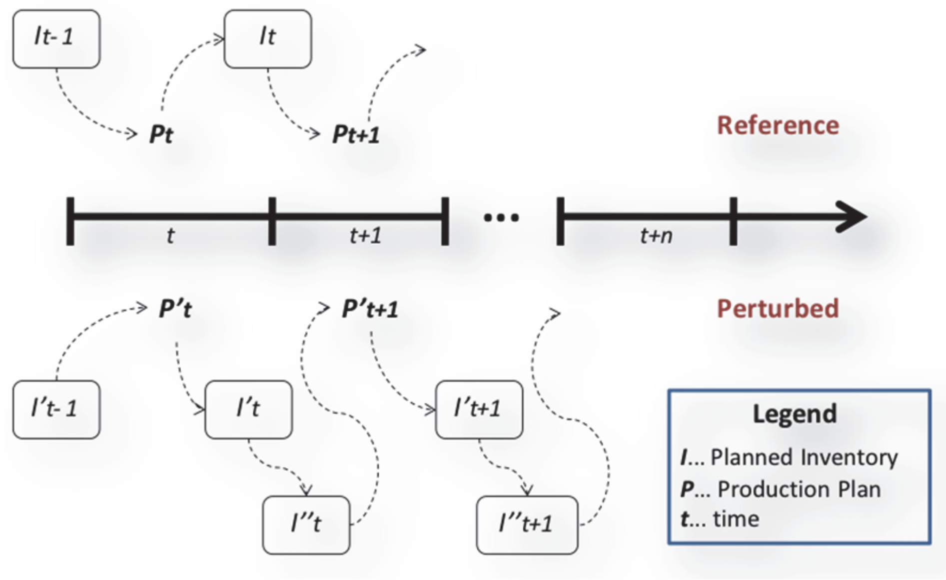

Fig. 6. Production update logic

Figure 6 shows two situations. In the upper half, the situation called 'reference' can be found, where no perturbation takes place. It is an ideal world where all plans are executed exactly when they are supposed to be, i.e. no uncertainties are taken into account. In this situation, at time t, a given agent performs its planning activities resulting in a plan called P_t. Plan P_t is calculated based on the inventory level of the execution system at $t-1$ (i.e. I_{t-1}) which is obtained though the Production Update procedure. Together with P_t, the I_t is also calculated and used as input information for the planning process of the time $t+1$ (i.e., P_{t+1}). This is repeated until the end of the simulation horizon ($t+n$).

In a real world situation, uncertainties happen all the time and what has been planned as an inventory level for a given moment is not exactly what is really obtained. This is due, for example, to machine breakdowns or the stochastic process of the production system. This situation is represented in the 'perturbed' side of Figure 6. As one can see in this figure, the inventory level planned for time $t\text{-}1$ (I_{t-1}) is different, and we call it I'_{t-1}. This perturbed inventory level will affect the ideal P_t, resulting in a perturbed P'_t, which in turn generates a perturbed planned inventory level for the period t (I'_t). This perturbed planned inventory considered past influence (t-1, t-2, ...) on the present (t), i.e. perturbation is being accumulated across time. In addition, this planned inventory (I'_t) will also suffer from uncertainty occurring at time t, resulting in a double perturbed inventory level for t, which is called I''_t. Now, inventory I''_t considers past and present perturbations.

When time advances from t to t+1, the planned inventory I''_t is used to calculate the production plan at t+1, which is called P'_{t+1}. Based on this plan, a perturbed planned inventory level for $t+1$ (I'_{t+1}) is calculated. Then, similarly to time t, a double perturbed inventory level for t+1, is generated, giving us the I''_{t+1}. This logic is repeated until the end of the simulation at t+n.

It is important to note that the agents try to cope with these accumulated perturbations by adjusting their plans, which is a quite relevant aptitude of supply chain planning and control systems. Figure 7 demonstrates the FORAC Platform control mechanisms that affect its resilience, i.e. the ability to bounce back from unforeseen disruptions (Klibi et al., 2011), by comparing the perturbed inventory to the reference inventory in a simulation. The reference is the ideal case where no perturbation exists and all agents can determine the optimum inventory levels according to their objective functions and constraints.

To exemplify this mechanism, the graph in Figure 7 shows the results of inventory disruptions (i.e. $[(I''_t - I'_t)/\ I_t]$*100) for the time bucket of one day and a simulation horizon of 181 days (i.e. t = 1, 2, ..., 181 days). As one can see, inventory perturbations were introduced at the sawing agent level every 14 days. In this case, every 14 days the sawing agent has to replan all activities to compensate for perturbations. The first perturbation (14th day) was positive, i.e. more inventory than planned resulted from the production process. The next two perturbations were also positive, while the fourth was negative leading the system to attain the ideal situation. The remaining perturbations were negative, that is, fewer inventories than planned resulted from the production process. In all cases, it can be noted

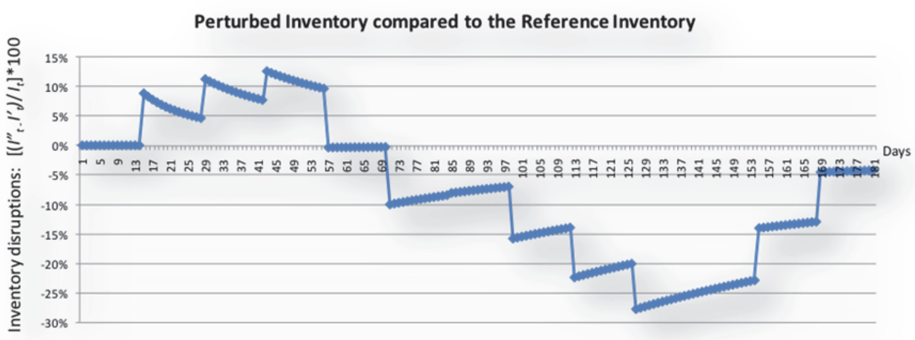

Fig. 7. Drying agent: absorbing uncertainties from the manufacturing system

that the agent tries to adjust the plans for each time period so that the reference (ideal situation, i.e. 0%) can be attained.

Besides manufacturing system perturbations, another relevant supply chain uncertainty (Davis, 1993) can be modelled in the platform, the demand. The demand agent can generate stochastic demand following a method developed by Lemieux et al. (2009). The basic principle consists in randomly generating a total quantity of products for each relation *client-deliver-product* and for the entire simulation horizon. Next, products from this total quantity have their delivery dates set stochastically, as well as the date when the demand will be sent to the deliver agent. This stochastic generation can use a seasonality factor, if desired. Two types of typical demand behaviour can be simulated: spot (sporadic customers) and contract (long-term relationship, whose demand cannot be cancelled and penalties apply in the case of late fulfilment). More detailed information about this mechanism is provided by Lemieux et al. (2009).

All these perturbations are performed by the platform through a traditional random number generation approach and since a lot of data is needed a fast and flexible generator is employed. The selected uniform number generator was the Mersenne Twister (Matsumoto & Nishimura, 1998), which provides random numbers for a considerably long period of time without slowing down the algorithm. The transformation of the random numbers into random variables follows a simple method for discretizing the density function of the probability distribution desired. Simulation analysts can select different probability distribution functions, such as normal, exponential or triangular. More details about number variables generation in the FORAC Platform is found in Lemieux et al. (2009).

Other important technical information concerns how agents perform their planning activities. Both Demand Propagation and Supply Propagation for each agent are geared up with specialized optimization models. They are depicted in Table 5 in terms of objective functions, processes and optimization method, according to Frayret et al. (2007).

The planning approaches described in Table 5 are radically different from each other in regard to their nature, as explained by Frayret et al. (2007). The authors mention that the Sawing agent (both Demand and Supply Propagations) are designed to identify the right mix of log type in order to control the overall divergent production process. What changes for the demand and for the supply propagation are the objective functions and constraints.

Drying, on the other hand, is batch-oriented and tries to simultaneously find the best type of green rough lumber to allocate to the kilns and the best drying process to implement. What is interesting in this approach is that it tries to find a feasible solution in a short time, but if more time is available, it will try to find a better solution using a search algorithm through the solution tree.

Finishing employs a heuristic approach to find what rough dry lumber type will be used and how much should be planed considering setup time. For more details on how planning engines work, the reader is referred to Gaudreault et al. (2009).

The last issue concerning simulation functioning is the time advancement mechanism used to manage all these uncertain events and planning activities. We opted for a central simulation clock, which aims at guaranteeing that all agents are synchronized so that none of them are late or in advance. In this case, all agents use the same simulation clock instead of each agent having its own clock. This was used to simplify the time management effort. The general functioning logic is simple. The simulator has a list of all agents participating in

	Objective Function for Demand Propagation	Objective Function for Supply Propagation	Optimization Method Employed	Processes Characteristics
Sawing Agent	Minimize lateness	Maximize production value	Mixed-Integer Programming	Divergent product flows; co-productions; alternative process selection; only compatible processes can be executed within the same production shift
Drying Agent	Minimize lateness	Maximize production value	Constraint Programming	Divergent product flows; co-productions; alternative process selection
Finishing Agent	Minimize lateness	Maximize production value	Heuristic	Divergent product flows; co-productions; alternative process selection; only compatible processes can be executed within the same production shift

Table 5. Planning engines for each agent

the simulation and their corresponding state, which can be 'calculating' or 'standby'. When at least one agent is working (sometimes more than one could be calculating in parallel), time advances in real time. When all agents are on standby, time advances according to the simulation list. This means that the simulator looks for the next action to accomplish and advances the simulation time until the realization moment of this action. Next, the simulator asks the concerned agent to perform this action. This central clock management mechanism implies that when an agent receives a message involving an action, it adds this action and its respective time of occurrence to the simulation list. This action can be triggered immediately or later, depending on its time of occurrence.

The prototype in the softwood industry was implemented in a large Canadian lumber industry in order to validate the d-APS architecture. The validation was conducted over 18 months of close collaboration with the planning manager and his team. Outputs were therefore validated both, in an industrial context and a changing environment. Results of the FORAC Platform compared to the company's approach were very encouraging. Two main advantages were identified: the quality of the solution of the proposed d-APS system was superior, and the resolution time was considerably shorter. This allows the supply chain planner to create several simulated plans quickly.

The FORAC Platform and the dataset of this company is also currently being used in several research projects in the FORAC Research Consortium. For example, Santa-Eulalia et al. (2011) evaluated through simulation the robustness of some tactical planning and control tactics under several supply chain uncertainties, including the demand, the manufacturing operations and the supply. Cid-Yanez et al. (2009) study the impact of the position of the decoupling point in the lumber supply chain. Gaudreault et al. (2008) evaluated different coordination mechanisms in supply chains. Forget et al. (2009) proposed an adaptive multi-behaviour approach to increase the agents' intelligence. Lemieux et al. (2009) developed several simulation mechanisms in order to provide the FORAC Platform with a d-APS with simulation abilities, such as a time advancement method, random numbers generation, and so forth. Several other developments are being incorporated in this d-APS in order to transform it into the first commercial system in the world employing the distributed planning technology for the forest products industry.

