From Network to Web Dimension in Supply Chain Management

Thèse

Driss Hakimi

Doctorat en science de l'administration
Philosophiae Doctor (Ph.D)

Québec, Canada

Résumé

Cette thèse soutient que la dimension réseau, étant actuellement la portée du domaine de la gestion de chaîne logistique, contraint l'avancement de ce domaine et restreint des innovations conceptuelles et fondamentales capables d'adresser les grands défis économiques, environnementaux et sociaux. Les concepts de chaîne et de réseau ne reflètent pas la complexité des flux physiques, informationnels et financiers générés par les interactions qui ont lieu dans des réseaux interconnectés. Ces concepts n'offrent pas les fondations théoriques pour supporter des interventions allant au-delà d'un seul réseau et laissent échapper des opportunités nécessitant une vision multi-réseau. Ainsi, la dimension "web", celle des réseaux de réseaux, est proposée comme une extension de la dimension réseau. Cette extension peut être vue comme l'étape naturelle suivante dans la progression qui a commencé par le niveau de gestion des opérations internes, est passée au niveau de la chaîne logistique et se trouve actuellement au niveau du réseau logistique.

Après l'investigation théorique des raisons et de la façon d'intégrer la dimension web dans le domaine de la gestion de la chaîne logistique, la thèse étudie des implications importantes de cette intégration sur la collaboration inter-organisationnelle et le processus de prise de décision dans des environnements de webs logistiques. Elle démontre, en exploitant l'exemple des réseaux interconnectés ouverts, des potentialités inimaginables sans une vision web. Une méthodologie de conception d'un modèle de simulation permettant l'évaluation et la comparaison des webs ouverts par rapport aux webs existants est proposée.

Puisque l'aide à la décision est une composante importante de la gestion de la chaîne logistique, la thèse contribue à déterminer les besoins des gestionnaires et à identifier les lignes directrices de la conception des outils d'aide à la décision offrant le support adéquat pour faire face aux défis et à la complexité des webs logistiques. Ces lignes directrices ont été compilées dans un cadre de conception des logiciels d'aide à la décision supportant la dimension web. Ce cadre est exploité pour développer quatre applications logicielles offrant aux praticiens et aux chercheurs des outils nécessaires pour étudier, analyser et démêler la complexité des webs logistiques.

Abstract

This thesis argues that the network dimension as the current scope of supply chain management is confining the evolution of this field and restricting the conceptual and fundamental innovations required for addressing the major challenges imposed by the evolution of markets and the increased intricacies of business relationships. The concepts of chain and network are limitative when attempting to represent the complexity of physical, informational and financial flows resulting from the interactions occurring in overlapping networks. They lack the theoretical foundations necessary to explain and encompass initiatives that go beyond a single chain or network. They also lead to overlook substantial opportunities that require beyond a network vision. Therefore, the "web" dimension, as networks of networks, is proposed as an extension to the network dimension in supply chain management. This new scope is the natural next step in the progression from the internal operations management level to the supply chain level and then to the supply network level.

After a theoretical investigation of why and how the web dimension should be integrated into the supply chain management field, the thesis studies and discusses important implications of this integration on inter-organisational collaboration and of the decision-making processes in the logistic web environments. It demonstrates through the example of open interconnected logistic webs some of the potentials that cannot be imagined without a web vision. A methodology for designing a simulation model to assess the impact of such open webs versus existing webs is proposed.

Since decision support is a key element in supply chain management, the thesis contributes to determine the needs of supply chain managers and identify the important axes for designing decision support systems that provide adequate assistance in dealing with the challenges and complexity presented by logistic web environments. The identified elements result in the establishment of a foundation for designing software solutions required to handle the challenges revealed by the web dimension. This conceptual framework is applied to the prototyping of four applications that have the potential of providing practitioners and researchers with the appropriate understanding and necessary tools to deal with the complexity of logistics webs.

Table of Contents

List of Tables

List of Figures

Glossary of Used Abbreviations

CASN:	Complex Adaptive System Network
CIRRELT:	Canada and the Interuniversity Research Center on Enterprise Networks, Logistics, and Transportation
DC:	Distribution Center
DSS:	Decision Support Systems
DW:	Distribution Web
EDI:	Electronic Data Exchange
ERP:	Enterprise Resource Planning
ETM:	Electronic Transportation Marketplace
FIPA:	Foundation for Intelligent Physical Agents
GDP:	Gross Domestic Product
GUI:	Graphical User Interface
ITN:	Information and Trading Network
JIT:	Just In Time
KPI:	Key Performance Indicators
LW:	Logistic Web
MASCOT:	Multi-Agent Supply Chain Coordination Tool
MBOL:	Master Bill Of Lading
MW:	Mobility Web
NIIIP:	National Industrial Information Infrastructure Protocols
P&G:	Procter & Gamble
PI, π:	Physical Internet
POS:	Point Of Dale
RW:	Realization Web
SC:	Supply Chain
SCM:	Supply Chain Management
SN:	Supply Network
SW:	Supply Web
TQM:	Total Quality Management
www:	World Wide Web

Dedication

To mom and dad,
and to the beautiful soul of my grandmother…

Acknowledgments

First, I want to present not only my thanks, but also my admiration to my advisor, Professor Benoit Montreuil, who inspired me in many ways. I want to thank him for all the effort he makes to provide his team with a great research environment, precious guidance, and financial support. I appreciate his open-mindedness, his attention to details, his scientific rigor, and his non-stop quest for challenges. I thank him for creating an atmosphere, which helps us to produce high quality scientific research while developing our own autonomy and scientific vision. Second, I would like to thank my co-advisor, Professor Olivier Labarthe, for offering me the right assistance, sharing his knowledge with me, and supporting me both scientifically and professionally. Both Benoit and Olivier were always supportive and encouraging me to strive beyond my limits. Thanks to both of you for all your discussions, feedback, guidance, and trust in my choices throughout this research work.

I would also like to express my gratitude to the professors who participated in this thesis, the thesis project, the Ph.D exam committees, and the doctoral courses: Young Jun Son, John Fowler, Jean-Marc Frayret, Daniel Pascot, Sehl Mellouli, Alain Martel, Fayez Boctor, and Angel Ruiz.

My deepest appreciation is extended to Université Laval, the Faculty of Business Administration and, beyond them, all the wonderful people that work hard to make our doctoral experience memorable. I must mention Marie-Claude Beaulieu, Jacques Renaud, Carole Lalonde, Johanne Nadeau, Catherine Vézina, Dominique Bernier, as well as many others who work behind the scenes.

Within our research center (CIRRELT), I would like to thank all of my colleagues, those who left and those who are still with us. The support and administrative staff: Pierre Marchand, Stéphane Caron, Olivier Duval-Montminy, Martine L'Heureux, Mireille Leclerc, and special thanks to the lovely Louise Doyon for always resolving all of our administrative issues. My colleagues who participated in the conception or the development of our software tools and simulations presented in this work: Caroline Cloutier, Alexandre Morneau, Mathieu Audet, David Dastous St-Hilaire, Anne Larach, and Sébastien Giguère.

Other colleagues with whom I had the privilege to work on other projects: Edith Brotherton, François Barriault, Collin Thivierge, Zachary Montreuil, in addition to so many others.

I would also like to express my gratitude to Professor Eric Ballot for participating in the thesis committee and for welcoming me during my six-month scientific sojourn in his laboratory at Mines ParisTech. I thank him, as well as his team consisting of Rochdi Sarraj, Shenle Pan, and XU Xiaozhou for the brilliant collaboration, the riveting discussions, the rich experiences, and their generous hospitality.

Furthermore, I would like to extend my sincere gratitude to the institutions that provided support for projects developed in this doctoral thesis: Canada Research Chair in Enterprise Engineering, the Discovery Grant Program of the Canadian Natural Science and Engineering Research Council, the NSERC/Bell/Cisco Business Design Research Chair, the French PREDIT transportation research program, and the French Ministry of Transportation MEDDTL; grant number 10-MT-PREDITGO4-4-CVS-124-20. I also profoundly thank Procter & Gamble Canada for both their financial support and their proactive collaboration; Adrian Schiller and Randy Young have my most heartfelt thanks for their involvement in the field-testing of the logistics web technologies.

I would like to acknowledge the financial encouragement and support that I received through many scholarships and awards. The Association Québécoise du transport recognized my involvement in the PREDIT for the Simulation of Physical Internet Enabled Mobility Web by honoring me with its Doctoral Thesis Scholarship for 2013. In 2011, the Canadian Purchasing Research Foundation awarded my dissertation its prestigious Codère CPRF Doctoral Thesis Scholarship, identifying it as the best doctoral thesis in supply chain management and purchasing in Canada. The Fonds Québécois de Recherche sur la Nature et Technologies (FQRNT) granted me its International Training Program Scholarship. Université Laval gave me the International Mobility Office Scholarship. The Faculty of Business Administration honored me with the Dean's excellence award and its financial support program. Finally, the CIRRELT received me with its doctoral welcoming excellence award, and later, honored me with the doctoral thesis excellence award.

Furthermore, I am happy to have met many graduate and undergraduate students during my studies with whom I have not only shared similar interests, exchanged cutting edge ideas, and offered unwavering support to each other, but also developed important friendships: Salma Naccache, Helia Sohrabi, Roli Nigam, Claudia Herescu, Moez Charfeddine, Salman Kimiagari, Jean-Philippe Gagliardi, Joelle Bouchard, Muhammad Mohiuddin, Oualid Abidi, Walid Klibi, and many others.

I also want to express my sincere gratitude to all of my friends in Canada, who have become my extended family, for always being there when I need them, for supporting me, and for shedding happiness and joy on my life: AbdelGheni, Fatima-Zahra, her mother, and Youssef; Hamza and Intissar; Nabil and Ghizlan; Mustapha and Lorraine; Akrem, Driss, Abdel Hak, Morad, Abdel Kader, Rachid, and Siham.

My great appreciation and thanks to my dearest heavenly angel Lois for her never-ending unconditional support and understanding during my busy and long doctorate journey and for editing the English of this thesis.

My deepest gratitude goes to my family for their patience and love throughout all of my studies and my life. Thanks to my wonderful parents who always encouraged us to study and who made our achievements their priority in life. Thank you for your unconditional love, for your unlimited support, for your endless devotion through every step I did in this world, and for brightening my universe all the time. Thanks to my amazing sisters, brothers and their families who are always soothing me, caring about me, and reminding me how lucky and honored I am to have them in.

To all of those I may have left out, thank you.

General Introduction

When the concept of supply chain was first introduced as a relationship between multiple actors aiming to fulfill market demand, it was presented as a linear chain with unidirectional flow of products originating from suppliers and flowing toward the final market (e.g. Hayes et al., 1984). Then the notion of supply network emerged to explain the effects occurring between overlapping supply chains and to introduce softer and behavioural aspects related to the study of supply performance (Harland, 1996; Lamming, et al., 2000). Supply networks addressed the complexity that companies operating within multiple supply chains have to manage, by emphasizing that a chain is a part of a larger system, which it influences and by which it is influenced.

Such leading companies as Dell consider their entire supply chain as an organization and try to control production, distribution and retailing by selling directly to final customers (Magretta, 1998). Retailers, such as Metro and Wal-Mart, have many stores and several distribution centers all over the world, and pilot complex supply relationships with numerous suppliers, subcontractors, and logistic providers (Krafft, et al., 2006). Some manufacturers, besides owning many distribution centers, operate multiple plants located in different countries and concurrently produce multiple product categories (Galbraith, 2009).

An organization can own multiple sites that maintain complex relations with each other. Internally, such an organization operates a complex logistics network with complex inter-organization informational and physical flows. The organization as a whole, as well as each of its sites, must also cultivate relationships with external partners that are likewise complex organizations, each with its own logistics network. The result is a meshing of multiple networks, constituting a network of networks, with complex sets of relations and flows of goods, resources, information, and money.

As companies start to understand that they are operating within supply networks, they realize that their partners are also operating within their own supply networks. They are learning that interactions among these many networks influence their business. Leading organizations are extending horizontally, vertically, and virtually, building complex relationships with various partners in order to increasingly control their supply context.

For companies that are in avant-garde position in terms of supply chain management, especially those operating diverse sites, the network dimension appears to be limitative; not reflecting the full scope of their supply and logistics reality. While supply chain management is still caught in the network dimension, numerous supply initiatives no longer require thinking at a network level, but rather at a web level, explicitly recognizing that networks overlap and interact with other networks.

The awareness and consideration of the web dimension in supply chain management raise important questions regarding the pertinence of this dimension from theoretical and practical points of view. While it is easy to perceive the complexity and challenges of dealing with notions such as supply web and logistic web, especially in day-to-day and decision-making activities, it is crucial not to overlook the wide range of opportunities offering an increasing number of potential collaborators and different kinds of resources. Restriction to a supply chain or a supply network vision means that at most each member can exploit its relationships within these frames. Considering a supply and logistic web perspective implies exploiting a huge potential of resources, markets, and workforces.

In this thesis, the importance of the web dimension in supply and logistics management is highlighted and the pertinence of extending the scope of supply chain management from the network level to the web level is investigated. These issues are presented from various theoretical and practical facets. The present research work provides a contribution that sets the first steps toward understanding and exploiting a supply and logistic web, vision enhancing the current supply chain management paradigm.

Positioning and Stating the Research Problem

The investigation of supply chain management research reveals that the focus is mostly limited to the network level. A main characteristic of this level is the exchange of flows between the members of the supply network. In fact, for a member to be part of a supply network, the inclusive criterion is to receive and/or ship products or parts over the network. At first, it seems important to improve the relationships between the partners involved in physical exchanges and efficiently control the physical, informational, financial and decisional flow within the network.

A supply network is implicitly defined relative to entities such as nodes, companies, facilities or products. The supply network of a company can generally be constructed by starting with the products and services it provides. Then on the up side the network is expanded by identifying the entities involved in making these products and services and providing the supplies and activities needed to make them, going back all the way to primary materials, parts or services, tracing the supply links between them. This is usually stated as going up to its suppliers, the suppliers of these suppliers, and so on as pertinent. On the down side, the supply network is expanded by following the company's products all the way to their final users, embedding the distributors, logistics providers, retailers, and so on, as well as their supply links. This is usually stated as going down to its clients, the clients of its clients, and so on, until the final users. The supply network of a company can be quite extensive, yet it has definable boundaries.

Yet, each upside member of a company's supply network has usually other products or services not purchased by the company, involving a wider network of suppliers, and it has several other clients and final users. Similarly, each downstream member of the supply network generally serves other clients and may well have several other suppliers for other competing or entirely unrelated products or services. Simply stated, each member of a company's supply network has its own distinct supply network that has impact on the company's performance. Drawing the networks of all the members generates a network of supply networks overlapping each other. This requires rising from a network perspective to a web (network-of-networks) perspective. This perspective makes it difficult to assume that it possible to efficiently control and manage a supply network by not considering the impact of other networks with which it shares resources and clients. If actors of any of these networks only consider their own nodes, flows and relationships, omitting that of other overlapping networks, their decisions will be based on a small number of network-centric factors while neglecting a large number of web-centric factors.

Figure 1 illustrates a simplified example of overlapping supply networks. Let first focus on Manufacturer 2. It supplies retailers 1, 2, and 3. In order to manage and optimize its activities and reduce its costs, Manufacturer 2 establishes consolidation strategies. Purchasing, production, inventories and shipments are all managed considering the total combined expected deliveries to clients. Financial and human resources are also attributed to the entire activity of the manufacturer, and cannot be completely dedicated by client. Any bilateral collaboration with one client will influence the other clients; hence, such collaboration cannot possibly reach its full potential as long as it does not take into consideration its impact on the other actors. Now focus on Retailer 2. It faces the same implications when considering its suppliers as well as its distribution centers and its stores regarding handling and managing the supplied products. Products from various suppliers share common storage areas, shelves, and resources. In a such context, any strategy positing the possibility of completely isolating the activities dedicated to one partner from the rest of the other activities of a company is economically unjustified.

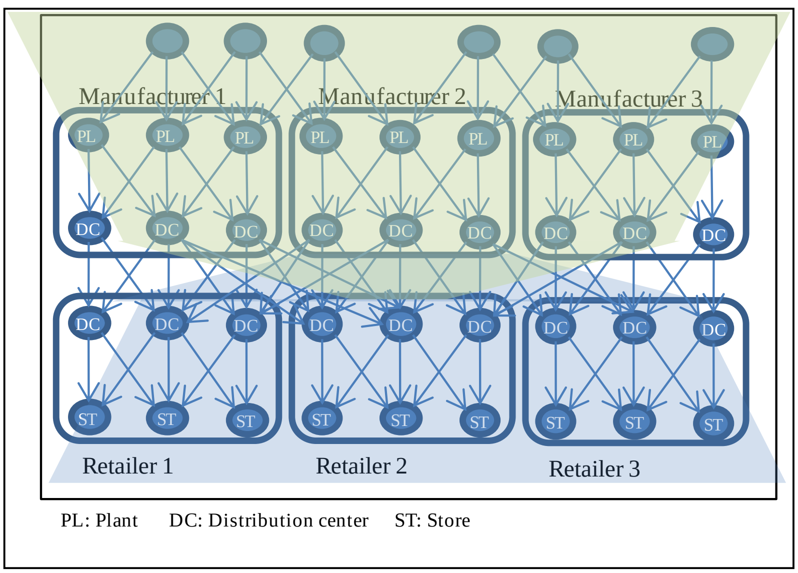


Figure 1: Focus of Manufacturer 2 vs. Focus of Retailer 2

Montreuil (2011) argues that logistics in its widest sense, including the way physical objects are moved, stored, realized, supplied and used across the world, is living a real efficiency and sustainability crisis at three levels. Economically, logistics swallows between 5% and 20% of the Gross Domestic Product (GDP) of most countries and its worldwide cost grows faster than world trade. Environmentally, it is among the heaviest polluters, energy consumers and greenhouse gas generators and materials wasters. This negative contribution is growing while nations' goals aim for heavy reductions. Socially, it is failing to provide fast, reliable and affordable accessibility and mobility of physical objects for the vast majority of the world's population. Furthermore, logistics offers too often precarious logistic work conditions. Indeed, the world is facing a Logistics Sustainability Grand Challenge.

While this Grand Challenges is global and far-reaching, most of the proposed solutions have limited impacts and are focusing on supply networks, chains, or even single organizations; the majority of scientific contributions on supply chain management still deal with the chain and network perspective. The contributed information system models as well as the structural models, whether they are analytical, mathematical, statistical, or simulation based, have concentrated on a single network or on even a smaller part of the network. These models exploit the data resulting from the flow of goods and supply activities. This kind of data is relatively affordable to collect, access, and share among the members of the network involved in the same flow stream because of the apparent at least partially common interest. The size of the network, the number of products, transactions, and flows contribute to making very imposing the database to assemble and take into consideration. This has forced those using structural models to simplification approaches such as aggregations and abstractions and those adopting information system models to limiting approaches by considering smaller parts at a time.

Though other sciences like marketing, knowledge management, and finance recognize the impact of external factors on business and go far beyond the exchange of flows to study and improve the performances of organizations and networks. Supply chain management is still in general stuck within the boundaries of supply network. These types of sciences adopt approaches that are more open and look to the problem from angles that are wider and richer, reflecting an awareness of more complex relationships and behaviours defining the environments influencing organizations. Isolating a certain flow of goods and making abstraction of almost anything except this flow is a strong simplification that results in the overlook of main pieces of the puzzle required to shade light on the tackled problems and make the right decisions. Limiting the space of analysis and action to a supply network and its flow of goods has two mains downfalls: a myopic vision and a narrow range of action.

The myopic vision occurs because of (1) the overlook of important external elements that although not considered may have major impacts on network performance and (2) the ignorance of the impact of internal decisions and actions on the external environment, notably on the various members and their supply networks. Since not all these decision elements are taken in account, managers struggle to see the global picture and to understand what is really happening around them, especially in the midst of action. They lack knowledge about what kinds of impacts have external events and actions of actors outside of their supply networks. In some instances, they are not even aware that these elements have any influence as the modeling equations they have been trained to work with do not take them in account. Overall, this results in incomplete information, leading to imprecise decision support that is finally producing inaccurate decisions. In addition, managers do not capture how their own actions and decisions influence the environment of their networks and how the environment is adjusting and responding to their own actions. This makes it difficult to evaluate the efficiency of their decisions and gather learning to improve their strategies, policies, plans and activities.

The narrow range of action and thinking restricts innovations and large scale open visions that could exploit potentials overweighting those provided when considering only the supply network and its members. Because of dominant mindsets, embodied through widely accepted concepts and practices, the way resources are owned, used, and shared is dictated either by possessiveness (buying or renting them) or by granted accesses through close partnerships with other actors.

Getting away from this mindset, consider for example an open sharing system where it is easy, secure, and reliable for any actor to lend to or exploit the unused capacities of resources (e.g. storage, transportation, and production capacities) of other interested actors without having to put together strategic supply network partnerships. Provided such an open system, the manoeuvring range of any actor dramatically widens. The potential for drastically improving individual and global performance considerably increases. Therefore, why should one be limited to a handful of options in front of an ocean of possibilities? In general, assuming that the punctual required capacities of all businesses in a certain territory are significantly less than the total available capacities, looking beyond the boundaries of the supply network makes even more sense toward efficiently using resources, easily accessing supply, demand, workforce, and financial markets, and rapidly and sustainably achieving returns on investments.

All these elements tend to demonstrate that supply chain management should move from a sole focus on the network level to embedding a wider and deeper web dimension so as to face the current challenges. The web dimension opens a space where significant non-marginal solutions and results could be achieved. It leads the way towards next generation supply chain management and logistics. A sensible evolution, the network-to-web step may steer the field to actively contribute to the finding of solutions for the Grand environmental, economical, and social Challenges.

The goal of this doctoral research thesis is to investigate the validity, potential, implications and requirements of supply chain management moving to the web dimension. This will be done from a theoretical point of view by analysing the evolution of supply chain management's scope and theories, showing the field readiness to embrace the web dimension and attempting to provide a theoretical framework for the integration of the web dimension into supply chain management. This leads to a need for investigating the impact of this integration on inter-organisational collaboration and decision making process in logistic web environments in addition to questing the way the current webs are created and whether there are alternative forms of web. Moreover, since decision support is a key element in supply chain management, the thesis seeks to determine the needs of supply chain managers and identify the important axes for designing decision support systems that provide adequate assistance in dealing with the challenges and complexity presented by logistic web environments.

Research Questions

The first set of questions asks whether the network dimension is sufficient to address the issues facing the supply chain management field represented by researchers, practitioners, and decision makers. Are there researchers attempting to solve issues beyond the network dimension while being trapped in the limitative framework of supply network? Is there a real need for a new extension of the scope of the supply chain to embrace the web dimension? What kinds of contributions should be expected from this extension?

To answer these questions, the scientific literature is examined related to the evolution of the supply chain and supply network concepts, the identification of the limitations of the dominant research streams in supply chain management, and the progression of the theories in supply chain management. The outcome suggests that the web dimension is the next stage for the supply chain management to adopt and that there is a definite need for it from different aspects.

The second set of questions revolves around the meaning of moving to a web dimension in supply chain management. How to identify, define, and present supply or logistic webs? How to position and interpret the web dimension in logistics and according to the supply chain management theories? What are the general implications of adopting the web vision on the existing logistics systems? Specifically, what are the impacts on the decision processes? How supply chain decisions can be supported and made when considering the web dimension? This involves a reflection and a proposition of a framework for designing logistic web decision support systems and the development of some prototypes exemplifying this framework.

The third set of questions deals with the exploration of new ways of looking at logistics and supply systems, as well as leveraging these systems to a new era of efficiency, sustainability, and performance. It addresses how to transform our existing logistics systems to be more efficient and sustainable through the web perspective by using open, secure, and reliable logistic webs. How can the web dimension leverage our global logistics system far beyond its current performance, in a way that the network dimension would never be able to enable? Here, we study the potential of moving from a current logistic web toward and open logistic web enabled by the promising concept of Physical Internet introduced in Montreuil (2011).

These questions are addressed in this document in the following way:

- The first set of questions consists of interrogations driving the present research work and justifying its existence. It is normal to be addressed all over this thesis with different levels of focus over the chapters and sections. It is dealt with mainly in chapter two and the first section of chapter three, with some important aspects in the remaining of chapter three, as well as various supporting elements in the remaining chapters.

- The second set of questions is the subject of the two first subsections of the second section of chapter three and the entire chapter four.
- The third set of questions is tackled in the third subsection of the second section of chapter three and the entire chapter five.

Research Methodology

The research methodology adopted in this thesis reflects the process that led us from the awareness of the web dimension in supply chains and logistics to demonstrating the need and importance of considering this dimension in supply chain management as well as identifying the associated benefits of adopting a web perspective. This process capitalizes on the design, development, and use of decision support software applications and simulators to investigate and analyse new perspectives, and study and documents the results. The three phases hereafter describe the essence of the process.

The first phase concerns the identification of the research questions and objectives. The first time we were aware of the web dimension was when working in a context of many multi-sited companies trying to engage in large collaborative initiatives. Each site or product category of anyone of these companies generates a supply network distinct from the other networks. In order to understand the dynamics of any of these networks, it was necessary to investigate the impact of the other networks overlapping it. It became clear that the issue goes beyond the network level to reach a web dimension level. It was striking to notice that it was easy to generalize this observation since over-all, the supply network of any site or product will overlap other supply networks, which it is going to influence and by which it will be influenced.

The second phase deals with the question whether the web dimension was recognized and addressed in supply chain management scientific literature. The study of the literature revealed that most researches related to supply chain management address only issues within at most the network scope. A minority of research works goes beyond this scope, yet with no explicit consideration of the web dimension. This literature review phase revealed the lack of existing frameworks able to encompass the research problem and trace the path toward solutions. It also attested to the existence of other research problems, such managing packages created from products of different supply networks or sharing resource among independent networks (e.g. transportation marketplaces), which are extending beyond the borders of supply networks recognized today as the most advanced existing framework in supply chain management.

The goal of the third phase is to validate the fact that the web dimension has to be integrated into supply chain management and how can this dimension be approached from a scientific point of view to fit in the knowledge body of the field. The assumption driving this phase was that for the web dimension to worth inclusion, it should promise substantial potentials and generate considerable benefits far beyond what the network dimension can provide. The answer was based upon a qualitative study of the implications of applying the web perspective to the existing logistics systems on one side, and investigating other forms of logistic web systems capable of delivering unprecedented levels of performance on the other side. To support and explore more in depth the conclusions of the qualitative study, the two remaining phases were designed.

The fourth phase focuses on extending the proposed vision about applying the web dimension to the existing logistics systems. This is done by transforming the decision support requirements in web contexts identified during the qualitative study of the third phase to a conceptual framework for designing logistic web decision support system. This phase details the criteria for designing logistic web software applications capable of tackling the complexity of logistic web environments and providing managers with smart and flexible tools for visualizing, assessing, mining, and monitoring logistic web contexts and their performances. These theoretical bases were prototyped into the first generation of four business intelligence applications, which are the logistic web mapper, logistic web playback, logistic web monitor and logistic web simulator. The specific methodologies applied for developing these applications will be presented when the prototypes are introduced.

The objective of the fifth phase is to provide an advanced and quantitatively supported investigation of the potential benefits of evolving from the existing logistics systems toward open, interconnected, and global logistic web systems.

Thesis overview

In chapter two, the thesis engages in arguing that the logistic web dimension is the extension of the supply network dimension and that the time is due to embrace this dimension in order to reorganize the knowledge structure of supply chain management and stimulate new innovative researches in the field. In a first part, it begins with a literature review of which the first part examines the evolution of the supply chain scope from internal operations, to dyadic relationships with clients and suppliers, then to collaboration among members of supply chains, and finally to collaboration among members of supply networks. The second part investigates significant contributions considering issues going beyond the range of supply network. The third part highlights the web dimension as an extension of the network dimension in supply chain management.

Chapter three discusses, in its first part, how to fit the web dimension into the knowledge body and theories of supply chain management. It reviews the literature concerning the evolution of supply chain management and produces a framework associating each stage of this evolution to a set of dominating theories and paradigms. Then, it tries to position the logistic web dimension and the potential theories able to support it within this framework. In the second part, the chapter studies the implications of the logistic web concept on supply chain management from three aspects: inter-organizational collaboration, decision-making, and advanced ways for exploiting the web dimension.

Chapter four presents a vision for addressing the complexity resulting from taking in account the logistic web dimension and what the decision support for supply chain management should consider when dealing with the logistic web dimension. Using a multidisciplinary approach, the chapter proposes a conceptual framework for designing logistic web decision support systems that take into consideration the complexity of supply and logistic web environments. The chapter discusses a suggested global architecture supporting a set of decision support systems and details the design requirements for each of its components. Additionally, the chapter introduces examples of logistic web tools and presents three prototypes developed by our team in the CIRRELT research center based upon the proposed global architecture and the design requirements. The logistic web mapper supports static mapping and investigation of logistic web contexts based on historic data. The logistic web playback allows to replay the past history of logistics events while providing analysis and assessment capabilities. The logistic web monitor helps following various aspects of the evolution of the current state of logistic web contexts in real time. The chapter proposes also a conceptual framework for designing a holistic, multi-agent logistic web simulation platform for simulating complex large-scale logistics environments.

Chapter five investigates how the web dimension can leverage the logistics system far beyond its current economic, social, and environmental performance when this system is enhanced to be an open, reliable, and interconnected logistic web. It represents a methodology for designing a multi-agent simulation platform capable of reproducing and contrasting the existing logistic web systems and the open interconnected logistic web systems. We exploit the case of simulating a Physical Internet enabled logistic web in France to demonstrate the kind of result that can be expected from evolving from the current mobility system to a Physical Internet enabled mobility web.

Chapter six concludes the thesis by summarizing its content, highlighting the main contributions of this research, and identifying potential following steps of this work and future research avenues.

Supply Chain Management: From Chain and Network Dimensions to the Web Dimension

The concepts of supply chain, supply network, and extended collaboration between partners are increasingly pushing the limits of what should be considered when dealing with Supply Chain Management. Managers who were only dealing with adjacent partners, first further needed to look at the entire supply chain, then at the entire supply network, and finally at the networks interacting with their supply network. Current research contributions suggest that supply chain management is suffering significant limitations because the complexity imposed by supply environments is not adequately taken in consideration.

Approaching the supply chain issues holistically by incorporating knowledge stemming from various research disciplines has been feeding the supply chain field and ensuring its pertinence and continuity. Nevertheless, when trying to deal with the new challenges, as well as the daily-basis supply chain management questions facing managers, the concepts of supply chain and supply network lack the capacity to handle the complexity of physical, informational, and financial flows and interactions between different actors of a supply context. Thus, a broadening of the limits of the scope of supply chain management is necessary. This chapter introduces the web perspective as an extension of network dimension in order to provide a framework that explains the complexity of supply and logistics environments, supports advanced supply chain innovation, and is able to trigger new research avenues.

We first observed the importance of recognizing the impact of the logistic web in a collaborative research project between Procter & Gamble (P&G) Canada and the Interuniversity Research Center on Enterprise Networks, Logistics, and Transportation (CIRRELT) lead by Professor Montreuil. P&G Canada and some of its key clients intended to extend their collaboration through joint initiatives. The goal of P&G Canada was to provide supply chain innovation to its clients via Joint-Value-Creation supply chain strategies.

The project began by investigating various ways of improving collaboration between P&G Canada and its clients. In the beginning, different issues were considered and many paths were investigated. The first potential initiative was to model the entire supply network of P&G Canada. The second was to model the supply chain involving P&G Canada and one retailer; starting from the production process at the plants to the exposure of the products on the store shelves. This initiative had as an objective to control the flow and the inventory through the supply chain in order to increase the product availability on the shelves of the retail stores. The third initiative was aimed to support the launch of new products at the stores of another key client. This initiative was intended to avoid the occurrence of stock-outs at the stores and to develop a fast responsive strategy to support the store crews in introducing new products to eventually enhance product image and ensure product survival in the market. The fourth example of initiatives was to model and simulate the retail stores selling P&G products.

These ambitious aspirations defined in the target initiatives, when considered closely, were faced with a common challenge. Whenever an initiative was addressed, the issue of supply context complexity and the lack of the proper decision support tools needed to handle this complexity became evident. When we tried to address bilateral collaboration between P&G Canada and each one of its clients, it was a challenge to isolate the managerial decisions and operational actions dedicated to one client from those dedicated to the others. Moreover, instead of dealing with a situation where a firm operates within a supply network, as is usually discussed in the literature, we found ourselves in a situation where a complex network was dealing with other complex networks, creating a large network of overlapping networks. P&G Canada can be seen as a complex manufacturing organization operating several distribution centers and many factories. Already at the internal level, P&G Canada can be seen as a supply network since each of its sites, whether it is a plant or a distribution center, operates within a supply chain. Some clients of P&G Canada, such as Wal-Mart, Shoppers Drug Mart, and Loblaw, are complex retail organizations with multiple distribution centers and stores. With each of these clients can similarly be associated a supply network.

While the above example presents the case of multi-sited companies, the same idea applies to any kinds of supply networks, even those consisting of single companies, because each member will be part of multiple networks at the same time. In order to handle issues arising from such contexts, there is a need to consider the web dimension as the new scope of supply chain management rather than the limitative network dimension.

The literature review in this chapter has the objective of investigating the existence of scientific frameworks that cover the research problem identified earlier. Having already argued that supply chain management is dealing with the web dimension, we are now going to demonstrate that the available supply chain research does not provide the requisite theoretical tools to tackle issues resulting from the dynamicity and complexity generated within web of supply networks. Another objective of this literature review is to emphasize that the supply chain is still a dynamic concept in evolution and that there is a need to further extend its boundaries in order to support contributions that consider issues beyond the scope of what is known today as supply chains and supply networks.

The first section explores how supply chain management emerged from operations management and how its scope expanded gradually from a focus on relationships among adjacent partners, to the entire supply chain and then to a network of supply chains. The second section examines papers concerned with supply chain management issues beyond the chain and network scopes. Each of the two sections concludes with a synthesis summarizing the content of the section and discussing the main implications. The third section presents the web dimension as the natural evolution toward which the scope of supply chain management is heading. The chapter ends with a conclusion summarizing the learning from this literature review.

The Evolution of Supply Chain Management: from Internal Operations to Supply Networks

Harland (1996) suggested that the term 'supply chain management' is used in the literature to refer to the management of four different levels of supply chain (Figure 2). These four levels are:

- First, the internal supply chain that integrates business functions involved in the flow of materials and information from the inbound to the outbound ends of the business;
- Second, the management of dyadic or two party-relationships with immediate suppliers;
- Third, the management of a chain of businesses, including a supplier, a supplier's suppliers, a customer, and a customer's customer, and so on;
- Fourth, the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers.

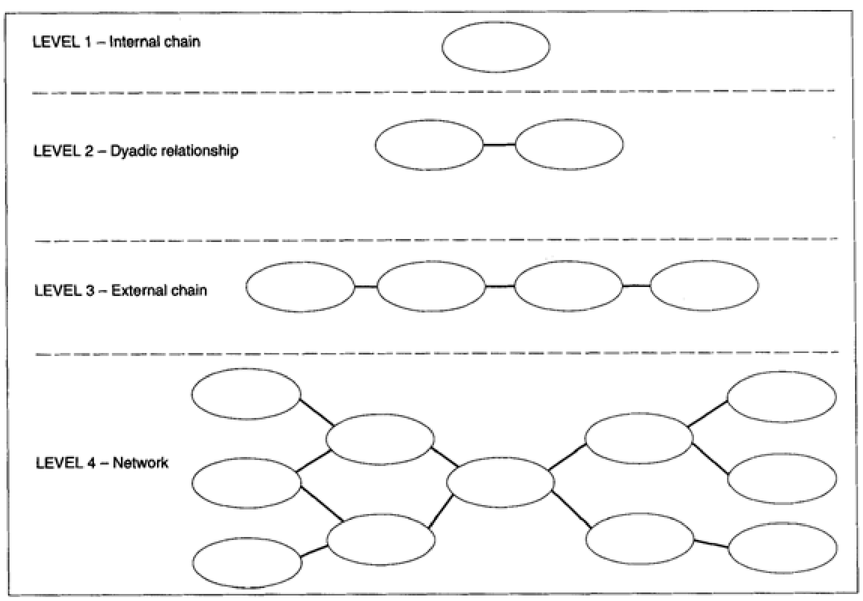


Figure 2: Levels of research in supply chain management; Source: Harland (1996).

Harland's (1996) classification of supply chain levels was of great importance to researchers trying to define supply chain management literature analytical frameworks or supply chain classifications (Lamming, et al., 2000; Croom, et al., 2000; Tan, 2001; Capari, et al., 2004; Chen, et al., 2004). For example, Croom et al., (2000) used this classification as one dimension in their two dimensional content analysis matrix, which they proposed as a framework to study the literature of supply chain management. The matrix provides for each level of supply chain the content exchanged in terms of assets, information, knowledge, and relationships.

In our opinion, it is more appropriate to relate the evolution of supply chain management to two periods; a period before supply chain management and a period of supply chain management. The former is the equivalent of Harland's internal level and the second includes the remaining three levels. The reason for this classification is based upon the conceptual foundation on which the paradigms dominating the two periods are built. As it will be explicitly highlighted in the next sections, the paradigm that dominated the era before supply chain management is based upon the concept of resource ownership, while the supply chain itself is based upon the idea of partner collaboration and the consideration that a company is an entity in a larger system.

Before Supply Chain Management: Operations Management

The internal supply chain level, as introduced in Harland (1996), refers to the exchange of the physical and informational flow between different departments of a company (Figure 3). In fact, the first use of the term 'supply chain management' in scientific literature referred to the integration of the internal business functions of purchasing, manufacturing, sales, and distribution in a context of intra-business operations (Harland, 1996). Many researchers do not consider the internal level as a supply chain level because at this stage the collaboration with external partners is not explicitly taken into consideration. It is important though, in terms of the study of supply chain evolution, to understand that the advancement of the internal operations management and the continuous seeking of process efficiency were the trigger to the recognition of the importance of the collaboration with external partners and the creation of the supply chain concept. This is especially true with regards to contributions which emphasize viewing a company as a sub-system of a larger system, which includes the trading partners, and stress that efficiency should be sought for the entire system (Ackoff, 1960; Forrester, 1961; Lockyer, 1962).

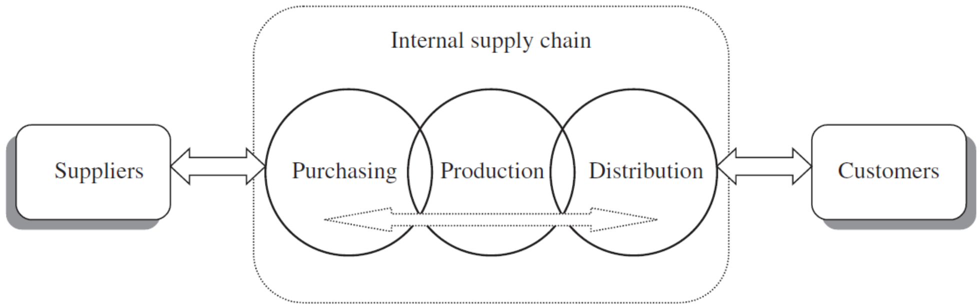


Figure 3: The Company's Supply Chain According to Chen et al., (2004)

Investigation into the roots of the supply chain concept shows that the operations management field is the ancestor of the supply chain management concept. The domain of operations management, previously known as “factory management” (Filippini, 1997), is one of the oldest fields of study taught in business schools, even before the inception of finance and accounting (Meredith, et al., 1990). The industrial revolution resulted in major changes to man’s life style, as well as to the means of production. *“The invention of the steam engine by Watt and the spinning jenny of Hargreaves led to a new era of substituting the manpower by external energy sources and to major changes in the planning and organization of work”* (Johnston, 1994). Factories were created as complex production units that required advanced management skills and knowledge. *“Factory management developed with the beginning of the industrial revolution during the period when factories were created and developed into efficient and remorseless production units”* (Johnston, 1994).

Factory management saw many contributions that shaped what we know today as operations management. The first paradigm that shaped the beginning of capitalism and influenced operations management is the concept of labour division introduced by Adam Smith in his book *The Wealth of Nations* (1776). “*Adam Smith’s treatment of the division of labour provided a masterful analysis of the gains from specialization and exchange upon which, it is no exaggeration to say, the discipline of economics was nurtured*” (Rosenburg, 1965). ‘Scientific management’ introduced by Frederick Taylor in 1911 is considered by some authors *the* major historical landmark for the operations management field. *“Taylor’s approach to the planning and control of the activities of the work-force resulted in techniques such as method study, time and motion study, planning and progress charting,* *pay incentives and standardization of practices. These are the direct descendants of many of the principles of modern operations management which are now such a great part of present day practice."* (Johnston, 1994).