4. Final remarks

This chapter discusses the present and the future of APS systems in two parts. First, in Part I, traditional APS systems are introduced theoretically followed by a discussion of some systems available on the market and, finally, on how APS systems can be properly implemented in practice, according to our experience in the domain. It is interesting to notice that each solution on the market is different and offers different advantages and drawbacks. Companies desiring to implement such a system have to manage several trade-offs in order to discover the best application for their business requirements, which can be tricky in some situations.

In addition, Part I also discusses three case studies in large companies in order to illustrate the current practice through three typical APS projects: system recovery, system maximization and system readiness. Our experience in recovering APS indicates that implementing such a tool without a structured planning process and without maturity from the company in terms of the seven dimensions of the transformation might lead to project failure. In terms of APS maximization, system subutilization is normally a symptom of problems related to operating logic, misaligned indicators, unclear roles and responsibilities or a lack of knowledge about the system logic or Supply Chain Management logic. Problems related to the technology are also present, but they tend to be the least demanding. Finally, in our experience with APS readiness, we discussed and illustrated the importance of making a complete study prior to the system implementation to assure that the company is ready for a transformation path.

In Part II we pointed out that traditional technology and practice still have many limitations, thus we explore possible avenues for APS systems. By highlighting some flaws in traditional approaches in creating sophisticated simulation scenarios and modelling distributed contexts, we introduce what we call a distributed APS system and we provide some insights about our experience with this kind of system in a Canadian softwood lumber industry.

The system proposed by FORAC Research Consortium explicitly addresses simulation and distributed planning approaches. Practical experience with this system is producing interesting results in terms of the quality of the solution, planning lead-time and the possibility of creating complex simulation scenarios including complementary possibilities, such as different negotiation protocols between planning entities within a supply chain. Several improvements are planned for d-APS in order, in the coming years, to deliver the first commercial d-APS in the world employing agent-based and distributed technologies.

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13

The Supply Chain Process Management Maturity Model – SCPM3

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1. Introduction

In recent years, a growing amount of research, much of which is still preliminary, has been dedicated to investigating maturity models development for the strategic management of supply chains (Chan and Qi, 2003; Gunasekaran *et al.*, 2001; Coyle *et al.*, 2003).

The concept of process maturity derives from the understanding that processes have life cycles or developmental stages that can be clearly defined, managed, measured and controlled throughout time. A higher level of maturity, in any business process, results in: (1) better control of the results; (2) more accurate forecast of goals, costs and performance; (3) higher effectiveness in reaching defined goals and the management ability to propose new and higher targets for performance (Lockamy and McCormack, 2004; Poirier and Quinn, 2004; McCormack *et al.*, 2008).

In order to meet the performance levels desired by customers in terms of quantitative and qualitative flexibility of service in demand fulfillment, deadlines consistency and reduction of lead times related to fulfilling orders, firms have developed repertoires of abilities and knowledge that are used in their organizational process (Day, 1994 *apud* Lockamy *and* McCormack, 2004; Trkman, 2010). In two past decades, management of supply chain processes has evolved, also because of these new demands, from a departmental perspective, extremely functional and vertical, to an organic arrangement of integrated processes, horizontal and definitely oriented to providing value to intermediate and final costumers (Mentzer *et al.*, 2001). This new pattern of logistical process management had lead towards the development and application of different maturity models and performance metrics useful as support tools to help define a strategy and to face trade-offs, as well as to identify items that are considered critical to quality improvement of logistical services rendered to the client.

The purpose of this article is to explore the concept of maturity models and to answer an important question specifically directed to the management of supply chain processes. What best practices are fully matured and in use at what maturity level? This paper will more fully define the maturity levels based upon the capabilities of the company using statistical analysis of a global data set.

2. Theoretical framework

2.1 Maturity models and logistical processes management

The maturity model represents a methodology which applications are related to definition, measurement, management and business processes control that have been shown to be very similar management approaches concepts to BPR (Business Process Reengineering), attracting a growing interest not only of companies but also of researchers, directly involved in this area (Chan and Qi, 2003; Gunasekaran *et al.*, 2001). Although its origins are not directly linked to logistics, a growing number of reports has been seen in recent years that represent the use of maturity models based on KPI – Key Performance Indicators - to analyze the activities from logistical supply cycles to manufacturing and distribution support itself (Lahti *et al.*, 2009). Those exploratory experiments are expected to consolidate in order to define an agenda of research in the field of logistics, mainly the *supply chain management* (Chan and Qi, 2003; Gunasekaran *et al.*, 2001).

In the following section, the main maturity models currently used by companies to analyze the performance of their logistical processes will be presented. References will be shown about the SCOR measurements (Supply Chain Operations Reference Model), the CSC Framework model, developed by CSC – Computer Sciences Corporation – and the Business Process Orientation Maturity Model, developed by a group of researchers at DRK Research.

2.2 CSC framework

The CSC Framework was developed by CSC (Computer Sciences Corporation) and tested in 2003 for the first time, through a research involving 142 people in charge of supply chain management. Supply Chain Management Review readers and CSC clients composed this sample. Among the 142 components, 71 came from companies and independent consulting firms, while the other 71 came from groups, divisions, business strategic units or subsidiaries. The work's main objective was to identify the logistics function's development stage in the surveyed companies, considering their levels of excellence in the five maturity stages in supply chain, which are presented below (Poirier and Quinn, 2003; 2004).

At the model's first level, the company prioritizes the improvement of its functional processes. At this stage, internal efforts are made that aim at the integration of different functional areas of each company that integrates the supply chain. The SCOR model is used with a great effect in the initial stage, where the logistics and supply areas are more emphasized. The benefits normally include a drastic reduction in suppliers and logistics service providers, rationalization of the product mix and a greater volume of purchases. At level 1, the main inefficiencies faced by many companies concern the results of low inter-organization integration process, the barriers in businesses works, and the no-happening or no-expressive sharing between information systems and agents in the expanded value chain.

At the second level, attention is given to logistics gains, focusing more on the use of actives and the effectiveness of its physical distribution. Demand management becomes a critical factor, and the preciseness of predictions can be the main driving force for more acuity on the company's operations in the planning, programming and production control areas. Supply chain orientation gains more importance with a more strategic management of the organization's immediate supplier and client bases.

According to Poirier and Quinn (2004), the company's dominant "logistical culture" inhibits, many times, the progress of its actions towards superior excellence levels, given some premises shared by companies that find themselves in this development stage: (i) all good ideas need to be internally built; (ii) if external help is needed, it means that the internal team is not doing its job. (iii) if external information can be used, we will do so but we will not be share it with anybody. The company can only expand its efficiency levels when its leadership, especially the one linked to the operation areas, decides to break with these premises and dissipate the restrictions that they impose.

At the third level, the company develops or redesigns its inter-organizational processes and starts to create a business network with few and carefully selected allies. During this stage, important suppliers are invited to participate in planning, operations, and sales sessions (S&OP – Sales and Operation Planning), bringing supply and demand closer to each other. Global relationships are established with logistical service suppliers, qualified in relation to transport functions, logistics and storage, and clients are encouraged to give feedback regarding current and desired products. Business allies, at this level, work together, using various tools and collaborative techniques to reduce, through mutual initiatives and shared results, cycle times, especially time-to-market, using their actives more efficiently.

The fourth level is characterized by collaborative initiatives. Companies start using methodologies such as Activity Based Costing (ABC) and the Balanced Score Card to transform the supply chain into a value network of partners, who work towards the same strategic goals. Information is shared electronically, and inter-company teams are formed to find solutions for specific client problems. E-commerce technologies are considered crucial for this level, guaranteeing real-time sharing of all relevant information at each point of the value chain. Development and using of models and methodologies for implementation in design, planning and collaborative replenishment are crucial at this stage of the inter-organizational relationship evolution.

The fifth and most advanced stage in the supply chain is the most difficult goal to achieve. It is a developmental stage characterized by a complete join between agents throughout the whole supply chain. According to Pourier and Quinn (2003; 2004), only a few organizations in a few sectors reach this stage. It is a stage of complete collaboration throughout the network and of strategic use of technology information to achieve position and status in the market. At this stage, companies usually reach extraordinary order prediction levels as well as a reduction in the cycle time throughout networks connected completely electronically.

2.3 The business process orientation maturity model

The concept of Business Process Orientation suggests that the companies may increase their overall performance by adopting a strategic view of their processes. According to Lockamy and McCormack (2004), companies with great guidance for their business processes reach greater levels of organizational performance and have a better work environment that is based on much more cooperation and less conflicts.

A very important aspect of this model is the use of SCOR to identify the processes' maturity (Lockamy *and* McCormack, 2004; SCC, 2003). The SCOR measurements were adopted by their process orientation characteristics and their growing use among professionals and academics who are directly involved in logistic matters. The five stages of the maturity model show a progress of activities when the supply chain is efficiently managed. Each level contains characteristics associated with factors such as predictability, capability, control, effectiveness and efficiency.

Ad Hoc, the model's first level, is characterized by poorly defined and bad structured practices. Process measurements are not applied and work and organizational structures are not based on the horizontal process of the supply chain. Performance is unpredictable and costs are high. Cross-functional cooperation and client satisfaction levels are low.

At the second level, **defined**, SCM's basic processes are defined and documented. There is neither work nor organizational structure alteration. However, performance is more predictable. In order to overcome company problems, considerable effort is required, and costs remain high. Client satisfaction levels improve but still remain low if compared to levels reached by competitors.

At the third level, **linked**, the application of SCM principles occurs (Supply Chain Management). The organizational structures become more horizontally prepared through the creation of authorities that overlooks functional units. Cooperation among intra-organizational functions, supply managers and clients transform into teams that share measures common with SCM, and into objectives with a horizontal scope in the supply chain. Efforts for continuous improvement are made aiming to stop problems early and thus achieve better performance improvement. Cost efficiency grows and clients starts to get involved directly in the improvement efforts of intra-organizational processes.

At the fourth level, **integrated**, the company, its suppliers, and clients strategically cooperate in the processes' levels. Organizational structures and activities are based on the SCM principles and traditional tasks, related to the expanded value chain processes, start to disappear. Performance measurements for the supply chain are used, with the advent of advanced practices, based on collaboration. The process improvement objectives are geared towards teams and well reached. Costs are drastically reduced, and client satisfaction, as well as team spirit, becomes a competitive advantage.

At the final level, **extended**, competition is based in multi-organizational supply chains. Multi-organizational SCM teams appear with expanded processes, recognized authority and objectives throughout the supply chain. Trust and auto-dependence build the support base of the extended supply chain. Process performance and trust in the extended system are measured. The supply chain is characterized by a client-focused horizontal culture. Investments in the system's improvement are shared, as well as the investment's return.

3. Building the Supply Chain Process Management Maturity model – SCPM3

However, while previously developed maturity models outline the general path towards achieving greater maturity the idea of our paper is to more clearly identify which particular areas are important in the quest for achieving greater maturity at which level. We answer the questions: What best practices are fully matured and in use at what maturity level? This will more fully define the maturity levels based upon the capabilities present within the assessed company.