The moving assembly and production lines introduced by Ford in 1913 were also a major step in shaping the operations management field and starting the mass production era (Wood, et al., 2003). World War II was of great importance to the advancement of operations management since the military industry supported operations management research (Johnston, 1994). During the 1950s, numerous techniques were introduced and studied, such as time and motion study, plant layout, and production control. In addition to many "new" techniques, such as PERT/CPM, inventory control, Monte Carlo simulation, and simulation and queueing theories, being created, several chapters were written about personnel management, finance, marketing, and organization management (Johnston, 1994; Filippini, 1997).

In the 1950s and 1960s, the focus was on cost minimization as a primary operations management strategy; mass production was the dominating solution with little attention being given to product and process flexibility (Tan, 2001). The 1970s and 1980s recognized the widespread use of computers and Manufacturing Resource Planning (MRP) in organizations. Managers began to realize the impact of large work-in-process inventories on manufacturing cost, quality, new product development, and delivery lead-time (Farmer, 1997). "*Manufacturers resorted to new materials management concepts to improve performance within the 'four walls' of the company*" (Tan, 2001).

Supply Chain Management Era

The paradigms that dominated operations management before the 1950s all have the implicit assumption that a firm should best own and control its own resources. This was a significant handicap, preventing openness with regards to the collaboration between partners of the supply chain. A firm was a closed box, receiving supplies and selling goods. Efforts to increase efficiency or to gain a competitive advantage centered on improving internal processes and procedures. Vertical and horizontal integration were logical options for a company to gain control of other parts of its supply network. These beliefs "*hindered* *both scholars and managers from recognizing the gains in capability that occurred when firms created trusting, cross-firm relationships that they then used to share knowledge and expertise*" (Miles, et al., 1994). The purchasing function was considered a complementary part of production and its impact on production was neglected (Farmer, 1997).

> New product development was slow and relied exclusively on in-house technology and capacity. Bottleneck operations were cushioned with inventory to maintain a balanced line flow, resulting in huge investment in work-in-process inventory. Sharing technology and expertise with customers or suppliers was considered too risky and unacceptable and little emphasis appears to have been placed on cooperative and strategic buyer-supplier partnership (Tan, 2001).

Filippini (1997) asserts that all studies related to operations management during the 1950s implicitly assumed that:

- "*the production system both is cut off from the environment and is strategically neutral;*
- *it is prevalently characterized by technical features;*
- *and the final aim is that of maximizing the productivity of labour.*"

The paradigm that led the change is the "systems thinking" or the "system view". The system view was introduced by von Bertalanffy (1950) who first applied it in physics and biology. The system thinking was then applied to the field of management in the early 1960s by many authors such as Ackoff (1960), Forrester (1961), and Lockyer (1962). Croom et al. (2000) suggested that the origins of supply chain management are unclear, but its initial development was driven by the techniques of industrial dynamics linked to the work of Forrester (1961) and the Total Cost approach to distribution and logistics of Heckert et al. (1940) and Lewis (1956). According to Capari et al., (2004) the concept of logistics integration was introduced by Bowersox (1969) through the notion of *cost-cost* tradeoffs that stipulate that the lowest total cost might not be achieved by pursuing the lowest cost of each logistics process.

The system view suggested that a firm should be related to its environment and be seen as an entity in a system. This view declared that management efforts should target improvements through the entire system, rejecting the ownership assumption stipulating that a company can only seek efficiency through its own resources. *"It is only when a factory is understood to be part of a whole – a sub-system within a system – that its management can be truly successful"* (Lockyer, 1962). System thinking suggested that the company should be an open system operating in an environment and that the relationships with the entities of this environment are of great importance for the company's success. Based upon a series of case studies, Forrester (1961) suggested that the industrial dynamics and the varying behaviour of organizations in a supply chain can result in a distortion of the point of sales demand as it propagates upstream the supply chain, resulting in the "bullwhip effect" phenomenon (Lee, et al., 1997). He concluded that the success of industrial companies is subject to *"interactions between flows of information, materials, manpower and capital equipment"* (Giunipero, et al., 2008).

System thinking led the evolution from the focus being on internal operations to the supply chain management perspective whether it is on the dyadic, the chain or the network levels. However, even if the concept stipulated that the whole system should be considered in order to improve global performance, there was an evolution from dyadic relationships, to the supply chain, and finally to the network, in what was considered the applicable realm of supply chain management. This evolution reflected a natural progression from one level to the next, as experiences and learning accumulated and the technologies and concepts evolved. In the next subsections, we gradually expose the levels of supply chain management, starting with the dyadic relationship, then supply chain, and finally the supply network.

Dyadic Relationship Level

System thinking led scientists and practitioners from focusing on the operational level, to a wider strategic vision when they started considering external actors as contributors to the failure or success of companies. Johnston (1994) believes that two imperatives played an important role in transforming operations management to a more holistic and integrative concept. First, the strategic imperative which resulted *"in the evolution of operations* *management into a more integrative, strategic-oriented subject, less concerned with internal efficiencies and more concerned with the effectiveness of the subject alongside other functions."* The second imperative *"has been a specific concern with service operations and recognition of the importance of service as a competitive weapon for both service and manufacturing organizations"* (Johnston, 1994). This resulted in two important aspects that relate operations management to supply chain management. First, considering the suppliers strategic partners; this led to partnership relations with direct suppliers. Second, the importance of service as a competitive tool, which led to the collaborative relationships with direct clients.

Although system thinking did not imply that a company should only focus on relationships with its direct partners, engaging in collaborative actions with adjacent suppliers and clients was the natural, intuitive, and easiest step for a company to start collaborating. Technological advancement provided the necessary support to boost the integration between supply chain collaborates (Spekman, et al., 1998); Movahedi et al. (2009) call this period the 'integration era'. They consider that this era commenced in the 1960s, upon the development of Electronic Data Interchange (EDI) systems, and continued by the introduction of enterprise resource planning (ERP) systems until it ended in the 1990s. EDI is an electronic ordering system that integrates multiple other functions, such as storage, logistics, materials acquisition, and shipping (Tan, 2001). EDI provided the proper support for dyadic partnerships. Sharing information through EDI with supply chain partners is a critical component of supply chain management (Ellram, et al., 1989). EDI helped to improve logistics efficiency, increase customer service levels, accuracy and timeliness of transferred information, cycle reliability, and decrease cycle time (Tan, 2001).

The first applications of dyadic relationships date back to the time when EDI was invented, and a noticeable spread of this practice occurred during the 1980s. According to Harland (1996), research on the dyadic level of supply chain relationships discussed the following different business trends: (i) the increasing incidence of vertical disintegration, (ii) the implementation of supplier-based reduction programs, (iii) focusing on operations, (iv) outsourcing, (v) just-in-time, and (vi) the increasing popularity of partnerships and partnership sourcing.

Supply Chain Level[1]

According to Tan (2001), the concept of supply chain management emerged as manufacturers experienced strategic partnerships with their immediate suppliers. Toyota introduced the lean production system during the 1950s to 1980s by implementing Just In Time (JIT) and by integrating the suppliers into the production process (Fujimoto, 1999). Childerhouse, et al. (2000) believe that the development of the lean supply chain resulted in better synchronization due to the kanbans, improved coalescence due to supplier integration, and some reductions in demand amplification.

The intense global competition in the 1980s and the worldwide recession of the late 1980s and early 1990s urged managers to question existing value creation models and cost reduction practices throughout their organizations at the strategic level (Harland, et al., 1999; Tan, 2001; Movahedi, et al., 2009). Companies were forced to seek lower cost, higher quality, and reliable products with greater design flexibility (Tan, 2001). Companies turned to solutions applied by the Japanese automotive industry for new options. JIT and total quality management (TQM) were the dominating paradigms of that time. JIT and TQM were not only studied by Americans and Europeans, but also many western companies implemented these paradigms (Johnston, 1994; Harland, 1996; Farmer, 1997; Childerhouse, et al., 2000; Tan, 2001). The application of these techniques improved the internal efficiency and companies began to feel the impact of external suppliers on their performance. "*In the fast-paced JIT manufacturing environment with little inventory to cushion production or scheduling problems, manufacturers began to realize the potential benefit and importance of strategic and cooperative buyer-supplier relationships*" (Tan, 2001). However, with the idea of ownership still being rooted in the mindset of western companies, an open collaboration with external partners seemed too risky. A solution was supplier quality control by purchasing only from qualified or certified suppliers (Tan, 2001; Chen, et al., 2004). With supplier certification, EDI, the success of dyadic experiences, and

[1] This section is an extension of section 2.1 in Hakimi, D., Montreuil, B., & Labarthe, O. (2009). Supply Web: Concept and Technology. *7th Annual International Symposium on Supply Chain Management, Toronto, Canada.*

the resulting benefits, companies started building trust with their partners and feeling the importance of collaboration.

A supply chain was originally viewed as having a linear, unidirectional structure including only physical downstream flows with its set of nodes focused on a single organization (Hayes, et al., 1984). Scott et al. (1991) see the supply chain as "*the chain linking each element of the process from raw materials through to the end customer*". Figure 4 represents the first supply chain illustration. The chain focuses on manufacturers/assemblers. On the left side, the component parts producers are fed by material fabricators who are supplied by raw material producers. On the right side, the manufacturers/assemblers feed wholesalers or distributors, who in turn feed retailers who finally serve the consumers.

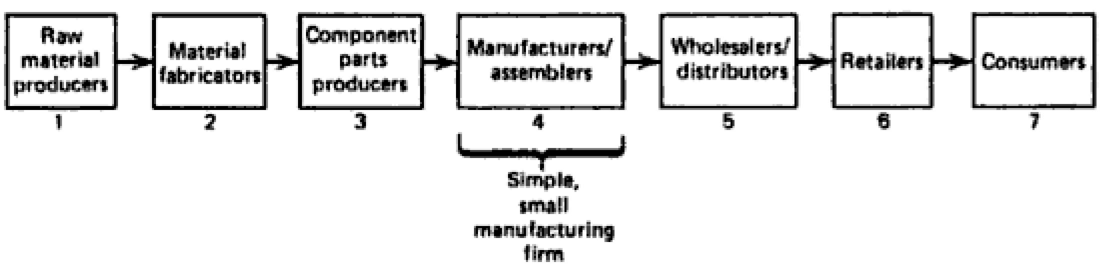


Figure 4: Supply Chain according to Hayes, et al. (1984)

In this context, as the consumers' demand passes upstream the supply chain, it is distorted and amplified, resulting in excess stock holding, obsolescence, and production costs (Childerhouse, et al., 2000). In order to deal with the fact that the lean approach does not effectively address the volatility of the demand, the *agile supply chain* concept was introduced as an alternative. The agile concept stipulates that information about the demand of a point-of-sale should be transmitted upstream as fast as possible and that this demand should drive the production and distribution activities instead of the demand perceived from transactions with direct clients (Childerhouse, et al., 2000). The Leagile concept is "*the combination of the lean and agile paradigms within a total supply chain strategy by positioning the de-coupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the de-coupling point*" (Childerhouse, et al., 2000) (Figure 5). These two last concepts emphasize the importance of information exchange through the entire supply chain, broadening, therefore, the vision of business actors.

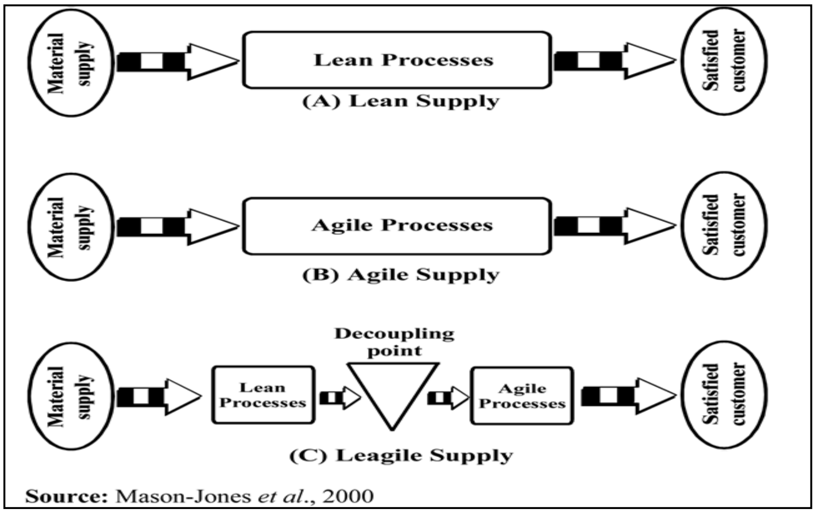


Figure 5: Lean, Agile and Leagile Supply. Source: (Childerhouse, et al., 2000)

In the early 1990s, the supply chain concept started to consider the information flow going upstream in addition to the physical flow going downstream (Helper, 1991; Biemans, et al., 1995; Killen, et al., 1995)(Figure 6). Towill, et al. (1992) defined supply chain as "*a system, the constituent parts of which include material suppliers, production facilities, distribution services, customers linked together via the feed forward flow of materials and the feedback flow information*".

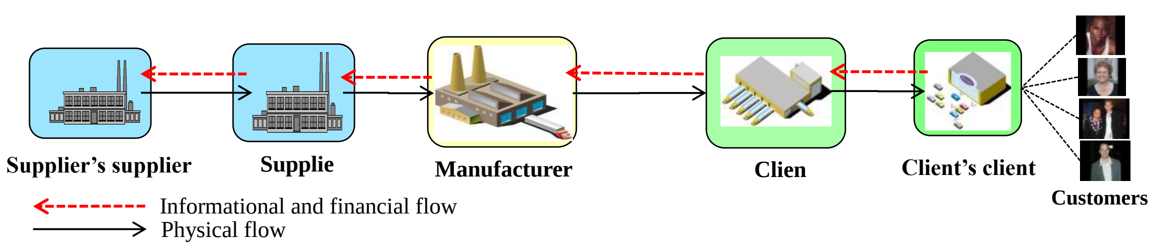


Figure 6: Linear Supply Chain with Upstream Informational and Financial Flow

The introduction of the supply chain concept, and its associated supply chain management concepts, affected business operations and extended the notion of inter-organizational collaboration to an unprecedented level. It urged companies to look beyond inner operations and relationships with upstream and downstream partners. It emphasized the importance of information exchange through the entire supply chain, extending, therefore, the vision of business actors. However, while relationships with suppliers were improving toward a more sophisticated reconciliation of cost and quality considerations (Tan, 2001), the main driving reasons behind adopting a supply chain management strategy was the traditional view of achieving the lowest initial purchase prices and assuring supplies (Spekman, et al., 1998). Dominant assumptions in this context were that trading partners are interchangeable, that it is risky to limit the number of potential suppliers, and that the open competition results in advantages for buyers (Spekman, et al., 1998).

From Supply Chain to Supply Network[2]

Although supply chain management began achieving wide acceptance during the 1980s and early1990s, the concept was just starting and supply chain management theories and strategies were actively developing. According to Lummus et al. (1999), this period underwent the development of a series of supply chain initiatives that began with the quick response program in the textile industry. The program is a partnership where retailers and suppliers work together to respond more quickly to consumer needs by sharing information. Later, the Efficient Consumer Response (ECR) concept was introduced to the retail industry. ECR enabled distributors and suppliers to more accurately anticipate future demands. It also permitted them to react more efficiently by promptly and accurately propagating the information flow upstream the supply chain. The beginning of the 1990s also saw many important supply chain initiatives introduced by private companies. For example, in the computer terminal business, Hewlett-Packard systematically linked its distribution activities with its manufacturing activities. Also, Wal-Mart created the Vendor Management Inventory (VMI) initiative by making its suppliers responsible for managing the inventory of their products in Wal-Mart's warehouses (Lummus, et al., 1999).

As these new initiatives were emerging, the linear schematization of the supply chain began to appear extremely limitative. It was recognized as clearly overlooking the complexity of the supply operations since it does not explicitly show other non-linear relationships that can profoundly affect the behaviour of the actors as strategic partners, and consequently,

[2] This section is an extension for section 2.2 in Hakimi, D., Montreuil, B., & Labarthe, O. (2009). Supply Web: Concept and Technology. *7th Annual International Symposium on Supply Chain Management, Toronto, Canada.*

the performance of the supply chain. Therefore, the linear representation was gradually extended to look more like a network than a chain (Harland, et al., 1990; Womack, et al., 1990; Harland, 1996; Womack, et al., 1996).

Defining the supply chain in association with part of the operations, such as a product family or a specific site, has the advantage of decreasing complexity. Figure 7 provides such an extended supply chain representation. It depicts a manufacturer's supply chain for a family of products. Examination of the schema makes it obvious that this is not a commonly known chain. It does not have a linear structure, but rather a tree structure with downstream material flows and upstream informational and financial flows. This presentation is useful from Manufacturer 1's point of view, since it gives a complete image of the players, operations, and relationships involved in supplying the product family. It shows a higher level of organizational complexity than was provided with the classical linear representation illustrated in Figure 6.

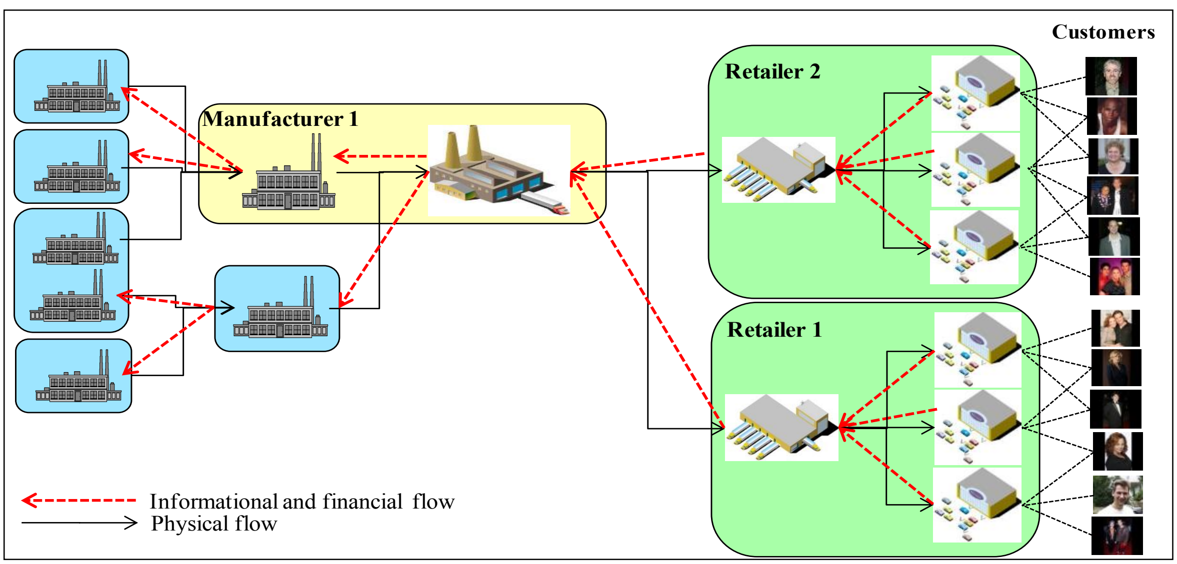


Figure 7: Product Family Supply Chain

Yet, when dealing with the behavioural aspects of supply chain management, that is to say the day-to-day operations, relationships, and interactions, it is necessary to consider the interactions engaging all the elements of the supply context (Cavinato, 1992; Harland, 1996; Lamming, et al., 2000; Lowson, et al., 2002). For example, because there are frequently serious issues and unique circumstances associated to transportation mode sharing, storage site sharing, and work force sharing, etc., managers responsible for a product family can rarely work in isolation from other product families. Moreover, since firms are simultaneously part of multiple supply chains, a wider perspective is important in order to understand the effects of change in supply chains (Hertz, 2002).

The evolution from the linear vision of the supply chain to the concept of network coordination is attributed to Porter (1985) who stipulated that the coordination of complex global networks of company activities offers competitive advantages (Spekman, et al., 1998). However, it is the notion of supply chain overlapping that resulted in the emergence of the supply network concept. The notion of supply network has emerged to explain the effects occurring between overlapping supply chains and to introduce softer behavioural aspects related to the study of supply performances (Harland, 1996; Lamming, et al., 2000). Hertz (2006) emphasized that firms must take into account the impact and reactions of other chains when changing or developing supply chains. Increasing global cooperation, vertical disintegration and a focus on core activities have led to the recognition that firms are linked in a networked supply chain. This strategic viewpoint has created the challenge of effectively coordinating the entire supply chain, from upstream to downstream activities (Spekman, et al., 1998; Chen, et al., 2004).

The existence and evolution of supply chains depends upon several factors: information sharing, collaborative planning, specialization and outsourcing (Kemppinen, et al., 2003), integration technologies and internet-based solutions (Movahedi, et al., 2009), collaboration (Spekman, et al., 1998). Collaboration between partners of the same supply network developed as the members of the supply network recognized that their network is competing with other networks. Firms began to consider their suppliers as partners to both their successes and failures, and started trying to fully integrate their business with them by building trust and stable relationships. Modern competition is "*supply chain versus supply chain*" rather than "*firm versus firm*" (Ketchen, et al., 2007). Success is no longer measured by a single transaction; competition is evaluated as a network of co-operating companies competing with other firms along the entire supply chain (Spekman, et al., 1994).

Supply networks "*...consist of interconnected entities whose primary purpose is the procurement, use and transformation of resources to provide packages of goods and services. Supply networks therefore essentially consist of a set of interconnected supply chains, encompassing both upstream and downstream relationships."* (Harland, et al., 2004). They generally exist as components of wider inter-organizational value creation networks (Harland, et al., 2004). For example, they can include innovation partners as well as marketing partners. The definition of supply chain management has begun taking the concept of supply network into consideration. Christopher (1992) defined supply chain management as the management of

> the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer. Thus, for example, a shirt manufacturer is a part of a supply chain that extends upstream through the weavers of fabrics to the manufacturers of fibres, and downstream through distributors and retailers to the final consumer.

Cooper et al. (1993) see supply chain management as an approach whereby the entire network, from suppliers to the ultimate customers, is analyzed and managed in order to achieve the 'best' outcome for the whole system.

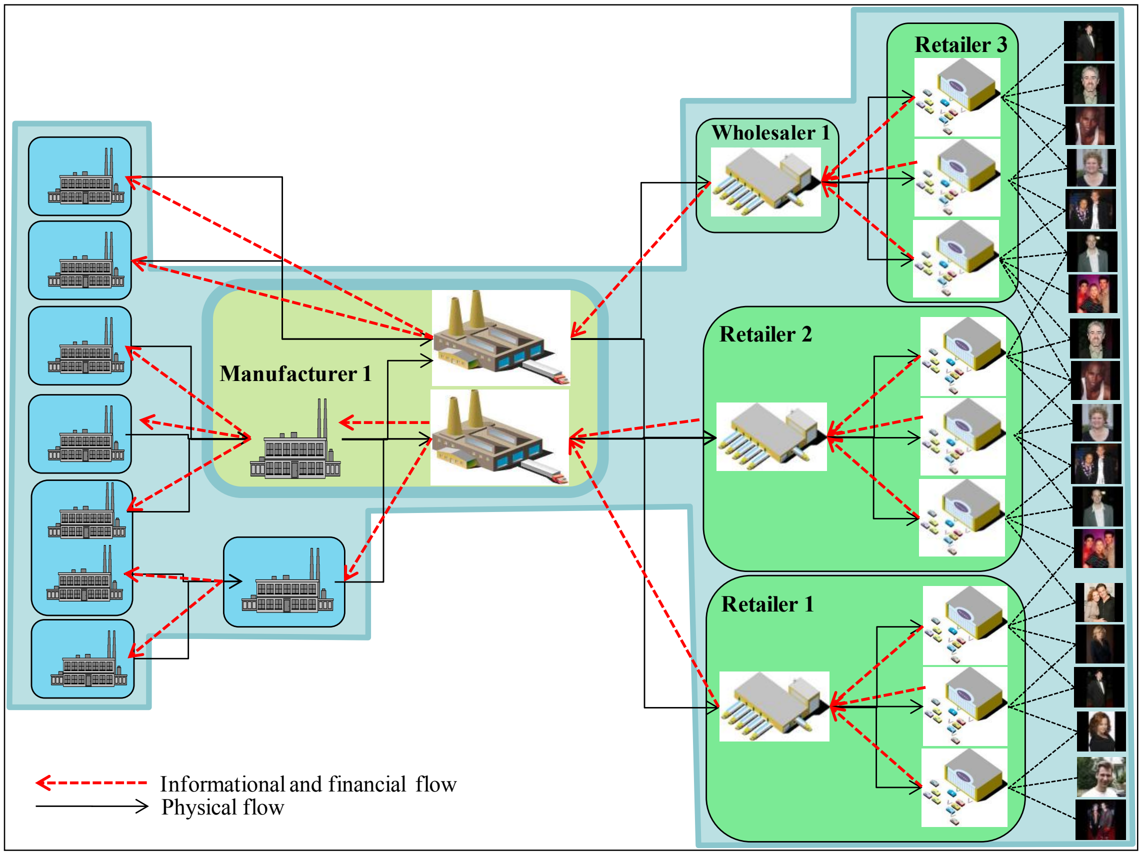


Figure 8: The Supply Network of a Manufacturer

Figure 8 presents, as an example, the supply network of Manufacturer 1. Internally, it illustrates that Manufacturer 1 has two product assembly plants and one module assembly plant feeding them. Upstream it depicts an external module assembler feeding the product plants, and six parts suppliers. The upper two are feeding the upper product plant. Subsequently, there are two suppliers feeding the internal module plant. The next and second lowest parts supplier has two plants from which it feeds both the internal and external module plants. Finally, the lowest plant exclusively feeds the external module plant. Downstream, Figure 8 depicts the upper product plant feeding the distribution center of a wholesaler that services the three stores of retailer 3. The lower product plant focuses on supplying both retailers 1 and 2. It feeds the unique distribution center of each retailer. The first retailer's distribution center services three stores, as does the second retailer's distribution center. In summary, the supply network shows all sites and flows involving the manufacturer's products and services.

Based upon the key actors of Figure 8, several other supply networks could have been included. Each of these would have focused on a key actor or set of actors. For example, we could have added the supply network of the wholesaler or the supply network of retailer 3. In this network, manufacturer 1 would have been one of many suppliers that the wholesaler deals with. Similarly, retailer 3 would have one of the clients of the wholesaler, indeed the only one to whom it sells the products of manufacturer 1.

Synthesis

The evolution of the supply chain concept gradually extended the scope of supply contexts. Table 1 summarizes this evolution by highlighting its different stages and the chief paradigms that dominated each stage. First, the focus was on internal operations, then on dyadic relationships with adjacent partners, followed by members of a supply chain, and finally on members of a supply network. The internal level focuses on the company as an independent and autonomous entity. Any optimization or efficiency seeking was done internally without involvement of trading partners. The sense of ownership and resource control dominates the mindset of managers. The change came from the systems thinking that stipulated that a company is a sub-system in a wider system. The success of a company cannot overlook the impact of the environment on its internal operations. The application of systems thinking in operations management resulted in the recognition of the supply chain and the introduction of supply chain management.

Period	Level	Dominant Paradigms	
Before Supply Chain Management (Operations Management)	Internal	Resources Ownership	
Supply Chain Management Era	Dyadic relationships	Direct collaboration	Systems thinking
	Supply chain	Extended collaboration	
	Network	Network co-ordination	
		Overlapping supply chains	

Table 1: Supply Chain Management: Periods, Levels, and Dominant Paradigms

The evolution from the internal level to the supply chain started gradually with dyadic relationships between companies and their suppliers and between them and their clients. Japanese practices such as JIT and TQM, in addition to supplier certification, fortified these dyadic relationships. Although integration technologies were in their beginning stages, they provided the support for basic information exchange. Companies began to increasingly trust their trading partners, as well as realize that ownership of resources is not the ultimate pathway to success. They also started seeing the potential of collaboration with the direct suppliers and became interested in the next supplier-tires. This resulted in the lean supply chain, which was initially viewed as a linear chain.

Since companies normally operate within multiple overlapping supply chains that influence each other and for which the impact of interactions is not negligible, the supply chain concept evolved rapidly to the supply network concept. The concept of supply network is a broader and richer concept that gives us a better understanding of the company and its interactions within the environment. Integration technologies are evolving very fast, allowing higher degrees of integration, collaboration, inter-organizational knowledge and expertise sharing, and multi-level decision support, making them more affordable and easier to implement.

Beyond the Network Dimension

The supply chain concept is still emerging and its evolution is heading in multiple directions. The concept is faced with issues such as globalization, outsourcing, customization, and market fragmentation and polarization (Eschenbächer, et al., 2003; Storey, et al., 2006). More and more companies are looking for international and intercontinental sourcing, creating global supply networks (Movahedi, et al., 2009). The e-commerce and the digital era are shaping the supply chain networks (Rosenbaum, et al., 2000). The intensive use of novel technologies, including: Internet, wireless, and connective technologies, such as RFID and GPS, is supporting complex collaborative supply chain management initiatives and creating new opportunities and possibilities that were unimaginable before.

When examining some contemporary scientific contributions, it appears that the concept of supply network should not be the limit of what supply chain management can consider. Selected researchers have begun to consider issues beyond the boundaries of supply networks or are discussing external factors that influence the behaviour of these networks. A supply network should be considered a system that exists in a wider environment and that adapts over time (Choi, et al., 2001). For example, Pathak et al. (2007) argue that the initiation of mechanisms such as modification of infrastructure or changes in regulatory policies by entities that exist in the external environment of the network may influence its construction. Stuart et al. (1998) and Lazzarini et al. (2001) assert that in order to promote knowledge exchange, it is becoming increasingly important to focus not only on how suppliers transact with buyers inside a supply network, but also on how they interact between themselves across multiple supply networks. As the concept of overlapping supply chains leads to the creation of the supply network concept, the concept of overlapping supply networks is shaping the next level of supply chain management. In the following sections, we are going to take a closer look at some contributions that tackle issues involving more than a single supply network and bring about issues resulting from the web dimension. This will be done first in the context of supply chain management, then in transportation.

Beyond the Network Dimension in Supply Chain Management

Lazzarini et al. (2001) suggest that the literature on inter-organizational collaboration addresses supply chain and supply network analyses as two distinct strands. Supply chain focuses on the vertical relationships among the members of the chain, while supply network extends to dealing with the horizontal relationships between firms belonging to a particular industry or group.

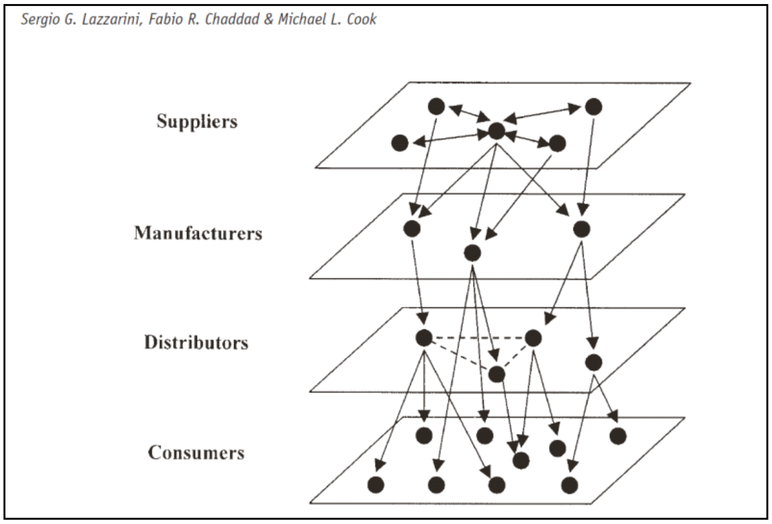


Figure 9: An Example of a Generic Netchain

The authors suggest that, on the one hand, supply chain analysis alone is not qualified to handle relations among actors of the same supplying level since it concentrates on issues related to vertical transactions, such as logistics management and the design of activities between buyers and suppliers. On the other hand, supply network analysis is not specifically concerned with vertical relationships. A framework that combines the two concepts into a hybrid analysis will provide the best from the two concepts in terms of inter-organizational collaboration assessment. It is argued that such analytical integration is necessary because supply chain analysis and network analysis have focused on distinct types of interdependencies involved in inter-organizational collaboration. Thus, they introduce the concept of netchain.

> The netchain is a set of networks comprised of horizontal ties between firms within a particular industry or group, such that these networks (or layers) are sequentially arranged based on the vertical ties between firms in different layers (Figure 9). Netchain analysis explicitly differentiates between horizontal (transactions in the same layer) and vertical ties (transactions between layers), mapping how agents in each layer are related to each other and to agents in other layers.

The netchain approach recognizes that complex inter-organizational settings contain different types of interdependencies associated with distinct sources of value. All types of interdependencies are simultaneously considered in the same model in order to make good use of all sources of value. Important implications of the concept result from combining the concepts of supply chain and supply network. Instead of assuming that the world is arranged either vertically or horizontally, netchain considers various types of interdependencies that govern the complex inter-organizational relations (Lazzarini, et al., 2001). Since the performance of complex systems should be enhanced through a shift from designing on the basis of a given set of interdependencies to designing by manipulating the set of interdependencies (Levinthal, et al., 1999), following the netchain perspective, managers can develop social ties where activities are mutually adjusted instead of planned and at the same time pursue flexibility to position their firms in valuable networks to benefit from new information and knowledge diversity (Lazzarini, et al., 2001). The netchain model can also be used to explain and analyse more than one netchain in cases where firms from diverse industries develop competing networks. Delimiting a firm netchain can be determined through the study of the boundaries of vertical and horizontal relationships.

Knowledge-based networks (Miles, et al., 2007) are another example of going beyond the boundaries of supply network. Besides the normal capabilities of product and process improvement, provided by resource-based supply chains, some networks are enhancing the process of innovation through cross-industry knowledge sharing. Some firms start actively seeking new ideas from other members of their supply networks that do not necessarily operate in the same industry. The process of collaboration among supply network members results in the generation and sharing of not only planned, but also of unplanned knowledge outputs. According to Miles, et al., (2007), this kind of knowledge is more promising since it can be an endless source of evolution for companies, their businesses, and their products. The authors believe that collaborative efforts based on trust, knowledge, and norms of information sharing and equitable treatment might result in highly entrepreneurial, cross-industry network organizations. Since knowledge-based networks develop across industries, they result in product and market innovations not ordinarily achieved by traditional networks. They have more potential to contribute to the long-term economic development of larger scales, such as a country or region. They provide an environment of knowledge sharing across and within industries, and thereby, generate new business. Miles et al. (2007) predict that groups of firms in complementary markets will form collaborative networks in which knowledge is created and shared for business purposes. These multi-firm network organizations will be able to pursue strategies of continuous innovation and will grow across as well as within industries.

The selling network (Alemany, et al., 2008) concerns complementary products and/or services of suppliers from different supply networks having more potential if sold together in combined packages. Suppliers acting in unrelated supply networks create packs containing combined sets of products and/or services resulting in new supply networks of overlapping supply chains of contributing suppliers. The resulting supply networks are called selling networks. Supply chains that manufacture, distribute, and sell complementary products/services, join together to form selling networks that can offer a complementary products/services package to clients. These products/services packages involve the combination or fusion of individual products/services from each chain involved in the selling networks, and offer greater added value to the client than the sum of the individual values of all the products and services that make up the package. This aspect forms the real basis of the business and, therefore, justifies the existence of collaborative selling networks (Alemany, et al., 2008).

Selling these packages to clients requires a certain degree of coordination among the participant suppliers in order to synchronize the fulfillment of the received orders. Alemany et al. (2008) focus on the order promising process of a product package in an extended collaborative selling chain domain. They describe the development of a conceptual framework to support the characterization, design, and/or management of the order promising process in the context of collaborative selling networks of products/services packages.

According to Choi et al. (2008), when the buyer–supplier relationship is formed, the buyer brings to this dyad its own extended business network and so does the supplier. In this case, two networks are interacting. The buyer should select a supplier, not only based upon performance of the actual dyadic relationship, but also upon the nature of the relationships that the supplier maintains within its network. Even if a supplier has a limited performance, if its network contains important players, they can eventually drive the supplier to improve its performance in the future. Suppliers' selection should consider direct and indirect business relationships.

The consideration of all the suppliers of a certain buyer results in a larger network that merges the networks of these suppliers. Choi et al. (2008) refer to this notion as the concept of structural embeddedness since organizations, suppliers, and buyers, are embedded in this large network. When this concept is applied to supplier management, it can help understand a supplier's performance by looking beyond the supplier itself. *"Buying companies should develop their capability to measure their suppliers' structural embeddedness or what we might call the ''network awareness'' capability. This capability refers to a buying company's ability to effectively and efficiently scan the external networks of its key suppliers beyond its direct relationships with them."* The concept of structural embeddedness is based upon the Social Network perspective that focuses on the study of the actors, as well as the social relationships among them (Choi et al. 2008).

Beyond the Network Dimension in Transportation

With the incessant increase in gas prices, low profit margins, high competitiveness and increasing environmental standards, the transportation industry is required to increase its efficiency and use more environmental friendly solutions. Traditional consolidation strategies are not anymore enough to face the new challenges (Ballot, et al., 2010a). The truck industry for example is said to be still perform a substantial percentage of empty travels (Montreuil, 2011). Many authors believe that the substantial efficiency of the transport industry can be achieved by adopting more open and co-opetition approaches among the shippers and carriers (e.g. (Montreuil, 2011), (Schwind, et al., 2011)). This section reviews some of the existing and innovative mechanisms of collaboration and transportation sharing that deal with more than a supply network dimension and that aim at reducing empty travels, increasing the transportation efficiency, and reducing the environmental impact of the industry.

Horizontal Cooperation in Transportation and Logistics

According to Cruijssen et al. (2007), while horizontal cooperation is well addressed in maritime and aviation shipping, it is still in its infancy in the landside transportation. Focusing on road transportation, Cruijssen et al. (2007) view horizontal logistic cooperation as "cooperation between two or more firms that are active at the same level of the supply chain and perform a comparable logistics function on the landside". After a review of the existing research, the authors conclude that while they believe horizontal cooperation can result in economies of scale that could limit the increase of transportation costs, congestion, and emissions, they pinpoint the lack of conceptual classifications necessary to guide practitioners in implementing horizontal cooperation.

Horizontal transportation cooperation has attracted the attention of researchers interested in the transportation of logs from forests to mills. In general, trucks travel empty in their way to the forest. Filling the trucks as much as possible during the back travels is therefore highly desired and the horizontal cooperation seems to help reaching this goal. Using a simulation approach, McDonald et al. (2001) compared pooled/shared and privately owned trucking systems for log transportation from a forest to a set of mills. They found that for the same number of trucks, pooling increased the volume of delivered wood and reduced the average trailer waiting time. Murphy (2003) focused on the reduction of the number of trucks on the road and obtained through a binary linear program a decrease of up to 50% of the truck fleet sizes of two medium-sized New Zealander forest companies. In a Chilean timber transportation context, Weintraub et al. (1996) report a 32% fleet size reduction. Frisk et al. (2010) estimate a 14.2% (8 million euros/year) transportation saving and a 20% emission reduction resulting from a collaboration of eight southern Sweden forest companies. In the furniture industry, Audy et al. (2008) study the impact of benefit sharing in a coalition of four Canadian companies shipping to the USA market.

In the context of horizontal cooperation among a larger number of actors, Ballot et al. (2010a) studied the notion of logistics network pooling. This notion is based on the idea of using selected warehouses or distribution centers of some members as hubs used to consolidate shipments having similar destinations in order to fill trucks as much as possible. They report a reduction of around 25% of CO_2 emission in a combination of two

French retailers' supply networks involving 100 suppliers with a total of 164 warehouses and 59 distribution centers.

Since horizontal logistics cooperation is a contractual relationship that involves a predetermined set of actors sharing resources, it poses the problem of benefit sharing (see Hajdukova (2006); Audy et al. (2008); Nagarajan et al. (2008) and Frisk et al. (2010)).

Transportation e-Marketplace

Electronic Transportation Marketplace (ETM) or auction is another form of transportation capacity sharing which involves larger communities than those of horizontal collaboration. Goldsby et al. (2003) define them as "internet-based mechanisms that match buyers and sellers of transportation services with claims of reducing the administrative costs of transportation procurement to virtually nothing". Named also online freight marketplaces, they are portals where transportation capacity is bought and sold for short-term (spot market) and longer-term contracts (Nandiraju, et al., 2005). They can be classified in three categories: clearinghouses where carriers and shippers post their requirements and carriers post their available capacity, auction houses where transportation capacity and demand are auctioned, and freight exchanges where the online marketplace application matches at competitive price the posted shipper's demands to the announced carrier transportation capacities (Nandiraju, et al., 2005). It is believed that this type of markets can provide substantial economic and environmental benefits, but their potential is still not fully exploited as they lack appropriate optimization (Regan, et al., 2003) and functionalities, and have limited number of users (Schwind, et al., 2011).