From a database containing 90 process capabilities indicators of supply management processes, composed by respondents from 788 companies located in USA, Canada, United Kingdom, China and Brazil, an exploratory factorial analysis (EFA) was conducted. EFA using Maximum Likelihood aims to find models that could be used to represent the dataset organizing the variables in constructs, i.e. groupings. Dataset was composed by respondents whose functions were directly related to supply chain management processes. The sample deliberately included companies from different industries in order to get a cross industry perspective. The study participants were selected from two major sources:

Set 1 - The membership list of the Supply Chain Council. The "user" or practitioner portion of the list was used as the final selection, representing members whose firms supplied goods rather than services, and were thought to be generally representative of supply chain practitioners rather than consultants. An email solicitation recruiting participants for a global research project on supply chain maturity was sent out to companies located in USA, Canada, United Kingdom and China. The responses represent 39.3% of the sample composition with 310 cases.

Set 2 - In Brazil, the companies were selected from a list of an important educational institution of logistics and supply chain management in the country. An electronic survey was done. From a total of 2,500 companies contacted, 534 surveys were received, thus yielding a response rate of 21.4 percent. After data preparation, 478 respondents were included in the sample, representing 60.7% of the total sample.

From the results, considering a cutting point of eigenvalues bigger than 1.0, 16 constructs were considered which were able to represent 64.3% of the overall data variance. The Kaiser-Meyer-Olkin measure of sampling adequacy, representing the proportion of the variables' variance that could be caused by the factors, got a very high result of 0.958, indicating that the results of the EFA can be useful for the dataset. Moreover, the Bartlett's Test of Sphericity was conducted resulting in a significance value lower than 0.0001 demonstrating a good relationship between the variables that would be considered to detect a possible structure or model. Additionally, the Goodness-of-Fit also demonstrated that those 16 groupings have an excellent adjustment for the dataset with a significance also lower then 0.0001.

Further, the 16 constructs previously detected by EFA were submitted to a content analysis, considering the meaning of each question used to compose the questionnaire used for data collection. Such procedure enables a refinement resulting in a new list of 13 groupings, leaner and objectively composed, that were used to subsidy the first version of the Supply Chain Process Management Maturity Model (SCPM3). The Cronbach's Alpha for each of the 13 groupings was calculated and all groupings got values superior to 0.6 showing a good scale reliability.

Additionally, by conducting a collaborative effort with a group of specialists in process management and supply chains, the 13 groupings were labeled considering the variables comprising them. A complete list of groupings and their respective variables can be found in the appendix of this paper.

In order to identify the hierarchical relationship between the groupings and also the key turning points (McCormack *et al.*, 2009) that could be used to classify them in different maturity models and its respective cutting points detonating a level change, a set of cluster analysis procedures was conducted. Cluster analysis, also denominated as "segmentation analysis" or "taxonomic analysis", aims to identify subgroups of homogeneous cases in a population. In this sense, the cluster analysis can identify a set of groups that minimizes the internal variation and maximizes the variation between groups (GARSON, 2009).

Aiming to prepare the dataset for the cluster analysis, based on the sum of scores of all variables from each grouping it was generated a new variable for each grouping. Later, a variable Maturity Score was generated by summing all new indicators generated for each grouping representing the maturity score for each one of the 788 cases of the sample.

Further, the TwoStep cluster analysis was then conducted, considering the maturity score as a continuous variable and taking a fixed number of 5 clusters – each representing one maturity level – aligned with the traditional classification of the existent maturity models that are composed by five different evolution levels. The TwoStep cluster analysis groups cases in pre-clusters that are treated as unique cases. As a second step, the hierarchical grouping is applied to the pre-clusters. The 788 cases in the sample were then classified considering its positions in each of the five clusters, i.e. in each of the five maturity levels identifying its respective turning points.

Considering each cluster as a distinct maturity level and taking the centroids identified for each cluster, the turning points for each level were established based on the minimum score for level 1[1] and the average between two centroids for the others, as can be illustrated in Figure 1.

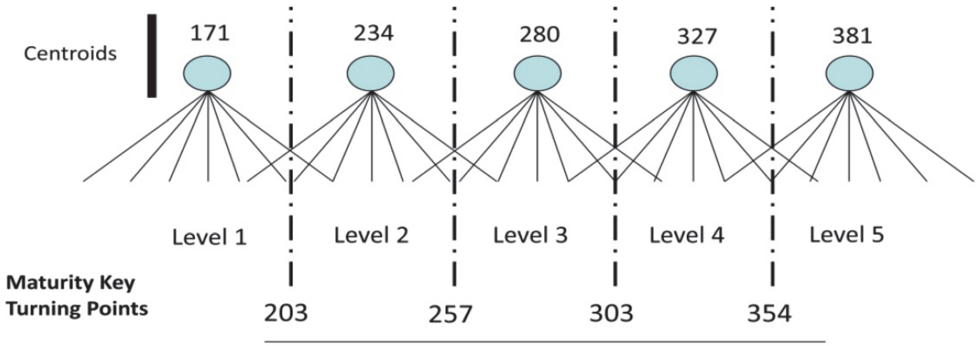

Fig. 1. Maturity Key Turning Points based in centroids scores. Source: Research Data

Taking the key turning points all the 788 cases were then reclassified regarding their maturity level and further identified in a new variable "LMaturity". In this sense, companies with maturity scores between 90 and 202 points were positioned at maturity level 1; between 203 and 256 points at level 2; ranging between 257 and 302 at level 3; between 303 and 353 at level 4; and above 354 points at maturity level 5. Such classification was based on a previous definition of the maturity levels as discussed by McCormack, Johnson and Walker (2003), with the turning points identified considering the data of this present research.

The internal turning points in each process grouping – i.e., the points that can be used to define a change in a maturity level for each group – were further identified by means of the cluster analysis with K-means algorithm. This method, by using the Euclidian distance, defines initially and randomly the centroids for each cluster and later initiates the interaction cycle. In each interaction the method groups the observed values taking the cluster average which the Euclidian distance is more close. In this sense, the algorithm aims to minimize the internal variance of each cluster and maximize the variance between clusters. The cluster centroids change in each interaction considering its new composition. The process continues until saturation is reached – with no more changes in centroids – or until the maximum limit of interactions is reached.

As conducted previously, the definition of the key turning points (McCormack *et al.*, 2009) were based at the centroids scores. For the first level the minimum score for each construct was taken and for the others, the centroids average of the previous level and the level itself was considered for each group.

Aiming to find evidence about the relationship of precedence between groups, the Euclidian distances correlation matrix was used as reference. This matrix was calculated based on a dissimilarity measure – i.e. the distance between the variables – based on the squared root of

[1]Minimum score reachable by the *Maturity* variable, considering the sum of the 90 questions, each scored with a minimum value of 1.

the sum of the squared differences between the items. As discussed by Székely, Rizzo e Bakirov (2007) the correlation of the Euclidian distances can be considered as a new alternative to measure the dependence between variables. In this sense, by taking the scores from the proximities matrix as reference, the hierarchical analysis of the groups was conducted based on the Euclidian measure and the average link between groups. As result of this procedure a dendogram was generated (Figure 2) representing the precedence between each group of indicators of capabilities in supply chain management processes.

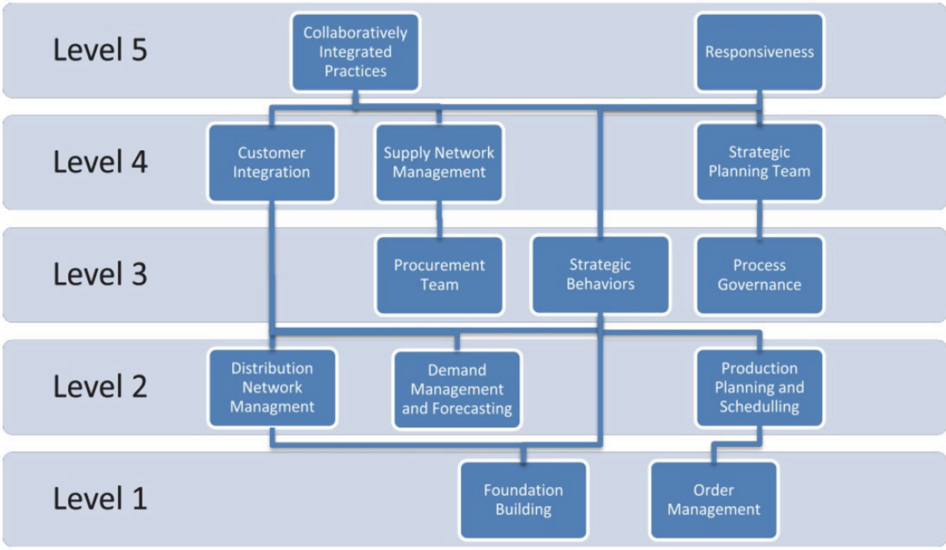

Fig. 2. Process groups organized by maturity level. Source: Research Data

To test the hierarchical relationships between groupings and the model composition and aiming to identify possible potential adjustments, path modeling and structural equation analysis was conducted. The tests were conducted relating the constructs of the maturity model with a performance variable (PSCOR), generated by summing the scores given by the respondents for the overall performance at the SCOR areas of Plan, Source, Make and Deliver. As a result, a new list of relationships between variables was generated indicating that, in case of change, it could improve the model adjustment reducing the scores of Chi-Square test. By using a cutting point of 200 points to determine which relationships could generate a significant improvement for the model adjustment, the constructs of *Strategic Behavior* and *Strategic Planning Team* were considered, if related, to improve the model adjustment. By understanding that the strategic behavior conditioned by firms developing teams to strategically plan their processes in supply chains, the relationship was considered valid. Additionally, looking at the composition of the construct *Strategic Behavior*, it is possible to notice that those indicators of capability in process refers, in general, to evidences about the existence of a strategic planning team working based on a wide view of the chain, considering the profitability of each customer and each product, working on the relationship with business partners, defining business priorities and evaluating the impact of the strategies on the business based on performance measures previously defined.

In addition, the relationship between groups was tested and all weighs were calculated and validated considering a p-value < 0.001, except the group *Strategic Planning Team*. Such group, when considered as a reflexive variable to *Responsiveness* and *Collaboratively Integrated Practices*, was rejected by the significance test. This results shows that it is not possible to assure that the estimated regression weigh is different to zero, and, therefore, it is not possible to consider a direct relationship between those constructs. Considering those results, the construct of *Strategic Behavior* was repositioned at the model inverting the precedence relationship previously identified, positioning it as a successor of *Strategic Planning Team*. After adjustment the model considering the new structure, was resubmitted to the structural equation modeling and path analysis and a new table with the new regression weighs was generated. All estimated regression weighs for the new model, considering the relationships between groups, were considered significantly valid. Thus, the visual representation of the model was readjusted considering the new precedence relationships, as well as the turning points previously identified that can be used to determine the change of levels in a maturity scale for supply chain management processes.

Finally, after the model and the relationship nature of the variables was discussed by specialists of the *BPM Team*[2] and some final adjustments were suggested to be implemented in the model and further validated by empirical research by connecting the construct of *Foundation Building* as a direct antecedent of *Demand Management and Forecasting*, *Production Planning and Scheduling* and *Supply Network Management*. Such suggestions were considered valid and adopted to be tested in future research by considering that the background generated by *Foundation Building* is a necessary condition for companies develop capabilities that enable an effective demand forecasting and demand management, generating important outcomes to be considered by the production planning and scheduling processes and also for the management of the suppliers network.

The final SCPM3 model emerging from the statistical analysis is presented in figure 3 and discussed below. The best practices present at each maturity level are show at the level where they become fully mature (the practices are additive as the company progresses).

Level 1 – Foundation – is characterized by building a basic structure, aiming to create a foundation for the processes to avoid ad hoc procedures and unorganized reactions, looking to stabilize and document processes. At this level, the critical business partners are identified and order management best practices are implemented considering restrictions of capacity and customer alignment.

Companies positioned at Foundation Level have the following characteristics:

- Process changes are hard to implement. Changes usually are energy consuming and hurt the relationships between those professionals involved. Changes are slow and need big planning efforts.
- There is always a sensation that customers are not satisfied with companies performance in delivery times. The commitments with the customers cannot be considered reliable and the company does not have an adequate control about what was ordered and not yet delivered.
- They are not prepared to generate deliveries to customers when some special treatment is requested. Processes are not flexible and, therefore, a lot of alternative resources are used to try to attend customers expectation generating unnecessary expenses for the organization.

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[2] The Business Process Management Team is a global group of researchers lead by Prof. Kevin McCormack dedicated to investigate best practices and management models for process management.

- Inadequate demand forecasts and lack of internal processes integration generate problems caused by sellers promising more than companies have productive capacity to deliver and its inventory levels can support. Additionally, the company doesn't have control and not properly document shortfalls situations.
- Process of order placement, distribution and procurement are not properly documented.
- Companies information systems do not fully support all supply chain processes.
- Companies have not yet identified suppliers for product and services as strategic. Service levels with suppliers are not appropriately agreed, understood and documented.

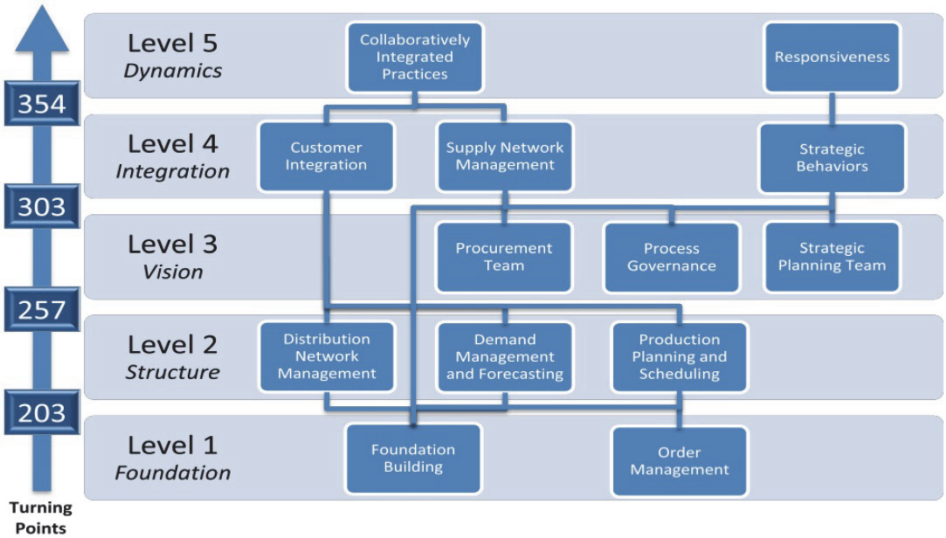

Fig. 3. SCPM3 final version. Source: Research data

At Level 2 – Structure – processes start to be structured in order to be further integrated. Control items are implemented in demand management processes, production planning and scheduling and for the distribution network management. Downstream, distribution network management practices are structured and the processes are defined. Demand starts to be evaluated in more detail. In other the direction, the processes of production planning and scheduling are structured taking the demand management and forecast as inputs.

Companies positioned at Structure Level have the following characteristics:

- Investments are made to document the flows of planning and scheduling, develop metrics to verify the adherence of planning by production scheduling and to the business needs.
- Plans start to be developed in more detail considering each item or service to be produced.
- Production plans start to integrate along company's divisions and the applied methodologies consider capacity constraints.
- Information systems start to support the operations and integrate with organizational processes.
- Demand is evaluated for each item/service considering historical data of orders and a process of demand management and forecasting implemented and formalized.

- Mathematical and statistical methods, together with customer information are used as baseline for distribution planning and demand forecasting.
- Forecasts are frequently updated and reliable. Forecasts are measured for accuracy and become the baseline for the development of plans and commitments with customers.
- Impact of future process changes is evaluated in detail before being implemented.
- Each node at the distribution chain has the measures and controls implemented. Automatic replenishment practices are in place in the distribution network.
- Distribution processes are measured and controlled and participants are rewarded based on those measures.

When organizations reach Level 3 – Vision – process owners are established and become responsible for its management and performance results. Procurement processes are evaluated by a team that looks strategically to the acquisitions in order to align the interests of the marketing and operations department. At this level, organization can be assumed to start to develop a strategic behavior considering a broader perspective of the supply chain.

Companies positioned at Vision level have the following characteristics:

- There is a procurement team formally designated and meeting periodically with other organizational functions such as marketing and operations.
- The process of order commitment has an owner that guarantees that commitments with customers are fulfilled. Similarly, the key processes of distribution, planning of the supply chain network, demand planning, procurement and operations have formal owners.
- Companies have a team responsible for the development of the operational strategic planning formally designated. The functions of sales, marketing, operations and logistics are represented on this team.
- The operational strategic planning team meets regularly and uses adequate tools for analysis to identify the impact of the changes before it is made.
- There is a planning process of operation strategy documented. When the team meets and make adjustments at the strategies, such adjustments are properly updated at the documents.

At Level 4 – Integration – companies seek to build a collaborative environment with their supply chain business partners. The organizational processes integrate with the processes of suppliers and customers in a collaborative platform. The forecasts are developed in detail, considering the demands of each customer individually. The relationship with upstream partners becomes more solid and integrated. The company, based on a set of concrete metrics and health data about the process flow, starts to use analytics and become more strategically driven with its supply chain partners.

Companies at Integration level have the following characteristics:

- Starts to develop, with its partners, the capability to respond to the demand signals working in a "pull" way.
- Functions of sales, operations and distribution collaborate with the process of production planning and scheduling.
- Information about customer planning starts to be considered as an input for the company's planning. Forecasts are developed for each customer, individually.
- Changes in processes are implemented smoothly and guided by a documented process.
- The company aligns with its suppliers developing plans.
- Measures and controls are implemented to appraise the suppliers performance.

- Suppliers have access to inventory levels of the company and the information about production planning and scheduling are shared.
- Critical suppliers are considered partners and have broad access to company's information about production.
- The strategic planning team, established at the previous level, now continuously accesses the impact of its strategies based on supply chain performance measures.
- The strategic planning team is involved in the process to select new members and partners for the supply chain and actively participates in the relationships with suppliers and customers.
- The strategic planning team appraises the profits generated by each customer and each product individually and, based on such appraisal, defines specific priorities for each customer and product.

Level 5 – Dynamics – is characterized by a strategic integration of the chain, when processes support collaborative practices between partners and generate a baseline enabling the chain to be responsive to market changes. The chain starts, therefore, to behave dynamically, continually improving its processes considering its key performance indicators and reacting synchronized and fast to the changes in the competitive environment.

Companies positioned at the Dynamics level have the following characteristics:

- Functions of sales, marketing, distribution and planning collaborate between themselves to the process of order commitment and to develop forecasts.
- The order commitment process is integrated with the other supply chain processes.
- The demand management process and the production planning and scheduling are completely integrated.
- Companies establish a close relationship with customers and have control about demand and capacity constraints.
- Companies attend to the short term demands of customers and act in a responsive way.
- The supply times are considered critical for the production planning and are continuously revised and updated.
- Companies follow the orders and measure the percentage of orders delivered on time

4. Using the SCPM3 – A DRK methodological purpose

The following set of steps can be used as a guideline for managers and consultants as a roadmap for process improvement to maximize the return of the investment in supply chain management.

The bases of the application can be defined in three inter-related macro stages, as follows:

The Discovery stage involves the scope definition to be evaluated – i.e. the focus of the analysis – and aims to identify possible adjustments necessary to the basic indicators. (Appendix A), in order to collect information about specific points related to the defined scope and to proceed with data collection for the indicators of capabilities in supply chain management processes.

The Knowledge stage approach the communication of the results obtained in the previous stage: the contextualization of the results, the communication of the recommendations for improvement. At this stage also the knowledge unification in the organization happens about: a) What is a maturity model for supply chain process management?; b) Why access the indicators of capabilities of supply chain management processes?; c) How the maturity models can be applied?; and d) What can the organization learn from using the model?

Fig. 4. Macro stages to apply the model. Source: Elaborated by the authors

At the Reuse stage, the application of the knowledge becomes operational by planning and implementing the recommendations and preparing the organization to restart the DRK cycle with a new stage of research.

The figure 6 illustrate the stages on a maturity cycle, that are further presented in more detail, aiming to provide guidelines to organizations looking to reach continuous improvement in their supply chain management processes:

At the Discovery phase, initial step to apply the SCPM3, it is defined the scope of the analysis considering the broad of the vision under different perspectives for supply chains (internal, dyad or external).

After the scope definition, it is necessary to identify the possible adjustments that would be necessary to the questionnaire (Appendix A), adding new complimentary questions aiming to gather information specific to the previously delimited scope. Such adjustments should be made with caution and followed by key professionals in the organization that have a strategic view about the supply chain processes.

The next step comprises of the data collection with 20 to 30 professionals with a broad view about the organization and its processes. After to proceed to the data collection and the preliminary data analysis, it would be recommended to apply deep interviews with some professionals in order to capture some business specificities on the scope.

The next step, Knowledge, aims to present the results of the research and the recommendations to the supply chain. It consists of four steps sequentially defined:

1. Alignment of the concepts about SCPM3;
2. Proceed to generate the preliminary results evaluation, based on the scores obtained on the indicators. What would be the maturity level of the organization and which would be the critical points to be developed and improved in order to reach a superior level;
3. Based on the data gathered, proceed with the evaluation of each group and identify the points that must be improved in each group of the model;

4. Compare each indicator with a benchmarking database for reference and present the results with recommendations for processes improvement and efforts prioritization.

At the next step, an implementation plan for the recommendations must be elaborated and implemented. In the end, the organization must be prepared to restart a new cycle and revise its processes to continuously improve.

As a result for each cycle, the following deliverables are expected to be generated:

- Visual representation of the positioning of the organization at the SCPM3
- Scores by each group of the model
- Scores in each SCOR area (Plan, Source, Make and Deliver)
- Benchmarking of each score with the reference database, identifying the major gaps, weaknesses and strengths.
- A recommendation list and potential benefits for each recommendation, prioritizing each action and considering: cost reduction, inventory reduction, faster cycles and improvement of service levels delivered to company's customers.
- An executive report summarizing each cycle.