Travel Planning

Freight horizontal transportation cooperation, transportation pooling, and freight ETM generally focus on a single transportation mode at a time. A multimodal perspective of transportation integration has been dealt with more for human mobility. For example, Yim et al. (2004) proposes a multi-agent travel planning system able to compare multimodal (train/plan) options. Moreover, some travel planning solutions provides more than just transporting passengers from sources to destination. For instance, Camacho et al. (2001) propose another multi-agent planning system that deals with the transportation from the origin to the destination, lodging and transportation at destination, and the return to the origin of the travel or to some other town. This system considers airplane, train, or bus as traveling options.

Synthesis

The examples presented above, in supply chain in general and transportation in particular, encompass issues far beyond the network dimension. The netchain concept focuses simultaneously on the vertical and horizontal business relationships among actors of the different layers of a supply context. It is also suggested that the concept can compare the performance of multiple supply networks. The knowledge-based network concept raises the issue of knowledge sharing across independent networks and industries. Knowledge sharing can occur even among non-overlapping supply networks. The selling networks suggest that suppliers from various supply networks, selling complementary products or services, can create combined packages in order to generate more value for the customer and to boost sales. Structural embeddedness claims that the networks of each of the suppliers of a certain buyer form a large network that should be considered for supplier management. In transportation, the notions of horizontal collaboration, e-Marketplace, and travel planning suggest that when actors from different networks share their facilities and means, substantial reductions of CO_2 emissions and economic savings could be achieved. Table 2 summarizes the principal ideas of these concepts, highlighting the fact that they consider more than one supply network.

Contribution	Concept	Main idea
Lazzarini, et al. (2001)	Netchain	Combining Vertical relationships of SC with horizontal relationships of SN
Miles, et al. (2007)	Knowledge-based networks	Knowledge sharing among unrelated SNs
Alemany, et al. (2008)	Selling network	Creation of packages by combining products from unrelated SNs
Choi, et al. (2008)	Structural embeddedness	Consideration of the impact of the suppliers' SNs on the organization's performance
Weintraub et al. (1996), McDonald et al. (2001), Cruijssen et al. (2007), Audy et al. (2008), Nagarajan et al. (2008)Frisk et al. (2010), Ballot et al. (2010)	Horizontal Cooperation	Resource sharing among actors of multiple networks
Goldsby et al. (2003), Regan, et al. (2003), Nandiraju, et al. (2005), Schwind, et al. (2011)	Transportation e-Marketplace	
Camacho et al. (2001), Yim et al. (2004)	Travel Planning	

Table 2: Beyond the Scope of the Network Dimension in Supply Chain Management

As a conclusion, on the one hand, the single network dimension in supply chain management seems to be limited in providing a framework that can explain, enclose, and support ideas beyond the network frame, at least at three levels. The first level involves the consideration of the overlapping of multiple supply networks, while the concept of supply network is concerned with the supply operations within a single supply network. The second level concerns the impact of direct and indirect non-supply actions taken by members from inside or those from outside the supply networks. The third level deals with the potential provided by the sharing of different kinds of resources among actors of networks not having explicit supply operations. Aspects of global knowledge sharing, non-supply behaviour consideration, in addition to supply behaviours, as well as multiple network interactions are expected to be among the key elements of the future of the supply chain management field.

On the other hand, the research examining issues beyond the boundaries of the network dimension brings new aspects to the supply chain management field. These aspects include the exchange of knowledge between distinct supply networks, the overlap of supply or distribution channels, and the sharing of resources between unrelated supply networks.

However, except for the netchain, none of the concepts presented above claims or supports extending the supply network to a following level. The concept of netchain, considering only the horizontal collaborative interactions among the same-tier actors, is not enough to encapsulate and explain systems resulting from selling, knowledge-based, or e-Marketplace networks for instance. Without a framework that formalizes the web dimension in supply chain management, this kind of research will continue to be fragmented. To remediate to this lack, the next subsection presents the leap from the network dimension to the web dimension in supply chain management.

Web Dimension in Supply Chain Management

The literature suggests that supply chain management is to embrace broader and increasingly more open dimensions that encompass aspects from more than one network by considering the overlapping supply networks and the collaboration among unrelated networks. The management of supply operations has to consider supply as well as non-supply activities of external networks that influence directly and indirectly the organization's operations. Complex interactions, dynamics, relationships, and resource sharing should be reconsidered and managed on web dimensions instead of on only the supply network dimension.

While in this thesis the notion of supply web is used as a network of supply networks, the wording "Supply Web" can be found in some scientific articles where it generally refers to the exploitation of digital web-based applications such as e-procurement and e-selling for inter-organizational processes integration and supply chain management (e.g. Christianse, et al., (2000) and Schlegel, et al. (2009)). Keskinocak et al. (2001) used the term "Supply Web" to describe supply chains that increase their flexibility by exploiting the high-speed communication and tight connectivity provided by Internet. In another stream of thoughts, Kumar et al. (1998) use the term "relationship web" as a mean to build supply chains by exploiting the social and personal relationships within families, friends, and employees.

The first introduction of the web dimension as an extension of the network dimension into supply chain management was in (Montreuil, et al., 2009). Then in (Hakimi et al. 2009) a supply web (called a logistic web in subsequent researches) was formally defined as a network of interrelated supply networks, each embedding interlaced supply chains, involving multiple organizations with collaborative or competitive supply relationships. Since then, the importance of the web dimension gained a strategic importance in our research in the CIRRELT, especially that related to Physical Internet (PI, π), thanks to the perceived potential in terms of economic, environmental, and social improvements. This research highlights the importance of a reliable global logistic web characterized by openness, interconnectivity, standardization, and encapsulation.

In order to improve, by an order of magnitude, the efficiency and sustainability of logistics in its broad sense, Montreuil (2011) exploits the internet, which revolutionized the digital world, as a metaphor to propose the Physical Internet concept as a novel concept aiming to guide and stimulate the innovation in the physical world toward a conciliation of service objectives, efficiency, and sustainable development. The concept intends to render the way physical objects are transported, handled, stored, realized, supplied and used throughout the world more economically, environmentally and socially efficient and sustainable. The Physical Internet uses the concept of universal interconnectivity of logistic networks and services. It proposes to encapsulate merchandises and products in world-standardized, eco-friendly, modular, networked, and smart containers that can be distributed and flowed on open, fast and reliable multimodal transport systems (Montreuil, 2011).

The Physical Internet supports the web dimension as it aims to enable the efficient and sustainable implementation and operation of an open and global logistic web, termed the Logistic Web. As depicted in Figure 10, the Logistic Web is the set of openly interconnected physical, digital, human, organizational, and social actors and networks aiming to serve the worldwide dynamic and evolving needs for efficient and sustainable logistics. As described in Montreuil (2011), this global web consists of five interlaced constituents: the Mobility Web, the Distribution Web, the Realization Web, the Supply Web and the Service Web. The Mobility Web deals with moving physical objects within the interconnected set of openly available unimodal and multimodal hubs, transits, ports, roads and ways, exploiting a mix of movers (e.g. transporters, conveyors, handlers). The Distribution Web is concerned with deploying objects within the interconnected set of openly available warehouses, distributions centers, and storage areas. The Realization Web is about making, assembling, personalizing, and retrofitting objects in the interconnected set of openly available production, personalization, and retrofit centers and factories of all types. The Supply Web focuses on providing, getting, and supplying objects through the interconnected set of openly available suppliers and contractors. A service web is a web aiming to serve the needs for physical object usage. It is focusing on the accessibility of the services provided by, through, and with physical goods and beings. The Service Web is expected to enable efficient and sustainable collaborative consumption on a worldwide basis, such as peer-to-peer lending and sharing of goods and facilities. When the name of any of these Webs is written in lower caps, it refers to some subsets, such as a logistic web for fast-moving consumer goods distribution within the French territory or a logistic web involving a specific company.

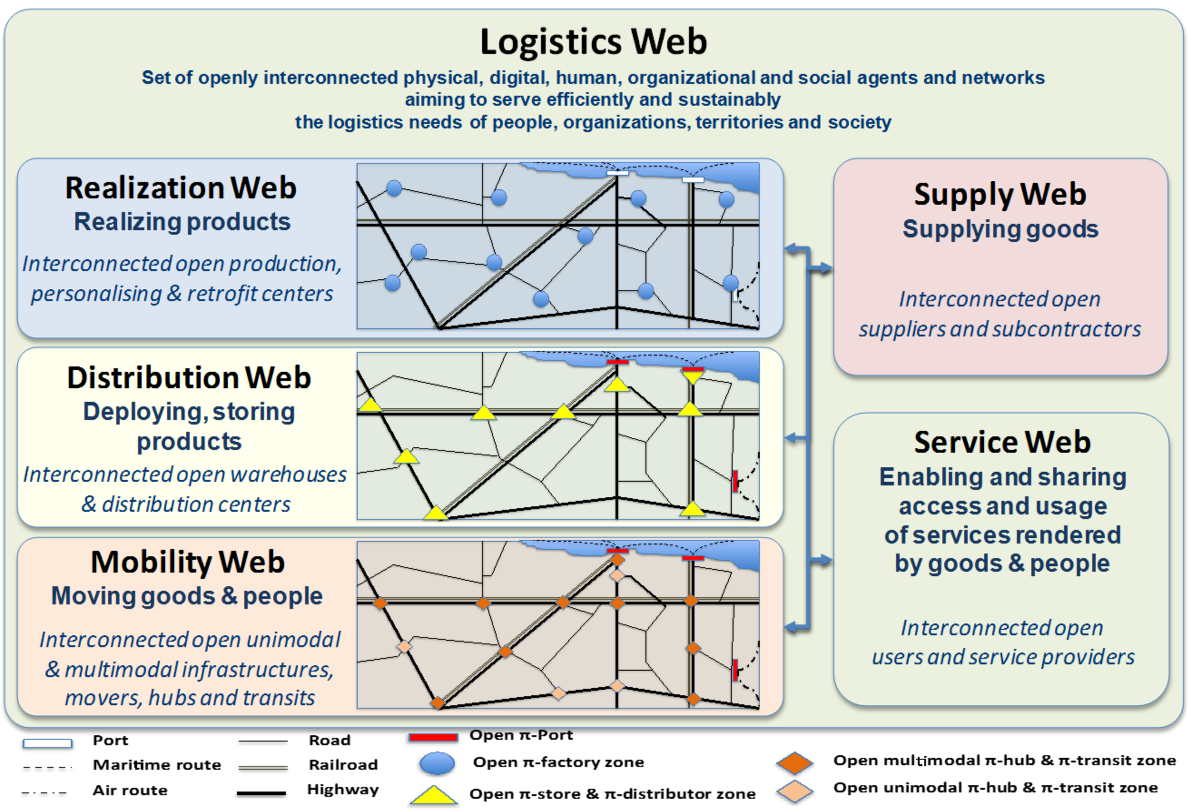


Figure 10: The constituents of the Logistic Web

The Logistic Web focuses on a functional perspective by viewing the global web as a set of webs of actors serving the same functions. The underlying principle is that an open sharing of resources can bring large and global economic, social and environmental benefits. The sharing of resources does not require necessarily an implicit intention of collaboration between actors or any long-term commitment as it is stipulated by supply chain and supply network concepts. Any actors can exploit any resource as long as this resource is made available by its owners and the sharing requirements are met. This justified the definition of the embedded webs based on the functions they perform: the Mobility Web for mobility functions, the Distribution Web for distribution functions, the Realization Web for realization functions, and the Supply Web for supply functions.

The meaning of "openness" used in the context of Physical Internet refers to the accessibility, willingness, and availability of actors and networks to deal with any other actor or network (Montreuil, 2011). The notion of "openness" is not a prerequisite for the definition of the five mentioned webs: logistics, supply, realization, distribution, and mobility webs. It is rather a necessary condition for these webs to be π-enabled and π-supported. In other terms, as an example, a distribution web is not required to partially or globally consist of open distribution centers and warehouses to be called a distribution web. However, for it to be π-enabled it must at least partially consist of open distribution centers and warehouses. In a Physical Internet environment, distribution centers and warehouses that are not openly sharing their resources can still work with and use, through the Physical Internet, resources of those which are open. The π-environment guarantee all its users, whether they are open or not, access to all the open distribution centers and warehouses. These centers and warehouses, as well as other non-open actors and networks, are like private networks in digital internet, which are not open to the World Wide Web (www) but are still connected to it and can use it.

Supply webs and logistic webs exist and existed with or without our awareness of their existence as is the case with supply chains and supply networks. The chain and network dimensions were not created but were merely discovered by researchers and practitioners. Nevertheless, after the identification of these dimensions, companies intentionally started creating and exploiting different forms of supply chains and supply networks. The same idea applies to the web dimension. Logistic Webs have existed since the time supply networks existed because these networks are naturally, though not openly and intentionally, connected through their inherent overlaps. When the notion of openness is considered, there is an intentional action to create open logistic webs in order to make good use of their potential. According to Montreuil (2011) open logistic webs are logistic webs with the following characteristics:

1. Their nodes are openly accessible to most actors, whether they are producers, distributors, logistics providers, retailers, or users;
2. The service capacity of their nodes is available for contract on demand, on a per-use basis, be it for processing, storage or moving activities;
3. Dynamic and interlaced virtual private networks are created by actors for realizing and deploying the products, services, and solutions in anticipation of and response to stochastic demand from clients.

The Physical Internet perspective advocates actors and networks to adopt intentionally and preferably an open attitude and behaviour in order to share and make good use of the unused storage, mobility, and production capacities dynamically available over the entire Logistic Web. The assumption here is that at any period of time the global required capacity of logistics resources is significantly lower than the global available capacity over the entire Logistic Web. By openly sharing the available capacities, there will be an intensive exploitation of resources, which will eventually results in increasing efficiency and reducing waste at all levels.

Conclusion of the Chapter

In this chapter, we argued that the scope of supply chain management should extend beyond the network dimension by embracing the web dimension. We began by looking at how supply chain management emerged from the concept of operations management, which was previously known as manufactory management. The shift from the notion of resource ownership to collaboration between organizations motivated this emergence. We then followed the gradual evolution of supply chain management from a focus on dyadic relationships among adjacent partners, to a collaboration among members of a supply chain and then among members of a supply network. Next, we showed that the network dimension supported by the concept of supply network is unable to deliver the necessary understanding and theoretical foundation for supporting research contributions that consider issues beyond its scope.

The literature review suggests that supply chain management is heading toward a broader and increasingly more open concept that includes aspects from more than one network by considering the overlapping of multiple networks, as well as the collaboration and resources sharing among unrelated supply networks. The management of supply operations will consider supply activities of external networks and the non-supply activities that influence the organization's operations, both directly and indirectly.

The study of the evolution of the supply chain concept shows that this evolution was dictated by the progressive increase in the awareness of external members influence on the internal performance. This increase of awareness was guided by the advancement of concepts, theories, and paradigm feeding each step, and by technologies enabling the achievement of new perspectives. Today, the technological and conceptual advancements are preparing the new phase of transition toward supporting the web dimension in supply chain management.

Integrating the web dimension into supply chain management has the potential to provide global, large scale, and unprecedented economic, environmental, and social benefits especially when considering open, reliable, and interconnected logistic webs. The Physical Internet enabled Logistic Web, and its constituents, the Mobility, Distribution, Realization, Supply, and Service Webs, proposed by Montreuil (2011), provide a strong illustration of the magnitude of the impact of moving from a network level toward a web scale in supply chain management. In addition, considering the web dimension is expected to fill the theoretical and managerial gaps left by the supply network concept. For example, all the contributions identified in this chapter as extending beyond the scope of supply network, such as Netchain (Lazzarini, et al., 2001), selling networks (Alemany, et al., 2008), and logistics pooling (Pan, et al., 2013), can be easily included and represented within a logistic web as different forms of overlapping supply networks.

The Web Dimension and Supply Chain Management Theories

This chapter has the objective to demonstrate that there is a theoretical gap in supply chain management theories requiring the consideration of the web dimension. Then, it shows, by studying some practical implications of the web dimension on aspects of supply chain management, that the consideration of the web dimension is necessary in order to address and deal with important issues currently faced by supply chain management.

In terms of supply chain management theories, the consideration of the web dimension arises two important questions. Firstly, do the existing supply chain management theories deal or consider the web dimension? Secondly, if not, then how to integrate the web dimension into the supply chain management knowledge body? It is necessary to understand the recent research advancement in supply chain management to accurately determine the amplitude of the implications of the answers to these questions. This is the subject of the first section.

Regarding the practical implications, the web dimension provides the potential to see and exploit relationships beyond the limits of the members involved in physical exchanges over supply networks. The second section looks to the inter-organizational collaboration with members of the logistic web and how it may help understand more the factors affecting a supply network or any part of it and access knowledge and resources beyond that available for the organization or its supply network. However, in order to make good usage of the web dimension, it is important to understand the decision support process and requirements involved when this dimension is taken in account. The third section investigates the potential benefits that can result from applying an open, reliable, interconnected and global web vision in logistics and supply chain management. By taking a functional point of view, this section demonstrates that open, interconnected logistic webs may change the way logistics is done today and enable fundamental improvements of outcomes in terms of efficiency and sustainability.

Positioning the Web Dimension According to Supply Chain Management Theories

This section aims to position the web dimension within supply chain management by investigating the state of the supply chain management evolution in terms of theoretical foundations and dominant paradigms. It demonstrates that existing supply chain management systems do not support the logistic web dimension. Subsection one studies the dominant theories explaining supply chain management. Subsection two examines contributions highlighting that these existing theories are focusing more on structural aspects while an emphasis on the complexity of supply environments is required. They suggest that supply chain management should centre more on behavioural aspects and relational dynamics. The last subsection provides a synthesis of the section and argues that the incorporation of the web dimension involves a paradigm shift in order to identify and make the best use of the new potential.

Reviewing Supply Chain Management Theories

In the previous chapter, the literature review helped identify different levels of the supply chain by looking at what was and is considered within the supply chain's scope and how the concept evolved from focusing on internal operations to broader perspectives, gradually including more tiers of actors resulting in logistic webs embedding supply networks. Here the focus is on examining supply chain management as the set of techniques used to manage supply chains and supply networks. The evolution of supply chain management involves an intensive interaction among many theories, paradigms, and concepts, making supply chain management a rich and complex concept, as we know it today. The result is a dynamic field created around a large body of knowledge about this concept. This section investigates diverse streams that influenced the way supply chains are managed by looking at theories and views explaining supply chain management.

After almost thirty years of existence, supply chain management is still evolving and attracting different kinds of research related to a variety of fields and knowledge bodies.

According to Chen, et al., (2004), in addition to using the term ‘supply chain management’ to explain the internal and external management of information and material flows, it is used to discuss strategic and inter-organizational issues and to explain relationship development between a company and its suppliers. It is also viewed as an approach in purchasing and supplying, as well as an organizational alternative to vertical integration. Among the first publications that looked at the history of using the term ‘supply chain management’ in the literature is the work of Harland (1996). The author suggests that the term was largely used in several emerging and unconnected bodies of knowledge. In a former article (Harland, 1995), she states that there was little consistency in the use of the term and little evidence of the clarity of its meaning. During the last decade, many authors started trying to set frameworks and taxonomies for supply chain management theories and initiatives in order to address the different facets of the concept and its evolution.

Huan et al. (2004) believe that the origins of supply chain management can be traced to the very late 1950s. However, it is not until the early 1980s that the field started to attract a significant number of researchers, with an important increase in the number of publications since 1990. They classify supply chain management research into three categories:

1. *Operational*: this category is concerned with fulfilling customer orders by following the most profitable way in managing daily operations in facilities such as plants and distribution centers. It is supported by the development of mathematical tools, software, better manufacturing methods, and technologies that aim to efficiently operate an entire supply chain.
2. *Design*: this category focuses on finding the right geographic locations for facilities belonging to a supply chain and on meeting the global supply chain objectives at minimum costs. Four types of models used for this purpose are encountered in the literature: (1) deterministic analytical models, (2) stochastic analytical models, (3) economic models, and (4) simulation models.
3. *Strategic*: this category considers supply chain management a strategic tool that allows a firm, supply chain or supply network to gain competitive advantages. Business managers have to make complex strategic decisions that require understanding the dynamics of a supply chain and developing objectives for the entire chain.

According to Camarinha-Matos et al. (2005), collaborative networks manifest in a variety of forms, such as advanced and highly integrated supply chains, virtual enterprises, virtual organizations, professional virtual communities, value constellations, and collaborative virtual laboratories. They argue that a scientific discipline for Collaborative Networks should be developed given that a large body of empirical knowledge related to these kinds of networks is available and that there is an urgent need to consolidate this knowledge to establish such a scientific discipline. They list diverse theories and tools that can be applied to collaborative networks specifying the scope and readiness for each theory. Among these are the complexity theory, social network analysis, multi-agent systems, and federated systems. While this contribution deals with collaborative networks in general and does not specifically address supply network, the implications are naturally extrapolated to supply network as a kind of collaborative network.

Miles et al. (2007) affirm that supply chain research previously focused only on how to move products efficiently among firms within an industry, but now it includes a substantial amount of organization theory. The organizational history of supply chains has evolved over the last three decades and this evolution can be divided into three periods. Each period is associated to a theoretical concept, which highlights a dominant supply chain management stream. The first period is related to the resource-based view whose primary concern is to render operations more efficient throughout the supply chain. Management techniques developed prior to and during this period, such as benchmarking, business process reengineering, and total quality helped organizations focus on their relationships with suppliers and partners in order to achieve maximum efficiency across their network. The automobile industry provided leading actors such as Toyota that created the lean production, BMW that started incorporating the suppliers' ideas into its designs, and Ford Motors that embraced collaboration with external suppliers after it was the most vertically integrated company in the USA. The second period is associated to the knowledge management perspective. The focus shifted from efficiency (better use of resources) to effectiveness (leveraging relationships) as leading firms began improving the innovation processes by incorporating the ideas and expertise of their suppliers and partners into the management of supply chains. This period is characterized by a heavy investment in trust-building and the creation of organizational culture and processes assuring equity among partners. The current period is a network collaboration period. Some companies start exploring how to extend and operate supply chains efficiently and effectively within and across industries. Collaborative networks are dynamic and the roles of collaborating members can change over time in response to market behaviour and strategic objectives.

Miri-Lavassani et al. (2009) examined the history of individual efforts that tried to provide theoretical foundations for various areas related to the supply chain since 1995. They extended the work of Miles et al. (2007) by proposing five additional theories or views. The authors distinguish between views and theories, stating that theories indicate a mature and scientific development status while views or perspectives are presented with a lack of sufficient foundation, predictive capacity, or maturity.

Theory/View	Justification for application of theory in SCM studies
Transaction Cost Analysis	Reducing cost generated through asset specify and uncertainty. Vertical Integration
Resource-based view	Tangible and intangible resources influence the creation, sustainability, and competitive advantage of the firm
Knowledge-based view	Knowledge is a source of competitive advantage Exchange of knowledge increases the SC value creation
Strategic choice theory	Establishment of structural forms Manipulation of environmental features Choice of relevant performance standards
Agency theory	Conflict raising from delegation of authorities: encourages internalization Positive relationships: encourages collaboration
Institutional theory	Monitoring environment for collaborative opportunities Following best practice
Systems Theory	Simplifying the relations among the components of the systems, in order to gain better understanding and analysis of values generated by SC
Network Perspective	Several-party inter-organizational relations increase the resources capabilities and competencies of the individual firms

Table 3 : Application of Supply Chain Theories; Adapted from Miri-Lavassani et al. (2009)

The eight theories and views of supply chain management studies presented in Miri-Lavassani et al. (2009) are resource-based view, transaction cost theory, knowledge-based view, strategic choice theory, agency theory, institutional theory, systems theory, and network perspective. A short description of each one of these theories is given in Table 3.

By examining the development of supply chain management studies, Movahedi et al. (2009) define three eras of supply chain evolution: the supply chain creation era, the supply chain integration era, and the supply chain globalization era. These eras are not following a chronological progression, instead they are defined based on the predominance of targeted characteristics. The creation era originated in the 1980s with the worldwide recession of the late 1980s and early 1990s. This recession incited managers to re-evaluate common practices of that time in terms of models for cost reduction and value creation at the strategic level. “Reducing cost” and “increasing the value added” were the key words of this era. The integration era capitalized on the same objectives (cost reducing and value adding) but through the integration of several organizations. It began with the creation of the Electronic Data Exchange (EDI) systems in the 1960s and had strengthened through the introduction of Enterprise Resource Planning (ERP) systems during the 1990s. It continued its evolution with the expansion of internet-based collaborative systems. The globalization era commenced in the late 1980s with the generalization and intense adoption of global outsourcing in several industries. It is the era of inter-organizational relationship expansion beyond national boundaries. It is characterized by the cross-border supply chain that consists of organizations aiming to increase their competitive advantage, value-adding, and reduced costs through global sourcing.

New Trends in Supply Chain Management Research

Supply chains are in constant evolution and extension. The development of information, communication, connective, mobile and wireless technologies, and their rapid adoption for managing supply operations, results not only in various advantages, but also in many unique challenges. The significant amount of data made available through these technologies increases the complexity of designing business information systems. These systems should consider this data, make good use of it, and support its future evolution. Moreover, the increasing concerns about customer satisfaction and demand fulfillment generally make the customer the center of attention for all players in supply context. This focus brings even more variation into the design, configuration, production, and delivery of products through the entire chain.

The previous section investigated the chief contributions dealing with what is supply chain management and how supply chains and supply networks were and are managed. An implicit assumption of this kind of research is that the supply chain management field is reaching a maturation point, and that a framework for a supply chain management discipline can now be established. This section presents other contributions bringing to light important issues that some researchers consider key elements in the future evolution of supply chain management. The following two subsections focus on the complexity inherent in supply contexts and the gap between the dominant supply chain management research and the evolving needs of managers. The third subsection argues that this gap is reflected at the technological level, given that most available decision support tools do not provide managers with the appropriate assistance in complex logistic web environments.

Recognizing the Complexity of Supply Operations

Supply chain management research involves and crosses over numerous disciplines, such as marketing, logistics, operations management, strategic management, and industrial economics. It is characterized by the application of multiple existing theories like resource based theory, network theory, strategic management, inter-organizational relations, institution theory, general systems theory, and game theory (Camman, 2009; Miri-Lavassani, et al., 2009). Supply processes are interconnected and interdependent through the exchange of physical, informational, and financial flows. Changes in any part of the supply network propagate over the entire network. The high uncertainty and stochastic nature of processes, demands, and markets make supply chain management very challenging (Stefanovic, et al., 2009).

Supply networks embed numerous inter-organizational relationships, sometimes crossing multiple industries and involving complex interconnections between multiple suppliers, manufacturers, assemblers, distributors, and retailers. Decisions in this context require the consideration of a large number of factors from multiple dimensions and perspectives (Pathak, et al., 2007). In addition, each company is still an autonomic unit with its own goals, operational policies, organizational structure, and information technology platforms.

This autonomy is in constant conflict with the systemic vision of supply chain, making it hard to plan globally and to take decisions regarding the inventory, transportation, and location strategies (Stefanovic, et al., 2009). In supply networks, cause and effect relationships are difficult to grasp; behaviours are dynamic and actions of some members can potentially affect any other member of the network. Moreover, since supply networks are complex systems, their global performance, and their behaviour is a nonlinear dynamic function of a large number of activities performed in parallel by interacting entities (Pathak, et al., 2007).

Despite this reality, supply chain and supply network research is still dominated by hard and structural approaches. Most past supply chain management research that considered issues beyond the dyadic relationships tends to be hard and structural (Harland, 1996; Giunipero, et al., 2008). It focuses primarily on specific issues occurring within diverse elements of a certain supply context, such as a firm, a dyadic relationship, a chain, or a network, without necessarily considering the direct and indirect interactions influencing these elements. Although the contribution of this kind of research is undisputable, it does not capture the complexity of the nature of supply environments (Camman, 2009). Notably, the research examining broader network-level effects, existing in real life supply networks, is unfortunately absent from this body of work (Pathak, et al., 2007).

Hard and structural approaches, consisting of mathematical and operations research models, generally do not perform well in modelling complex systems, such as supply networks and logistic webs that include many relationships, features, parameters, and constraints. This is because these approaches start with many assumptions (Stefanovic, 1999), simplifications, and aggregations. Choi et al. (2001) states that the behaviour of a complex system cannot be written down in closed form; it is not amenable to prediction via the formulation of a parametric model. The noncomplex assumptions (e.g., linearity, a buyer–supplier dyad, sparse connectivity, static environment, fixed and non-adaptive individual firm behaviour) rule decision making in supply networks and lead problems to remain often hidden, leaving plenty of room for understanding and improving the underlying processes (Pathak, et al., 2007).

Supply Networks as Complex Adaptive Systems[3]

Many authors begin by pointing out that softer, behavioural, and systemic approaches are required in order to tackle the real daily challenges facing supply chain managers (Harland, 1996; Beamon, 1998; Choi, et al., 2001; Lazzarini, et al., 2001; Vonderembse, et al., 2006; Pathak, et al., 2007; Camman, 2009; Stefanovic, et al., 2009). Camarinha-Matos et al. (2005) claim that more researchers have begun looking into the "soft computing" area in order to find suitable approaches for modeling aspects related to human behaviour in collaborative organizations and to handle the issues of decision making and behaviour management in the contexts of incomplete and imprecise knowledge. Camman (2009) proposes an integrative reflection framework that aims to provide an understanding of how the multiple relationship dimensions, within individuals, firms, or group of firms, articulate together to contribute in the design of a collective strategy.

Research investigations in the supply network field have started exploring the merits of complexity theory and the Complex Adaptive System perspective in order to address the problem of complexity and adaptivity of supply networks (Pathak, et al., 2007). Monostori et al. (2006) believe that a key to tackling this problem is to realize that production networks should not just be treated as a "system", but as a complex adaptive system. The reality of supply environments involves two important aspects: complex relationships among the members of the supply network and a very dynamic and evolving environment. Complexity science provides a conceptual and methodological framework to approach and consider these issues (Pathak, et al., 2007). Therefore, for ever more researchers the supply network should be considered a Complex Adaptive System Network (CASN) (Choi, et al., 2001; Surana, et al., 2005).

After highlighting the characteristics of complex adaptive systems, Zhang et al. (2009) argue that supply chain networks are complex adaptive systems because of the following reasons:

- their structures embody several scales;

[3] This section is an extension of section 3.1 in Hakimi, D., Montreuil, B., & Labarthe, O. (2010b). Supply Web Agent-Based Simulation Platform. *Proceedings of the 3rd International Conference on Information Systems, Logistics and Supply Chain, ILS 2010 – Casablanca (Morocco), April 14-16.*

- they consist of entities strongly coupled with degrees of freedom and correlations over long lengths and timescales;
- they feature the coexistence of competition and cooperation;
- they are characterized by nonlinear dynamics involving interrelated spatial and temporal effects;
- they are in quasi-equilibrium and combine regularity and randomness;
- they feature an evolving behaviour and self-organization; and
- they are in a perpetual adaptation and evolution.

Pathak et al. (2007) define a CASN as

> a system of interconnected autonomous entities that make choices to survive and, as a collective, the system evolves and self-organizes over time. CASN consists of four key elements: (i) organizational entities exhibiting adaptivity, (ii) a topology with interconnectivity between multiple supply chains, (iii) self-organising and emergent system performance, and, (iv) an external environment that coevolves with the system.

Regarding how the CASN concept can contribute to supply chain management through its four elements, Pathak, et al. (2007) state that each of these elements can maintain several properties, such as capacity and service level (entity); path length, redundancy, and clustering (topology); efficiency and flexibility (system); and demand, dynamism, and risk (environment). The properties of these elements can be used to describe the state of a CASN at a moment in time or over a finite span of time. It is the interactions across these entities over time and the evolution of their properties that the supply chain management discipline seeks to understand more fully. Some of these properties may already have well-accepted measurements or metrics, such as a firm’s inventory holding costs, while others, such as supply chain agility, may require additional refinement (Pathak, et al., 2007).

One of the important implications of the CASN is taking into account the changes of the network’s internal states. These changes can be initiated by elements residing both inside and outside the CASN. Entities from the external environment of the CASN can initiate actions that may affect the network (Pathak, et al., 2007). These external entities can be, for instance, other supply networks, government agencies, or public and private organizations. Another set of implications has to do with the management aspect of the supply network. The CASN offers managers a new perspective and a new mental model through which they can view, analyse, and handle their business worlds, while being aware of the impacts of the adaptivity of other firms, the complexity of the overall system, and the dynamicity of the surrounding environment. The concept will also steer researchers to study the complex decision-making processes in the context of dynamic, complex, and broad supply networks (Pathak, et al., 2007). Another implication is the ability of the complex adaptive system perspective to approach real world management issues by integrating more realism and empirical data into research models (Anderson, 1999).

According to Pathak et al., (2007), since the pioneering article of Choi et al., (2001) which examined how supply networks carry the properties of complex adaptive systems, there have been a small number of articles, such as Surana et al. (2005) and Braha et al. (2007), which used the complex adaptive system view in supply network research. These articles suggest that the supply chain management discipline has yet to embrace the complex adaptive system perspective. Pathak et al. (2007) also state that after careful examination, they notice that almost all the contributions regarding complexity theory occurred outside the operations management and the supply chain management disciplines, and that, according to Amaral (2007), the special issue of Management Science on Complexity Theory did not contain a single article that deals purely with supply chain issues.

Integrating the Web Dimension to Supply Chain Management Theories

The articles presented above focus on diverse theories and views that explain the evolution of supply chain management. They implicitly suggest that most theories and views co-exist with various levels of dominance since the early stages of the supply chain concept. However, by contrasting, from one side, the supply chain levels (internal, dyadic, chain, and network) discussed earlier, and from the other side, the supply chain management categories, periods or eras defined in these articles, it is possible to establish associations between each supply chain level and its dominating theories or views. Table 4 illustrates this association for the four discussed articles above.

Dimension	Miles, et al. (2007)	Huan, et al. (2004)	Movahedi, et al. (2009)	Miri-Lavassani, et al. (2009)	
Internal level	A prior period of development of management technique	Operational category	Creation era	Transaction analysis and strategic choice theory	
Dyadic relationship	1st Period : Resource-based view	Design category		Agency theory Resource-based view knowledge Management view Institutional theory	System theory
Chain	2nd Period: knowledge management perspective	Strategic category	Integration era Globalisation era		
Network	3th period: network collaboration period			Network perspective	

Table 4: Association of Supply Chain Levels to Suggested Categories of Supply Chain Management Theories

The periods suggested by Miles et al. (2007) can be mapped, in the same manner, to the supply chain levels. The internal level, which focuses on improving the internal operations of the organization, fits the period of development of the internal management techniques. The first period overlaps both the dyadic relationship and external chain levels since the resource-based view applies to dyadic relationships and to the lean supply chain. Part of the external chain level is addressed in the second period (knowledge management perspective) which also covers a part of the network level. The remaining part of this last level is associated to the network collaboration period. Likewise, the operational category of Huan et al. (2004) can be linked to the internal level, whereas the dyadic relationship level correlates to the design category. The chain level was first dominated by the design category and then by the strategic category. This last category also incorporates the network level. The creation era of Movahedi et al. (2009) can be mapped out to the internal level, as well as to the first part of the dyadic relationship level. The integration and globalization eras include a part of the dyadic level, in addition to the chain and network levels. Supply chain management theories and views, defined by Miri-Lavassani et al. (2009), are mapped out in the following way. The system theory applies to all supply chain levels since the concept of supply chain itself is based upon the notion of systems. What’s more, the transaction analysis and strategic choice theory are mapped out to the first level of the supply chain. Dyadic relationships and chain levels, along with part of the network level, were all influenced by the agency theory, the resource-based view, the knowledge management view, and the institutional theory. The network perspective dominates the rest of the network level. The resource-based view and the knowledge management perspective were differently assigned under Miles et al. (2007) and under Miri-Lavassani et al. (2009) due to how these papers define these views.

On the one hand, the review of the articles mentioned above reveals the diversity and impressive number of theories, views, paradigms, and initiatives that shaped the supply chain management concept. This testifies to the complexity, dynamicity, and importance of supply chain management. It also shows that each of these theories and views provides a partial understanding of the global picture of supply chain management. As suggested by Camarinha-Matos et al. (2005), combining the knowledge resulting from these views and theories into a large scientific discipline, can result in proffering a deeper understanding and a richer framework for tackling the challenges that supply chain management still presents to researchers and practitioners.

On the other hand, other authors believe that the available supply chain management research is mainly hard and structural, therefore limiting the manoeuvrability of managers when dealing with real world business issues and daily managerial questions. Researchers begin to realize the importance of considering supply chain management issues from a softer point of view. It is believed that an important paradigm shift will arrive from the application of complexity theory in supply chain management. Real world supply networks are complex systems that evolve and adapt to their environments. Thus, according to complexity theory, they are complex adaptive system networks. The examination of the literature shows an important lack of research regarding the supply networks as complex adaptive systems in operations management and supply chain management.

In general, the literature review reveals a certain consensus among researchers regarding the complexity of the supply chain management field. For some, this complexity manifests itself in the various theories and concepts contributing to the creation of the knowledge constituting supply chain management. This kind of research assumes that supply chain management is maturing and that the consolidation of available contributions is susceptible to produce a body of knowledge that encompasses most supply chain management issues. For others, the complexity of supply chain management is hidden in the intricacy of the relationships and exchanges occurring in supply networks. This kind of research indicates that supply chain management should embrace the complexity theory and softer approaches. It also argues that supply networks should be considered complex adaptive systems.

Overall, the study of all these streams of research shows the noticeable overlook of the web dimension and its potential contributions to supply chain management on practical and theoretical levels. While some of the theories cited above can explain some aspects of the web dimension, they are unable to deal with its most important contributions such as those associated with the characteristics of the Logistic Web as an open, interconnected, and global web. Considering resource sharing among members from separate supply networks at a global scale, viewing supply activities from a functional perspective instead of structural perspective, and considering the indirect impact of external supply actors on the internal performance of a certain supply network are examples of axes that are specific to the web dimension.

Moreover, Pathak et al. (2007) argue that because organizations exhibit adaptivity and can exist in a complex environment with myriad relationships and interactions, it is a natural step to identify a supply network as a complex adaptive system network. Since a logistic web is a network of supply networks, it will exhibit even more adaptivity and will exist in an even more complex environment. For this reason and by applying the same argumentation as Pathak et al. (2007), logistic webs should also be considered as complex adaptive systems. Viewing logistic webs in this manner implies that the issues and conclusions driven by applying the complex adaptive system perspective to supply networks are extrapolated to logistic webs.

The web dimension in supply chain management can be viewed at least from three perspectives. The first one considers a web an overlap of multiple supply networks; the second one focuses on a global open and interconnected global Logistic Web, which is emphasized by the Physical Internet concept; and the third states that because logistic webs are networks containing supply networks, they will exhibit even more adaptivity and will exist in environments that are more complex. Table 5 represents the projected integration of the web dimension into categories of the supply chain management theories illustrated earlier in Table 4.

<table>
<tr><th>Dimension</th><th colspan="5">Theories and Views</th></tr>
<tr><td>Internal level</td><td>A prior period of development of management technique</td><td>Operational category</td><td rowspan="2">Creation era</td><td colspan="2">Transaction analysis and strategic choice theory</td></tr>
<tr><td>Dyadic relationship</td><td rowspan="2">1st Period : Resource-based view</td><td rowspan="2">Design category</td><td rowspan="4">Agency theory
Resource-based view
knowledge
Management view
Institutional theory</td><td rowspan="5">System theory</td></tr>
<tr><td rowspan="2">Chain</td><td rowspan="4">Integration era
Globalisation era</td></tr>
<tr><td rowspan="2">2nd Period: knowledge management perspective</td><td rowspan="3">Strategic category</td></tr>
<tr><td rowspan="2">Network</td></tr>
<tr><td>3th period: network collaboration period</td><td>Network perspective</td></tr>
<tr><td rowspan="2">Web</td><td>Overlapping networks period</td><td>Coopetition category</td><td>Web dimension awareness era</td><td rowspan="2">Web perspective</td><td>Complexity theory</td></tr>
<tr><td>Logistics Web period</td><td>Open sharing of resources category</td><td>Global interconnectivity and openness era</td><td>Physical Internet</td></tr>
</table>

Table 5: Theoretical Integration of the Web Dimension into Supply Chain Management

We argue that the periods following the network collaboration period (the 3th period) will the overlapping networks period and the Logistic Web period. Even if we presented the overlapping networks period prior to the Logistic Web period, we think that these two periods may evolve in parallel and there will be a perpetual support and influence between them. The overlapping networks period will characterize a coopetition category where competing members of logistic web (including its supply web constituent) will collaborate on aspects that made them achieve common benefits without harming their distinct activities (Hakimi, et al., 2009). The Logistic Web period will be a period of open sharing of resources among different actors of large webs without consideration of the competing nature between these actors since the resources sharing will be done on a different level than that on which the normal competition occurs. The overlapping network period will define a web dimension awareness era where the actors are conscious of the impacts coming from external networks and the Logistic Web era will drive an era of global interconnectivity and openness of resources sharing among the logistics actors. Both periods will evolve under the web perspective but the overlapping networks period will exploit more the complexity theory and the Logistic Web period will be based on principle of resource sharing such as those advocated by the Physical Internet.

In conclusion, the available supply chain management theories and perspectives are unable to explain or deal with the integration of the web dimension into supply chain. A new paradigm shift is required to lead the evolution toward effectively exploiting the web dimension in supply chain. Viewing logistic webs as complex adaptive overlapping networks with large global resources excess susceptible to be shared in order to reach global economic, environmental, and social efficiency is a key around which the evolution of supply chain will turn in the future years. The Physical Internet is already leading the evolution toward this direction.

Implications of Considering the Web Dimension

Why, from a practical point of view, the “Web” dimension in supply chain management is needed? This a legitimate question that can surface after the theoretical discussion covered so far. To answer this question, one can say that the benefits of the adoption of a web perspective outweigh by an order of magnitude that of sticking to a network or chain level. To support this statement, this section first discusses the impact of the web dimension through the example of inter-organizational collaboration in logistics. However, in order to make the most usage of the web dimension, decision support systems should enable this dimension. Therefore, the second part of the section studies the implications of the web dimension on the decision support process.

Enhancing Inter-organizational Collaboration: Implications of the Web Dimension on Collaboration

Firms are operating inside the supply web that is embedding supply networks, themselves embedding supply chains. Success is no longer measured only at the level of a single company. Competition is not only assessed at the company level, but also at a network level by considering a network of co-operating companies, competing with other firms along the entire supply chain (Spekman, et al., 1994). The traditional boundaries of firms are dissolved: decisions on the use of resources should concern both internal and external capacities, and the internal flow of materials should be synchronized with the incoming and outgoing flows (Monostori, et al., 2006). Furthermore, in addition to the vertical form of collaboration among the members of a supply chain, collaboration can occur horizontally among competing organizations (Alemany, et al., 2008).

The level of collaboration, which is based upon the level of trust between partners, is a key component in developing collaboration among partners. This collaboration has resulted in the evolution of the supply network concept (Bitran, et al., 2006). Trust-building among the members of supply networks offers an alternative to the notion of resource ownership and produced more collaboration resulting in increased potential benefits for companies. Partnerships and long-term business relations among the members of a supply chain or supply network are now founded on building trust, and creating organizational cultures and mechanisms that support equitable treatment among collaborating actors (Lee, et al., 1992; Nooteboom, et al., 1997; Spekman, et al., 1998; Miles, et al., 2007).

Spekman et al. (1998) define four collaboration intensity levels (Figure 11): open market negotiations, co-operation, co-ordination, and collaboration. The open market negotiations level is the basic buyer-supplier relationship where no collaboration exists. The client seeks the suppliers offering the best prices and buys from them. The exchange is limited to placing orders and receiving shipments. At the next level, cooperation, basic essential information is exchanged between partners, and in some cases, suppliers, and customers engage in long-term contracts. The next level is coordination, in which workflows and information are exchanged in a manner that permits JIT systems, EDI, and other mechanisms that attempt to coordinate operations among trading parties. The last level is collaboration, which engages partners in joint planning and processes beyond levels reached in less intense trading relationships.

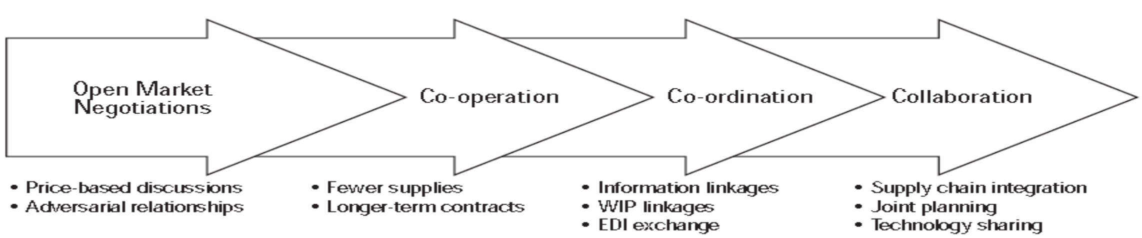


Figure 11: The Levels of Collaboration Intensity; Source: (Spekman, et al., 1998)

As organizations start trusting their partners, sharing information and knowledge, and integrating processes along the supply chain, they begin to realize the potential of integrating yet further partner-tiers in the collaboration process resulting in even more extended supply networks. The creation of supply chains and supply networks provided new business opportunities for firms selling a variety of product lines and having differentiated customer bases (Hertz, 2002; Alarcon, et al., 2009).

The adoption of a web vision has the potential for pushing collaboration even further. The Logistic Web concept and Logistic Web technologies can bring the inter-organizational collaboration to an unprecedented level. The holistic approach for understanding and managing supply relationships will redefine business interests and partnerships of companies as did the concepts of supply chain and supply network. Standardized cross-organizational logistic web databases and advanced logistic web business tools will facilitate cross-organizational communication, analysis, and knowledge transfer.

Information sharing with a member of a logistic web allows an organization to indirectly benefit from this member's relationships and to extend its own understanding of the logistic web environment. Information sharing agreements result in overlapped collaborating groups. Figure 12 shows an example of three groups. The members of each group are sharing logistics data. Organization 6 has access to organization 2's data, but not to the rest of the group 1 members' data. However, organization 6 may benefit from its data sharing with organization 2 in at least two ways. First, organization 2 has access to logistics data from all its suppliers, which can provide it with more understanding of its logistics operations, and therefore allows it to improve its relationships with its partners, organization 6 included. Second, in the case of collaborative projects regarding specific actions, such as new product launchings, if the two organizations combine their efforts, they can monitor a larger part of the logistic web affecting the performance of their collaboration, as illustrated in Figure 12. Knowledge transfer, strategic adjustment, and indirect impact assessment can be acquired and transferred from one side to another without necessarily transferring confidential data. Moreover, the impact of the collaboration between organizations 2 and 6 will reach the remaining members of group 1 through organization 2, and the rest of group 3 through organization 3.

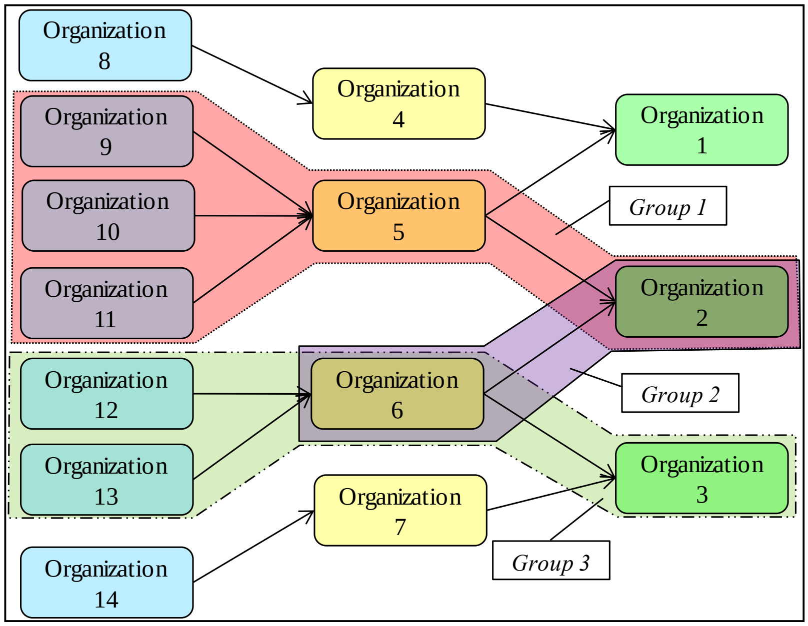


Figure 12: Information Sharing Groups inside a Logistic Web

The concept of collaboration can be extended not only to members of the same logistics network, but also to those who indirectly affect, or are affected by, this logistics network. For example, if the products of organizations 6 and 7, supplying organization 3, are complementary, the two members can decide to share logistics data in order to maximize their sales, or, joined with organization 3, to create a strategic alliance towards increasing their global performance. Examples of these situations are found in Keskinocak et al. (2008) and Alarcon et al. (2009).

In the case of a client-supplier relationship, partners can share logistics data about the overlapping parts of their common supply network. While shared data is limited to information about products exchanged, these partners can gain by sharing information about the logistics context of these products. For example, in the case of a manufacturer-retailer relationship, where the retailer's distribution centers ship the manufacturer's products to the retailer's stores, in addition to sharing quantities of the manufacturer's products shipped to the stores, the retailer can also give information about how many trucks were shipped between the distribution centers and the stores that contained the manufacturer's products, and what were the weight, volume, and value percentages occupied by these products in the trucks. While the retailer cannot share with the manufacturer confidential data of its other partners, it still can share percentages related to the retailer's products. If other partners give the necessary authorization to the retailer, for example through a multilateral agreement, the manufacturer can then have access to the other partners' data related to the retailer's operations.

In the case where two members are not direct partners, meaning that they do not share a direct product flow, as for instance two retailers, they still can share information about a certain manufacturer's product flow involving their operations since they are indirectly influencing each other through their relationships with the manufacturer. If they are not competitors, sharing information about the manufacturer's products can increase their understanding of their joint impact on the manufacturer and their indirect impacts on each other. Furthermore, if the manufacturer is part of the collaboration, the understanding will be more complete and strategies can be developed to maximize the benefit for everyone.

In the case of two competitors, Keskinocak et al. (2008) suggest that a necessary and sufficient condition for a buyer to collaborate with another buyer is that the sharing should result in an increase of sales. It can be debated that expected profit increase may be more pertinent, yet this gives the essence of multi-buyer collaboration motivation. In the exceptional case where a client has a single direct supplier and the supplier has only one direct client, the two partners can share all of their supply network data because neither of the partners is dealing with the competitors of the other partner.

While more in-depth research is required to identify which information should be shared with which member and in which context, each member should seek to optimize gain versus loss from data exchange through bilateral agreements with potential members. The bilateral agreement should specify the data provided by each one of the parties, the time, and frequency of the exchange.

Web Dimension Implications on SCM Decision Support

Managing supply chains and networks within logistic webs requires sophisticated and adapted technologies. Current decision support systems do not yet address all key aspects of the real complexity of supply chain systems. This subsection investigates the nature of the existing supply chain decision support systems and then defines decision support system requirements in complex supply environments.

The Nature of Existing Decision Support Approaches and Technologies in Supply Chain Management[4]

The advancement of supply chain management would not have been possible without the support and intense use of diverse technologies. According to Nof et al. (2006), manufacturing companies are facing both classic and novel problems at business and legal levels in a dynamic, complex, and stressful environment. They highlight that these problems involve uncertainties, globalization challenges, and the need for rapid change, cooperation, conflict resolution, coordination and scheduling, better and more realistic models, more effective understanding and interaction between diverse models and markets. Managers face the challenge of using and analyzing data in order to exploit its potentials at various levels of aggregation, expertise, and needs. The logistics data is related to several companies and the interactions among them. Examples of commonly shared data are sales, orders, forecasts, inventories, and deliveries. In this situation, the technology can be considered no less than an enabler and facilitator of partnerships with suppliers and customers (Spekman, et al., 1998).

Moreover, considering supply networks and logistic webs as complex adaptive systems reveals an important aspect about the nature of the currently dominating research in supply chain management. This research focuses on variant studies adopting structural approaches using surveys, discrete-event simulation, case studies of dyads, or analytical models (Pathak, et al., 2007). In addition, the available supply chain software solutions are mainly internally oriented and single company focused. Given the dynamics of logistics contexts, these software solutions are insufficient and additional features are necessary, notably to deal with inter-organizational coordination and complexity. Eschenbächer et al. (2003) affirm that popular solutions available in the market such as supply chain management applications address only the cooperation between an enterprise and its closest suppliers or customers while the supplier's suppliers and the customer's customers are not taken into

[4] This section is an extension of section 2.1 in Montreuil, B., Labarthe, O., Hakimi, D., Larcher, A., & Audet, M. (2009). Supply Web Mapper. *Proceedings of International Conference on Industrial Engineering and Systems Management (ISEM2009).*

consideration. They also state that although the logistics management of an enterprise toward its direct neighbours might be optimized, the overall supply chain is far from optimal. Fisher (2003) asserts that generally, supply chain performance has never been worse in spite of all the technology and new techniques. He attributes this poor performance to the shortage of frameworks that support managers in choosing which methods are appropriate for which contexts. Storey et al. (2006) suggest that managers need to adopt dynamic approaches that adjust to their needs instead of a “best practice” approach.

Information and communication technologies offer important perspectives for business analysis and decision support. Software solutions on the market provide applications that focus on the management of a company’s processes. Among their features, we find the automated placement of orders, inventory policy determination, product flow control, and shipment monitoring. Cost reduction, revenue increase, uncertainty control, and the need for customer satisfaction are the cardinal reasons motivating the investments made by companies in these solutions (Fawcett, et al., 2007). However, many of these solutions were deployed during the last decades but there is a perceived gap between the needs and the available computer solutions that were initially conceived for use in departments such as finance, accounting, and production. Zhang et al. (2009) believe that tackling the complexity imposed by supply networks as complex adaptive systems has been beyond the existing tools and techniques and requires revival and extensions.

Supply chain management solutions face the challenges of dealing with increasing mass customization of products at lower costs and better quality, addressing recycling and environmental concerns, enabling efficient reconfiguration capability, and integrating new technological solutions, from nanotechnology sensors to wireless communication (Nof, et al., 2006). According to Chou et al. (2004), supply chain management software has been confronted for over a decade with two major challenges. The first one consists of integrating supply chain management solutions, based upon the Web, with a legacy of current internally oriented applications focused on a single company, mostly based upon other technologies, such as a central server or client-server software architecture. The second challenge is to connect heterogeneous information systems of various actors to facilitate the virtual integration of organizations into networks whose members can be partners or competitors. It is crucial to understand why current software solutions are unable to meet these challenges adequately.

Information and communication technologies have an enabling role in the implementation of collaborative practices. These technologies are at the origin of evolutions in capabilities and in the sophistication of architectures supporting the new forms of interactions (Pramatari, 2007). Davenport et al. (2004) maintain that supply chain management software applications primarily deal with optimization and advanced planning. Applications dealing with advanced planning, such as Enterprise Resource Planning systems, integrate functions such as purchasing, supply, production, transport, distribution, and sales (Helo, et al., 2004). The implementation of transversal collaborations requires inter-organizational information systems supporting the decision-making process in such contexts (Ballou, 2006). The satisfaction of the companies' needs remains limited with regard to the integration of external partners' data (Edwards, et al., 2001). This underlines the improvements needed in order to increase the synergies between companies evolving in complex logistics environments. Pramatari (2007) presents the key limitations and the points to improve upon in the deployment of these solutions, such as data-integrity and synchronization issues, the quantity of the automated inter-organizational system links, and the user involvement issues.

In conclusion, there is a lack of a holistic vision in the dominant existing approaches for decision support in supply chain management and a shortage of technologies able to address the complexity and the dynamicity of real logistics and supply environments. The next subsection investigates what kinds of requirements are necessary to provide an adequate decision support in complex logistics systems at a web dimension.

Decision Support Requirements in Complex Supply Environments

Gorry et al. (1971) classify decisions based on whether the tasks are structured, semi-structured, and unstructured, as shown in Figure 13. For the well-defined structured tasks, it is possible to entirely or partially automate the problem solving process resulting in a completely or partially programmed decision support. Then the possibility for automation decreases with the decrease of the problem structuring degree. Many researchers such as

Weiss (2000), Adla and Zarate (2007) and DePass (2007) suggest that in order to improve the chances of success of a decision support system, it is important to integrate the decision-maker in the decision loop to fully exploit the human aptitude to perceive and to judge.

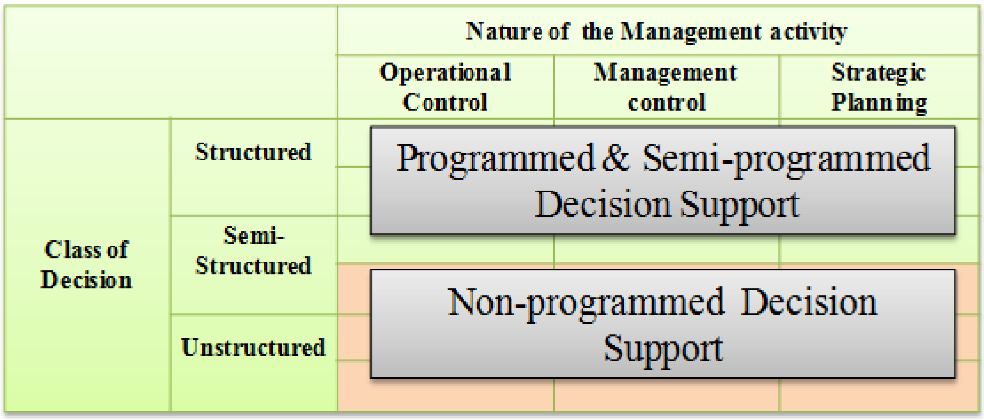
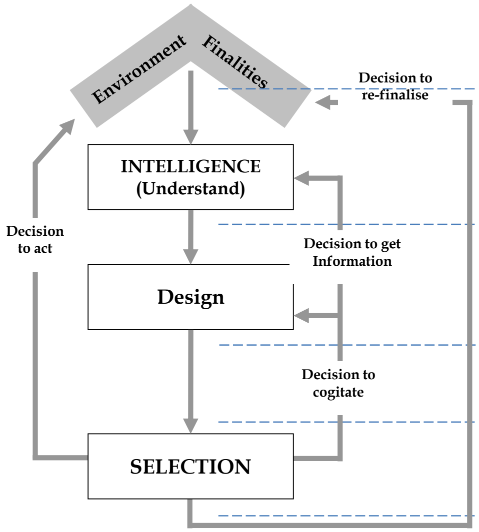


Figure 13 : Types of Decision-making Based on the Nature of the Problem and the Management Level

To understand what decision support systems or business intelligence tools should offer to support the management of supply operations in logistic web contexts, it is necessary to study the process of decision making in these environments. There is a variety of decision process models (Jankovic, et al., 2009). Here we exploit the canonical model of the decision-resolution process (LeMoigne, 1999) developed after the Intelligence-Design-Selection model of Simon (1960). Figure 14 shows, in the left part, the canonical model stipulating that, in a complex environment, the decision process consists of four phases: evaluation, intelligence, design, and selection. The process is a non-linear mechanism, which may iterate many times over two or more phases and be applied entirely within each phase (Simon, 1960). In complex logistics contexts, this process involves a cross-organizational, multi-actor, and multi-decisional-layer interaction (Lee, et al., 2008).



Types of Decision Support	Characteristics of Decision Support
• Perception • Observation • Evaluation	• Accurate capture of dynamics and details • Multi-dimensional disaggregation and aggregation • Time dimension investigation • Prioritization of what is displayed • Attention attracting • Intuitive, interactive and interconnected manipulation
• Problem identification • Comprehension • Analysis	• Multi-dimensional view of problems • Customized analysis • Multi-user decision support • Collaboration decision Support (cross-organisational and cross-departments)
• Alternative solutions	• Generation of solutions • Proposition of solutions
• Solution evaluations • Selection of a solution	• Solutions' outcome assessment (qualitative and/or quantitative) •`What-if analysis • Holistic evaluation of the impact

Figure 14: Application of the Canonical Model of Decision-Resolution Process to Complex Supply Contexts

Decision support may be required at each of the four phases of the decision process. However, its nature varies from a phase to another. Figure 14 presents for each phase the decision support types and characteristics in a logistic web context. The evaluation phase in not shown on the model since according to Simon (1960) it can be merged with the intelligence phase because the end of each decisional process defines the action of which the results will trigger the next process.

The evaluation phase consists in observing the environment and reviewing the results of action plans maintained at the selection phase. The evaluation phase dictates which problem(s) and which element(s) of a problem are the most related to a certain anomaly to be address or gap to be filled. In this phase, using their ability to perceive and observe, managers aim to detect anomalies and gaps in a very dynamic environment flooded with data. Decision support in this phase should enhance this ability by highlighting and prioritizing the issues to address. In order to do so, it is essential to capture an accurate image of what is happening using sophisticated tracking and communication technologies such as RFID, GPS and bar-codes. These technologies provide a continuous data feed reflecting the state of the environment and allow monitoring of a logistics context using visualization software solutions.

The resulting visualizations should support various degrees of aggregation enabling managers to examine any desired level of detail from the most aggregated to the most disaggregated. They should:

- Provide the possibility to investigate the past, monitor the present, and study future projections;
- Provide easy-to-understand displays that give a global image while attracting the user's attention to the most urgent matters;
- Be intuitive and interactive, easy to manipulate
- Support viewing different aspects of an issue from various angles.

The intelligence phase involves identifying, understanding and framing the problem requiring decision support. In this phase, human intervention is hardly replaceable. Although there are some efforts to exploit artificial intelligence to produce learning software agents, it is still too immature to devolve the entire decision process to software applications. Managers are required to use their intelligence to identify, understand, and analyze a problem after they perceive anomalies and gaps in the previous phase. They should investigate different paths leading to the roots of the problem in order to identify the real causes. For this task, managers use their ability to investigate and analyze. Therefore, the decision support should focus on accentuating these abilities by offering mining tools that support drilling in and out through multiple dimensions.

In complex logistics environments, decision-making involves ever more actors (Zaraté, et al., 2009). Multi-user, cross-department and cross-organizational decision-making is thus a necessary ingredient to maintain and cultivate the notion and the culture of collaboration that governs the logistics activities. Decision support systems should communicate information according to customizable Key Performance Indicators (KPI) in multi-viewer displays for users from different backgrounds and with diverse interests in order to facilitate reaching global solutions and consensus, and make the best use of collaborative strategies and opportunities.

In the design phase, alternative action plans are proposed and potential solutions are constructed. Unless the problem is well defined and very structured, it is difficult to create software algorithms capable of suggesting potential solutions. Whereas the contribution of decision support systems in general can be significant during the other phases of the decision process, so far it is very limited in substituting humans in this phase when high levels of complexity, dynamicity, and interactivity are involved. To design alternative potential solutions, managers have to rely on one side both on their knowledge and on their logic, and on the other side on their judgment ability.

However, the concept of Physical Internet suggested by Montreuil (2011) has the potential to increase the structuration of logistics activities through the standardization of the logistic web nodes, transportation means, and loading units, as well as through the intensive use of connective technologies. The expected outcome is more automation of the decision process and more programmed decision support during the design phase. This subject will be addressed in more detail in subsection 3.3 and section 5 upon the discussion of the Physical Internet impact on supply chain management and the design of a simulation supporting the Physical Internet approach.

The selection phase results in choosing after careful examination the best solution(s) among the alternatives proposed in the previous phase. It consists in assessing the potential outcomes from the implementation of the suggested solutions through what-if analyses. Exact and heuristic optimizations can be used for this type of decision. However, simulations can more suitable, though they may require a significant time and resource investment for developing the simulator and running simulation experiments. In the context of logistic webs, simulation approaches must be holistic, concurrently aiming for modeling comprehensiveness and fine granularity, so as to enable the understanding and assessment of the complex, composite and propagating impacts resulting from a decision. Logistic Web simulation should not only aim to provide an insight into the final empirical results, but also to allow managers to visualize through animations, graphs and key performance indicator cockpits the dynamics and interactions between the elements of a simulated logistic web.

While the current chapter continues studying the implications of the web dimension, the following chapter will focus on introducing a conceptual framework providing guidelines for developing supply and logistic web decision support systems. In the context of our research, such systems have to support a combination of non-programmed, unstructured vs. semi-structured, strategic, tactic vs. operational, cross-department vs. cross-organizational, and single-actor vs. multi-actor decision making contexts. The proposed framework provides an advanced decision support for various aspects of the four phases of the decision process. It sets guidelines for designing tools that will allow managers to visualize, investigate, mine, and monitor a logistic web context and its performance as well as using a holistic simulation approach to study future projections and alternative pasts. Although, our logistic web tools do not explicitly support the programmed decision support, we will extensively study how it can be implemented and simulated in subsequent chapters.

The Potential Benefits from an Open, Reliable, Interconnected, and Global Web Vision

So far, the emphasis was on the implications of the web dimension on logistics and supply issue from organizational/structural/relational perspective by dealing with webs of interconnected organizations. This perspective highlights the fact that the existence of a supply network of organizations within a logistic web implies complex interactions and impacts that go beyond the boundaries of the network. Now, the focus will be more on a functional perspective by viewing the global logistic web as a set of webs serving the main logistics functions, which are the mobility, distribution, supply and service. The underlying principle is that an open, and secure sharing of resources in an interconnected logistic web can bring large and global economic, social, and environmental benefits. The sharing of resources does not require necessarily an implicit intention of collaboration between actors or any long-term commitment as it is stipulated by supply chain and supply network concepts. Any actor can exploit any resource as long as this resource is made available by the owners and that the sharing requirements are met.

Montreuil (2011) proposes an open, reliable, interconnected logistic web enabled by the Physical Internet (PI,π) concept. The Physical Internet has the potential to revolutionize the fields of logistics, transportation, supply chain management, material handling, and facility design by notably exploiting the concepts of openness and universal interconnectivity of logistics networks and services, and generalizing standardized, modular, and smart containers (Montreuil, 2011). The concept emphasizes and exploits the notion of an open global logistic web as a web of which the actors can openly share their available storing, transportation, realization, and service capacities with any other actor as long as the predefined standards are met. The notion of Physical Internet is an example that demonstrates and emphasizes that the web vision offers possibilities beyond comparison to what the network vision could provide. By introducing the notions of open realization, distribution, supply, service, and mobility webs, the Physical Internet vision provides an unprecedented level of flexibility and resource sharing capabilities.

In the following subsections, we detail some of the implications of an open and interconnected logistic web. The first subsection views the web dimension in logistics from a functional point view. The second subsection investigates how the Physical Internet can affect supply chain management and change the definition of what is viewed today in supply chain management as strategic, tactic, and operational. The last subsection discusses the impact of Physical Internet and the Logistic Web on business models and opportunities.

The Web Dimension in Logistics: a Functional View

As it was highlighted in 2.3, the Physical Internet enables the Logistic Web, which can be grasped through its five key constituents: the Mobility Web, Realization Web, the Distribution Web, the Supply Web, and the Service Web. At this level of the discussion, it is important to stress that these webs are considered multi-tier webs. For example, the global distribution web can be seen as a web consisting of continental distribution networks. At a continental level, each of these distribution networks can be seen as a distribution web consisting of Intra-continental inter-country distributions networks, and so on. Montreuil (2011) emphasizes this fact by stating that the Physical Internet is to be based on the same conceptual framework whatever the scale of the involved networks. This can be expressed in a Russian-doll style multi-level way, with networks being embedded in wider networks, each operating according to physical internet protocols and standards (Montreuil 2011):

1. Intra-center inter-processor networks;
2. Intra-facility inter-center networks;
3. Intra-city inter-facility networks;
4. Intra-state inter-city networks;
5. Intra-country inter-state networks;
6. Intra-continental inter-country networks;
7. Worldwide inter-continental networks.

Taking a functional point of view instead of a structural point of view, we were able to define the functions associated to logistics activities into realization, distribution, mobility, supply, and service functions. These functions can target and occur at any tier of the seven tiers defined above, as well as at the interactions between these tiers. Any of these function groups can be either a client or supplier of itself or any other group functions. Figure 15 is a simplified and aggregated representation of these functions and the interactions between them at one level, which should not lead to the overlook of the multi-tier complexity. Each of these function groups can interact with other functions within its own group or with functions of any other groups. These interactions can occur between functions of the same level or different levels.

Realization functions have as ultimate objective to produce and/or process goods (raw materials, components, and products) in order to add value to them and produce entities that are designed to final customers or to the re-integration or reuse by other realization functions in the same or other facilities. They consist of operations such as extracting, mining, producing, assembling, personalizing and retrofitting. They occur in sites and facilities belonging to the realization web, such as plants and assembling factories.

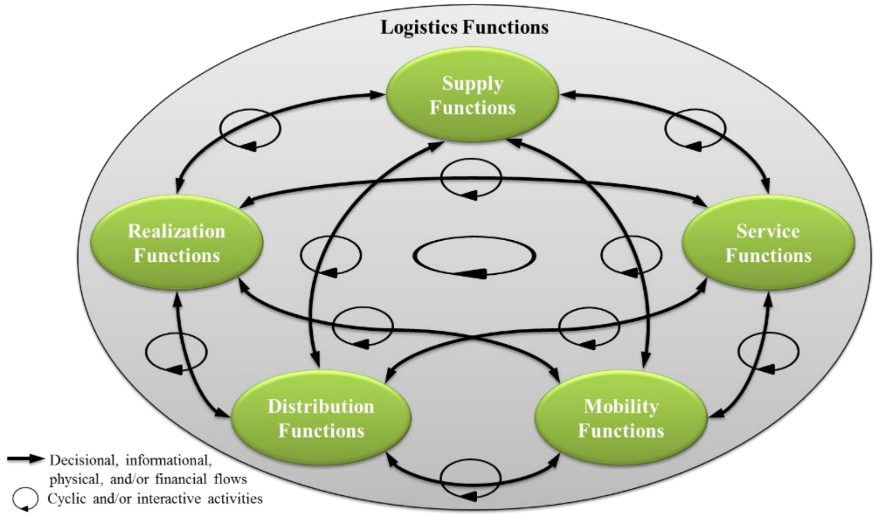


Figure 15: A functional Point of View of the Logistic Web

Distribution functions are activities that consist of distributing, storing, and deploying the products and components resulting from the realization functions. They occur in facilities belonging to the distribution webs such as warehouses and distribution centers. The objective of these functions is to deploy, store, distribute and make available the products and components for their immediate or postponed utilization by other realization functions or customers.

Mobility as it is designated in the Physical Internet vision involves moving physical entities including goods and humans. In this work the focus is only on moving the entities resulting from realization functions such as products and components. In this context, mobility functions deal with moving from sources to destinations the materials, goods and components of various shapes and natures resulting from realization activities.

Distribution and mobility functions are generally not perceived as value creation function but necessary functions required to render product either usable or available for more value adding or for consumption. In addition, achieving efficient, smart and smooth distribution and mobility helps increase the performance of the global process of value creation. For example, without the ability to efficiently transport the maritime containers, it would be impossible to imagine and support a global market and business as the one we are experiencing today. Limitative distribution and mobility functions may in the same manner hinder the process of value creation and block the evolution of markets.

The supply functions are activities whose objective is to get or provide supplies. Supply functions are performed by the actors of a supply network in order to exploit the opportunities and deal with the challenges of their logistic webs, with the goal of acquiring, buying and securing access to materials, parts, assemblies, products, and systems (Montreuil, et al., 2013b). They involve a nonlinear interactive process involving the realization and distribution functions using the facilities of logistic webs to make available raw materials, components, and products to the intermediary and final consumer markets. In Physical Internet contexts, supply functions can additionally deal with sharing space and storage capacities in open distribution webs, and with sharing realization capabilities and capacities in open realization webs. At a strategic level, supply functions aim to selecting suppliers and establishing contracts with them, as well as determining the storage, delivery and service level policies and agreements.

Finally, the service functions in a logistic web aim to enable the accessibility to the services provided by, through, and with physical goods and beings. The objective is to provide efficient and sustainable cooperative consumption on a worldwide basis, such as peer-to-peer lending and sharing of good and facilities or facilitating the remotely access to worldwide expertise by allowing specialists to virtually manage a situation or a team from far away.

Each one of these groups of functions can have a client or a supplier vocation, even concurrent client-supplier vocation, be they realization, distribution, mobility, supply, service, or overall logistics functions. For example, from a distribution web perspective, a supply chain manager can look to rent to other actors the excess of the storage capacity of its company's distribution center located in a certain area, while he tries to find storing spaces in distribution centers located in other areas to stock its company's products.

Strategic Implications

The standardization of logistic web elements into π-nodes, π-movers, π-containers, π-roads, etc.[5] and the high exploitation of connective technologies, as suggested by the Physical

[5] The Greek letter "π" pronounced "PI" is used as the abbreviation for Physical Internet. When the letter "π" is attached to an element as in the wording π-node, which is read pi-node or Physical Internet node, it

Internet concept, has the potentials to increase the regularity, uniformity, and integration of supply operations of multiple independent supply chains within a homogenized logistics environment. The Physical Internet will lead to more structuring in supply activities resulting in more automation of the decision process, more standardization of logistics operations, and easier and smoother resources sharing.

In a Physical Internet environment, the high standardization level of the containerization, realization, distribution, mobility, and communication protocols will increase the integration between the four groups of functions resulting in smoother and easier interactions between them and a higher and efficient exploitation of the resources of the Logistic Web. Thanks to the high standardization, the sharing of resources provided by the realization, distribution, and mobility webs will create open, shared, worldwide-distributed excess capacities for logistics functions within many industries. Thus, at least temporary and for an important part of the industry, the question of resources may shift position with functional questions from strategic to tactical.

To highlight this point, let's push things to the extreme and assume that for a certain industry, (1) the realization web supports producing the products, of this industry, at any region of the world, (2) that the distribution web supports storing and selling these products worldwide, and (3) that the mobility web can move these products between any two facilities of this industry's Logistic Web. What would be the implications on supply chain management for a company that want to sell its products worldwide? In this situation, the design question "where to produce?" should not acquire a strategic characteristic. As long as Physical Internet standards are met, owning or outsourcing, exploiting the same resources over time or dynamically configuring the supply network should not acquire a strategic priority for this company. The strategic questions are now related to the functional aspects. The questions "how to produce?" and "what types of resources are required by the production process?" gain the strategic aspect as they will be the main elements that provide and preserve the competitive advantage of the company.

---

indicates that this element meets the standards defined by the Physical Internet concept for it to be used in a physical internet environment (Montreuil, 2011).

Approaching the Logistic Web from a functional point of view, allows us to ask "how" questions instead of "where" questions. The "where" is relatively an accessory question when assuming a dynamic availability of capacities. The priority shifts from a focus on first defining resources to first defining what to be done. As long as the entire Logistic Web is open and exploitable by any company, the "where" question is more a tactic question of which the answer can be dynamic decisions that exploit the entire web availabilities instead of the limited resources belonging to the company or its partners. Before, "where" questions were related to design aspects and once the "where" decisions were made they were to exist for long-term horizons. In a physical internet context, they can be seen, in many situations, as tactical questions the answers of which can evolve over time and adapt to labor, supply, and demand markets' changes and fluctuations.

In general, viewing the Logistics and Supply Webs from a functional instead of structural perspective will lead to revising priorities and reconfiguring what is now considered strategic, tactic, and operational. Consequently, this will lead innovations at various levels and create new business opportunities. The next section will investigate how this evolution may influence existing business models and create new ones.

Business Model Implications

Defining logistics activities within the global logistic web according to the functional approach provides an endless number of opportunities in terms of identifying business opportunities according to new business models (Montreuil, et al., 2012). As it was mentioned above, each of the group functions defined above consists in itself of a multi-tier hierarchy of subgroups functions. If it is possible to identify the space consisting of all the elementary functions resulting from all the logistics activities, then theoretically any combination from these functions, from a single simple production operation to a complex exploitation of global logistics activities, can be associated to a business opportunity. Below, some examples are presented to show how new business models may be created.

In the Physical Internet approach, mobility functions acquire a special character since the other functions (supply, realization, and distribution) depend on them, and can almost never make sense without them. The mobility is always assumed even if it is not mentioned. The

Supply Web level, where the supply functions and decisions occur, may not deal necessarily and explicitly with mobility functions though they are required for the accomplishment of supply activities (Figure 16). The supply, realization, and distribution webs will deal for example with the questions of how, where, and when to produce and deploy products and the mobility web will take care of moving products to the designated destinations. In this case, companies can build business models that turn around designing products, and setting and managing dynamic supply networks. They may even not own realization and distribution facilities nor manage mobility functions; they will rely on the Physical Internet to produce, transport and distribute their products.

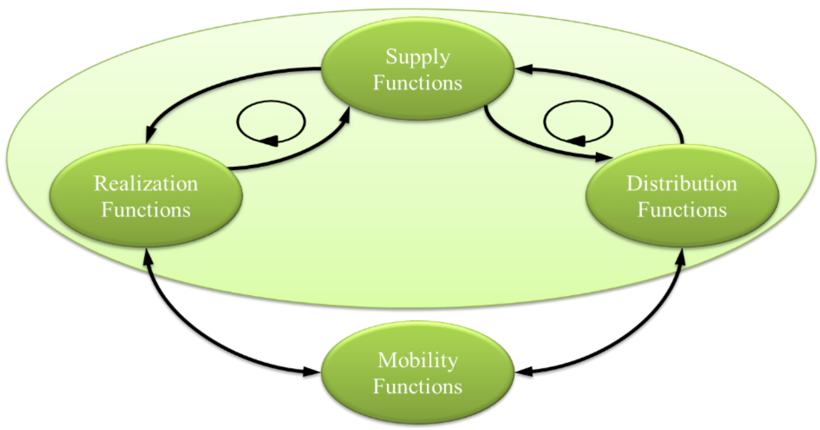


Figure 16: Mobility supporting a supply web business model

Figure 17 presents another form of mobility supporting supply where the supply functions are not explicitly taken in consideration. While Figure 16 focuses on an intentional action of grouping the realization and distribution, and supply functions to highlight either an organizational integration or collaboration toward active supply chain management, Figure 17 represents contexts where realization and distribution actors act as independent entities exchanging physical flows. Though there is a financial and informational flow exchanged between realization and distribution, the actors are not aware or at least do not collaborate to adopt a common supply chain management vision.

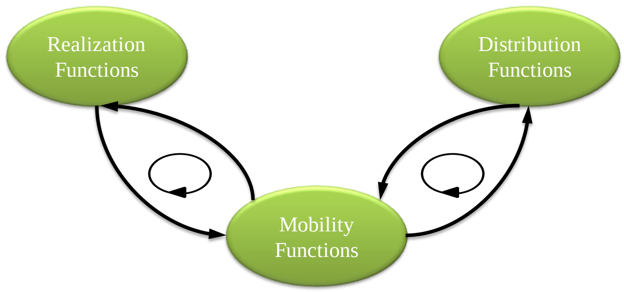


Figure 17 : Mobility supporting supply without a Supply Chain Vision

Figure 18 illustrates mobility supporting realization. The entire production process is spread over many realization facilities linked by exploiting the mobility system belonging to the company or to the Physical Internet. In this context, the mobility functions are part of the realization process as they have as a role to move goods in order to make them available for the next processing stage. They can occur intra-facility such as moving products from a production station to another or inter-facility such as transporting components from a production site to an assembly site. Even if the mobility functions are part of the realization process, the company can exploit the Physical Internet for the inter-facility transportation as an external activity.

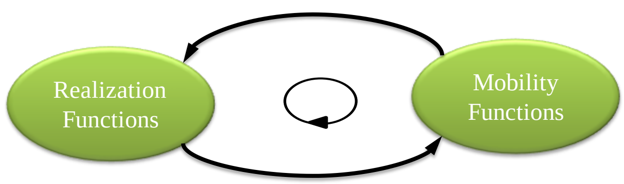


Figure 18: Mobility for Realization

Mobility for distribution aims to move goods from realization sites to distribution sites and between distribution sites (Figure 19). In this case, the objective of goods mobility is not to receive further processing, but rather to change the location of goods for various strategic, tactical, operational, and/or sales reasons. A distribution company may focus on determining the quantities of products to be stored within different geographic areas over time, while delegating to Physical Internet service providers the decisions of identifying the exact open distribution centers where to store its containers and how to move to these destinations.