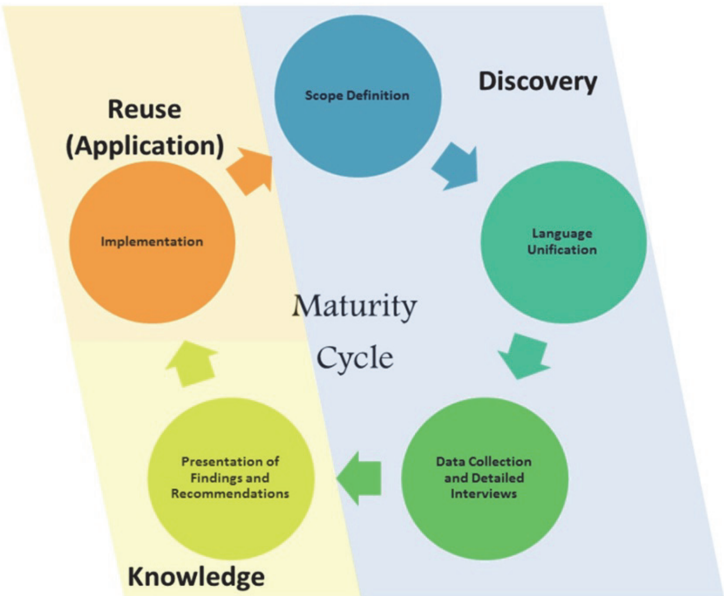

Fig. 5. SCPM3 Cycle. Source: Elaborated by authors

5. Conclusions and recommendations

In recent years, a growing amount of research has been dedicated to investigating ways to provide the right information for the right people in order to develop supply chain capabilities and resources to competitively bring products and services to the market. Key literature on the concept of business process management suggests both that organizations can enhance their overall performance by adopting a process view of business and that business-process orientation (BPO) has a positive impact on business performance.

The concept of process maturity derives from the understanding that processes have life cycles or developmental stages that can be clearly defined, managed, measured and controlled throughout time. A higher level of maturity, in any business process, results in: (1) better control of the results; (2) more accurate forecast of goals, costs and performance; (3) higher effectiveness in reaching defined goals and the management ability to propose new and higher targets for performance.

In order to meet the performance levels desired by customers in terms of quantitative and qualitative flexibility of service in demand fulfillment, deadline consistency and reduction of lead times related to fulfilling orders, firms have developed repertoires of abilities and knowledge that are used in their organizational process. In the two past decades, management of supply chain processes has evolved, also because of these new demands, from a departmental perspective, extremely functional and vertical, to an organic arrangement of integrated processes oriented to providing value to intermediate and final costumers. This new pattern of logistical process management had lead towards the development and application of different maturity models and performance metrics useful as support tools to help define a strategy and to face trade-offs, as well as to identify items that are considered critical to quality improvement of logistical services rendered to the client.

The SCPM3 model is the first SCM process maturity model the uses rigorous statistical analysis to define maturity levels and the best practices present at each level. This model is based upon a global data set of hundreds of companies across many industries. Therefore, the model will more closely represent what is really occurring rather than a preferred path to maturity represented by anecdotally developed models. This makes the SCPM3 broadly applicable as a benchmarking instrument. A company can complete the assessment using the indicators in Appendix A and use this score to place themselves on the maturity model. In this way, they can develop an action plan to improve process maturity incorporating best practices only as they are relevant to reaching the next maturity level, thus avoiding getting ahead of themselves and trying to implement best practices that do not have the precedence components in place. This will make the improvement efforts more effective and sustainable leading to less time needed to achieve each maturity level.

6. Appendix A - best practice measures

Construct Name	Question Text
Demand Management and Forecasting	Do your information systems currently support the Demand Management process?
	Do you analyze the variability of demand for your products?
	Do you have a documented demand forecasting process?
	Does this process use historical data in developing the forecast?
	Do you use mathematical methods (statistics) for demand forecasting?
	Does this process occur on a regular (scheduled) basis?
	Is a forecast developed for each product?
	Does your demand management process make use of customer information?
	Is the forecast updated weekly?
	Is the forecast credible or believable?
	Is the forecast used to develop plans and make commitments?
	Is forecast accuracy measured?

Construct Name	Question Text
Strategic Planning Team	Do you have an operations strategy planning team designated?
	Does the team use adequate analysis tools to examine the impact before a decision is made?
	Does this team have formal meetings?
	Are the major Supply Chain functions (Sales, Marketing, Manufacturing, Logistics, etc) represented on this team?
	Do you have a documented (written description, flow charts, etc) operations strategy planning process?
	When you meet, do you make adjustments in the strategy and document them?
Strategic Behaviors	Does the team look at the impact of their strategies on supply chain performance measures?
	Does the team have supply chain performance measures established?
	Is the team involved in the selection of supply chain management team members?
	Does this team look at customer profitability?
	Does this team look at product profitability?
	Does this team participate in customer and supplier relationships?
	Has the business defined customer priorities?
	Has the business defined product priorities?
Procurement Team	Is there a procurement process team designated?
	Does this team meet on a regular basis?
	Do other functions (manufacturing, sales, etc) work closely with the procurement process team members?
Supply Network Management	Do you "collaborate" with your suppliers to develop a plan?
	Do you measure and feedback supplier performance?
	Do suppliers manage "your" inventory of supplies?
	Do you have electronic ordering capabilities with your suppliers?
	Do you share planning and scheduling information with suppliers?
	Do key suppliers have employees on your site (s)?
Production Planning and Scheduling	Do you have a documented (written description, flow charts, etc) production planning and scheduling process?
	Do you measure "adherence to plan"?
	Does your current process adequately address the needs of the business?
	Are plans developed at the "item" level of detail?
	Are your planning processes integrated and coordinated across divisions?
	Do you have weekly planning cycles?
	Are you using constraint-based planning methodologies?
	Is shop floor scheduling integrated with the overall scheduling process?
	Do your information systems currently support the process?

Construct Name	Question Text
Distribution Network Management	Does your information system support Distribution Management?
	Are the network inter-relationships (variability, metrics) understood and documented?
	Are impacts of changes examined in enough detail before the changes are made?
	Do you use a mathematical "tool" to assist in distribution planning?
	Is the Distribution Management process integrated with the other supply chain decision processes (production planning and scheduling, demand management, etc)?
	Does each node in the distribution network have inventory measures and controls?
	Do you use automatic replenishment in the distribution network?
	Are Distribution Management process measures in place?
	Are they used to recognize and reward the process participants?
Order Management	Do you maintain the capability to respond to unplanned, drop-in orders?
	Do your information systems currently support the order commitment process?
	Do you measures "out of stock" situations?
	Can rapid re-planning be done to respond to changes?
	Are the customer's satisfied with the current on time delivery performance?
	Do you measure customer "requests" versus actual delivery?
	Given a potential customer order, can you commit to a firm quantity and delivery date (based on actual conditions) on request?
	Are the projected delivery commitments given to customers credible (from the customer's view)?
Process Governance	Do you have a Promise Delivery (order commitment) "process owner"?
	Is a Distribution Management process owner identified?
	Do you have someone who "owns" the process?
	Is there an owner for the supply chain planning process?
	Is there an owner for the demand management process?
	Is a "process owner" identified?
Foundation Building	Are changes made in response to the loudest "screams"?
	Are deliveries expedited (manually "bypassing" the normal process)?
	Do you promise orders beyond what can be satisfied by current inventory levels?
	Is your order commitment process documented (written description, flow charts)?

Construct Name	Question Text
	Is your Distribution Management process documented (written description, flow charts)?
	Is your Procurement process documented (written description, flow charts)?
	Does your information system support this process?
	Are the supplier inter-relationships (variability, metrics) understood and documented?
	Do you have strategic suppliers for all products and services?
Responsiveness	Do you meet short-term customer demands from finished goods inventory?
	Are supplier lead times a major consideration in the planning process?
	Are supplier lead times updated monthly?
	Do you track the percentage of completed customer orders delivered on time?
Collaboratively Integrated Practices	Do the sales, manufacturing, distribution and planning organizations collaborate in the order commitment process?
	Are your demand management and production planning processes integrated?
	Do sales, manufacturing and distribution organizations collaborate in developing the forecast?
	Is your order commitment process integrated with your other supply chain decision processes?
	Do you automatically replenish a customer's inventory?
Customer Integration	Do you "build to order"?
	Do the sales, manufacturing and distribution organizations collaborate in the planning and scheduling process?
	Is your customer's planning and scheduling information included in yours?
	Are changes approved through a formal, documented approval process?
	Is a forecast developed for each customer?

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14

Using Web Technologies for Supply Chain Management

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1. Introduction

Nowadays, companies have to face global competition in order to stay on the market. In order to be competitive, they have to employ new strategies based on new technologies. Internet based Supply Chain Management is the solution that supports collaboration in the Supply Chain as the foundation for gaining competitive advantage and maintain market share. There are many Web technologies necessary for the design and implementation of a Web based SCM application, their employment being determined by the SC partners information systems and applications and the level of integration needed. Traditional technologies are considered complex and very expensive because they have to integrate heterogeneous information systems. In this chapter, we study the up to date concepts and technologies related with Internet based SCM model. We propose a new SCM model based on new Web technologies and intelligent tools to optimize the SCM application. We conclude that this model allows the design and implementation of SCM software with lower investments. Thus, Web based SCM software will be available for small and midsized companies which will have easier access to resources so that to satisfy the demand. The results will be competitivity growth, higher profits and more satisfied customers.

First section introduces the concept of Internet or Web based Supply Chain and the issues connected to this concept: management techniques, technologies, architectures from specific literature. The second and the third section present the necessary steps to follow for the design of the physical and virtual Supply Chain network. We propose an architecture for the eSCM application and a framework for its design and implementation. The last section introduces the newest Web technologies employed very recently for the optimization of SCM software, which allow the design and implementation of eSCM applications with lower costs and increased efficiency.

2. Web based supply chain. Literature review

A Supply Chain is a network of suppliers, manufacturers, warehouses, distributors and retailers who, through coordinated plans and activities, develop products by converting raw materials to finished goods. Supply Chain Management (SCM) involves various approaches used to integrate suppliers, manufacturers and distributors in performing their functions: materials procurement, materials transformation in intermediate and finished products, the distribution of these products to distribution centers and from here to point of sales and to the final customer.

The management of Supply Chain assumes to provide the appropriate strategy to deliver products and services to customers in the right quantities, to the right locations and at the right time to meet the required service level with minimal cost. Through collaboration, information sharing and usage of internal information systems and Internet technologies, companies can create efficient value systems, and get competitive advantage.

The Internet has brought new opportunities for the Supply Chain field. Companies have to adapt their Supply Chain to the Internet and to connect through Web technologies with their business partners to create Supply Chain networks. The combination of SCM (Supply Chain Management) concepts and the Internet tools resulted in a Web based application called e-SCM. E-SCM model uses Supply Chain competencies and resources and exploit them in a more efficient manner into an extended virtual organization. E-SCM applications support companies to win competitive advantage because they create more value for the customer and have the goal to satisfy the client requirements in the best possible way and in real time.

E-SCM applications allow the creation of extra value for the customer and have the goal to satisfy the client requirements in the best possible way and in real time. Migration to a web based approach for SCM applications is required for streamlining Supply Chain activities, maintaining a consistent quality of service and controlled distribution of the data which otherwise cannot be achieved.

According to Ross (Ross, 2003), SCM represents much more than these. In order to figure out its entire extent, we should approach it from three perspectives:

- tactical: SCM is an operations management technique that seeks to integrate and optimize the capabilities of internal business functions and to direct them to new opportunities for cost reduction and increased channel throughput by working with the matching functions from the Supply Chain partners, customers and suppliers. Tactical SCM can be divided in four activities: suppliers management and inventory optimization, product and service processing, customer management and customer order management, channel support activities for facilitate financial transactions, marketing information flows, electronic information transfer, integrated logistics

- strategic: SCM transforms the linear, sequential SC into a networked SC focused on functional and strategic interoperability through collaborative partnerships for the correlation of SC processes. The SC process correlation creates unique sources of value by unifying resources, competencies, capacities of the entire network (Ross, 2003).

These tactical and strategic approaches are focused on the evolution of business network, resulting in innovations, new processes and technologies, increased reliability and speed and mass customization economies.

- Web technologies: e-SCM enables the integration and synchronization of all SC information and processes. Web based applications allow the reduction of transactional costs with 80% compared to private network cost. E-commerce standards (e.g. XML, Java) enable low cost integration of customer, supplier, product information and competencies from SC partners, the transmission of documents and data in real time at every level in the Supply Chain. E-SCM generates more value for customers through the agile, flexible, collaborative intelligent systems built on dynamic networks of Web enabled partners.

In order to implement an e-commerce system, the concept of value is important from customer's point of view, because the client generates company revenue. The value to the customer has to be considered in the moment of the creation of the e-commerce system management strategies. First, the products have to be in accordance with customers' requirements, to be available and to be accessible for them on the company sites. Customers are attracted by the products low price and high quality and value added services.

Using e-SCM applications, the value added for each product can be increased.

The Internet enables the connection of Supply Chain partners through Web technologies and allows SCM networks achieve new capabilities: real time information sharing for collaborative planning, forecasting and replenishment, visibility and management of SC event in real time, SC integration, and collaborative relationships on all levels of the network.

Collaboration allows inventory optimization, provides more value for the customer and satisfies their needs. Synchronization of processes and information from all network nodes to quickly respond to the customer needs. This is possible if customer event-driven data are available in real time across the supply network, allowing concurrent decision making while decision is transmitted in the SC system. Synchronization can provide agility and flexibility which allow to respond to changes in customer demand and supply dynamics.

eSCM applications have to centralize and manipulate data from ERP systems of SC partners trough Web technologies. They include tools for end-to-end integration of business process. The Web front end should be linked to the back-end order processing, manufacture, procurement, accounting and distribution modules included in the ERP system. Integration tools allow data access and manipulation of shared information for each Supply Chain node. These are: standards for documents transmission, access to data sources through standard database interface (e.g. ODBC), support for standard data formats (XML), application adapters to hook e-commerce packages into back-end systems, specialized business process workflow engines, business intelligence tool capable of supporting, extracting and validating data in and out of a multiple, heterogeneous system, integration and collaboration application services.

The most used method for linking back-end applications and systems for e-commerce is to provide appropriate Web interface. There are several options for this purpose: porting of Web servers on proprietary platforms, developing middletier functionality to map between browser and back-end protocols and interfacing e-commerce applications that have standard browser interfaces with back-end applications.

Usually, e-SCM business system can be divided into three **components:**

- **ERP** (Enterprise Resource Planning) system is the centre of present business solution. It has connected with Web-based applications to form groups of business software functions: production, purchasing, CRM, SCM. These applications have to be interconnected so that to provide complete reports on customers, demand, suppliers, supply, finance, manufacturing, delivery, etc.
- **Middleware** consists of e-SCM applications enabled by communication standards such as EDI and XML. Internet based standards like XML that allow quickly generation of transaction documents
- **Web based applications** are directly integrated with ERP backbone through EAI (Enterprise Application Integration). These applications comprises a variety of

supplier and customer-side software applications: CRM (Customer Relationship Management) for customers management, CPC (Collaborative Product Commerce) for collaboration of manufacturing and product designers for new product development, SCM (Supply Chain Management), **e-**Procurement applications include exchanges to facilitate acquisition, e-Finance and Human Resources application. ESCM portals extract data from ERP system for trading partners in the Supply Chain, reducing at the same time the cost of distributing and sharing content and applications.

The e-SCM model needs that ERP systems of the partner companies and e-business applications to be integrated in order to create information flows between Supply Chain nodes. Companies have to synchronize data about customers, processes and products internally and externally. This connection needs appropriate hardware platforms and software: integration standards for document formats to enable information transfer, Internet transmission protocols as well as open data formats to facilitate data transfer between companies, standard transformation and routing tools to convert and route data in different formats, tools for creation and management of distributed business processes and document exchange, security for data transfer.

Business process logic has to be separated from applications to create the collaboration needed. EAI (Enterprise Application Integration) allows the integration of company application using a set of technologies and services that form a middleware. Technologies available for EAI are used at different levels: data level – ODBC, Java Database Connectivity, application level-CORBA, JavaBeans (EJB), Component Object Model (COM/DCOM) and business process levels – Web Service Business Processes Execution Language (WSBPEL). There are specialized SC integration technologies such as ebXML, RossetaNet developed on the basis of generic integration technologies. The above technologies provide physical integration. The logical integration includes agreements on concepts and model integration (Chandra & Grabis, 2007). The Supply Chain middleware should provide access to data from different companies and transaction processing. When a transaction takes place, the data passes through to the middleware layer, is translated in a language like XML or Java and is sent in a readable format to another application layer.

The process oriented layer is named Business Process Management (BPM) and integrates process across business units, applications, enterprises so that to align business processes and to deliver key information. BPM provides visibility to business processes residing on different computers and architectures to support the monitoring and synchronization of business processes and events management across networked Supply Chains.

SCM portal are considered the most used applications for collaboration in the Supply Chain. Portals are front-end interfaces to enterprise information systems. Enterprises develop their own portals to provide access to company applications and Internet and intranet-based content. At the same time they can develop portals for their customers and attract them with customized services, provide intelligent information search, automatic alerting for customers using settled rules or software agents. Portals link to internal applications to retrieve data from internal data sources (ERP data), data from Web, or other vertical portals. The data should be displayed in a manner that enables decision making in a short time. The same portal can be used for different departments and business partners with controlled access and customized options. A portal for Supply

Chain Management can provide access to company inventory in a different way for suppliers, customers and employees. The development of wireless technologies, allows enterprises to extend their portal services to their mobile users. SCM partners will be able to access the e-SCM applications through their mobile appliances: smart phones, PDAs, laptops etc.

We can conclude that the design and implementation of an eSCM application need to connect heterogeneous environments and to automate processes and data flow so that to react in a timely manner to demand changes. In order to achieve all these, numerous development tools are needed such as: programming languages, hardware and software infrastructure, IT management services, business integration for all the supply chain partners, standardization and connection of business processes for the entire chain. At the same time, transactional data from different applications and ERP systems have to be integrated, processed and sent in a standard format such as XML to the partner that needs that information. Once the data about demand, customers, orders, production, inventory, resources, supply, delivery, forecasting are available in real time to the right node in the supply chain, the managers have to make the right decisions about every strategic activity of the network and its members. This can be accomplished only by using decision support tools that use statistics and business intelligence to discover patterns in customer behaviour and market conditions and foresee the future changes and trends. In this way, companies can meet customer requirements before their competitors and gain competitive advantage.

3. The design and Implementation of an eSCM application

An important activity before implementing a Supply Chain information system is network design and configuration. Then relationships must me settled with partners for information exchange and performance improvement to create the suppliers and customers network. Companies must reduce the number of suppliers and select those with greater potential for collaboration in a process of supply base optimization. After designing the physical Supply Chain and the collaboration model, the SC partners should establish the network integration model so that to result a virtual organization to respond to customer requirements.

An effective Supply Chain business architecture needs to determine the best competencies in the network for each Supply Chain activity so that each function to be executed by the most appropriate company in the Supply Chain. Then, the scope of collaboration should be detailed on activities and processes for each company and the allocation of resources. In order to measure the operational effectiveness of SC and continuous growth a set of a performance measurements have to be chosen.

In the SC literature and practice, there are four basic steps we have to follow in order to design an e-SCM application:

- Internal integration of business functions for internal optimization
- External Integration of SC operations between similar functions from network members. All the processes in the Supply Chain must be designed and coordinated so that to provide agility and flexibility to adapt to customer requirements.
- Strategic collaboration with suppliers and customers for product development and order fulfilment according to customer demand through the extranet system

- Design and implementation of a Web based application to streamline information flows and processes through collaboration

The purpose of e-SCM application architecture is to create a virtual SC network based on Web technologies. This application consists of a set of application components for cross-business processes that can integrate intra-enterprise and inter-enterprise business functions. This components should provide flexibility so that to able to quickly react to market changes so that to satisfy the customers in a more efficient manner. Companies need to achieve higher efficiency and increase profits, and to attain this goal, they must design and implement a Web based application for SCM. In order to justify this IT investment, the eSCM should bring significant cost reduction and revenue growth. This is not possible without an appropriate strategy.

First, the Supply Chain must be properly redesigned and then the member company information systems must be analyzed in detail. We propose a set of steps to follow in order to implement an e-SCM application. The steps we have to follow to build an e-SCM application are:

- process mapping
- internal integration of business function if this does not work through ERP systems or other applications
- value chain analysis to identify the value added sources
- collaboration settling for network design and configuration with the most important suppliers and customers: contract settling, stock management, distribution strategies, risk management, pricing, information sharing, etc.
- cost and resource management to reduce the bullwhip effect and increase profits
- external integration of business function and process standardization to achieve network integration
- selection of IT technologies for structuring of e-SCM application and the integration of companies information systems through e-SCM.
- design and implementation of e-SCM application
- synchronization and automation of processes and e-information flows in the Supply Chain network
- providing visibility of network transactions and processes to SC partners
- providing real time information about present and forecasted supply and demand
- e-SCM apllication has to support adaptation to marketplace and the real time response to changes in customer demand and supply dynamics.
- implementation of intelligent tools for decision making so that to provide a proactive behaviour on the market
- design and implementation of mobile version of eSCM application so that to be accessible from mobile devices

We propose an e-SCM model consisting of three modules:

1. Front-End Functions – gives static and dynamic information to the customer. In order to answer to the customer requests, these functions have to manipulate wide volumes of data. XML is used to integrate Web and server-based components and to pass information between EAI middleware servers and back-end databases. An important component here is customer module which allows order management, order track and trace, customer service, inventory reports, customers' management.