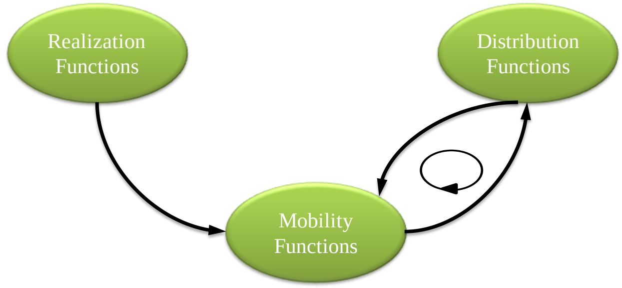


Figure 19: Mobility for Distributing

The examples presented above can result in multiple forms of companies operating under various business models for logistics activities. For instance, in the case of mobility for realization, a company can take in charge the entire design and realization process including or excluding mobility. It may also rather focus on the design of products and the definition of the condition of production while letting the selection of the realization facilities and the mobility to physical internet service providers, or yet to control a part of the production process and outsource the rest, etc. It is possible to suggest many other models, particularly when the multi-tier dimensions and different aggregation levels of elementary functions are considered. However, the examples listed here are considered sufficient to describe and illustrate the potential in terms of new business model opportunities that can be generated by the Logistic Web especially when it is Physical Internet enabled.

In addition to those related to logistics activities, new business models related to Physical Internet services can be conceived around intermediary activities linking different logistics functions or elementary functions. For example, assume that a manufacturer wants to ship products to a site of its client in a certain area. This manufacturer can contact a mobility service company and asks it to ensure the transportation of the products. In this case, the mobility service company is not necessarily a transport company as it can be a routing service provider that can access information about the available travels in that area. It can arrange the travel of the products by selecting a set of transport means that will deliver the products systematically from origin to destination while respecting the manufacturer's specified conditions. These kinds of intermediary services can apply to the intra-realization, intra-distribution and intra-mobility functions, as well as to any combination of these functions.

There are also many other business opportunities that can be developed around these functions such as new information technologies, research and development, standardization, consulting and other services, Physical Internet infrastructure development, and realization, distribution, and mobility means, tools, and equipment respecting Physical Internet standards.

Conclusion of the Chapter

The first objective of this chapter was to show the importance of the web dimension for supply chain management and to try to position potential future research contributions targeting this dimension according to different theories and perspectives that shape the supply chain management knowledge body. For this purpose, two principal streams dominating supply chain management research that are determining the new tendencies in the field were identified.

The first stream is trying to frame supply chain management in a common knowledge body or scientific discipline. It focuses on consolidating the knowledge related to the supply chain management field in frameworks, classifications, or taxonomies in order to harmonize the multiple theories, views, and paradigms that have contributed to the evolution of supply chain management.

The second stream believes that there is still a large gap between what supply chain management is offering and what managers need in terms of decision support. The proponents of this stream claim that most supply chain management technology is either structural or centered on a single company, or at most on a dyadic relationship, therefore limiting the manoeuvrability of managers. For example, Monostori et al. (2006) maintain that many supply chain management systems focus on internal transactional operations of a single site by offering information storage, retrieval, and sharing, but do not provide a real cross-organizational decision support. Thus, supply chain management should consider soft and behavioural aspects within supply networks and embrace perspectives that not only focus on the elements of the supply networks, but also underline the dynamics of the relationships between these elements.

After studying these two streams, the conclusion reached is that though the importance of the web dimension, it was overlooked in both streams and that some of the available theories may help tackle a number of issues brought by the web dimension but are insufficient to cover all aspects. Then, the web dimension was integrated as the new dimension in supply chain management and linked to the theories and views that seem more suitable to be applied to it.

The second objective of the chapter was to demonstrate that there is a necessity for the web dimension in supply chain management. Without this dimension, the field will be unable to explain phenomena related to overlapping networks, face global challenges, and stimulate and support innovations out of the network scope. This was done by studying some important implications of the web perspective on inter-organizational collaboration, decision support system process in supply chain management, as well as on supply chain strategic, tactic, and operational aspects, and on business models. The Physical Internet enabling the Logistic Web was provided as an example illustrating the positive economic, social and environmental implications for the adoption of a web dimension.

The following chapters will further examine the implications on inter-organizational collaboration and decision support systems from a technological point of view by primarily studying the design of logistic web solutions. The next chapter will expand and develop the design issues identified in section three of this chapter, namely the design of logistic web database systems and logistic web software applications.

Logistic Webs and Decision Support Systems

In the previous chapter, we looked at some general implications of the web dimension on supply chain management in particular and on logistics and different businesses in general. We investigated what the implications on decision support and on collaboration are for today's logistic webs and stressed out that the potential and benefits of the web dimension would be even greater if the logistic webs have to evolve to be open, interconnected, and reliable enabled. In this chapter, we focus on studying the existing logistic webs featuring embedded supply networks of supply chains. We emphasize here the web perspective as an extension of supply network concept to provide a more expressive and holistic framework that addresses the real issues facing companies and managers in complex and dynamic environments. In this context, the logistic web we refers to is an existing and dominant types of mobility, distribution, realisation, and supply networks centered around a company, a supply chain or a supply network. It is not open nor is it interconnected or global. To provide more understanding of these types of webs an example is illustrated through Figure 20, Figure 21, and Figure 22.

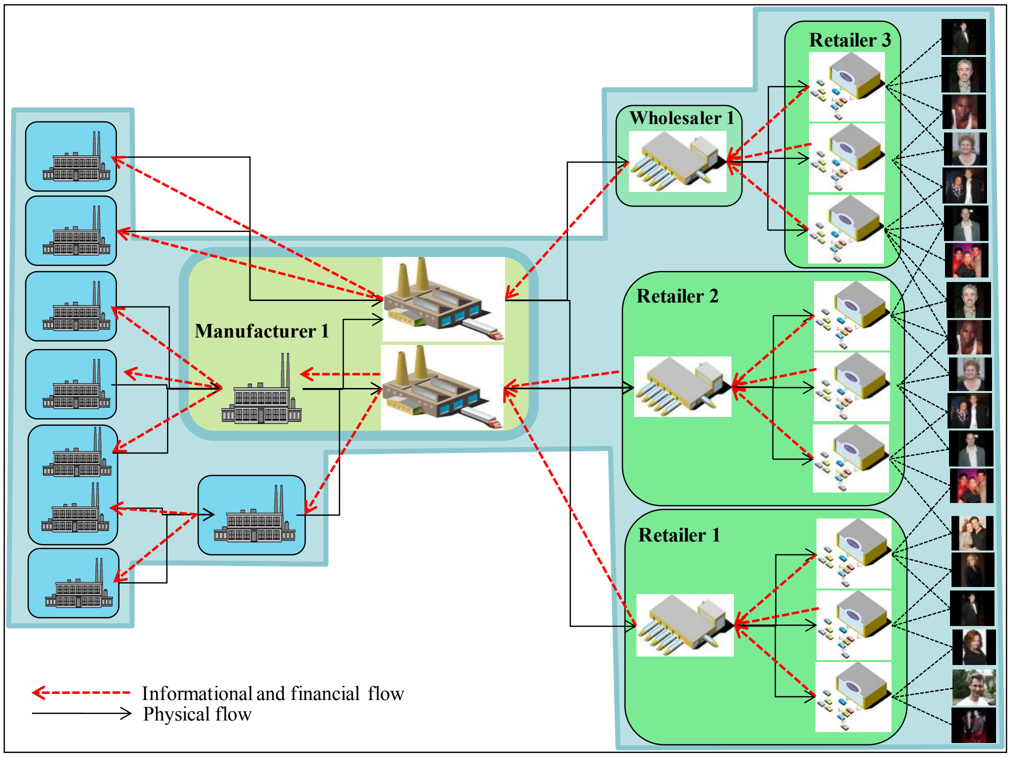


Figure 20: The Supply Network of Manufacturer 1

In Figure 20, mapping the supply network of manufacturer 1 provides its managers with a view of the manufacturer's impact on the upstream and downstream actors, and vice-versa on the impact of these actors on the manufacturer. Yet, this view is incomplete, offering a partial understanding of the relational reality. This incompleteness stems from the fact that the supply network of each of the actors involves other players not related directly to the business with manufacturer 1, yet having an impact on these actors and indirectly on manufacturer 1. For example, if a parts supplier is also supplying another competing manufacturer and is constantly having to decide to whom among both manufacturers it shall devote its productive capacity, then for manufacturer 1, the mere view of its single supply network is insufficient to understand its overall supply stakes and risks. It is only by working with the union of both supply networks that one can uncover these complex relationships and manage their impacts.

Generically, an actor may lose competitiveness and put itself at risk by ignoring the indirect impacts of partners of its partners. It is important for an actor to recognize that he is evolving in a supply network that influences and is influenced by other supply networks.

This space of interaction or influence between supply networks can be seen as a larger network of supply networks or a logistic web.

At the extreme, the global Logistic Web connects all suppliers and clients in the world through their relationships and flows. In practice, a logistic web is generally scoped around the supply networks of a set of targeted key actors, for example those defining an industry. Logistic Webs generally include a large number of actors and complex sets of flows and relationships among them. Their representation in totality thus looks like an indescribable and undecipherable spaghetti. It is therefore critical to examine it through selected views depicting targeted subsets of the logistic webs. Such views may be drawn only with the mutual consent of the key actors.

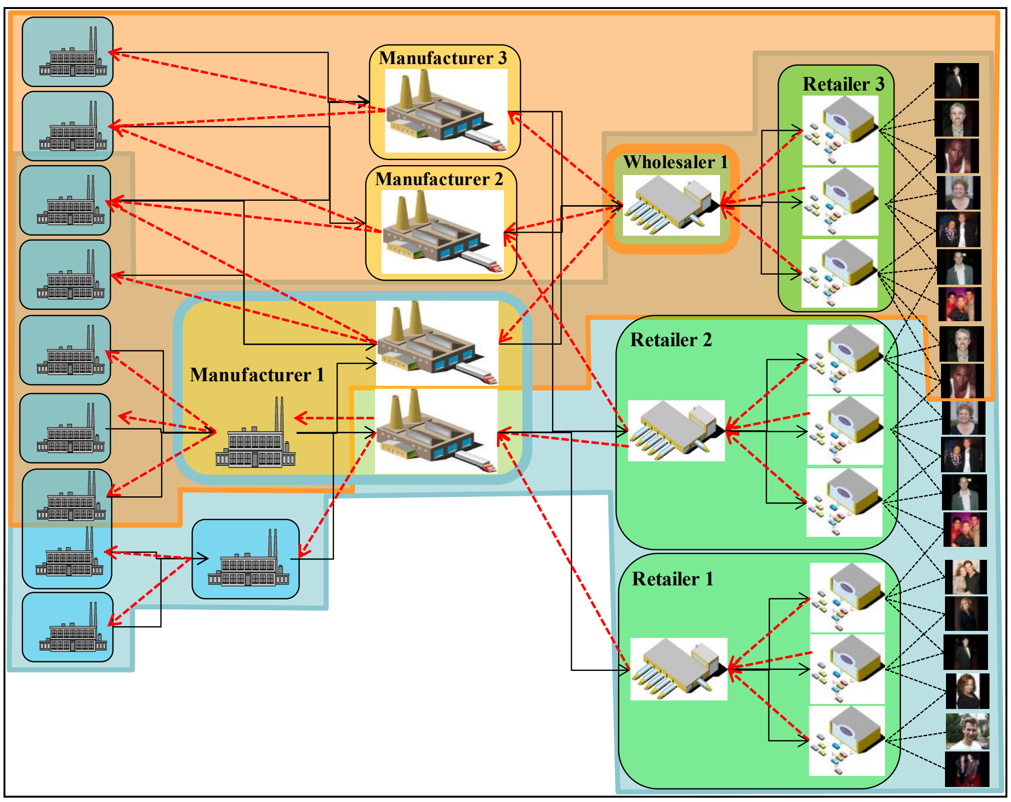


Figure 21: View of the Logistic Web Depicting the Union of the Supply Networks of Manufacturer 1 and of the Wholesaler's Business with Retailer 3

For example, Figure 21 presents a logistic web view depicting the union of the supply network of manufacturer 1 and of the supply network of the wholesaler's business with retailer 3. It shows the zones of overlapping between the two networks, as well as the zones of non-overlapping. It reveals that manufacturer 1 is one of the three manufacturers that the wholesaler deals with in supplying retailer 3. Regardless of whether the three manufacturers are competitors, the wholesaler looks at its entire supply network as one system, where the three manufacturers share the same final customers, its own resources and retailer 3's resources. Therefore, the view displayed in Figure 2 may be helpful for each of the manufacturers to understand the impact of other manufacturers on the wholesaler's and retailer 3's supply and inventory decisions. Moreover, any bilateral collaboration between the wholesaler and one of the manufacturers will reach its greatest efficiency only when both partners fully understand the impact of indirect players on their collaboration. As a further example of logistic web view, Figure 22 adds to the previous view of Figure 21 the supply network of retailer 1. It particularly reveals that the three suppliers of retailer 1 share the same external module plant, which may be a source of synergy and/or a capacity bottleneck leading to supply-side competition between the three manufacturers.

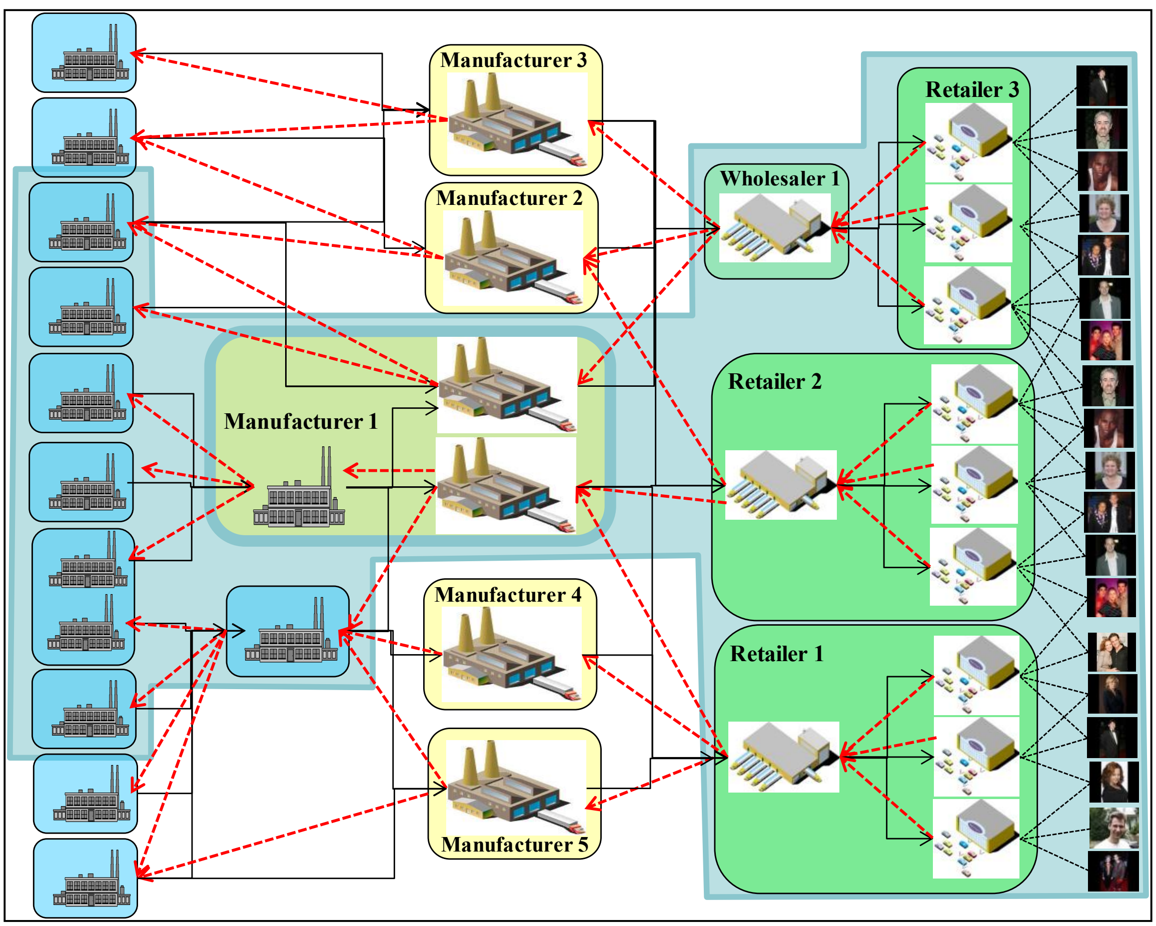


Figure 22: View Adding Retailer 1's Supply Network to the Logistic Web View of Figure 21

The web dimension presents many challenges for managers because of the complexity resulting from the inherent flow dynamics of thousands of products, as well as from the difficulty of adequately treating the numerous client-supplier relationships established between hundreds, or even thousands of actors who can be partners, competitors, or sometimes both at the same time. Dealing with the complexity of a logistic web does not necessarily imply a complication of supply chain management. On the contrary, it provides the opportunity to understand the real influence of the logistic web environment on logistics operations and decisions. Logistic Web considers elements that have been overlooked despite their major impact on supply networks and supply chains and opens a world of opportunities for exploiting large resources that are poorly and un-inefficiently used.

As logistic webs are complex adaptive systems, there is a need for fast, agile, and robust tools that support the multidimensional manipulation of data. Without proper and advanced decision support and business intelligence systems that integrate the knowledge and information from various companies, capture the essentials of a logistics context, and provide managers with the right and precise information required for decision-making, it becomes near to impossible to ensure and support the supply chain evolution and innovation within logistic webs and to sustain high-performance logistics operations.

The complexity of logistic webs imposes a need for a multidisciplinary approach to understand them and support the management of logistics operations within them. Multi-agent systems, business intelligence, visual analytics, Internet based solutions and simulation are concepts that have proven their utility in contexts of complex relationships, large volumes of data, unstructured decision-making processes, and high dynamicity. Mixing these concepts in a multidisciplinary approach for supporting decisions in the context of logistic web can result in the design of the most advanced tools.

Based upon the framework of decision support requirements in complex logistic web environment presented in the previous chapter, the objective of the current chapter is to identify the guidelines to design logistic web technologies. We will capitalize on our expertise, guidelines provided in scientific literature, and on our own creativity to prototype and produce an innovative kit of sophisticated logistic web business intelligence and decision support technologies.

The next section of this chapter is dedicated to a multidisciplinary literature review. It covers and interlinks aspects directly related to the issue of designing decision support systems for complex adaptive environments specifically in supply chain management. We identify the following pertinent subjects: decision support systems, business intelligence, decision support systems in supply chain, multi-agent systems, and data exchange mechanisms, simulation, and smart data visualization.

Section two introduces the conceptual framework for designing logistic web technologies, presents our proposition of logistic web solution architecture, and defines the principal design requirements for each component of the solution. This section starts by describing the holistic design vision, the logistic web solution, and the technologies of which it consists. It explains how a logistic web solution can be integrated into the information system of a company and how logistic web solutions belonging to different members are interconnected. Then each component is detailed and the criteria for its design are specified.

Section three presents a set of logistic web business intelligence and decision support systems exemplifying the suggested architecture. These software tools are the logistic web mapper, which is a static logistics mapping tool, the logistic web playback, which is a dynamic logistics history reviving tool, and the logistic web monitor, which is a real time logistics monitoring tool.

Section four details various aspects of the conceptual model of the logistic web simulation platform and discusses the methodology and the approach used to generate the demand scenarios provide as input for logistic web simulations. The chapter concludes with a summary and a discussion of its contents and future research avenues.

Multidisciplinary Literature Review

In the previous chapter, we demonstrated the lack of tools that can support managers in dealing with complex issues related to the management of logistics operations in logistic web environments. We will now examine the literature in order to determine the guidelines for designing the appropriate decision support systems that are able to support the complexity we are facing.

The first subsection of the literature review introduces the notions of decision support systems and business intelligence. Subsection two analyzes decision support systems in the supply chain, defines the criteria of supply chain management decision support systems, and investigates the use of multi-agent systems within supply chain management. Section three determines the key elements to be taken into consideration for designing multi-agent systems. Section four explores different approaches of data exchange through the study of the coordination and collaboration approaches in multi-agent systems for the supply chain. Section five reviews examples of multi-agent simulation applications. Section six introduces the visual analytics and highlights its importance for supply chain management. Section seven synthesizes the knowledge gained from this literature review.

Introduction to Decision Support Systems & Business Intelligence

Since we live in a world that is governed by complex laws and behaviours, we will always want to direct uncontrolled dynamics toward goals that suit our desires. However, since our capacity to process and use large amounts of complex data, resulting from our modern lifestyle, is limited, Decision Support Systems (DSS) are created to enhance and extend this capacity in order to make better decisions. Generally, these systems are not intended to execute actions in order to control the real world directly. Instead, they support the control personnel responsible for taking such actions. Thus far, no artificial system is able to replace the human ability to judge; therefore, there is a need to provide smart decision support tools so that we can maximize the accuracy of our judgements (Thomas, et al., 2005). Decision support systems can issue alerts to attract the user’s attention or supply answers to the user’s inquiries.

Decision support systems can be defined as "*interactive computer-based systems that help people use computer communications, data, documents, knowledge, and models to solve problems and make decisions*" (Power, et al., 2009). Business Intelligence (BI) is a form of decision support systems dedicated to the analysis of large volumes of data regarding firms and their operations. According to Dayal et al. (2009), business intelligence refers to technologies, tools, and practices for collecting, integrating, analyzing, and presenting large volumes of information to enable better decision making. Stated in a different way by Negash and Gray (2008), a data-driven DSS combines data gathering, data storage, and knowledge management with analysis to provide input to the decision process. Business intelligence systems are based upon sophisticated analysis tools exploiting a large database, typically a data warehouse, or a data mart. Examples of analysis techniques are diagram reports, slice-and-dice, drill down, ad hoc responses to queries, real-time analysis, and forecasting (Negash, et al., 2008). In general, Power et al. (2009) identify three major characteristics of decision support systems: (i) they are designed specifically to facilitate decision processes; (ii) they support rather than automate decision-making; and (iii) they respond quickly to the changing needs of decision-makers.

Weiss (2000) maintains that decision support systems are rarely designed to provide optimal solutions. Rather, they are used to suggest multiple alternatives and assess various options of satisfactory solutions to transit from a certain world state to another supposedly better state. In general, a decision support system should help address the following critical questions: (1) what is happening? (2) what may happen? and (3) what should be done? Regarding the first question, the system should be able to analyze, understand, and identify the criticality of a situation. For the second question, the system needs to evaluate the potential evolution of a situation and if the expected outcome is unfavourable, it should allow the user to take corrective actions. What-if analyses are provided through questions of the type "what may happen if…" which is considered as another variant of question (2). The objective of the third question is to provide potential actions that can be taken to improve the results of system operations (Weiss, 2000).

The evolution of information and communication technologies and computers facilitates the inter-organizational collaboration and integration. This results in a continuous increase in the complexity of logistics operations dictating a need for more complex decision support software. Johnson (2007) believes that as software complexity increases, the availability of the right decision support systems that deal with new issues decreases. He suggests that the dependability of software applications may limit the progress of automation within companies. DePass (2007) views the existing decision support tools as inflexible. The current systems do not integrate the user into the processes of decision-making. Future systems must support decision processes in dynamic contexts where perturbations and events are occurring at very high rates. They should perform what-if analyses, learn the users' preferences, employ large databases and knowledge bases, and support users in making fast decisions. What's more, DePass (2007) posits that the available systems are unable to respond quickly enough and that in order to meet today's planning demands, these tools need more flexibility and continuous improvement.

Decision Support Systems in Supply Chain Management

Supply networks consist of independent companies collaborating to exploit market opportunities. These companies are sharing skills, resources, and information. The scope of logistics operations is in perpetual expansion given globalization and international outsourcing. Supply chain management systems, supporting decisions in this sort of context, are facing increasing complexity as a result of market uncertainty and a rapidly changing environment. Recent advances in information and communication technologies provide a potential solution for these issues. The management of huge quantities of data, supplied by these technologies, is a challenge, but also an opportunity if the data is effectively exploited. However, without artificial intelligence tools and methods providing advanced managerial decision support, it is impossible to cope with these issues (Nof, et al., 2006).

In general, supply chain management is characterized by a high sensitivity to failure, a need for clear and well-structured logic supported by justifiable facts, a substantial mixture of information and knowledge from diversified sources, and a dynamic and extremely rapidly changing environment. For this reason, the utilization of decision support systems in supply chain management is justified according to Weiss (2000). Furthermore, the 21st century is imposing new challenges on DSS for supply chain management concerning their responsiveness and focus on cost and quality. Shen, Hao, Yoon, and Norrie (2006) affirm that the new generation of decision support systems for supply chain management has to face the challenge of six fundamental requirements concerning their responsiveness and their focus on cost and quality. First, there is a need for full integration of heterogeneous software and hardware systems within an enterprise, a virtual enterprise, or across a supply chain. Second, DSS should have an open system architecture to accommodate new subsystems (software or hardware) or to dismantle existing subsystems "on the fly". Third, there is a need for efficient and effective communication and cooperation among departments within an enterprise and between enterprises. Fourth, DSS should embody human factors into supply chains. Fifth, they should enable quick response to external order changes and unexpected disturbances from both internal and external manufacturing environments. Sixth, there should be fault tolerance both at the system level and at the subsystem level to detect and recover from system failures and minimize their impacts on the working environment.

Designing decision support systems based upon traditional centralized architecture does not fit the distributed nature of supply chains, networks, and webs. According to Nof et al. (2006), a centralized architecture has two main disadvantages: (i) the inability to meet distribution requirements in automation, and (ii) the inability to meet the goal of standardizing object-automation oriented approaches to design distributed automation architectures. Distributed systems should ensure the reliability and support of interactions among various software solutions under different hardware infrastructures. The authors emphasize that distributed technical intelligence through data/information processing, storage, and communication provides advanced automation for large and complex production and supply systems. Distributed systems should ensure the reliability and support of interactions among various software solutions under different hardware infrastructures. Reciprocally, the infrastructure should also be flexible in order to accommodate the evolution of these applications.

The most important questions to be addressed according to Monostori et al. (2006) are (1) how to achieve the appropriate representation of process models? (2) how to model various constraints within and between business functions, such as marketing, design, planning, manufacturing, and material supply? and how to use them in order to find the best-of-practice process? (3) How to maintain interdependencies within the network of organizational entities?

In order to tackle the challenges imposed by the new reality of supply chain management and to maximize the benefits from potential opportunities, researchers increasingly turn to multi-agent modeling. This flexible type of modeling is ever more deemed appropriate to represent the dynamics, complexity, and distributed aspect of supply chains given the great similarity between industrial systems and multi-agent systems. In both systems, actors are autonomous, have decision-making abilities, are able to collaborate and adapt to their environment (Moyaux, 2004; Labarthe, 2006; Shen, et al., 2006; Lee, et al., 2008).

Multi-agent systems have many applications in supply chain management. According to Kovalchuk (2009), these systems provide (i) distribution and control of data and resources; effective collaboration, communication, and negotiation among separate entities; (ii) coordination of the information flow; (iii) an integrated and unified framework, which is task independent; and (iv) resolution of distributed constraint satisfaction problems within supply chains. Monostori et al. (2006) categorize the applications of multi-agent systems in supply chain management into two types: (i) a general dominating approach that handles supply chain management as a problem of designing and operating a multi-agent system; and (ii) a second approach that uses some multi-agent characteristics to address specific problems in supply chain management, such as collaborative inventory management, bidding decisions, and material handling and inventory planning in warehouses.

The use of agents in e-Business applications offers a significant number of opportunities, thanks to characteristics such as autonomy, perception, reasoning, and act, and the capability to cooperate with other agents (Shen, et al., 2006). Kovalchuk (2009) believes that agent technology provides a natural way to design and implement efficient intelligent systems for supply chain management, where information is distributed and each link of the process is both self-focused and dependable on other links. Fox et al. (2000) summarized the characteristics that supply chain management systems should feature in fourteen elements among there is distribution, dynamicity, intelligence, interactivity, responsiveness, reactivity, cooperation, interactivity, availability, configurability, and adaptability.

There is a variety of applications developed and applied in manufacturing and the supply chain, based upon different methodologies and architectures (Monostori, et al., 2006; Shen, et al., 2006; Frayret, et al., 2007; Forget, et al., 2008; Lee, et al., 2008; Gaudreault, et al., 2009; Forget, et al., 2009; Gaudreault, et al., 2012) (Monostori, et al., 2006; Shen, et al., 2006; Lee, et al., 2008). The use of multi-agent modeling in manufacturing and supply chain systems knows an increasing interest from researchers and practitioners (Shen, et al., 2006). However, the research has not yet fully exploited the potential offered by multi-agent systems, primarily because of the obstacles to match multi-agent systems with practical disciplines such as manufacturing engineering and supply chain management (Lee, et al., 2008). In their extensive literature review, Shen et al. (2006) classify the research of agent-based systems for intelligent manufacturing under five categories: (1) enterprise integration; (2) enterprise collaboration (including supply chain management, virtual enterprises, and other collaboration types); (3) manufacturing process planning and scheduling; (4) manufacturing shop floor control; and (5) Holonic Manufacturing Systems. The fact that the research encompasses so many topics indicates that multi-agent systems can be applied to all the aspects of supply chain management at various levels of detail.

Lee et al. (2008) classify multi-agent research contributions in supply chain management into two categories, according to the problem addressed: (1) Research dealing with supply chain dynamics problems: This research seeks to handle the complexity and the dynamicity of supply chain networks by adjusting multi-agent applications to the real world supply chains. Decision-making is at the heart of this kind of research. (2) Research dealing with supply chain coordination problems: This research focuses on subjects such as information sharing, coordination between agents in virtual markets, and integration of the entire supply chain. The following two subsections are respectively going to look at these two specific categories because they are tightly linked to the subject of our research.

Multi-agent Systems for Supply Chain Dynamics

The multi-agent approach is particularly well adapted for designing decision support systems for supply chain management. The research related to multi-agent systems investigates notions such as autonomy, reactivity, goal-directed reasoning for the individual behaviour of agents, as well as cooperation, coordination, negotiation, and adaptivity in social and collective behavioral contexts (Bussmann, et al., 2004). These notions fit exactly the nature of logistic web environments. The application of decentralized agents in enterprise integration can allow diverse entities of the organization to remain connected with each other, without losing their autonomy. It enhances the collaboration and increases the flexibility, reliability, and performance of the entire system (Monostori, et al., 2006).

Moreover, agent-based modeling is recommended for designing software applications for complex adaptive logistics systems (Pathak, et al., 2007). Real world manufacturing systems and their environments encompass high complexity and dynamicity. They should be considered as “Complex Adaptive Systems” according to Surana et al. (2005) who argue that the most remarkable phenomenon exhibited by complex systems is the emergence of highly structured collective behaviour over time from the interaction of simple subsystems without any centralized control. The agent concept perfectly matches with the complex adaptive system features and forms a feasible implementation infrastructure for complex adaptive system simulation and realization (Shen, et al., 2006).

Besides the academic contribution, the research addressing supply chain dynamics includes projects for developing applications with and for the industry. According to Shen et al. (2006), software agents typically encapsulate existing legacy software applications using varied middleware approaches in these types of projects. They are related to various sets of domains, such as agile and intelligent manufacturing, product development, and warehouse planning. Examples of decision support applications that capitalized on the use of multi-agent approaches in modeling and dealt with the complexity of supply chain management include ADINS (Ahn, et al., 2004) and “Dialog” System (Främling, et al., 2006).

There are many considerations to be taken into account when designing multi-agent systems. Shen et al. (2001) identified a set of key issues relating to agent-based cooperative systems, such as representation, ontology management, agent structure, system architecture, communication, system dynamics, overall system control, conflict resolution, legacy systems integration, and external interfaces. Based upon their experience and review of several research projects, Shen et al. (2006) single out eight issues to observe when designing multi-agent decision support systems for manufacturing systems, including supply chain management systems[6]. These issues are: (1) agent encapsulation, (2) agent organization, (3) agent coordination and negotiation, (4) system dynamics, (5) learning, (6) optimization, (7) security and privacy, and (8) tools and standards. In the following subsection, we will review some of the issues that are most closely related to our research.

Agent Encapsulation

Three encapsulating approaches are used in agent-based systems: functional decomposition, physical decomposition, and a hybrid between these two decompositions. In functional decomposition, agents are not mapped on physical entities. They encapsulate functional modules such as order acquisition, process planning, scheduling, material handling, transportation management, and product distribution. In the physical decomposition approach, agents represent entities in the physical world, such as operators, machines, tools, fixtures, products, parts, features, and operations. In hybrid systems, heterogeneous physical agents are coordinated by other system-level functional agents. (Shen, et al., 2006)

Agent Organization

According to Lee, et al. (2008), on the one hand, Moulin, et al. (1996) identified three types of cooperative agents based upon autonomy and rationality: reactive, intentional, and social. While reactive agents principally react to environmental changes or other agents' messages, intentional agents are autonomous and act to achieve their goals, and finally, social agents combine features of both types and carry out action-plans. However, on the

[6] Manufacturing systems, according to Shen et al. (2006), include: (1) enterprise integration; (2) enterprise collaboration (including supply chain management, virtual enterprises and other collaboration types); (3) manufacturing process planning and scheduling; (4) manufacturing shop floor control; and (5) Holonic Manufacturing Systems.

other hand, Baker (1998) distinguishes three types of modeling architectures based upon governance structure: functional or hierarchical architecture, blackboard architecture, and heterarchical architecture (Figure 23). A similar classification of agent organization approaches, with some variation in the category names, is identified by Shen et al. (2006) for agent-based manufacturing systems: hierarchical, federation, and autonomous. First, the agent hierarchical approach is used to represent the real hierarchical structure of the organization. Next, federation architectures use a facilitator to coordinate multi-agent activities; there are three variations of the federation approach: Facilitators, Brokers, and Mediators. Finally, in the autonomous approach, an agent is not controlled or managed by any other software agents or human beings. It communicates and interacts directly with other agents, it has knowledge about other agents and the environment, and, finally, it has its own goals and motivations.

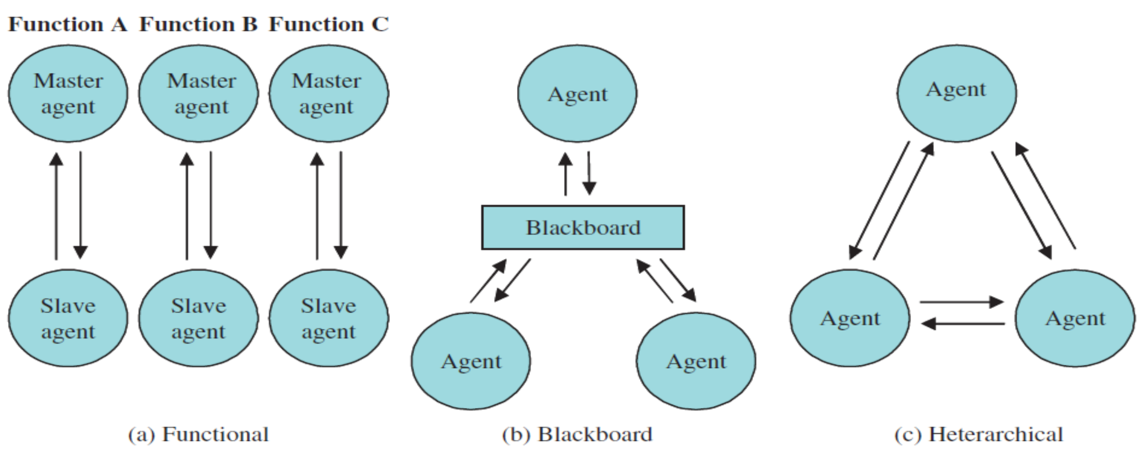


Figure 23: Generic Multi-Agent Systems Architectures (Lee, et al., 2008)

Agent Coordination and Negotiation

The determination of coordination mechanisms among agents is necessary in order to ensure goals reaching in agent-based manufacturing systems, and avoid chaotic system behaviour. It is a mean of solving complex problems in distributed systems as it is in natural social systems. In multi-agent systems, the coordination is either centralized or decentralized (Weiss, 2000). In centralized coordination, a hierarchy of coordinating agents operates to link agents in order to achieve intelligent coordination. In decentralized coordination, each agent is designed to find and communicate with potential collaborators in order to achieve its goals. Decentralized approaches are more flexible and theoretically easier to build, but they do not necessarily guarantee the best quality of intelligence as the system is not explicitly directed toward a common goal. Shen et al. (2001) detail five fundamental coordination mechanisms encountered in supply chain management literature: mutual adjustment, direct supervision, coordination by standardization, mediated coordination, and coordination by reactive behaviour.

Optimization

The agent-based approach capitalizes more on agility and re-configurability of manufacturing systems than on optimization. Thus, the notion of optimization differs in multi-agent approaches from that which is normally adopted in mathematical approaches. While in mathematical approaches, global optimization is obtained through simplified and aggregated mathematical formulations of industrial problems, in agent-based approaches optimization is tackled through efficient coordination mechanisms (Shen, et al., 2006).

Security and Privacy

The use of multi-agent systems distributed among multiple actors involves the exchange of confidential and private data. This raises concerns about security, privacy, and intellectual property. It is very important to ensure that the use of information in distributed contexts respects the requirements and conditions specified among partners, especially in the case of Internet-enabled agent-based manufacturing systems (Shen, et al., 2006).

Tools, Standards, and Modeling Approaches

The mass utilization of the multi-agent approach resulted in a variety of agent-based applications and platforms. There is a need for tools, which support the creation of agent-based applications, and standards unifying the manner in which these applications are designed. FIPA (Foundation for Intelligent Physical Agents) and NIIIP (National Industrial Information Infrastructure Protocols) specifications are examples of efforts trying to provide standardization for how agent platforms can interoperate. However, there is no particular standard for developing agent-based manufacturing systems (Shen, et al., 2006).

Many multi-agent modeling approaches in the literature are available. Some are presented with platforms and each has qualities and pitfalls (Amiguet, 2003). The research has progressed from a focus on agents to a focus on agent systems. Now researchers are concerned with how to model the agents within a system in order to obtain a multi-agent system that will accomplish established goals. A detailed taxonomy of multi-agent system mythologies is found in Lee et al. (2008). Amiguet (2003) proposes a two-level approach, providing both conceptual and operational dimensions. Van der Zee (2006) suggests a framework where agents feature decision-making abilities and represent actual entities in a manufacturing system like workstations, storages, planners, and information systems. Forget, et al. (2006) present a multi-behaviour planning agent model where agents are characterized by three kinds of competencies: a technical competency, a decision competency, and a social competency. The Gaia Methodology (Zambonelli, et al., 2003) is a structured, systemic methodology developed to provide a framework for the analysis and design of agent-based systems. It emphasizes five stages, each involving a set of models. The stages are: (1) collection of requirements, (2) analysis, (3) architecture design, (4) detailed design, and (5) implementation.

Bauer et al. (2005) propose a Model-driven Development Approach (MDA) for the design of agent-based systems. The approach exploits the UML 2.0 diagrams and a three-level model to translate system specifications supporting business processes and workflows into software characteristics. A similar approach is used by Labarthe (2006) in the context of simulation. The three models are: (1) Computation-Independent Model (CIM): This model is independent of computational technologies as it formalizes the detailed overall description and comprehension of business processes and workflows in an executive format. It is the most abstract model within MDA; (2) Platform-Independent Model (PIM): PIM models a system that is supposed to support the best way of operating the business model produced by the CIM. It is an abstract model that is independent of any software platform; (3) Platform-Specific Model (PSM): At this level, the PIM is transformed into one or more PSMs that translate the system specifications into an implementation for specific technologies. Lau et al. (2003) propose an infrastructural framework for designing and developing an agile supply chain system that helps adapt to unpredictable changes related to the management of suppliers and flow of parts within the value chain of the entire production network.

Coordination and Collaboration Approaches in Multi-Agent Systems

There are three types of enterprise collaboration: supply chain, extended enterprise, and virtual enterprise (Jagdev, et al., 2001; Shen, et al., 2006). Extended enterprise is a form of collaboration that involves the advanced integration of functions beyond the traditional ERP/MRP systems, such as customer relationship management, sales chain management, high-level executive decision support, and new business development. Supply chain is an open collaboration among firms that aims to acquire, transform, and deliver products to customers. Virtual enterprise is another form of enterprise collaboration where companies are virtually connected through an intensified use of information and communication technologies (Shen, et al., 2006).

The subject of coordination and collaboration is highly interlinked to the problem of data exchange between members, which is a key issue in designing logistic web decision support systems. In fact, without the exchange of data and information, it is impossible to imagine any form of collaboration or coordination among logistic web members. The multi-agent research supplies various mechanisms and techniques for collaboration and coordination between agents in a given system. Below are some contributions that attempt to deal with the problem of coordination in supply chain contexts.