2. Middleware Functions - the front-end passes the external request for further processing to the middleware application servers. The logic processing is mostly executed at this level.
- middleware SCM: order management, CPFR, production planning, replenishment management, delivery management, SC coordination and scheduling, decision support tools that uses analytics and artificial intelligence techniques such as multiagent systems. Agents provide the automation of replenishment, production tracking, orders fulfilment, event management.
3. Back-End Functions. Company information system or ERP system executes transactions processing, support all departments within an enterprise and manages internal and external resources including tangible assets, financial resources, materials, and human resources. The hardware should allow support for dynamic applications, scalability and flexibility.
The ERP system can include software for manufacturing, order entry, accounts receivable and payable, general ledger, purchasing, warehousing, transportation and human resources. ERP facilitates the flow of information between all business functions inside the boundaries of the organization and manage the connections to outside partners. It provides data to support the core business functions of the organisation including production, distribution, Supply Chain, financials and customer relationship management.
A basic e-SCM system should manage orders, production, purchasing, delivery to get the needed data so that to be able to synchronize the activities in the Supply Chain. The application should first be a Web based portal for information sharing, transaction execution and process synchronization with business partners, concerning demand, production and supply in real time.
This application should then be developed to integrate the components of the information systems of business partners and their applications, so that to automate the activities in the Supply Chain network under a common Web interface. Business processes automation involves process synchronization and integration.
Supply Chain members can dynamically interact and initiate business processes in the information system of its partner through predefining business rules first and then they can trigger events along the systems using eSCM application. This means that physical Supply Chain can become at least partially automated. Automation frees staff from routine work and they can monitor the system to improve it by including their experience and knowledge in application knowledge and rule database. They can involve in planning Supply Chain strategy to increase processes efficiency and.
The model can be extended to employ components for wireless usage that brings many advantages: allows SC applications to transmit real time data from the field, customer demand information is available in real time, employees can share information about activities and processes in the SC. Wireless technologies allow data access for collaborative information exchange and for tracking the position of items in the SC: RFID (Radio Frequency Identification) technology allows the real-time posting of data by mobile operators so that to identify products location in the Supply Chain network.
The architecture we proposed for eSCM, is based on traditional model for the Web based Supply Chain. In order to design and implement the model, the partner companies should invest substantial amount of money. However, new web technologies have arisen: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). These Internet based services should be deployed to outsource common competencies for the members of SC, because they provide common standardized infrastructure, platforms and software services, at a lower price and higher quality. At the same time these technologies

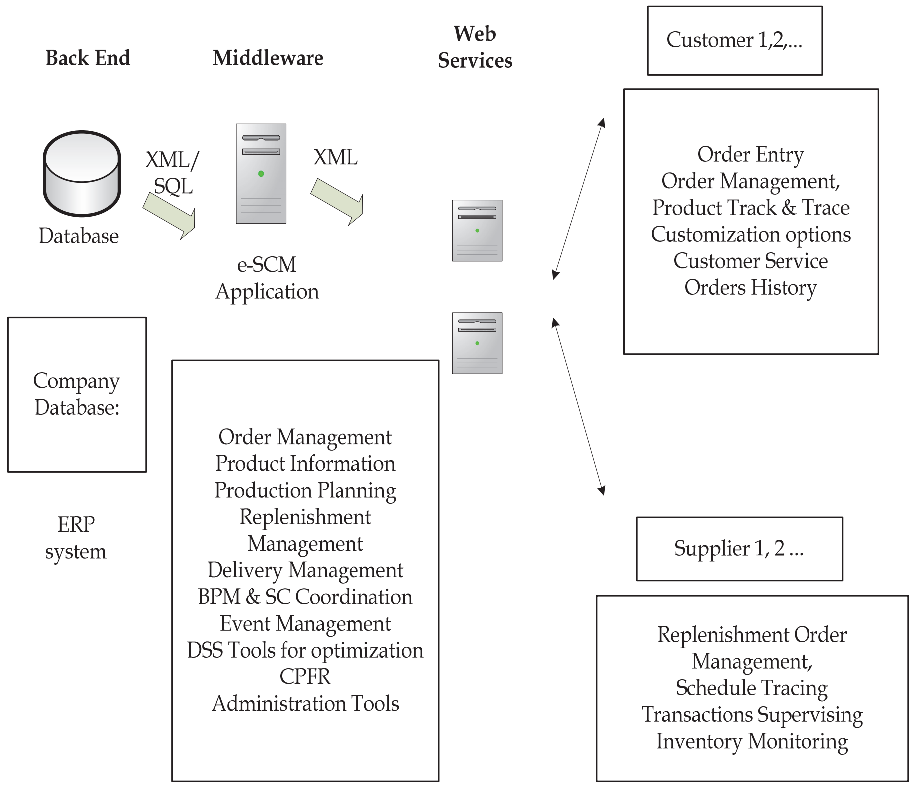

Fig. 1. The eSCM architecture

allow the creation of a dynamic network which can share information and resources in a very effective manner. Thus, the managers can make faster and better decisions based on real and accurate data to react to volatile markets and demand.
In the next chapter we will propose an agent based framework for decision support to automate and streamline the activities in the SC network. The last section presents the future developments of the proposed models to implement the new SaaS technologies.

4. Multiagent framework for eSCM application

Many technologies were used to automate and streamline SCM activities, but they could not provide enough flexibility to react in real time to market events. In this context, we use agent technology as an appropriate solution for designing Web enabled Supply Chain software, because it shows many of the characteristics a SCM system should have: autonomy, collaboration, proactiveness, adaptability, mobility (Moyaux, 2006). The model we propose intends to solve the problem of automating activities in eSCM for searching, manufacturing, scheduling, exception report, etc. in real time without or with a limited human intervention. The purpose is to manage real time information, events and demand faster, more effective and in a coordinated manner so that to synchronize the entire Supply Chain (Simchi Levi et al, 2008).
Software agents are autonomous program units supported by an execution environment. Software agents can use the network to send themselves to other processors, thus “moving ” around computers. Control system can benefit from agent technology in many ways. Modularity is the key for a control system and the property key of an agent system. Autonomy is another characteristic of agents that allows the user to accomplish the task. Proactive agents take initiative and change their environment, for example, once an agent has completed its task on a machine or is unable to do it, the agent migrates.
Creation of the service agent: the directory agent is running as a part of a system agent pool and this must create it on the agent execution environment :

- Sign in: each agent will register itself with following parameters: agent name and service agent address. The agent also signs in to the core service for each transaction that occurs between local and the central core service. This ensures location independence.
- Sign off: gent informs core service when his jobs are done or some information need to be transferred from service core database to the agent. When the jobs are finished the core service automatically will sign off the agent. Also, another problem which can occur during the authentication or the data transfer between the agent and the core is the network disruption which are checked by the core service which automatically will sign off the agent.
- Query: Every agent installed on the local or different network and authenticated to the core service can query the service.
- Cache: Each transaction in an agent execution environment will be kept in the tracking collection.

Analyzing these processes yields that there are two kinds of channel that are used to communicate within the environment with the core service system: The first one is the “Internal channel” and the second one is the “External Chanel”. The Internal channel is used for any transactions among agents and the core service in the agent execution environment. The External Channel is used in order to communicate among directory service agents.

Advantages of applying the agent technology to a distributed core service :

- Reliability: transforming core system from a monolithic system into a parallel system
- Versatility: Each system is able to access the remote core system and not every system can be fault-tolerant in their core
- Integration: This kind of system are much easier to integrate, the results derives directly from the characteristics of the agent architecture
- Remote access: The core system can be controlled remotely via LAN, WAN, etc.
- Security: A good solution to secure network security is to use a private or virtual network system which can prevent unauthorized personnel.
- Dependability: although the reliability of the system grows in term of fault tolerance and fault recovery it is necessary to determine the scheme of trade-off of the network which are simple because are based on availability of the network structure.

The only disadvantage of the core system with agents is the network availability.

The agent technologies are necessary to be developed and employed in SCM applications so that to replace humans for routine and even for complex tasks. We consider that multiagent systems together with web technologies can automate, connect and optimize SC processes.

The processes and operations can be automated by using intelligent agents not only for one company or one tier, but for the whole SC network. As we can see in the figure, the relationships can be extended from the manufacturer to the 2nd tier suppliers and raw materials suppliers. Once an order arrives, the manufacturer can send the purchasing orders directly to the 2nd and 3rd tier suppliers so that to quicken the whole purchasing process, eliminating intermediates. The agents can communicate to each other to manage operations, events and exceptions for every tier in the SC.

The proposed agent framework is designed for the automation of routine activities in the Supply Chain: order management, replenishment, inventory management, production, delivery, event management, and analytics. These agents manage the activities and optimize them so that to reduce costs, allocate resources efficiently, and streamline processes and information flows on the first tier of the Supply Chain. This architecture includes agents for communication, connection to database sources and servers and connection between application components. Company databases are managed by mySQL server, services are executed by intelligent agents built with Java. PostgreSQL was employed to provide for concurrent access to company databases so that to automate services and at the same time to allow human intervention and control. Open source software allows cutting costs with software acquisition and maintaining.

Customers are ordering products through the company site. They can choose the standard products or they can configure their own customized products. After the client registers with the company site, he places the order; the order is sent to the eSCM middleware and validated by the company employee. If the product is on stock, an invoice is generated, the payment date is set. After receiving the payment, the ordered product is delivered to the customer and the order is fulfilled. If the product is not on stock, a supply order is sent to the suppliers having the best price for the product. Usually companies have agreements on prices and quantities and a list of suppliers they use to work with. If none of the suppliers can deliver the product at the right time and price, the agent will search for another supplier on the Internet. Depending on the result, the employee managing replenishment will decide