Holmström et al. (2007) advance the idea of using intelligent products for managing collaborative designs and manufacturing and supporting intelligent deliveries in logistics. These smart products and deliveries become the service consumer in the network; the network becomes a service consumer focused. In this service consumer perspective, the service consumer itself (a product or a delivery) provides the key guidelines that help manufacturers and service providers identify the design of process networks that most efficiently add value to different industries and for different applications. The exchange of data occurs through the service consumer. Figure 24 illustrates the classic method of building the network through a company centric approach versus the proposed method of constructing the network around a shipment agent. To implement a service consumer centric network, Holmström et al. (2007) propose two alternatives:

- A centralized approach: links a control agent to the individual package or dispatch unit based upon the identity of the product or shipment. The identity of the agent is unique and mapped to the corresponding agent. It is accessible, via internet, to all the members of the network;

- A decentralized approach: the physical service consumer (a product or delivery) encapsulates an agent and information required to process it through the network. In this approach, the actors should agree to use the service consumer itself as a way for indicating guidelines about what it is that should be done for the service consumer. In this case, the service consumer will direct itself through the network to reach the customer at the end.

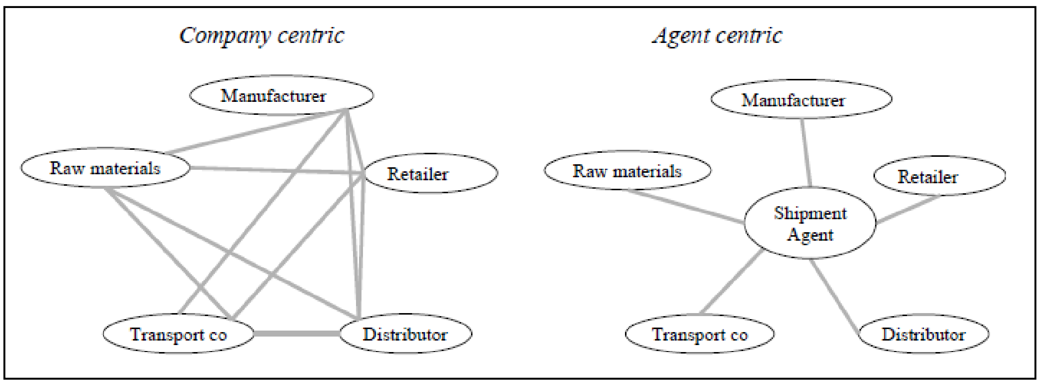


Figure 24 : Company Centric Network versus Shipment Agent Centric Network (Holmström, et al., 2007)

Gerber et al. (2003) believe that B2B-enabled dynamic networks of supply chain units will increasingly replace static supply chains. Therefore, an automated information and trading network is required to provide logistic web partners with logistic information and co-ordination services. The authors present an approach of agent-based Information and Trading Network (ITN) which they name CASA. CASA ITN provides integrated logistics services that allow the buyer to request hypothetical, non-committing estimations for transportation and storage from logistic providers during the process of negotiation with the seller; before buying the goods. The coordination is performed using auction mechanisms like Dutch, English, Vickrey, and First-Price-Sealed-Bid auctions.

The stated goal of the contribution of Kay et al. (2002) is *"to do for transportation what the Internet has done for communication."* The idea focuses on using smart packages as agents that can determine the best routing to final destinations based upon the transportation and storage costs. In order to minimize its individual transport cost, the package agent continuously negotiates with agents representing manufacturers, customers, trucks, and distribution centers until it reaches its destination.

Främling et al. (2006) present an agent-based information management model for managing, in a distributed way, the information of complex products at the component level. They also introduce an information management multi-agent platform called "Dialog" which uses seven types of messages for information management. The concept is built upon the idea of creating unique universal identifiers for products, and associating these identifiers to agents in multi-organizational systems corresponding to real products. The identification of a component or a product, which is the identification of the agent associated with it, has the format ID@URI were the URI is the Internet address of the server where the product agent is located and the ID part is a unique identifier for the product in this server. Figure 25 depicts how a composite product and its components are handled in the Dialog system.

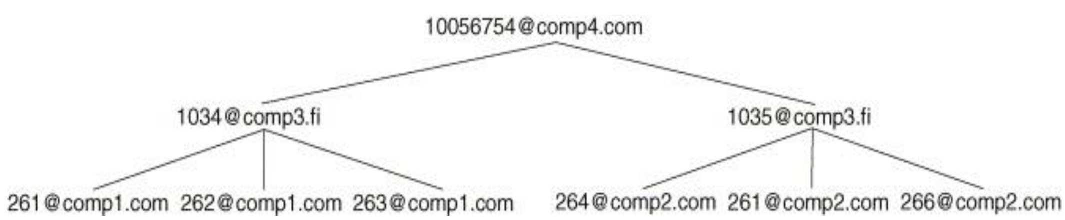


Figure 25 : Example of how Composite Products are handled in the Dialog System (Främling, et al., 2006).

This approach provides an interesting solution to the problem of product traceability as they progress through the supply chain. Product demand is not easily and rapidly translated into component requirements because the hierarchical association between the product and its components is performed over a series of manufacturing and assembling stages at different companies, each using its own identification standards.

Multi-agent Simulation in Supply Chain

According to Paolucci et al. (2005), research and interest in agent-based simulation have steadily increased. Simulation provides useful and essential insights into a wide range of scientific and applicative sectors. In agent research, simulation is a way of validating and assessing the impact of alternative designs on the performance of the considered system

(Paolucci, et al., 2005). The simulation is well suited and can play an important role in modeling complex environments, such as supply chain, and in addressing multi-decisional problems facing managers (Terzi, et al., 2004). Nof et al. (2006) argue that large and complex production and distribution systems should be first modeled and correctly represented according to granulated levels of detail to reflect their realities before creating decision support systems to manage them. They believe that the lack of these environments is a key problem in developing and testing today's manufacturing and logistics decision support systems. They think that the availability of such environments will allow researchers and developers to produce and assess accurate designs, platforms, and applications with reasonable levels of effort and resources. Santa-Eulalia et al. (2007) argue that there are three types of simulations: simulation for decision-making, simulation for technology evaluation, and simulation for education. They propose constructs for the definition of a supply chain simulation problem during the analysis phase of developing an agent-based simulation. Following are some examples of simulation tools found in supply chain multi-agent simulation research.

Sadeh et al. (2003) introduce MASCOT (Multi-Agent Supply Chain Coordination Tool) as an attempt to give users, from multiple tiers of the supply chain and with various abstraction level interests, the possibility to collaborate in order to efficiently manage the workflow within a supply network. Agents in MASCOT act as coordination and collaboration wrappers of real entities like plants, distribution centers, and warehouses. Sycara et al. (2003) present an infrastructure model of multi-agent systems called RETSTINA. This model is a set of services and conventions allowing agents to interoperate and indicate how the infrastructure should be reflected within agents to produce a multi-agent system. Telle (2003) suggests a simulation approach using a multi-agent model that links the supply chain level to the physical system composed of companies. The main agent in his model is the "Enterprise" agent composed of four subagents: a supplying system, a production system, a distribution system, and a pacification system. A supply chain system results from interconnecting Enterprise agents in a simulation environment. Rzevski et al. (2007) introduce MagentaToolkit, which is a set of multi-agent tools used to develop multi-agent applications without a need for any expertise in multi-agent technology. The kit contains three components, which are Multi-Agent Engine, Virtual Market, and Ontology Editor. Karageorgos, et al. (2003) present an agent-based approach for supporting logistics and production planning. The approach considers the availability and cost of logistic service providers, as well as the production schedules using negotiation mechanisms based upon a contracting protocol called Nested Contract Net. Li et al. (2007) propose a simulation approach for logistics system planning using “Swarm” which is a software package for multi-agent simulation of complex systems. Swarm provides a basic collection of concurrently interacting agents. The software can be used in a variety of disciplines such as economics, biology, and business management, and it provides a framework to model and monitor different systems.

Visual Analytics

How to smartly visualize information extracted from large amounts of data is of great importance to the subject of decision support system when considering the web dimension. This section begins by providing a review of the scientific literature that examines the importance of data visualization in complex environments involving large amounts of heterogeneous data and the principal considerations to be taken into account when building data visualization and mapping tools. The second part highlights the lack of visualization tools that can address the complex issues facing managers in logistic webs and investigates best practices for smart data visualization in collaborative contexts involving many actors.

Data Visualization

Recent advances in information and communication technologies allow companies to produce, collect, and store data in unprecedented amounts and at unparalleled rates (Keim, et al., 2006). In this situation, knowledge mapping, data visualization, and data mining tools gain critical importance in decision support as they can effectively present information (Wexler, 2001; Keim, 2002; Theus, 2003; Unlu, et al., 2009). Many data visualization and data mining techniques have been developed in order to help users capture the information hidden in the data (Keim, 2002; Han, et al., 2006). Visual Analytics is an emerging field, which focuses on the importance of integrating human judgement in the data analysis process through visual representations and interaction techniques (Keim, et al., 2006). For example, while graphics are an old visualization technique (Beniger, et al., 1978), recent research concentrates on rendering graphics more interactive and dynamic in decision support software applications (e.g. (Wilkinson, et al., 2005; Young, et al., 2006; Cook, et al., 2007)).

Thomas et al. (2005) define visual analytics as "*the science of analytical reasoning facilitated by interactive visual interfaces*". They state that the objective is to produce software solutions that facilitate the analytical reasoning process by exploiting and maximizing the human capacity to perceive, understand, and reason with regards to complex and dynamic data and situations. Visual analytics permits decision makers to interact directly with visually represented information in order to gain understanding so that better decisions can be made (Keim, et al., 2006). Visual analytics tools and techniques are used to "synthesize information and derive insight from massive, dynamic, ambiguous, and often conflicting data; detect the expected and discover the unexpected; provide timely, defensible, and understandable assessments; and communicate assessment effectively for action" (Thomas, et al., 2005). Visual analytics is a multidisciplinary field that combines data representations and transformations, visual representations and interaction techniques, analytical reasoning techniques, information sharing and communication techniques, as well as data mining and statistics (Thomas, et al., 2005; Keim, et al., 2006).

While the capacity for collecting and storing data is dramatically increasing, and the awareness of the importance of interactive data visualization is rising, the evolution of real propositions and software solutions is still limited. Most of the visualization solutions remain static (Theus, 2003; Keim, et al., 2006; Unlu, et al., 2009); they cannot face the challenges presented by the new era of information as they are based on old paradigms (Keim, et al., 2006), and/or they only focus on interactive graphic techniques without combining them with other techniques (e.g. Unlu, et al., 2009). Thomas et al. (2005) provide the following guidelines to develop visual analytics technologies: they should (1) allow the user to see and understand large volumes of information at once, (2) attract attention to what is most important, (3) provide multiple levels of abstraction for a problem, (4) support collaboration among multidisciplinary teams of members with various levels of expertise, (5) be built based upon a solid understanding of the visualization pipeline, the data characteristics, and the tasks to be performed, and (6) support both finding answers to questions and discovering alternative solutions.

Data Visualization in a Supply Web Context

Exploring, analyzing, and extracting knowledge from data resulting from routine operations in a single company presents numerous obstacles related primarily to the volume and homogeneity of data (Wexler, 2001; Keim, 2002). As supply chains and networks developed, schematizing and mapping them became more and more complex. In the context of logistic webs, managers face the challenge of using and analyzing data in order to exploit their potential at various levels of aggregation according to multiple dimensions and perspectives (temporal, geographical, etc.). The data comes from several companies and may involve interactions, such as sales, orders, forecasts, inventories, and deliveries, implicating more than one firm.

Likewise, supply chain management software solutions do not focus on visual analytics, but rather provide applications centered on the management of the processes of a company. Moreover, the need for real time information is becoming increasingly crucial. While this puts emphasis on the need for software solutions that are easily inter-connectable and can rapidly process large amounts of data (Helo, et al., 2005), the available supply chain management software applications only deal more with optimization and advanced planning (Davenport, et al., 2004).

According to Waldner et al. (2009), creating visualization tools for multi-source heterogeneous data that support collaborative actions presents many challenges since it involves taking into consideration the needs of decision makers coming from different backgrounds and with various levels of expertise. A portfolio of various linked cognitive maps is required to cover the broad range of strategic management concerns (Fiol, et al., 1991). Waldner et al. (2009) argue that the use of multi-view and multi-screen visualization is the natural next step, and that the design of this type of visualization should meet visualization, interaction, and environmental design considerations. In terms of visualization considerations, the level of detail should vary with the display and with the user. The interaction considerations should support the preservation of users' privacy, personalization of their actions, sharing information among them, and visual linking to guide their attention. The environment considerations should ensure a configurable and reconfigurable display environment, as well as application transparency.

Internet Based Solutions[7]

The increasing need for information exchanges creates an evolution toward new technologies such as Internet (Pramatari, 2007). This gives an opportunity to enhance the communications between computer systems of multiple companies (Davenport, et al., 2004). At the informational level, the objective is to guarantee transparency throughout the supply networks, accessibility to desired views, importability toward other applications, and respect of confidentiality at various levels of accessibility. At the management level, the objective is to have applications that enable aggregated or detailed analyses, acting as decision support systems for a variety of users from different companies with each user having his dynamic set of objectives.

The limits of commercial software solutions in terms of supporting seamless inter-organisational collaboration concern four aspects: conception, implementation, architecture, and availability (Edwards, et al., 2001). (1) At the conceptual level, the applications do not only have to integrate data from one company but also, data originating from various partners. (2) The implementation of generic software requires an adaptation of the company systems. The development of an adapted solution requires a considerable development time, which is often related to the complexity of the implied organizations. (3) From an architectural perspective, it is difficult for computer systems to integrate real-time connections with other partners. Various communications technologies such as Web services facilitate this type of access both internal data and to the data stemming from external partners. The development of a customized solution can catalyze integration by creating connections between organizations involved in the implemented software solution. Finally, (4) regarding availability, most systems limit the number of users through licensing contracts. Internet technologies authorize the access to applications hosted on Web servers

---

[7] This subsection is copied from section 2.1 in Montreuil, B., Labarthe, O., Hakimi, D., Larcher, A., & Audet, M. (2009). Supply Web Mapper. *Proceedings of International Conference on Industrial Engineering and Systems Management (ISEM2009).*

to an unlimited number of users while dealing with issues such as secure access control and data confidentiality protection. The integration of Web-Internet technologies to the software solutions on the market is thus necessary to meet the large-scale access and integration needs.

Synthesis

Supply chain decision support systems should reflect the complexity of logistics environments, the dynamicity, and adaptivity of the actors and their relationships. Multi-agent systems appear to fit naturally with supply chain management thanks to the ability of multi-agent approaches to represent interactions of a large number of independent and distributed actors within a single industry or over multiple industries (Lee, et al., 2008). Examples of contributions were given to better understand how multi-agents can be designed, what the chief concerns for their integration in supply chain management are, and which requirements decision support systems for complex systems with huge amounts of data should meet.

The literature review began with an introduction to decision support systems and business intelligence. Decision support systems are built to enhance the ability of humans to analyse tremendous amounts of data. Business intelligence is a form of decision support systems specific to the business management field. It involves much larger quantities of data and the use of data warehouses or data marts. The literature review examined decision support in supply chain management. Requirements for designing these systems were identified. Next, a variety of subjects, related to multi-agent systems in supply chain management decision support, was discussed. The multi-agent systems provide several features, such as autonomy, distribution, collaboration, and coordination, which are essential to the design of flexible, complex, and adapted solutions for supply chain management. These characteristics make the multi-agents the best approach to model decision support systems when considering the web dimension in supply chain management. Critical factors for designing these elements were emphasized and discussed, such as agent encapsulation, agent organization, agent coordination, and negotiation, system dynamics, optimization, security and privacy, tools and standards, collaboration, coordination, and data exchange mechanisms.

Moreover, the literature review has proven the importance of smart visualization in decision support in contexts of abundance data and information, and the lack of tools supporting this approach in supply chain management. Data analytics stipulate that in complex environments, fast and smart visualization should be of high priority, and interactive user interfaces should be made available to decision makers. Internet based solutions support complex communications between a large number of members and can guarantee access and confidentiality controls.

In conclusion, this literature review provides interesting guidelines for the design of business intelligence decision support systems for supply chain management in the context of complex adaptive systems such as supply networks and webs. The next section introduces our proposition of logistic web solution architecture and specifies the main requirements that the design of each components of the solution should meet.

Conceptual Framework for Designing Logistic Web Technologies

In this section, we capitalize on guidelines provided in scientific literature, on our expertise and on our creativity to combine various approaches, concepts, and techniques to propose a conceptual framework for designing technologies that support comprehensive and holistic non-programmed decision making in the context of the logistic webs. The first subsection presents the general architecture based on the holistic vision for designing logistic web decision support system discussed in the previous chapter, while the second subsection specifies the main requirements that should be met for designing each component of this architecture.

Holistic Global Vision for Designing Logistic Web Decision Support Systems[8]

Considering logistic webs as complex adaptive systems will bring out the importance of the direct and indirect relationships occurring in a broad logistics context and in evolving

[8] This section is an extension of section 2.4 in Hakimi, D., Montreuil, B., & Labarthe, O. (2009). Supply Web: Concept and Technology. *7th Annual International Symposium on Supply Chain Management, Toronto, Canad,.*

extended decision boundaries. The focus is not only on the logistics elements, such as nodes and links, but also on direct and indirect impacts of the behaviour and the interactions between these elements in a larger environment, as well as on the dynamic aspect of the logistics context. This highlights the importance of the granulated level of detail, which is required to address daily issues facing managers. Thus, soft modeling, which uses approaches such as complexity theory, systemic modeling, and complex adaptive system theory, are the most appropriate for designing logistic web solutions. The logistic web concept includes the supply network concept, which in turn includes the supply chain concept. It certainly broadens the field of vision for researchers and practitioners, and increases the level of complexity with which they are dealing.

Considering the web perspective does not signify that managers will be suddenly managing supply chains that are unrelated to their networks or that their tasks will be more complicated. It only means that, if managers deem it necessary, they can explore information about elements of the logistic web that directly or indirectly affect their decisions and operations. This implies that managers should be armed with sophisticated techniques of visualization, mining, monitoring, and assessment of the logistic web context. These techniques are crucial for managers to properly address the complexity that they are dealing with, filter the enormous amount of data, and focus their attention on their priorities. Considering the granulated details, in addition to relating elements to their context and to each other, should acquire a significant importance in logistic web solution modeling.

Managers should be provided with tools that allow them to deal with this inherent complexity and to concentrate their efforts on their tasks. Extracting pertinent views and information focusing on specific management tasks or decision-making situations becomes extremely complex. Without the capability for fast, smart, and easy manipulation of the huge quantities of data and information, managers are overwhelmed and struggle to understand what is happening around them. Managers should be able to zoom in, focusing on a specific issue, or zoom out, examining the issue in its real and global context.

In order to provide the double zooming-panning capability to both focus on a specific portion of the logistics context and to get a more global view of the logistic web, without losing the links between both levels of detail, two enabling conditions should be respected. First condition, the logistic web and its constituents should be modeled with as much comprehensiveness and granularity as possible, making explicit the actors' behaviour and the relationships and flows between the constituents. This model should be dynamically fed and updated by the actors participating in the logistic web, each responsible for its piece of the overall model, along the same lines as prescribed by Montreuil et al. (2000). Second condition, managers should be enabled to conceptually and geographically zoom, pan and mine the logistic web model, to delimit the piece of the overall logistics context they need to focus on, then to explore and assess it through multi-dimensional relationships, perspectives and indicators.

The first condition requires the construction and maintenance of a cross-organizational database that stores the modeled logistic web elements, their relationships, and behaviours. The second element can be achieved by using logistic web business tools that exploit the logistic web database and provide users with the ability to delimit logistics contexts without detaching them from the global environment. The cross-organizational database and the logistic web tools are the major components of what we call Supply Web Technologies.

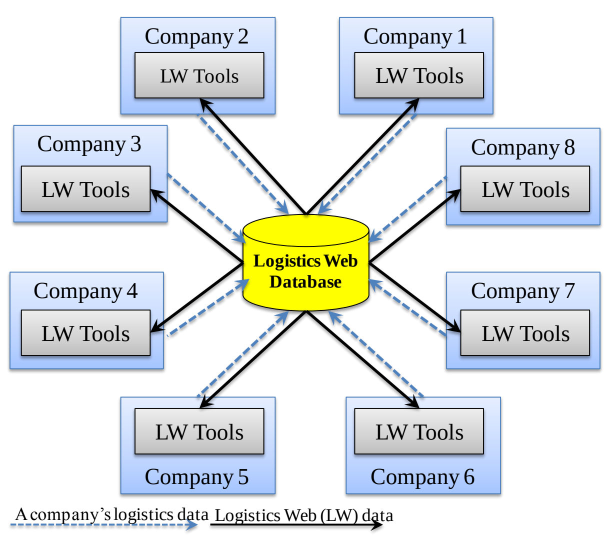


Figure 26: A Logistic Web Solution with a Shared Logistic Web Database

Figure 26 illustrates the basic idea of building a logistic web solution featuring logistic web tools and a shared logistic web database. As companies 1 to 8 are members of a logistic web, they can decide to build a common database that merges and homogenizes their logistics data. Each member contributes by integrating its logistics data into this database. The combination and homogenization of the data result in a consistent body of information reflecting the evolution of the logistic web state. This body of information feeds the global dynamic model of the logistic web.

In return for their database contribution, the members are granted access to the common model. Each member is provided with various software applications that access this database and exploit its content. Through these applications, users can employ various filters to retrieve information about specific logistics contexts. Because of the enormous quantity of data expected to be hosted in the database, the software applications should guide users to elements that acquire attention through smart selections and visualizations. These applications should provide high flexibility in terms of data manipulation and serve diverse purposes, manifold needs, and various users. These tools should be built to consider the real-life concerns of companies regarding data confidentiality and allow each actor to decide what to share with which member in the extended space of a logistic web.

In a utopian world, every member of a logistic web should have access to the logistics model and logistics data of all the other members in order to be able to display and query global views of the logistic web. However, in practice, not every member will be willing to share all its logistics model and data with everyone else. The model and data exchange depends upon the willingness of each member, the nature of relationships, and the degree of trust between collaborating members.

An alternative to a unique centralized logistic web model and database shared by all members is for each member to own, host, maintain, and control its logistic web model and database as featured in

Figure 27. Its logistic web database contains its own logistics data, in addition to the logistics data of members that have agreed to share logistics model and data. In this distributed alternative, it is easier for members to decide which data to share with whom. In

order to get the most complete view of the state of their logistic web, members should share models and data with as many members as possible.

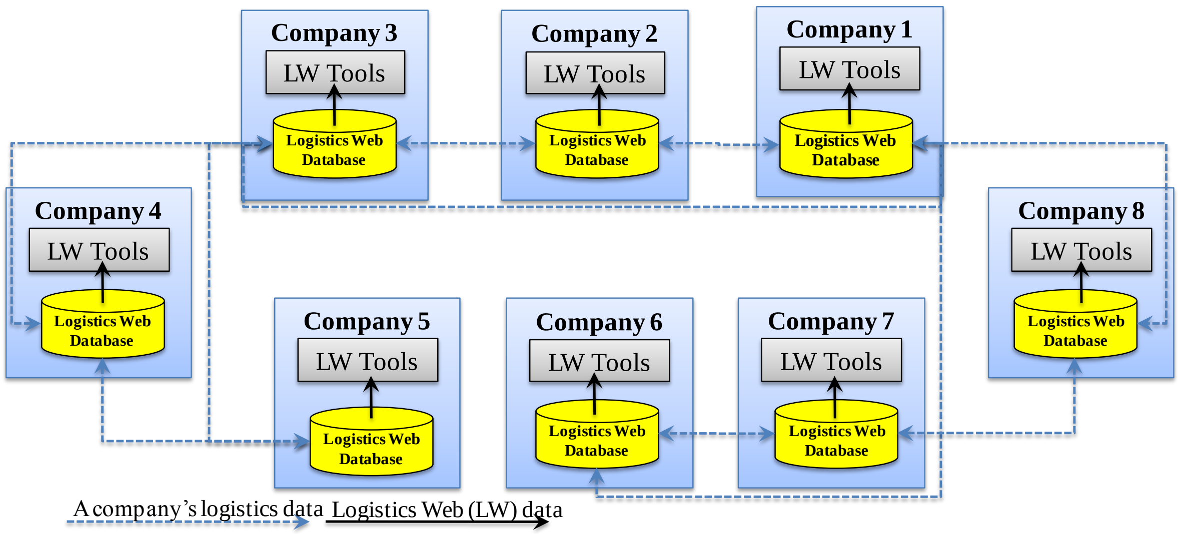


Figure 27: A Supply Web Solution with Distributed Supply Web Database

While the distributed alternative provides companies with expanded autonomy and ensures increased confidentiality and augmented data protection, the centralized alternative is extremely effective in the case of joint strategic initiatives for multi-organizational collaboration. A logistic web piloting room, equipped with logistic web tools connected to a shared database, can host an inter-organizational team of managers to monitor extended supply networks, manage supply operations, and make collective strategic decisions. In order to benefit from the advantages of both configurations, a set of partnering organizations within a larger logistic web can opt to create and maintain a shared logistic web model and database in a context of distributed logistic web databases. Figure 28 depicts the case where companies 1 to 3 of

Figure 27 have decided to build a common database for a certain collaborative initiative. While the three companies maintain their relations with the remaining members, they enhance their collaboration by integrating their model and data. As they share the same portrait of their logistic web, they are in a better position for aligning their vision and actions.

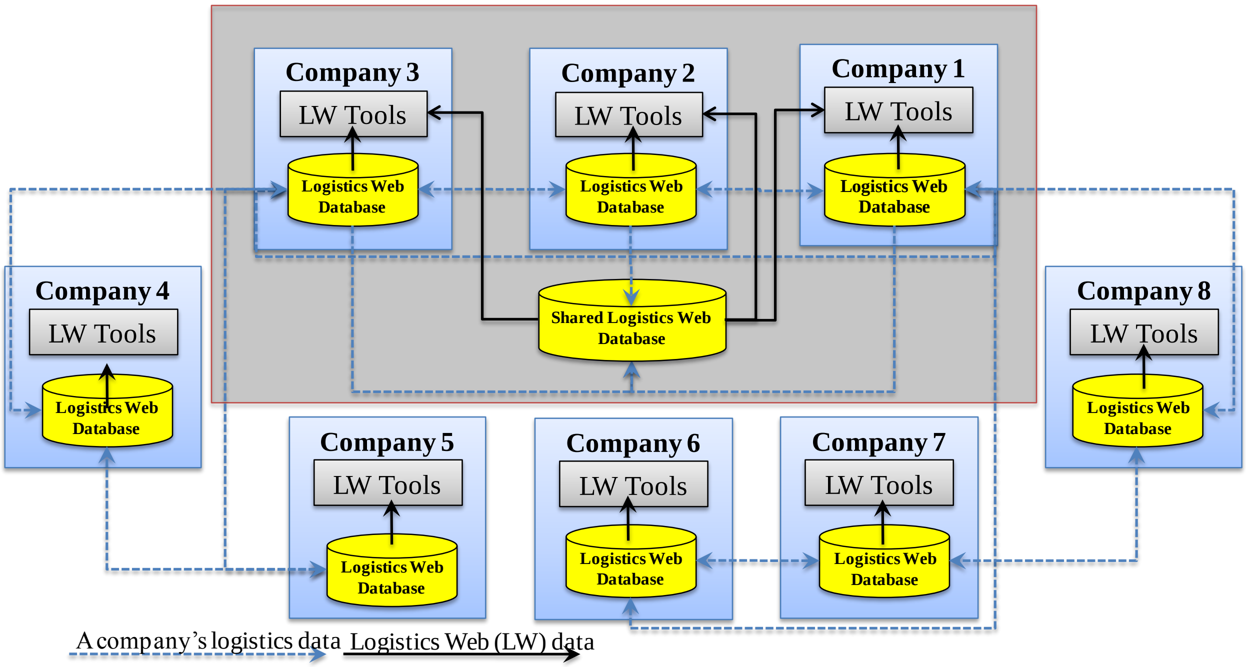


Figure 28 : A Shared Logistic Web Database in a Distributed Logistic Web Database Context

The Design Architecture

We argued earlier that a logistic web solution, as a business intelligence decision support system, should consist of logistic web tools connected to a logistic web cross-organizational database. This database captures a logistic web environment making explicit its elements, behaviour, and relationships. The design of DSSs in a logistic web context is based on a set of solutions deployed over multiple organizations. A logistic web solution consists of a database, a set of business applications, and a gateway, as illustrated in Figure 29.

The logistic web database reflects the logistics context of a number of logistic web actors from the point of view of the concerned member or alliance. Distributed logistic web databases are fed by internal and external standardized logistics data, whereas shared logistics databases contain external logistics data of the participating members.

- Internal logistics data: all logistics data maintained in the regular database systems of the concerned organization is transmitted frequently to the logistics database. It is, by default, data owned by the organization and stored in its databases. This data is of three kinds: data about the upstream flow with direct suppliers, data about the downstream flow with direct clients, and data about the flow between the organization's sites.

- External logistics data: comes from other members' logistic web databases according to the established bilateral agreements between the organization and these members.

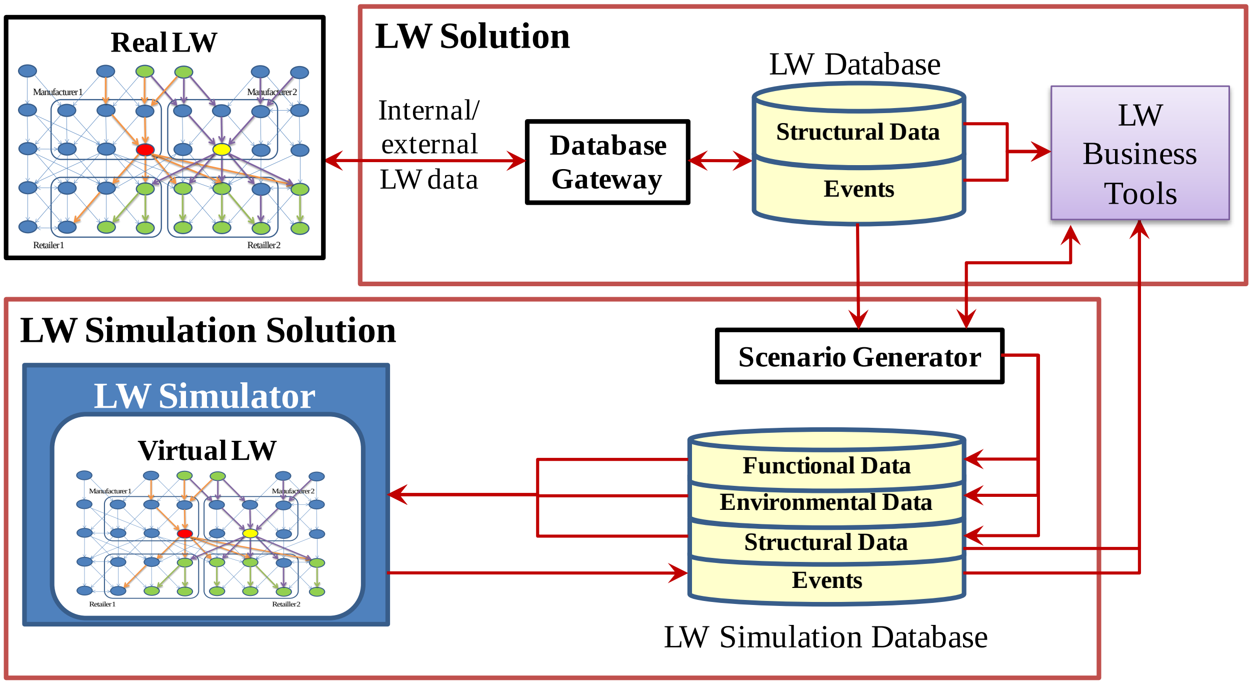


Figure 29 : Logistic Web (LW) Technologies Architecture

Generally, logistics data, whether it is internal or external, includes two kinds of data: logistics event data and logistics configuration or structural data. Supply events are rapid changing data reflecting the dynamics of the logistic web context. Examples of events include sales, orders, shipments, order handlings, and inventory updates. Supply configuration data is usually slow evolving and is used by the logistic web tools for constructing the logistic web model. It is exchanged once and partially updated when changes occur. This data provides information about (i) the nature of organizations: for example, whether an organization is a retailer or a manufacturer, and the structure and hierarchy of its sites; (ii) the location, nature, and general performance of sites: address, capacity, products handled in a site, inventory capacity affected to each product, time and cost of order handling, inventory cost in the facility, etc.; (iii) product characteristics: product category, weight, volume, cost, price, etc.; (iv) links between sites: criteria and conditions of ordering and shipping through a link, transportation cost, and time and shipped quantities; and (v) behavioural policies and processes, such inventory management policies and ordering processes.

Regardless of the owner of the solution, the logistic web database should have the same data structure and the same tables. This is important in order to obtain a general representation of any logistics context as sets of sites belonging to organizations and exchanging physical, informational, and monetary flows. Since the database merges data from multiple information systems belonging to different organizations, it is necessary to standardize the received data before transferring it to the database. This role is ensured by the gateway application, which makes sure that elements are uniquely identified and that the pieces of information are stored in the right database tables.

The logistic web tools are a set of business intelligence tools that provide a thorough understanding and decision support for a selected logistic web context by exploiting the content of the logistic web database to which they are connected. They support the evaluation and the intelligence phases of the decision process. They come in multiple instances that are used for multiple purposes according to the user's interest. Supply web tools are either used internally, by users in a given organization, or in a context of joint collaboration projects between two or more organizations, by cross-organizational teams. In the former case, they are linked to the organization's logistic web database. In the latter case, they are connected to a common logistic web database linked to the logistic web databases of the concerned members.

The logistic web simulation platform, which is created to support the selection phase of the decision process dealing with the evaluation, validation and selection of solutions, is a combination of the logistic web simulator and the logistic web simulation database. The simulator is a multi-agent application that allows simulating logistic web environments. It aims to substitute a real logistic web environment by a virtual logistic web world. The logistic web simulation database plays for the logistic web simulation solution the same role that the logistic web database plays for the logistic web solution. In addition, it contains the functional data required for agent behaviour definition and the environmental data used by the simulator to determine the elements of the virtual environment. The simulator takes as an input the structural data, environmental data, and functional data, and creates a virtual environment where agent applications copy the real world organizations' behaviour. The generated events of this simulated world are sent by the simulator to the simulation database. The logistic web business tools are connected to the logistic web simulation database to provide decision support capabilities as they normally do when connected to a regular logistic web database.

It is important to understand that the objective is to build persistent decision support systems intended for a long-term use within an organization. The logistic web database and the other software applications aim to deliver a virtual environment reflecting the company and its logistics context. This virtual environment is a digital being that lives and evolves in parallel to the company, thus aiming to provide at any time, an accurate digital image of the logistic web context that can be visualized, monitored, and analyzed. These systems are a long-term investment designed to grow with the company and give insights to many aspects of the management of logistics activities. They provide the possibility to study and investigate the real past and present as well as alternative pasts, presents and futures created through simulation experiments. This subsection presents the design considerations and specifications for the main components of logistic web technologies.

Design Specifications

This subsection presents the design specifications for the main components of logistic web technologies. These components, detailed in Figure 30, can be grouped in four categories according to the common design characteristics as depicted in Figure 30. These categories are: (1) the database gateways, (2) the event databases referring to the real world event database and the simulated event database, (3) the other data databases concerning the real world structural data as well as the functional, environmental and structural input data of the simulation, and (4) logistic web tools including the logistic web business tools and the logistic web simulator.

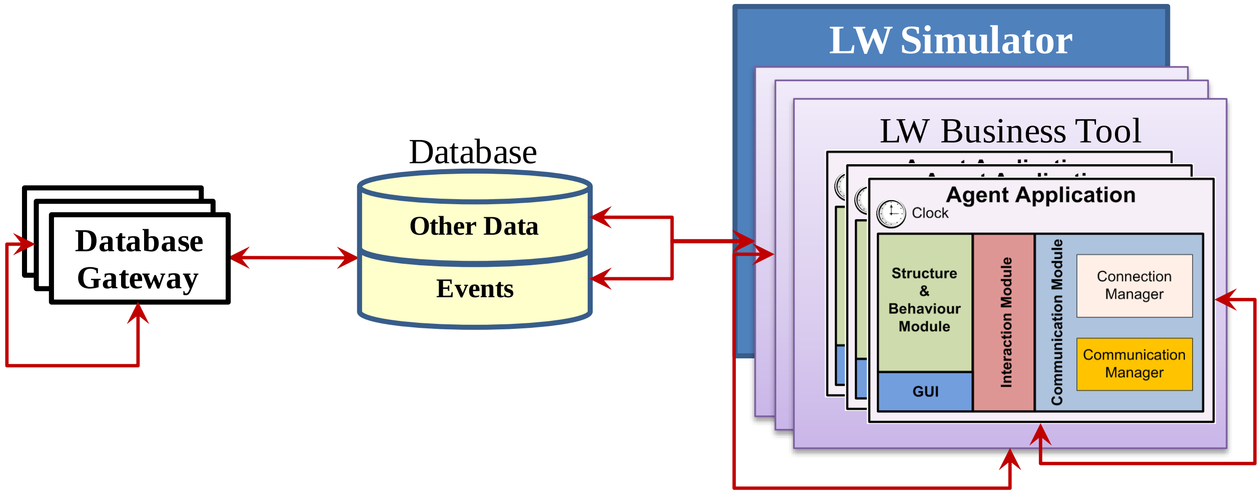


Figure 30 : Grouping the Components of a Logistics Decision Support System according to the Design Requirements

Databases

In a logistic web, information flows both downstream and upstream. Clients and suppliers need to obtain a global view of what is affecting their operations. Bidirectional data exchange through bilateral agreements facilitates collaboration and increases confidence between partners. The more bilateral agreements a member signs, the more complete its logistics model and data will become. The logistic web can be seen as a conceptual map, of which each member owns a piece corresponding to its own logistics network model and data. A member should get copies of as many other members' pieces as possible in order to get the most complete map.

Since there is no guarantee the data of various partners will have the same format and structure, an objective of logistic web technologies is to enable bringing together these heterogeneous data into one global distributed virtual system based upon standardization rules. Two conditions are necessarily required in order to design a decision support system at the logistic web scale.

The first condition is a generic, unified modeling and database structure that can express as many logistics contexts as possible. The basic structure of the logistic web database should be the same regardless of the logistic web solution owner. Whatever the logistics context, the same elements have to be considered, such as organizations, sites or nodes, products, product families, product categories, shipments, orders, and order lines. Any logistics context can be illustrated through physical, informational, and financial flows occurring between sites belonging to organizations. A logistic web database should allow the presentation of any logistics context as a set of nodes belonging to organizations and exchanging physical, informational, and financial flows.

The second condition is a unique identifier for each logistic web element. Each organization, each site, each product, etc., must have a unique identifier in the logistic web context. The uniqueness of the identification is normally respected within the same organization, but when data from multiple organizations is considered, this uniqueness is far from reach unless these organizations follow the same universal identification system. Supply web technologies should associate a global unique identifier with each logistics element. Barcode product identification, for example, consists of a header, a manufacturer's identification number, the item identifier, and a check digit (Brock, 2001). As a concept of unique identification for their agent applications, Främling, Ala-Risku, Kärkkäinen, and Holmström (2006) propose an ID@URI format, the URI is the Internet address of the server where the element is located and the ID part is a unique identity inside the server. Supply web technologies can use similar concepts to identify each unique logistic web element.

Meeting these two conditions results in logistic web databases where data from different logistic web members can be merged into the same structures and uniquely identified. Implications of this concept are important since each organization will only be required to standardize its data by creating the right protocols and scripts that translate its internal logistics data to standardized logistics data. These protocols are then integrated into the database gateway application, which will use them to create unique identifiers for data integration in the right tables of the logistic web database. Thus, any logistics data exchange between members owning logistic web solutions will always involve standardized logistics data. In this situation, the gateways should be able to integrate the received data by a simple insert query into the logistic web database.

Except for the events, all other data is either static or slowly evolving. In addition, the number of queries on this data is small. For example the structural data is accessed once at the start-up of the software applications and then only if changes occur; knowing that the number of changes is very limited. The integrity, the homogeneity, the durability, and the validity of this data are more important than its fast manipulation. Thus, a relational database system is well suited for the design of databases hosting this kind of data.

The event databases hold huge amounts of dynamic data frequently accessed by the logistic web applications. Fast and easy manipulation of these databases is vital. Therefore, they should be designed based upon the principle of data warehousing since this approach is as of now the most suitable for business intelligence and systems dealing with very high volumes of data (Moss, et al., 2003; Negash, et al., 2008; Dayal, et al., 2009). Data warehousing is the process of transferring data from source systems to an integrated data warehouse. Generally, data warehouses consolidate heterogeneous data coming from multiple systems featuring diverse data structures. These systems can belong to the company, its suppliers, external data providers, or other business partners (Watson, et al., 2007; Dayal, et al., 2009).

Logistics Data Sharing: Database Gateway

The database gateway ensures the liaison and the communication among logistic web solutions of collaborating organizations through the exchange of logistics data. It has four main functions: (1) receive internal data, standardize it, and store it in the right tables of the logistic web database; (2) receive external data from external actors, standardize it if needed, and store it in the right tables of the logistic web database; (3) request external logistics data from other actors; and (4) send already standardized internal logistics data to external members.

The exchange of data between members is done only through gateways. The gateway proceeds with the verification of the identity and source of the request, as well as the security of the link with the requested gateway. After that, it extracts the requested data, according to the bilateral agreement, and sends it. A member does not have the right to forward the data received from another member to a third member; he exclusively sends the data created by his own information system. If a member expressed an interest in another member’s data, he should obtain an authorization from the concerned member or sign a bilateral agreement and directly exchange the data with him.

A primary objective of the database gateway is to automate the integration of the internal and external logistics data into the logistic web database. This automation is still a challenge for business intelligence applications (Watson, et al., 2007; Dayal, et al., 2009). However, since each organization is supposed to standardize its internal logistics data, the exchange of data will involve only standardized data ready to be inserted into the right tables of the logistic web database. Thus, the integration of the data into the logistic web database can be automated if each organization defines and implements, in its database gateway, the scripts for translating its data to standardized logistics data.

Database gateways are Internet based applications (Pramatari, 2007) since they are expected to communicate using Internet protocols. The objective is to guarantee the scalability and extensibility of logistic web solutions, avoiding constraints on the number of connecting agents while offering the possibility to handle the issues of secure access control and data confidentiality. They can be implemented as agent-based applications. The literature related to collaboration and coordination in logistics chain multi-agent systems provides many techniques suitable for data exchange among partners of a logistics context (e.g. Kay and Jain (2002), Gerber, Russ, and Klusch (2003), Lau, Wong, Pun, and Chin (2003), Främling, Ala-Risku, Kärkkäinen, and Holmström (2006) and Holmström, Främling, Tuomi, Kärkkäinen, and Ala-Risku (2007)). The design of database gateways can be inspired by some of these techniques as long as the conditions of the universality of identifications and standardization of the database structure are respected. Regarding agent organization, a gateway application is an autonomous, social agent based application communicating with other agents. The gateways should be designed using a federate decomposition (Shen, et al., 2006) since they are not expected to encapsulate agents corresponding to physical entities existing in the real world. They consist primarily of procedures and functions for handling and exchanging data with other gateways.

Logistic Web Tools and Logistic Web Simulation Solution

As was emphasized in the literature, the multi-agent approach is currently the most suitable for designing applications for complex adaptive systems like logistic webs. The logistic web tools and the simulator are composed of multi-agent applications encapsulating agents representing real decision-making actors of a certain logistic web context. Thus, in terms of agent organizational structure, a federative architecture can be used for agent applications while a hierarchical architecture can be used for the encapsulated agents of the structure-and-behaviour module. This combination has the capability of reflecting realistically the structure of logistic web contexts. For agent coordination and negotiation, decentralized coordination can be applied with mutual adjustment to reflect the autonomy of firms and decision-makers in a logistic web context. To translate system specifications supporting business processes and workflows into multi-agent software characteristics, approaches such as the model-driven development approach (Bauer, et al., 2005) or the three-level multi-agent modeling of (Labarthe, et al., 2007) can be used. The behaviour of agents within the structure and behaviour module can be defined according to a modular approach (e.g. Montreuil, 2006) based on multi-level abstraction behavioural modeling in order to guarantee the scalability of the applications and the multi-functionality of the agents according to the desired type of decision support. For example, the same agent, at various levels of abstraction, can be used to reflect static states in a mapping context, to play the role of a specific actor in a real historic playback, or to act as a virtual agent in a simulated world.

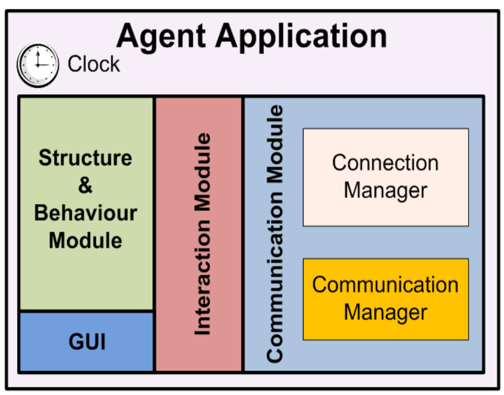


Figure 31 : The Components of an Agent Application

As shown in Figure 31, besides the structural and behavioural module, each of the agent applications contains three other modules: the communication module, the interaction module, and Graphical User Interface (GUI). The communication module ensures the exchange of all messages with the other agent applications through the Web by using TCP/IP protocols. The agent applications are distributed over many computers and each application can run on a single computer, share the same computer with other multi-agent applications, or be distributed on many computers depending on its needs in terms of processor and memory capacities required for its proper execution. In addition, this module guarantees the communication with the databases. The interaction module is the link between on one side the communication model, and on the other side the GUI and the structural and behavioural module. It consists of code procedures and functions that pack outgoing messages and pass them to the communication module, and that unpack incoming messages and transfer their contents to the GUI or to the structural and behavioural module.

The GUI is a core component of the agent application since it is the communication interface with the user. Its design should take a good care to deliver a clear, consist, pertinent, accurate, interactive, selective, and targeted message about complex situations, smartly combining text, numbers, and visuals. The design of GUIs should focus on using and developing visual analytics techniques (Thomas, et al., 2005) to unveil instantaneously crucial information hidden behind the large amount of data. GUIs should be multi-focus oriented and allow the delimitation of logistics contexts, customized performance analysis, and cross-department, cross-organizational multi-dimensional analysis. In addition, they should integrate business intelligence analysis functionalities such as slice-and-dice, drill down, and diagramming.

Visual illustration

The human brain assimilates illustrations much faster than numbers since it is much easier to grasp the content of an image than to understand a table full of numbers. Elements presented in a stronger color, larger size, or particular format can catch the user's attention more easily. Supply web tools should present the information in conceptual figures, graphs, and graphics rather than in tables, text, or lists of values. They should prioritize the use of color, size, and format coding for illustrations because in a context of abundant information, users' attention attraction is vital (Simon, 1996). An element presented in a stronger color, larger size, or particular format can catch the user's attention more easily. According to Thomas et al. (2005), the illustrations, provided through visualization tools, must:

- Facilitate understanding of massive and continually growing collections of data of multiple types
- Provide frameworks for analysis of spatial and temporal data

- Support understanding of uncertain, incomplete, and often misleading information
- Provide user- and task-adaptable, guided representations that enable full situation awareness while supporting development of detailed actions
- Support multiple levels of data and information abstraction
- Facilitate knowledge discovery through information synthesis, which is the integration of data based on their meaning rather than the original data type.

Delimitation of the logistics context

In most cases, users will be interested in a detailed view of a specific part of the logistic web, rather than in that of many parts or in an aggregated global view instead of a detailed global view. Thus, the delimitation of the logistics context is extremely important since it offers the possibility to capture a global view or look at a specific portion of the logistic web. A logistics chain and a logistics network are always linked to another word indicating a "focus" related to the analyst's interest (Harland, et al., 2004). Generally, a supply chain or network is associated to a site, organization, product, product family, product category, or combined focus. Supply webs can also be related to different focuses according to the analyst's point of view.

As demonstrated in Figure 32, the notion of "focus" can be extended to a notion of multidimensional focus that will serve in constructing the logistics context by intersecting four dimensions:

- Organization dimension for selecting organization(s) or site(s);
- Product dimension for selecting product(s), product group(s), sub-category(ies), category(ies), etc.;
- Time dimension for selecting a time frame; and
- Supply depth dimension for setting the desired visualization depth for upstream and downstream flows.

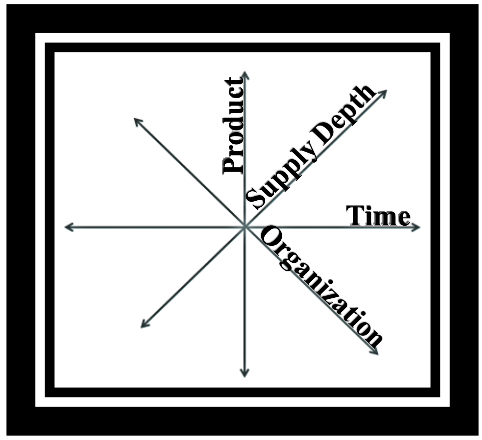


Figure 32: Four Dimensions for Delimiting a Logistic Web Context

While it can be very useful to associate a supply chain, network, or web to a focus in order to reduce complexity, it is crucial not to sacrifice the global view of a logistic web context. The image of the logistic web surrounding an organization should first be constructed in the logistic web database, and then filters representing users' criteria should be applied to delimit the logistic web context. In this way, the desired information can be obtained as specified by the user, with the same level of simplification and focus defined by zooming in or out through multiple dimensions, but without pulling out the selected piece from its environment. In the same way, it is also possible to let the user explore other links that he may realize are connected with his first analysis.

Multi-focus oriented

Supply web technologies should serve different purposes according to the user's orientation. They should ensure vertical (strategic, tactic, and operational) decision support (Giunipero, et al., 2008), as well as horizontal decision support by providing information to users in different departments of the organization such as logistics, marketing, finance, etc.

Customized performance analysis

Users should be able to customize the display of information by selecting the desired Key Performance Indicators (KPIs) and using preferred color, size, and format coding.

Cross-analysis

The tools must provide easy and smooth investigation of the four dimensions allowing cross, horizontal, vertical, and multi-organization analysis.

General Adopted Methodology for Designing the Prototypes

The development of the prototypes follows the guidelines and requirements defined in this section for designing logistic web decision support systems. Soft approaches like complex adaptive system view and social network analysis inspire the modeling of the prototypes through the entire design process. The raw data is considered as it is generated by the actors, without simplifications or aggregations. The logistic web database conception assumes detailed structural data and events, providing, thus, the global image of the logistic web environment without any distortion. The same rule applies to the logistic web simulation database found in the simulation platform.

The multi-agent framework is adapted from the three-level approach defined in Labarthe (2006). This approach seeks to capture the complexity and dynamicity of logistics contexts by mapping agents in the software with real world decision-making actors or systems. The framework translates business requirements to system requirements in the following three stages. First, a domain modeling of a selected logistics environment formalizes the overall description and comprehension of the logistics context in an executive non-technical language. Second, the conceptual model consists of transposing the domain model into an agent-oriented representation using the appropriate UML diagrams. Third, the operational model is developed based upon the conceptual model. It expresses the design requirements according to the programming language and to the technology that will be used for developing the software. The three types of models are produced for each application to be built.

The retained multi-agent framework is combined with the recursive modular protomodel based approach (Montreuil, 2006), which provides a modular technique for the representation of any logistics context by using generic components representing the supply chain entities according to their functional roles. This combination provides a conceptual framework capable of helping create agent-based simulations and business intelligence tools that can be adapted and developed to model any logistics context.

The development of the logistic web tools is being achieved by using Visual Basic.NET© and exploiting the SQL Server database management system. Some of the applications can export data to MS Excel spreadsheets and\or image files in order to facilitate the appropriation of figures and the analysis of obtained results. Geographical maps are generated using Map Extreme (Map Info©) to display customized maps, including additional elements such as nodes and flows. Web services and TCI/IP protocols are used for the communication among agent software applications.

These are the general elements of the methodology adopted for designing the prototypes of the logistic web applications and the logistic web simulation platform. Specific elements of the methodology related to each tool will be highlighted during the presentation of the prototypes.

Conclusion of the Section

The ability of companies to gather and store data by far exceeds their ability to both analyse and use it efficiently. This is the reason why more research needs to be done toward providing managers with the tools necessary to help them use the available data. On the one hand, the new concepts influencing the supply chain field, such as supply network, logistic web, traceability, B2B, and end-to-end collaboration, are driving a significant need for different kinds of data. On the other hand, the advances in monitoring and communication technologies produce an increase in the variety and size of the collected data. Moreover, the concept of the supply chain itself is forcing managers to take into account more than their company's internal issues. The concept of supply chain is too narrow to express the complexity faced by actors in the field; therefore, managers have to think in terms of supply networks embedding multiple supply chains, and in terms of logistic webs, embedding multiple supply networks. Without effective logistic web technologies, simple tasks such as visualizing, analysing, and understanding logistics dynamics, as well as following various KPIs, are hard tasks that can take months to be achieved.

This section establishes the basic elements required for logistic web technologies conceptualization and design. First, a logistic web database system that standardizes and unifies the logistics data of the logistic web members. Second, a set of business intelligence tools supporting complex decision-making. Through the entire thesis project, and specifically in this chapter, we present and discuss many concepts with the potential of supporting the design of innovative and powerful business intelligence tools. These concepts include complex adaptive systems, supply chain management, social network analysis, enterprise collaboration, multi-agent systems, business intelligence, decision support systems, visual analytics, Internet based solutions, and simulation.

In this section, based upon the literature review of contributions in these fields, guidelines for designing business intelligence systems supporting the decision-making in the context of logistic webs were defined. In the next two sections, we will demonstrate how our multidisciplinary approach can sustain the development of multidimensional logistic web tools based upon the predefined guidelines and requirements. In total, four tools will be presented: the logistic web mapper, the logistic web playback, and the logistic web monitor in the next section. The logistic web simulation platform in the subsequent section.

These four tools make up the logistic web toolkit that covers a large part of the spectrum of what decision support should address in the context of most of the existing logistic web. The three logistic web applications provide an understanding of the past and present of a logistic web context, and allow a local or global analysis of an organization's logistics environment. In combination with the logistic web simulation platform, these applications support the analysis of alternative past, present, and future scenarios for global or local sections of logistic web contexts.

Logistic Web Tools[9]

In this section, as architecturally depicted in Figure 33, three business intelligence applications are proposed as logistic web tools: the logistic web mapper, which is a static logistics mapping tool; the logistic web playback, which is a dynamic logistics history-reviving tool; and the logistic web monitor, which is a real time monitoring tool. While

---

[9] This section exploits the content of both Montreuil, B., Labarthe, O., Hakimi, D., Larcher, A., & Audet, M. (2009). Supply Web Mapper. *Proceedings of International Conference on Industrial Engineering and Systems Management (ISEM2009)* and Hakimi, D., Montreuil, B., & Labarthe, O. (2009). Supply Web: Concept and Technology. *7th Annual International Symposium on Supply Chain Management, Toronto, Canad.*

each of these tools is a standalone application intended to deal with certain aspects of the logistic web, they are complementary and can be used jointly to provide maximum benefit and full understanding of a logistic web context.

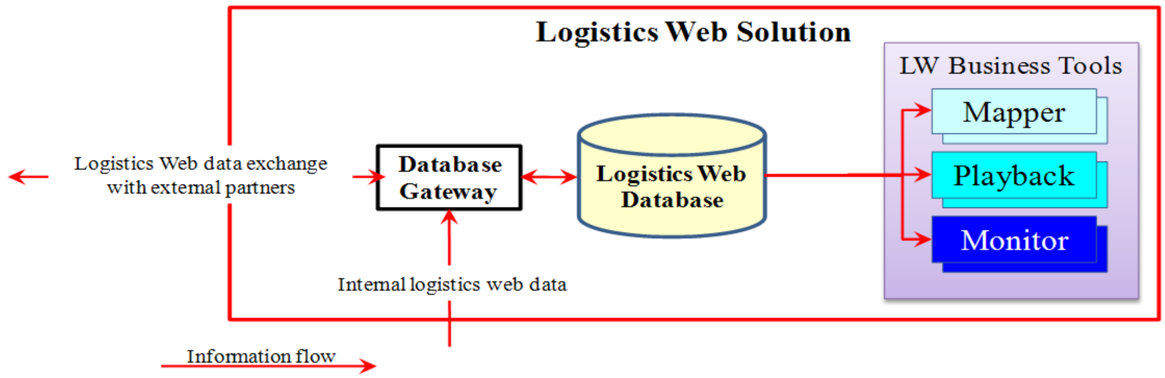


Figure 33: The Logistic Web Solution Structure

Objectives and approach

The objective of mapping a logistic web statically or dynamically is to obtain a representation of the existing relations between several selected actors, resources, and/or products for a certain time interval. In this case, we assume that a set of logistic web partners are willing and interested in collaborating and exchanging logistic web data in order to enhance their understanding of how their implications in various supply chain and networks impact each other and to improve the quality of their decision making processes and results.

The result of the logistic web mapping generally appears as static/dynamic conceptual or geographical maps intended to visualize existing relationships according to particular perspectives. The graphical representation of results can be displayed according to a dimensional axis system. The mapping process integrates the notion of map elaboration and it facilitates the assimilation of information. Typically, generated maps are integrated into dashboards used to monitor the status and key performance indicators of entities in a selected context. This section exposes the research objectives and some methodological elements specific to designing and prototyping the logistic web mapper, logistic web playback, and logistic web monitor.

The first facet of the research problem consists of homogenizing, linking, and exploiting large quantities of heterogeneous data originating from multiple companies. The second facet is concerned with the development of the schematization and mapping techniques for smart display of a variety of organizational entities according to various levels of aggregation and multiple dimensions. The third facet consists of displaying flows of organizational entities according to multiple time scales, from data grouped by years down to real-time data. The fourth facet considers various levels of aggregation and disaggregation, depending upon the user's selection of flow characteristics (physical, informational, financial, etc.). The fifth facet involves the information display modes, such as tables, graphs, schematics, magic cubes, and maps. Finally, the sixth facet deals with how to exploit the styles of the elements represented in maps and visualizations to attract attention based on the user's need. The union of the schematization and mapping features defines the conceptual framework of this research and permits the identification of the three business intelligence tools as visual analytics and decision support tools for logistics operation management in logistic web contexts.

Generic Conceptualization

The logistic web applications exploit and connect to the logistic web standardized database, containing data shared among collaborating organizations. Data sharing, standardizing, processing, and homogenizing are done according to the principles defined in the previous chapter. In order to be able to map and monitor the past or present dynamics of a logistic web context, the identifications of the supply chain sites, organizations, and flows should be standardized. Sites and organizations are defined as generic nodes, and flows as generic links as stipulated by the social network analysis view (Scott, 1988).

A node is an organizational entity within a logistic web. As depicted in the Class Diagram in Figure 34, a node can be of various types. Within the framework of this research, we have classified basic nodes as stores, boutiques, warehouses, distribution centers (with the responsibilities to distribute products to the other types of nodes, combining cross-docking, storage, consolidation, etc.), or plants. Certain nodes play more than one role; for example, a node can be a plant and a distribution center at the same time. A node can organizationally encapsulate several sub-nodes, as is often the case with business units that represent complex organizations such as multi-site manufacturers and retailers. For example, a business unit representing a retailer can group distribution centers and stores. A node is characterized by various elements including: i) a unique identifier, ii) a name, iii) no, one, or several addresses, and iv) a relationship with a parent node.

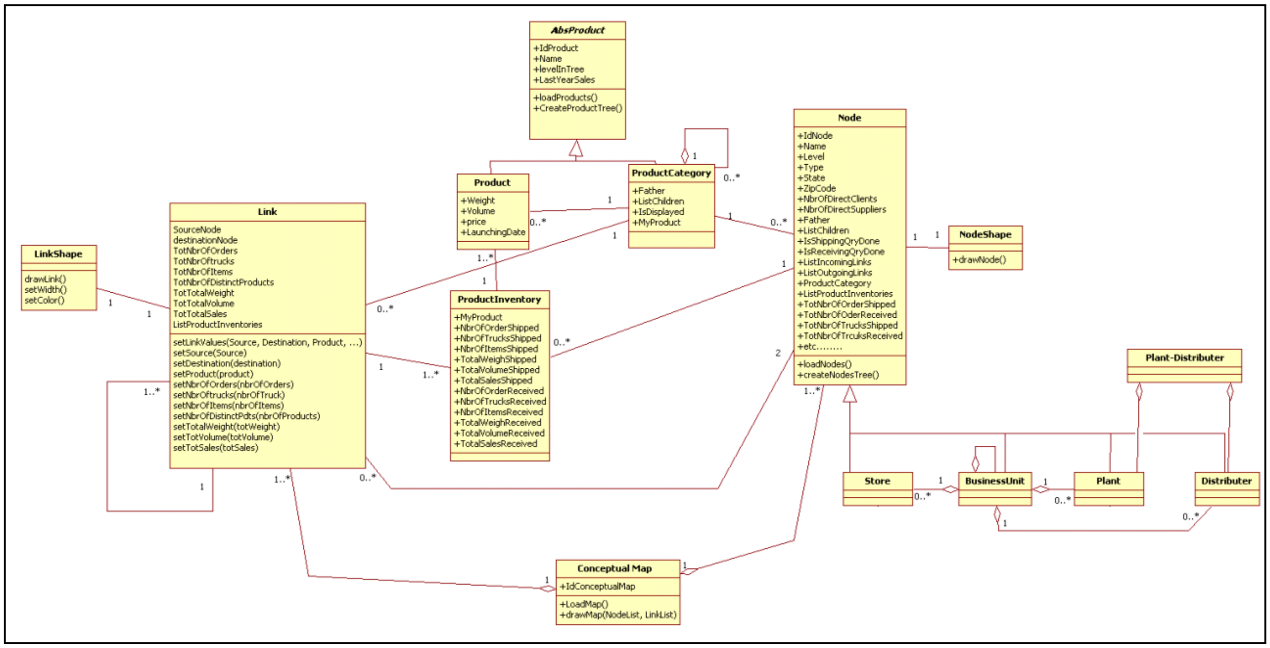


Figure 34 : A Section from the Logistic Web Mapper Class Diagram

A flow is an element, which represents the physical, informational, and monetary transactions between two nodes. A flow takes place through a link between two nodes of a logistic web. A flow is characterized by attributes including: i) the product(s) circulating in the flow, ii) source node, iii) destination node, iv) physical volume, v) total weight, and vi) monetary value.

A product is affiliated with product categories and linked to inventories indicating the quantities and other information about the product within its associated links and nodes. More elaborate and specific characteristics of nodes, flows, and products are presented upon the presentation of the logistic web mapper.

Logistic Web Mapper

This section presents the conceptual objectives and functions of the logistic web mapper. The logistic web mapper prototype, developed by our team, includes three principal interfaces, which will be detailed in the next sections. The application was tested on a large scale with the company P&G Canada and its clients. The figures, which illustrate the interfaces, are modified to respect the confidentiality agreements. The logistic web mapper is a business intelligence tool for statically visualizing, mining, and assessing the logistic web or one of its embedded networks. It helps users delimit a logistics context efficiently and explore it through a selected set of KPIs. It allows the mining of the logistics context by drilling down and up through multiple dimensions providing, thus, a multidimensional snapshot that can be explored from different points of view.

Overview of the Logistic Web Mapping Technology

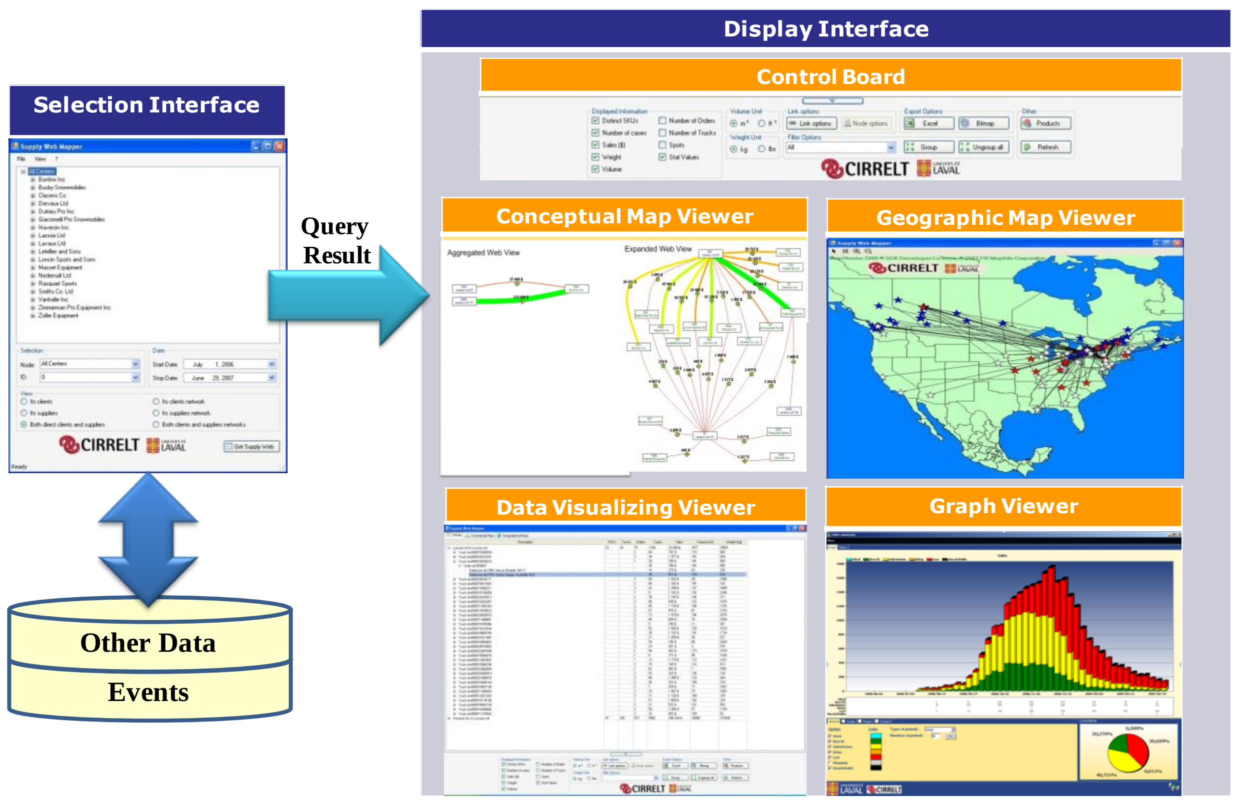


Figure 35: Structure of a Logistic Web Mapper

A logistic web mapper is a business intelligence tool enabling users to better understand and analyze their logistic web by exploiting available databases. It helps visualize, mine, and assess a logistic web and its performance. It allows the representation of multisource data in multidimensional and synthesized schemas and provides a snapshot of the selected logistic web, or of one of its embedded networks, for a certain time interval. Then, it allows the users to mine the data by drilling down and up through each dimension providing, thus, a multidimensional snapshot that can be explored from different points of view. The notion of data mining we refer to everywhere in this section is not the data mining as statistical methods that help extract hidden patterns from data, but, instead, the ability to drill trough different data dimensions to get more detailed or summarized views. The mapper is designed to meet the requirements of different managers in order to allow each one to obtain an adapted overview of the logistic web based on his own needs and functions. Structured as displayed in Figure 35, our prototype logistic web mapper involves a combination of two main interconnected interfaces. First, the selection interface is used to select a logistic web, network, or node. Second, the display interface which contains a control board and four specific interactive viewers: the conceptual map viewer, the geographical map viewer, the data-mining viewer, and the graph viewer.

In next subsection, we describe the key concepts and features of the logistic web selection interface. Then in subsection 2, we describe those of the display interface. We start with the control board that offers various customization and mining tools. Then we describe the four viewers of the display interface. The conceptual map viewer provides a representation of the selection as a network of nodes and flows. The data-mining viewer represents the data using a dynamic tree view, which can be manipulated at ease. The geographical map viewer deals with the presentation of the selection on a geographical map. There is no specific section on the graph viewer since it is easy for the reader to understand its nature. For each one of the viewers we describe the associated dashboards. The figures presented over the subsections 3 and 4 provide examples of how this application can deliver value to users for decision support and analysis.

Supply Web Selection Interface

In order to focus his attention on the desired issue and to limit the quantity of data to synthesize, the user has to choose the section of the network in which he is interested and the time span that he wants to investigate. This is done through the selection interface. In fact, in a context where a combination of supply networks belonging to multiple partners is considered in granulated levels of detail, and where the physical, informational and financial flows going through or generated by each one of the sites belonging to this logistic web are tracked on a daily base, it becomes very important to provide logistic web players with a tool that filters the data they are interested in and subtracts non relevant data. This pre-selection of relevant data is a key step in the design of a flexible tool that can handle large amounts of data efficiently and rapidly. The selection interface, which is used for this pre-selection, is the first screen that appears after launching the logistic web mapper. It provides the possibility to select the node to focus on, the network related to it, and the time interval to consider (Figure 36).

In the prototype, we have the user first select a supply chain node that can be a company, a business unit, or a specific site of a company. This action is done through the tree view presented on the upper part of the window, identified as point 1 in Figure 36 (hereafter 36.1). The selected node appears in the 'Selection' section of the interface (36.2) where it is possible to read the selected node name and its identifier. The 'View' section (36.3) allows the construction of the supply network related to the selected node. It determines the depth of the network starting from the selected node and going either ways: downward to the network of clients, upward to the network of suppliers, or both. Six options are available: (i) its direct clients, (ii) its direct suppliers, (iii) its direct clients and suppliers, (iv) its client network, including clients of its clients as far downward as possible, (v) its supplier network, including suppliers of its suppliers as far upward as possible, (vi) its overall client and supplier network combining (iv) and (v) above. These six options allow the user to focus his attention on the desired part of the logistic web. This can be either customer-centric, supplier-centric or both. This can be narrowly focused or may have a broader perspective. Indeed, the user can even request the mapping of the entire logistic web by selecting 'All Center' in the tree view. Obviously, in huge logistic webs, such a request may be highly time and resource consuming. It is also possible to limit the data to a specific time span by choosing a starting and ending dates in the 'Date' section (36.4). This can provide results by season, for example, or give information on dates related to important supply chain management decisions; therefore helping to measure the impact of these decisions.

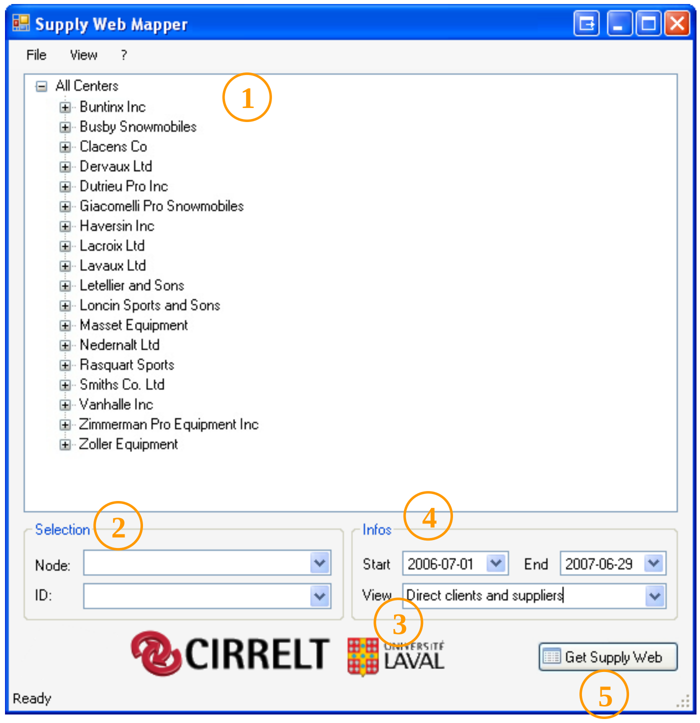


Figure 36: Selection Interface

The selection criteria dictate the results to be shown on the display interface since only the data related to the selected node and network will be loaded resulting into the display. After choosing all the desired criteria on the selection screen, the user can launch his query by clicking the 'Get Supply Web' Button (36.5). The time required to return the query result depends on the size of the flow exchanged by the selected network nodes. Once the result of the query is loaded and prepared, the display interface allows the user to visualize and manipulate it in multiple ways.

Display interface

The roles of the display interface are first to depict the results of the user's query in an intelligent, navigable and attention drawing manner and, second, to allow further analyses, manipulations, and data mining. The first role relies on the conceptual map viewer and the geographic map viewer. The second role relies on the control board, the data-mining viewer, and the graph viewer. The two latter viewers allow the user to explore the data in order to answer questions arising while investigating the conceptual or geographical maps. The user can customize the construction of the graphs based on the results presented in the other three interfaces. The graphs can, for example, show the evolution of different KPIs over time, illustrate market shares of different sites, or yet trace different products. The content of the data-mining viewer and the graph viewer are affected by what is performed by the user on the conceptual and geographic maps, since the latter viewers determine what should be shown in the former viewers (Figure 35). The geographic and conceptual maps are mutually affecting each other because manipulations on one should be reflected on the other, as indicated in Figure 35.

In addition, the display interface provides many tools for investigating, mining, and exploring the selected logistic web context, nodes, or flows from different points of interest such as products, shipped trucks, volumes, weights, or quantities. This allows highlighting KPIs that are most relevant to the user analysis. These tools or controls are mainly grouped in a control board, which can be seen as an extension to the selection interface since it provides more filtering and investigation options. In general, the display interface is equipped with tools that allow drilling in and out through the results of the user's query.

As can be seen in Figure 37 the display interface of our prototype is divided in two parts. Part (37.1) contains three tabs. Each leads to one of the three completed viewers, the graphic interface currently being under construction. Part (37.2) represents the control board through which the user can customize the display on the viewers, choose his preferred units of measure (e.g. 37.b, 37.c), and set the KPIs to be highlighted. The user can choose the data to display by selecting the desired elements in the 'Displayed Information' pop-up (37.a). The default displayed information is the number of distinct SKUs, number of cases, financial flow, number of shipped trucks, weight, and volume. The 'Excel' button (37.f) exports the current selections to an Excel file, while the 'Bitmap' button (37.g) saves the Conceptual Map in an image format (e.g. bitmap).

In the 'Filter Options' (37.e), the user can exploit node aggregation through grouping and ungrouping functionalities. More aggregation and disaggregation options of nodes and flows are available in the conceptual map by right clicking on nodes and links. In fact, the user can be interested to see the network of nodes corresponding to aggregated business units, actual sites, or a combination of both. By default, the presented data is aggregated by business units. The 'Ungroup All' button (37.h) disaggregates all business units to their sub-sites, detailing flows by sites rather than by business units. The ‘Products’ pop-up, accessible under the ‘view’ menu, displays the product category hierarchy as an expandable dynamic tree view. The user can drill in or out through the product category tree to choose any combination of products or product categories contained in the pre-selected logistic web.

Conceptual Map Viewer

The conceptual map viewer is a core component of the logistic web mapper. The flows resulting from a user’s query are mapped as shown in Figure 37. The nodes, either sites or business units, are represented as rectangles showing the name and the identifier of the node. The flows are represented through links shaped as curved lines joining nodes together.

The user has the possibility to customize the conceptual map via different tools made available to him. First, he can adjust the position of nodes and links by dragging them. He can group or ungroup a node, or link either via the control board, as presented in the previous section, or by accessing the disaggregation options through textual menu displayed by right clicking on the node or link. It is possible to have a global, aggregated view as a network of business units, or a detailed, disaggregated perspective depicting physical sites. Each set of sites belonging to a certain business unit can be identified by a color code and/or a business unit identification. Moreover, some business units can be aggregated while others are disaggregated, allowing the user to mine the network easily at his convenience.

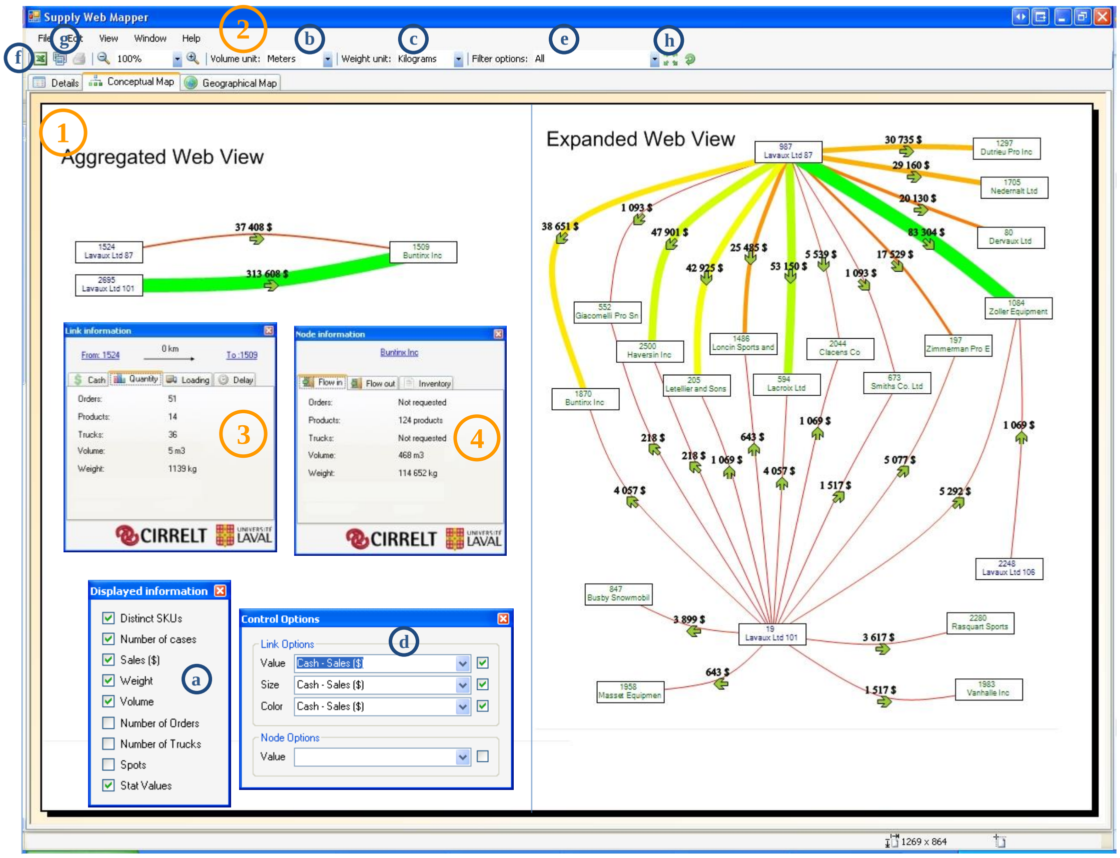


Figure 37: Conceptual Map Viewer

The right clicking textual menu on a node or a link provides also the option to show a pop-up containing information about the selected element. In addition to a clear identification of the selected node, the pop-up of a node contains three tabs: (i) ‘Flow in’ tab which shows key quantitative data about what the node received, (ii) ‘Flow out’ which gives the same quantitative data about what the node shipped and (iii) ‘Inventory’ tab which shows key inventory data of the selected node. The link information pop-up contains four tabs: Cash, Quantity, Loading, and Delay. The ‘Cash’ tab contains financial data about the flow that went through the selected link. The ‘Quantity’ tab gives quantitative information such as the volume, the weight, the number of trucks, and the number of orders that transited the link. The ‘Loading’ tab displays key information about the volume and the weight utilization of trucks that traveled the link. Finally, the ‘Delay’ tab displays information about the delays related to the flow (e.g. expected and effective shipping dates).

The link color, width, and value can be associated to different criteria. For example, the color can be related to the volume transited through the link, the width to the number of trucks, and the value to sales. Largest is the value criterion associated to the width, the ticker the link is (Figure 37). The association between the link color, width and value, and different criteria is done via the 'Link Option' of the pop-up (37.d) that can be accessed via the 'View' menu of the control board. In the same manner, the 'Node Options' of the same pop-up, allows customization of the size, color, boarder size, font text size and color, of the nodes. More customization is possible by using other features provided by the control board such as grouping and ungrouping nodes, selecting the preferred combination of products and product categories, as well as system units for weights and distances.

Geographical map Viewer

While the conceptual map viewer conceptually represents the selected logistic web, the geographical map viewer illustrates it physically, allowing zooming and panning as desired. The same flows found on the conceptual map are presented on the geographical Map according to the real location of the involved sites. An example of the geographical mapping is presented in Figure 38. The nodes are drawn as coloured stars on the map in the Figure. Each star is located in the exact geographical position of the site related to it, using its latitude and longitude coordinates. The flows are presented as lines between the nodes. The color and the size of a node or link are customizable in the same way as on the conceptual map. The white stars represent the nodes that shipped the finished goods sold in the selected network, the blue stars illustrate the final destination of the products, and the red stars are nodes through which the products transited.