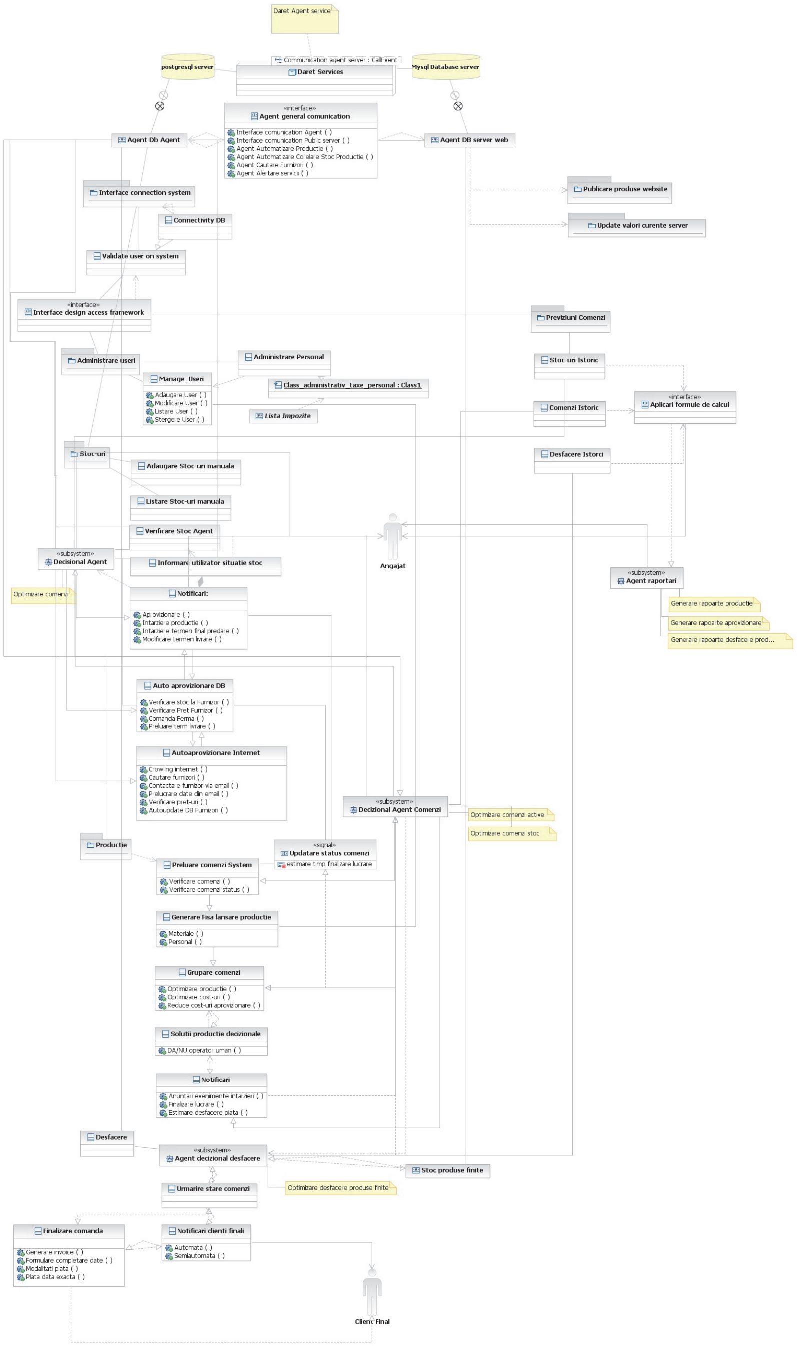

Fig. 2. Multiagent framework for eSCM application

on the supplier and will send an order to fulfil the order. If there is no supplier to deliver the product according to the client requirements, the order will be cancelled.

If the order needs to manufacture a customized product, the decision agent will generate the bill of materials and check the stock for the raw materials and components needed. If they are not on stock, the agent will trigger replenishment process in a similar way as in the product replenishment case. If the product cannot be manufacture in the due time, the agent will send messages to the customer to announce him about the delay. All the data about orders, production, and replenishment status are automatically updated and showed through eSCM application.

The agent can group the orders so that to order the same product just once but in higher quantities, if possible. Production is optimized also to use the resources to manufacture more similar products at the same time. Delivery is optimized through product shipment in lots or groups of products to the same destination or area. All these lead to cost reduction and significant increase in profits.

The application has a special module for customers so that they can manage orders, track and trace order status, order history, customer profile. This is an efficient tool to provide personalized interaction with the customer and to obtain customer profile which allows market segmentation and better satisfaction of clients' requirements.

Agents will send exception messages every time an unforeseen event is taking place and will update the information about items involved in this problem for the entire eSCM application: order management module, manufacturing and replenishment, customer module, etc.

The SC activities are automated by intelligent agents but the human user can interfere in the process and can take different decision if they consider to be more appropriate. In this way the system can be supervised and optimized by employees who are not busy to execute routine activities that are now being automated by means of agents. After the implementation of the system the application can be improved with specific observations from experts so that to achieve a higher efficiency.

This model automates the SC processes activities inside and outside company boundaries. The model will be extended so that to include new Web services based on cloud computing, such as SaaS, PaaS, IaaS. The new service oriented Internet tools allow cross-company teams to interconnect data and information through common shared applications so that to form collaborative Supply Chain nodes which integrate processes to optimize the Supply Chain network activity. The goal is to access resources and business partners, to manage them efficiently following a customer-centric strategy. Companies compete with the price, product, service quality, information services and e-business connection. For this reason, we will analyze in the next chapter how our model can be extended to include these service oriented Web technologies.

5. Cloud computing for supply chain management

Cloud computing supplies computational resources on demand via a computer network (Wikipedia). Traditional computing models require both data and software to be fully contained on the user's computer. In cloud computing, the user's computer may contain almost no software or data (only an operating system and a web browser). The provider's cloud computing services form the cloud. These services are provided via an Internet connection within one or more of the next layers: application, platform and infrastructure.

- Application services (SaaS- Software as a Service) deliver software as a service over the Internet to the client who doesn't need to install and run the application on his own computers. All the software management, update, maintenance and support are executed centralized, only on the provider's computers. The software allows collaboration through the network with business partners due to its model - single instance, multi-tenant architecture.
- Platform as a Service provides a computing platform comprise hardware architecture and software framework to support the software.
- Infrastructure as a Service (IaaS) provides computer infrastructure as a service: servers with multi-core processors, software, data-center space or network equipment.

Companies can use one or combinations of these services and they pay according to the pay-for-what-you-use model, achieving significant cost reductions. The service provider will deal with investment in licenses, infrastructure maintenance and upgrades. Software implementation is simple, with minimal technical requirements and easy management.

Cloud computing is an innovative business model which ensures an efficient outsourcing for Supply Chain collaboration software and infrastructure. We will prove the advantages of using cloud computing technology for SCM.

The Supply Chain and the cloud have similar features: are distributed, shared and dynamic, adapted their size, structure and functionality to support their business environment. Collaboration is supported by company software but is very expensive to implement due to the heterogeneous environment that must be connected. Cloud based centrally-hosted software is a cheaper and more efficient solution, providing cost and risk reduction and access to new technologies for better scalability and security.. Compared to the substantial investments in collaboration services required by traditional SCM models, Cloud computing reduces the cost of collaboration for SCM. The Cloud is considered a flexible, **cost-effective** pricing structure. Another advantage is remote implementation, customization, and integration, without additional investments. Despite huge investments needed for end-to-end integration of traditional Supply Chain, cloud is an affordable technology for small and midsize manufacturers.

SCM **business processes** are parallel and data are managed by each company's integrated information system. In order to extend these internal systems to SC level, companies have to connect them through networks. Cloud computing enables the networking of multiple and interdependent end-to-end processes (order fulfilment, collaborative forecasting and replenishment, market analysis). It supplies a collaborative framework allowing an effective process management through standardized processes.

SaaS provides a high level of security, so that company are able to share information without trust limitations. This creates **visibility** for each Supply Chain member for the entire network o that to support the decisional process.

Traditional systems don't have the **flexibility** and elasticity needed to scale computing infrastructure demanded by Supply Chain networks. Products, processes, demand, technologies and partners are continuously changing and Cloud computing can adapt to every type of user and to the strategy of the entire Supply Chain network (Singh, 2011).

Elasticity allows partners to change or switch applications with minimal cost. Thus, companies can launch new products or services or enter new markets.

Cloud computing enables the SC network to work on a single platform. SC members have a single view for all the processes and activities in their network. Thus, cloud technologies provide an efficient decision support tool which adapt to market changes and increase profits for each participant in the Cloud based SC.

The Supply Chain network can work with any supplier to match the needs of the customer without constraints. Thus, due to the advantages of cloud computing, companies reduce costs (such as total cost of ownership), reduce working capital, launch innovative products to market faster, work more effective, adapt to market changes and better satisfy the customer needs.

We will extend this e-SCM model to include cloud computing facilities which provide a cheaper and more standardized infrastructure, more resources available for Supply Chain partners. The eSCM application have to be redesigned so that company ERP system to work inside company premises and at the same time to send real time data for eSCM components working in the Cloud to provide outsourced services. The Cloud based eSCM application will support complex processes between multiple partners and will increase sensitive reactions to market changes. The Supply Chain activities outsourced with the Cloud are those which don’t need much customization:

- planning and forecasting
- logistics: inventory and transportation management, network strategy, warehousing, replenishment, order processing. For example, inventory tracking can be performed by asking suppliers to report into the cloud about the components shipment and their current status. This will allow a better planning and scheduling to fulfil the orders in due time and answer to customer needs.
- sourcing & procurement: for supplier management, contract management.
- service and spare parts management and distribution, reverse logistics processing.
- sales: for mobile facilities and more customers

Cloud Computing moves computing from the desktop to remote computers. Different computing devices such as PCs, handheld devices and cell phones connect to remote computers through wired or wireless connections. This service is an operational expenditure, so companies can afford these investments in cloud technologies.

In order to operate efficiently, Supply Chains need a real time exchange of knowledge and the ability to collaborate with their partners to manage events in real time. This is possible with the cloud as it provides these facilities for each type of business.

Manufacturing processes will benefit too from cloud computing, because real time information sharing and synchronization allows and agile and flexible production so that to react faster to demand and supply changes. Sales Forces will be the first users of cloud computing followed by CRM, Human Resource Management and email services.

Cloud computing will reduce transaction cost for trading partners. Transaction costs grow with the business growth. The cloud based eSCM application will adapt to supply-chain needs concerning collaboration and visibility, support for managing a dynamic and constantly changing network.

Companies don't want to replace their ERP system with new cloud computing applications due to the need for sharing information and trust problems. However, they will use a mix of on-premise, public cloud and private cloud based applications, depending on their dimensions of the company and Supply Chain needs. The concept of private cloud computing allow companies deploy technologies such as virtualisation and multi-tenant applications to create their own "private cloud" data centres. The public cloud will have more success for providing visibility in collaborative activities between partners. The company can make decision having the needed data in real time from the cloud. In order for this cloud based eSCM application to work, companies need to settle agreements to be able to share information without having trust problems so that to be able to collaborate.

We conclude that the e-SCM prototype model we proposed is based on classical and new technologies which are an appropriate approach for nowadays business trends and economic crisis. Once designed and developed, the e-SCM model can be extended and improved by adding new facilities based on new technologies available on the IT market.
Our contribution to SCM research is the study of Web based Supply Chain trends and the optimization proposals through Web technologies and intelligent tools. We consider that the convergence of traditional information system and new Web technologies is achievable with the purpose of solving Supply Chain problems. As a result we will obtain a virtual Supply Chain based on the best technologies capable of managing the physical Supply Chain in an efficient manner. The result will be more added values for the client and higher profits for the entire Supply Chain network. Another useful result of our research is the possibility of providing SCM applications with lower investments due to new cloud computing technologies. eSCM software becomes available for small and midsized companies which become more competitive, thereby better satisfying the customer.
In our future work we will optimize the design and implementation of eSCM application by using the most efficient methods and technologies, both traditional and modern. Our purpose is to be able to provide a Web based framework that meets the collaboration requirements of small and medium size companies. This framework will allow real time collaboration through the Internet for every type of company, regardless its size or domain, so that to be able to stay on the market even during crisis periods and increase profits.

6. Conclusion

Web based SCM is a complex issue and needs to be approached taking into consideration the need for collaboration in the global economy and the possibility of implementation. Traditional solutions are considered to be complex and very expensive. We have proposed a model based on old and new technologies which can make eSCM application available for small and midsized companies, with lower investments. This provides the possibility to access expensive resources and new business partners so that they become more efficient, can better satisfy the changing customer requirements and increase profits.

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