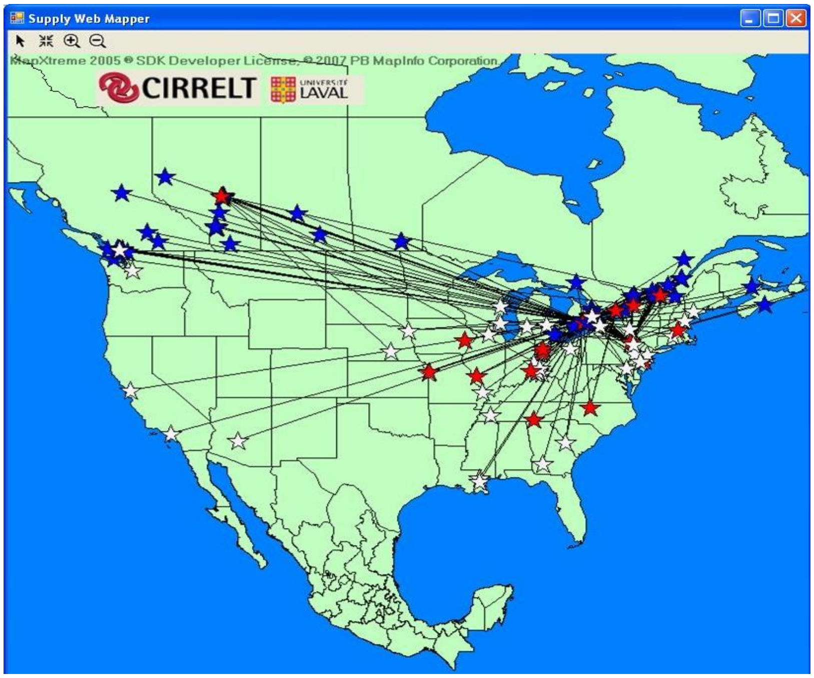


Figure 38: Geographical Map Viewer

Data Mining Viewer

Figure 39 exposes the data-mining viewer as a textual three-dimensional representation of the user's query result. It represents the synthesized data as flows between pairs of nodes of the selected logistic web and it is structured as a dynamic data tree view. First the tree view is presented as a two-dimensional table with lines showing the flows and the columns representing various measures such as number of SKUs in the flow, the weight, the volume, the number of orders and trucks. The third dimension is available by expending the lines, so that the user can easily investigate the flows. By successively expanding the flows, the shipped trucks, the shipped orders and order lines, the user can visualize their content and see different measures for each one, as illustrated in Figure 39. A primary goal of this viewer is to enable the user to drill in and out to better understand an aggregated measure or to explore in-depth some complex problem issues.

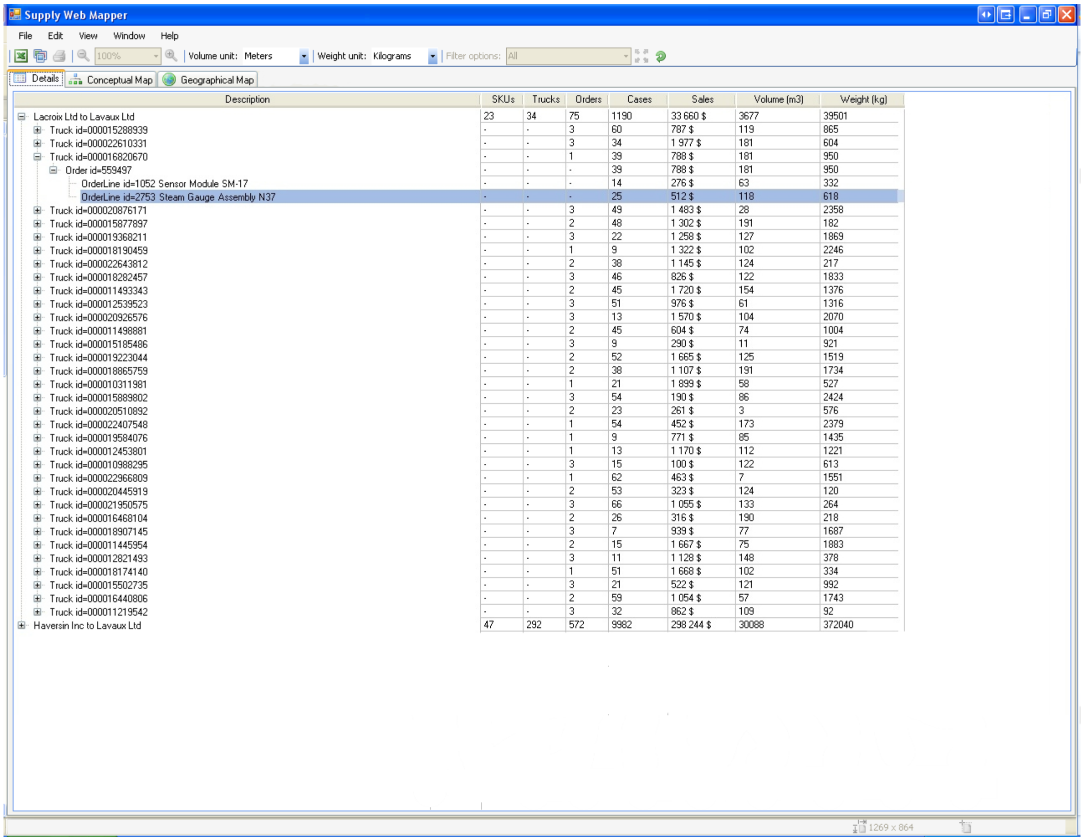


Figure 39: Data Mining View

The selection of KPIs, the grouping and ungrouping actions taken on the control board or on the conceptual map are reflected automatically on the data tree view. Another primary goal of this interface is to support the other interfaces since it focuses the most on the numerical display of data, and the least on the representation and attention drawing. In addition, selection of links and nodes on the conceptual and geographical map highlights automatically the corresponding data on the tree view.

Logistic Web Playback and Logistic Web Monitor

This section is a short introduction to the logistic web playback and the logistic web monitor. The architecture and structure of these two applications are very similar except that the playback is past focused while the monitor is real time oriented. Supply web playback is a dynamic business intelligence tool that enables users to replay, explore, and analyze past events, as well as go back and forth over the history of a logistic web context or one of its embedded networks. It reproduces the past of the selected logistics context in a virtual environment, at a controlled and accelerated pace, showing all the interactions and dynamics between the logistics elements. It helps to dynamically visualize, mine, and assess the logistic web.

From a conceptual perspective, logistic web playback consists of a synchronizer and three main interrelated components. Changes in any one of the playback components involve updates in the others. The miner allows the delimitation of the logistics context and the exploration of the obtained result. The visualizer displays the logistic web in an intuitive and customized way based upon the user's specifications. The visualizer supports numerous viewers dedicated to different aspects of the decision support. An example of the transport map viewer is shown in Figure 42. The decision supporter monitors the logistics events and draws the user's attention to important issues by generating appropriate messages and alerts, and by commanding smart displays on the visualizer's viewers. The synchronizer manages time evolution by controlling the logistic web playback access to the logistic web database, and by synchronizing the three components (Figure 40).

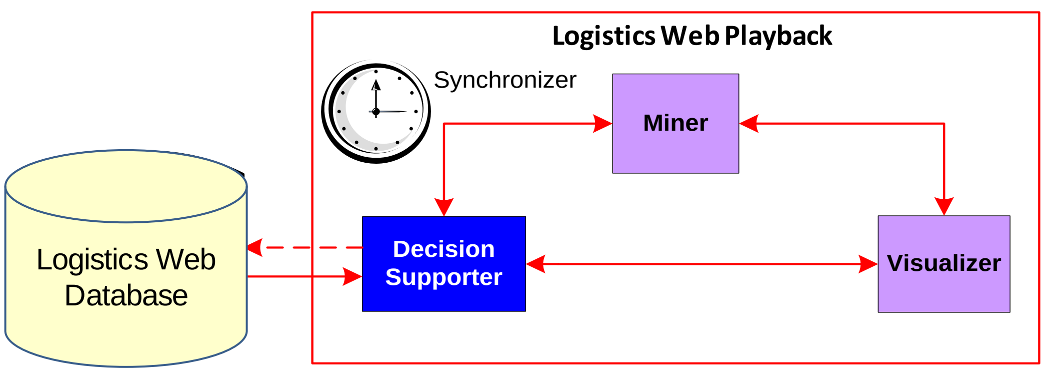


Figure 40: Supply Web Playback Conceptual Structure

The logistic web monitor is a business intelligence tool providing real time visualization, mining, and multi-criteria assessment of the supply chain. It tracks all the active logistic web events, while it monitors the state of logistic web elements. Relationships between events and states are continuously re-evaluated in order to detect any potential rapidly rising issues and to direct the focus of users toward important and urgent matters through decision support and smart visualization. The user can explore the current state of the logistic web and its embedded networks according to the desired KPIs and dimensions. As for the logistic web playback, the logistic web monitor is composed of a visualizer, a miner, a decision supporter, and a synchronizer, as depicted in Figure 41.

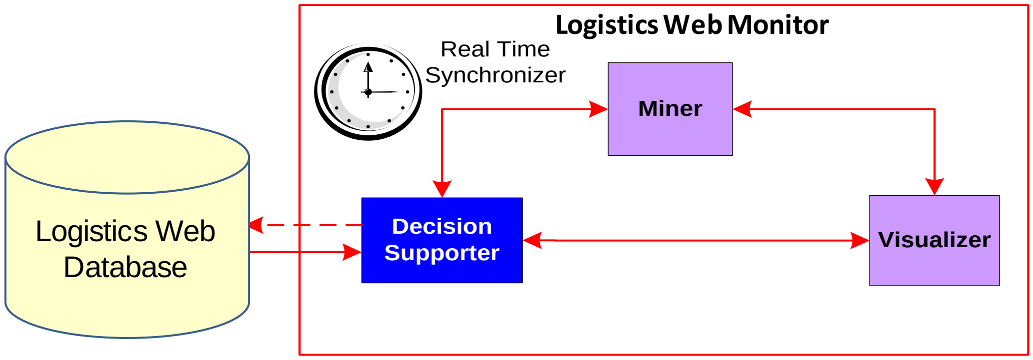


Figure 41: The Supply Web Monitoring Conceptual Structure

The real time synchronizer monitors the database and ensures that all the components of the playback are synchronized internally and with the database. In terms of the time frame, the logistic web monitor is more focused on real time and short-term past. Thus, it allows real time assessment of logistic web dynamics and evaluation of the impact of recent past decisions and events on logistic web behaviour and performance.

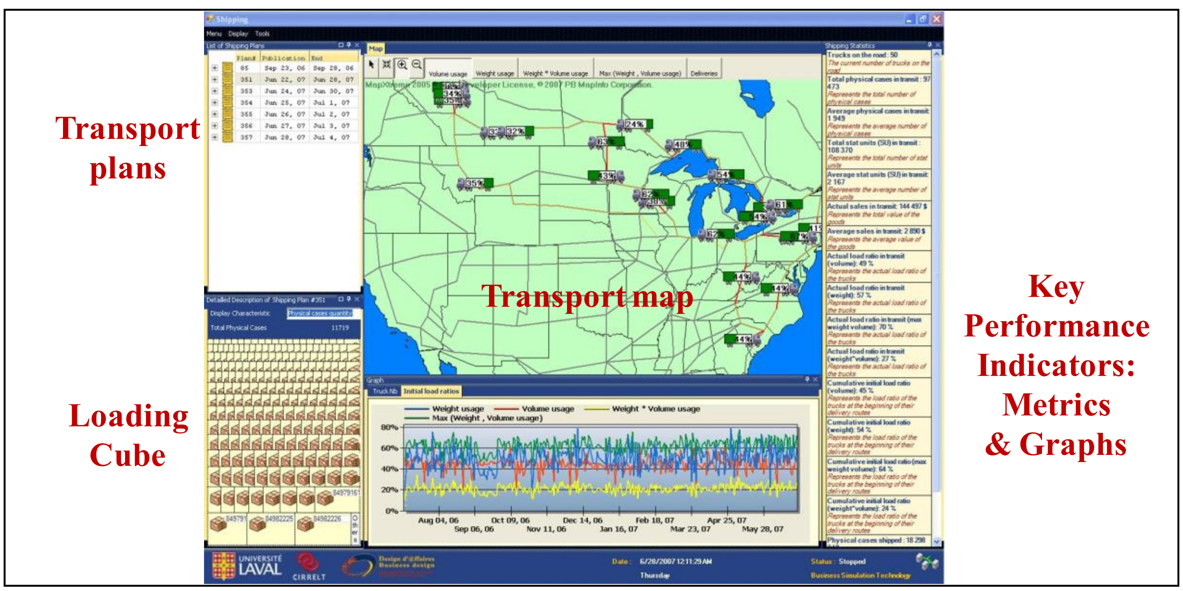


Figure 42: The Logistic Web Playback/Monitor Transport Map Viewer

Our prototypes feature three viewers thus far: the transport map viewer, sales map viewer, and inventory viewer. Figure 42 represents the transport map viewer. In the center of the figure, the dynamic transport map illustrates the evolution of deliveries. It dynamically displays the trucks travelling between sources and destinations, and provides evolving KPIs about the contents and routes of these trucks. Upon the selection of a truck on the transport map, transport plans reveals the selected truck's details such as source, destinations, departure date, expected arrival date, delay, weight, and volume. The loading cube permits the up and down drilling through the content of a transport plan, a truck, or a site. It supports the display of information according to multiple KPIs. Moreover, the evolution of general KPIs is tracked metrically (right of the figure) and graphically (center bottom of the figure).

Simulating Logistic Web Embedding Supply Networks

The use of the logistic web tools presented in the previous section assume the exploitation of the logistic web data provided by the actors of a certain logistic web contexts who are willing to collaborate and share their data. However, this kind of collaboration is not easy to achieve especially on a web level. This brings up the question of how an organisation or actors of a supply chain or network can still exploit the web dimension without the willingness of other logistic web members to participate in web-scale collaborations.

Holistic and highly detailed simulations provide advanced modeling of the lacking parts and help complete and attach the pieces of the puzzle. Partner behaviours can be modelled very realistically while those of non-contributing members of the logistic web can be approximated as best as possible. Each partner can decide to expose some or all the interns of its model to other partners, as well as some or all the outcome of simulated runs, depending on its confidence level with the other partners.

Logistic Web simulation is perceived as a key enabler for decision-makers to capture the impact of the web dimension and of new introduced changes. Such simulations can be used also for exposing to partners in a logistic web the potentials of adopting a collaborative vision or strategy through the result of live simulations. The simulation has been identified as one of the most effective and less expensive options for supporting the assessment of major joint initiatives, especially in the case of multi-sited partners, each with its own supply network. It is well known that changes in a part of a complex supply system can create waves of changes through the entire system (Stefanovic, et al., 2009).

To empower the applications introduced in the previous section with more flexibility and decision support features, a multi-agent, distributed and modular logistic web simulation platform is being be developed. The huge size of data and the number of events and operations in complex logistic webs impose many challenges for developing a generic, yet easily customized, simulation platform. The modeling approach focuses on conserving the complexity of logistic webs, while providing users with the right capabilities to tackle this complexity and make better decisions. The simulator will be conceived to produce virtual, parallel worlds and it will be an interactive application to allow users to follow the evolution of a simulation, interact with it by introducing or changing a strategic, a tactic or an operational decision and they can see the impact on the entire virtual logistic web in an accelerated mode. Thus, the simulation can be used by managers for testing different decisions and performing what-if analyses, as well as to teach new managers and introduce them into the complex logistics environment of a specific company[10]. The fist subsection introduced the conceptual model suggested for developing the logistic web simulation platform.

The market demand at the stores level is among the important drivers that affect the logistic web behaviour. Therefore, our logistic web models do not only consider the perceived demand of adjacent clients but also integrate daily product demands at the store level during the simulation progress. However, this kind of demand is not always exposed to all the actors of the supply network. The estimation of this demand is important to feed the simulation and produce accurate models reflecting as much as possible the reality of the targeted web context.

Logistic Web Simulation Platform[11]

As it was mentioned upon the presentation of the general architecture of the logistic web technologies, the logistic web simulation platform, of which an instance is referred to as a logistic web simulation solution, is a combination of the logistic web simulator and logistic web simulation database (Figure 43). The logistic web simulator is a multi-agent application that allows simulating logistic web environments. It aims to substitute a real logistic web environment by a virtual logistic web world.

---

[10] More benefits of the simulation are discussed extensively in the literature (e.g. Shannon, 1998; Law, et al., 2000).

[11] This section exploits the content of Hakimi, D., Montreuil, B., & Labarthe, O. (2010b). Supply Web Agent-Based Simulation Platform. *Proceedings of the 3rd International Conference on Information Systems, Logistics and Supply Chain, ILS 2010 – Casablanca (Morocco), April 14-16.*

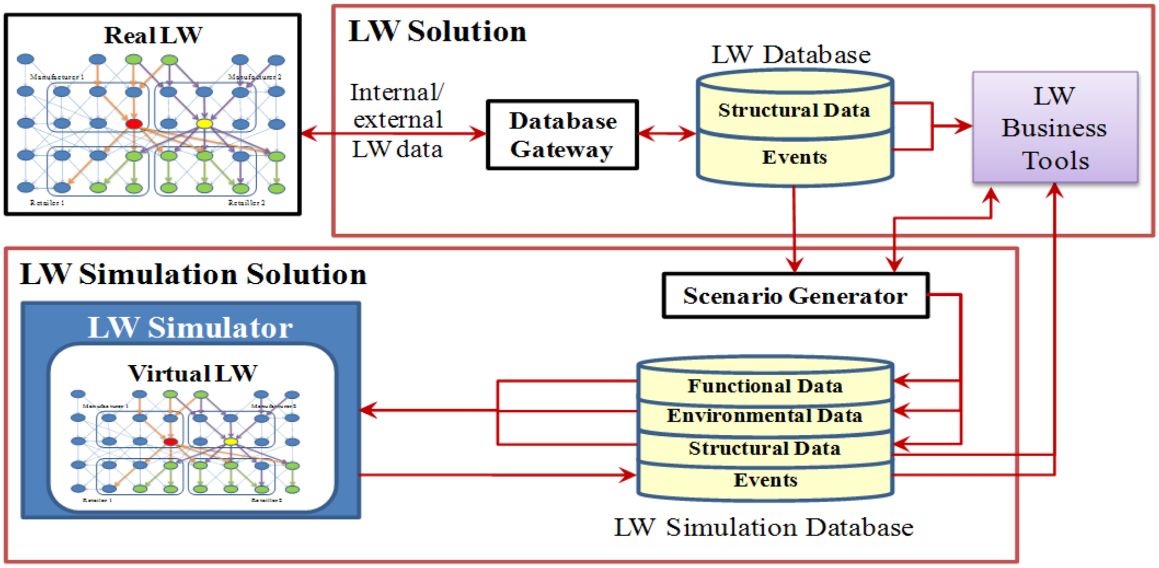


Figure 43: Interconnecting the Logistic Web Simulation Solution and the Logistic Web Solution

To model a logistics context, two types of data are necessary: the structural data and the functional data (Swaminathan, et al., 1998). In our research, the structural, or configuration data, is used to configure the logistic web context. It consists of data about the structure of the logistic web, such as the attributes of organizations, sites, products, and product families and categories. This type of data is found in both the logistic web database and in the logistic web simulation database. The logistic web functional data corresponds to the pieces of data composing the profiles of different actors of the logistic web. This data determines the behaviour and the decision-making process of the actors. Each one of the simulator agents is associated to an actor and uses his profile parameters to mimic his behaviour. Environmental data represents events influencing the virtual environment to which the agents need to adapt such as market demands.

The generation of simulated logistic web events is among the important functions of the simulator. Events data reflects the dynamics and the evolution of the logistic web over time. The simulator takes as an input the logistic web structural, environmental, and functional data, and creates a virtual logistic web environment where agent applications mimic the real world organizations' behaviour. The simulator sends the generated events of this simulated world to the logistic web simulation database.

The logistic web business tools such as logistic web mapper, playback, and monitor can be connected to the logistic web simulation database in the same way they are to the logistic web database. The switch between the two databases is made by a simple address change. There is no difference for these tools to be connected on a real world or on a simulated world. They offer the same main capabilities in both cases. Whereas the functional data is necessary for the logistic web simulation solution, since it is used to generate the agents' behaviour, it is not required for the other current components of a logistic web solution because they deal with the behaviours' results, which are the logistic web events, rather than with the behaviours themselves. Since the logistic web structural data and the logistic web events have the same table structures, and since the logistic web business tools do not require logistic web functional data, mapping these tools on either database does not affect their normal functions.

Building a generic logistic web simulator is a very challenging mission. While it is relatively easier to standardize the logistic web structural data and the events, it is very difficult to do so for the logistic web functional data because it is related to the internal behaviours of members and systems of each organization. Even if it is sometimes possible to determine certain dominating behaviours patterns, many exceptions make it hard to create common data structures, especially when the objective is the reproduction of granulated details. Since the standardization of the logistic web functional data is trickier than the standardization of the structural data and event, and because logistic web business tools do not require the logistic web functional data, it is much easier to build generic logistic web applications than to build a generic logistic web simulator.

The next subsections explain how we addressed this challenge. Subsection one describes the architecture of the logistic web simulator. Subsection two details our agent-based modeling approach. Subsection three discusses some applications of the logistic web simulation. Subsection four synthesises and concludes the subsection.

The Logistic Web Simulation Architecture

The logistic web simulator is a multi-agent platform. It consists of a set of multi-agent applications distributed on many computers inter-connected through the Web by using TCP/IP protocols. Each multi-agent application can run on a single computer, share the same computer with other multi-agent applications, or be distributed on many computers depending on needs in terms of processor and memory capacities. As shown in Figure 44, inspired from Ahn et al. (2004), the multi-agent application consists of four modules: the interaction module, the communication module, the behaviour module, and the Graphical User Interface (GUI) module.

The communication module is responsible for standardizing, sending, and receiving messages, and for communicating with the database. The interaction module packs the messages to send to the other agent applications and passes them to the communication module, which forwards them to the synchronizer application, which then transfers them to the right destination. The interaction module also receives external messages through the communication module, unpacks them, and transfers their contents to the right internal agent. As depicted in Figure 45, the behaviour module is the core of the application and contains the agents that determine the role of the application in the simulation.

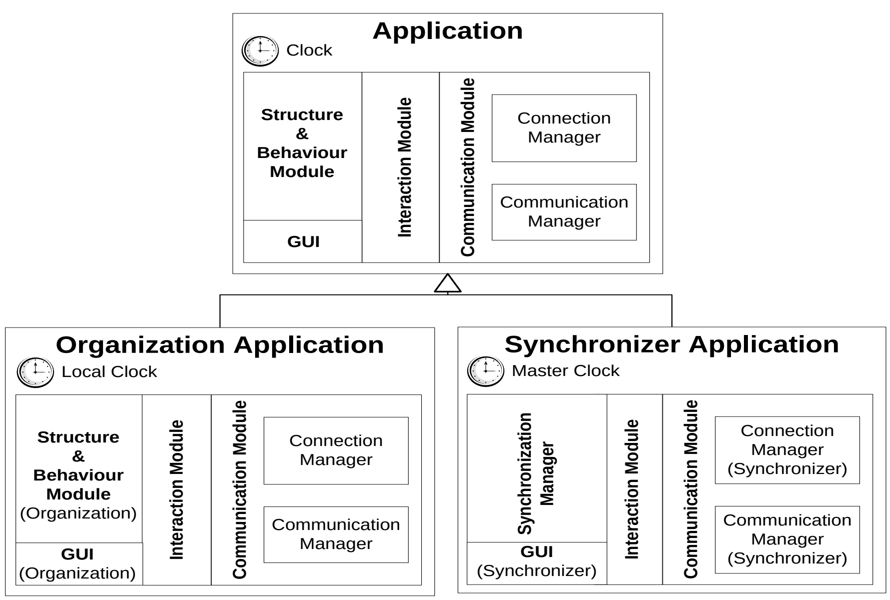


Figure 44: Components associated with the Logistic Web Simulation architecture

The type of multi-agent application depends on the type of the behaviour module associated with it. In the logistic web simulator, there are mainly two types of multi-agent applications based on the type of the behaviour module: multi-agent synchronizer and multi-agent organization (Figure 44).

In a logistic web, simulation there is one synchronizer instance and several organization instances. As illustrated in Figure 45, each organization instance represents a simulated organization (e.g. a company) of the simulated logistic web context.

The launching of a simulation engages the following steps:

- The synchronizer connects to the database and gets the list of available logistic web scenarios to simulate;
- Through the synchronizer GUI, the user selects the desired scenario. The synchronizer is now in the listening state waiting for the organization applications to request connections;
- Through the GUIs of the organization applications, the user associates each application to a company in the logistic web to simulate;
- Each organization application sends a connection request to the synchronizer;
- Upon receiving a connection request, the synchronizer establishes a TCP/IP connection with the requesting application. Then, it sends the information about the scenario to simulate;
- After receiving the information about the scenario to simulate, the organization application loads its profile associated with the selected scenario. The organization profile consists of structural data and functional data about the corresponding organization.
- The organization application builds the virtual organization by creating the necessary environment, objects and agents. All the elements are now in their initial states.
- The organization application notifies the synchronizer that it is in the “ready” state;
- After the synchronizer is notified that all participating organizations are ready, it sets its clock to the initial time and notifies the user that the simulation is ready for execution;
- After the user launches the simulation, the synchronizer starts the organization applications.

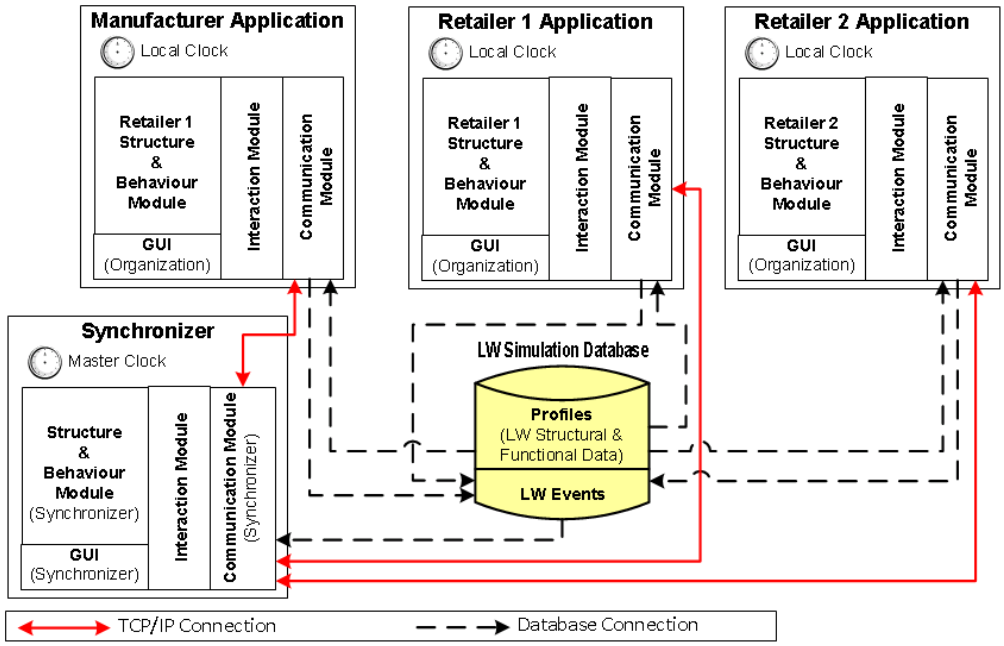


Figure 45 : Example of Logistic Web Simulation Architecture

The Synchronizer

The synchronizer ensures the coordination of the organization applications and the communication between these applications. It makes sure that different events are handled according to the right order of occurrence and that all the organization applications operate at the right speed according to the common master clock.

The Synchronizer's GUI provides user with the possibility to select and parameterize the scenario to simulate, launch the simulation, pause and play it, slow it or speed it, and stop it. It gives also general information about the simulation state such as the current simulation time and the connection status of the organization applications.

The connection manager establishes the connection with the database and the initial TCP/IP connections with the organization applications. It also reconnects the organization applications in case the established connections were lost.

The synchronization manager ensures the synchronization among all the participating applications by continuously validating that the time of the local clocks of these applications matches the time of the synchronizer's master clock and by closely following the execution sequence of events involving more than one organization. The synchronizer’s communication manager plays the role of a logistic web message dispatcher. The organization applications are not connected directly to each other. Each has only one bilateral TCP/IP connection with the synchronizer. When an organization sends a message to another organization, the message is sent from the sending organization’s communication manager to the synchronizer’s communication manager, which transfers it to the destination organization’s communication manager. When the synchronizer’s communication manager receives a message, it checks the destination address and forwards the message to the corresponding organization.

The Organization applications

The organization applications represent different members of the logistic web to be simulated. An organization can be seen as a combination of a head office, an information system, and a set of sites representing the physical nodes belonging to the organization. An organization can for example represent a retailer, distributor, or manufacturer. Depending on the role played by the organization, it may encapsulate stores, distributions centers, and/or factories, as shown in Figure 46.

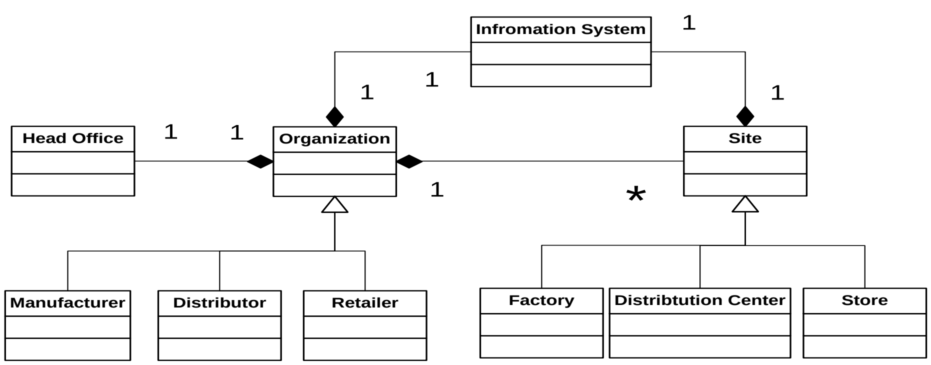


Figure 46: A Simplified Class Diagram Section Showing the Organization Structure

Figure 46 illustrates the basic and most generic organization and site structures found in a logistic web simulation. For example, a site can have basic attributes such as an address and unique identifier, can belong to an organization, send and receive orders and shipments, and manage a list of products. The store, which inherits the site’s proprieties, has also generic store behaviour and structure. It has a store room and front-store, handles market demand, and its agents manage the operations between the store room and the front-store.

Depending on the desired modeling level of detail, children classes can be added to refine the behaviour of different entities. For example, other classes such “Grocery Store” and “Electronic Store” can inherit from “Store” to reflect more specifications and advanced behaviours of the simulated entities. In the same simulation environment, instances of different abstraction levels can be found. Some stores can be modeled as sites, others as stores, others as grocery stores, and some others as stores of a specific retailer. This modeling approach is very important, especially in a logistic web context where the number of simulated entities can increase rapidly and where the focus is on detailed dynamics of the logistics context. This strategy has many advantages:

- Obtaining a fast and representative generic model: Since generic classes are already developed and their generic behaviour is representative of most logistics contexts, obtaining a first generic simulation featuring basic physical, information, and financial flow exchanges is a matter of adapting and putting the profiles of the organizations and their sites into the logistic web simulation database. A generic simulation is not designed to take in consideration the specific particularities of different industries but can provide a representative level of detail of a logistic web environment.
- Fast modeling of a complex environment: The more finely an entity is modeled, the more effort and time the modeling takes. Therefore, the combination of different levels of abstraction for different entities can accelerate the modeling process. The entities requiring more attention can be modeled finely and the others can be represented at different abstraction levels depending on their importance.
- Continuous development of customized behaviours: Creating customized behaviours for different entities can be done gradually by adding subsequent classes that inherit the proprieties of their preceding parents and by exploiting the potentials provided by agent-based modeling. The simulation can reach very granulated levels by modeling the important entities as close to reality as possible. For instance, a retail store floor can be modeled as a virtual world with the equivalent of real products, shelves and store equipments, and various management system agents and with customers shopping and employees working. Each customer and each employee can be modeled as a distinct person with a distinct profile.

- Testing while developing: After the first generic level is obtained, development of customized behaviour can be done by progressively adding new features. The evolution of the simulation development can be done smoothly by integrating the new features in an already working environment. Users can benefit from these new features as soon as they are integrated since it is not necessary to wait to make major changes in order to produce new versions of the simulation.
- Taking all the elements of a logistic web in consideration: Modeling the less important elements as generic entities with representative behaviour results in not sacrificing them by excluding them from the model or aggregating their behaviour in a simplistic black box. This way, their impact, their existence and their behaviour can be assessed, and then refined when deemed pertinent.
- Efficient processor and memory capacity management: Optimizing the use of the computing processor and memory capacity is a key in succeeding in simulating a large logistic web context. Generic behaviours require much less memory and processor capacity than do sophisticated and complex behaviours. Using generic instances for some entities of the model helps lower the burden on the network of computers and increase the smoothness of the simulation run.

Agent-Based Modeling Approach

Conceptually, the modeling approach used for the organizations modeling is a hybrid of the recursive modular protomodel based approach (Montreuil, 2006) and a multi-agent approach (Labarthe, et al., 2007). The organizations are multi-agent applications. The behaviour of their agents is mapped on the behaviour of real actors or systems in the modeled organization. Each site has a set of products to manage. It encapsulates an information system and other components depending on its nature. Figure 47 sketches an example of a retailer agent model. A generic store has a backroom a floor shop and a set of agents representing different store management systems.

The sales system fulfills the market demand using the shop floor inventory. The market estimation agent performs the demand forecasts based on the sales history. The resulting forecasts are transferred to the Inventory Management System (IMS). The IMS manages the inventory of the store room and the shop floor. It received the sales data from the sales system, the forecasts from the market estimation agent and evaluates the inventory levels to decide which products in what quantities to transfer from the storeroom to the shop floor. Depending on each product replenishment policy, the order manager generates the new orders and sends them to the head office order manager agent. The latter sends store replenishment requests to the distribution centers, monitors the product inventories of all the retailer sites and issue orders to the suppliers. The distribution centers fulfill the store orders, manage their inventories, and handle the received shipments.

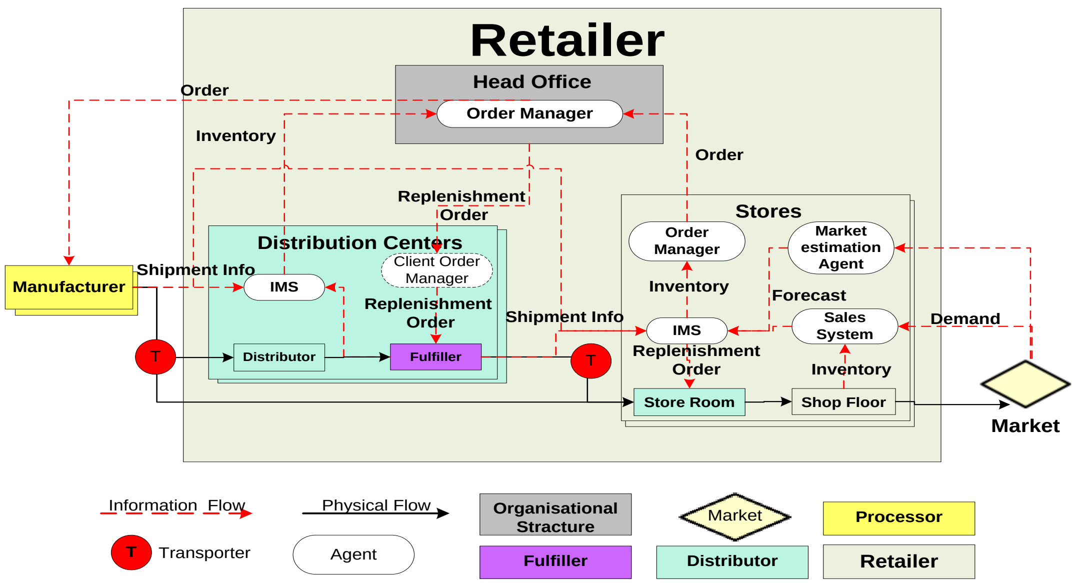


Figure 47: The Retailer Agent Behaviour Module in a Supply Context

Some Applications of the Supply Web Simulation Platform

The logistic web simulator can serve multiple purposes. Its link to the multi-dimensional, multi-user and multi-interface logistic web applications of the logistic web solution offers many features that can help provide different users with a practical and powerful managerial instrument which can serve multiple decision levels. This section presents a few applications of the simulator to illustrate how it can be used and how it supports managers and researchers in different contexts, each according to his interest and focus.

Integration of the Supply Web Simulation Platform with the Supply Web Technologies

As was mentioned earlier, the logistic web decision support systems allow statically, dynamically and real time visualization, monitoring, assessment, and mining of logistic web contexts and their performance. On the one hand, these applications provide the same capabilities when connected on virtual worlds created by the simulator as when connected on the real world (Figure 43). On the other hand, linking the simulation platform to the other logistic web technologies considerably leverages its capabilities.

The logistic web monitor acquires a special and important role when it is connected to a simulation. It is considered as the visualization module of the simulator. The monitor handles the logistic web events as soon as they are recorded into the database, by adjusting and visualising the states of the logistic web and updating the associated KPIs. When it is connected to a running simulation, it translates the event data into a visual output showing the evolution of the simulation. As long as the difference in time between the occurrence of an event in the simulation and the corresponding update on the monitor is very small, users can follow the evolution of the simulation on the monitor's visualizers. The monitors can provide screens focusing on different aspects of the logistic web such as transportation, inventory, sales and demand, or finance, allowing users to investigate different aspects concurrently.

Moreover, users can exploit different capabilities and features provided by the logistic web monitor, the logistic web mapper and the logistic web playback. They can investigate different KPIs by drilling in and out through product, organization, time, and/or logistics depth dimensions. They can track the evolution of customized KPIs over time on dynamic graphics and charts. They can focus on specific elements of the logistic web such as a product, set of products, site, or organization. They can have a panoramic view on large logistic web contexts, or they can go back and forth between focused and extended views.

Creating and Comparing Different Scenarios

The logistic web simulator agents represent the decision entities within a simulation. They encapsulate behaviours that shape their decision-making process. Simulating the organization's as-is behaviour involves developing agents corresponding to the key decisional actors and implementing the decision processes of these actors as behaviours of corresponding agents. The simulation model design aims to exhibit the closest possible real behaviour given development time and resource availability constraints. Organizations are interested in assessing the impact of infrastructure changes prior to the implementation. The adopted Multi-agent modeling approach offers the possibility of testing the impact of these changes because it involves only switching the parameters of the concerned agents to use a behavioural setting reflecting the new way of doing.

Since agents are used in the logistic web simulator for strategic, tactic and operational decision levels, different changes at any combination of these decision levels can be implemented and studied. It is possible to simulate management strategy changes over a supply network, from the highest level to the smallest level. The simulator can be used for any supply chain concept or strategy; from a lean, to an agile, or a leagile supply chains (Childerhouse, et al., 2000), as well as the integration of different techniques or policies such as Vendor Management Inventory (VMI) or global order processing (Alarcon, et al., 2009) approaches. In addition, simulating structural and functional changes of a logistic web requires merely creating new scenarios that reflect the changes in the configuration data and the concerned organizations' profiles. No changes will be required on the simulator except mapping the profiles of new organizations added in the database.

Comparing scenarios, whether they involve behavioural, structural, and/or functional alternatives, is empowered by the logistic web decision support systems that provide different multi-dimensional KPIs. The performance of a simulation can be measured according to the user's point of view. The customized KPIs provide a comprehensive understanding of the outcome of each scenario and major issues to be considered when choosing an option versus another option. The simulator is not designed for a pure quantitative statistically significant comparison. The size, depth and complexity of the modeled systems are generally too large for fast execution of a very large number of replications of each scenario, which is the realm of classical supply chain simulators highly simplifying and aggregating the modeled actors and behaviours. The simulator here introduced is rather designed as a powerful tool to provide comparisons of the impacts of different actions in the extended complex logistic web environment and on the relationships between actors.

Focus on Visualization and the Dynamics of Simulated Environments

The goal of the logistic web simulator is not to provide optimal solutions for local problems. The conceptual approach adapted for developing the logistic web simulator is based on soft and holistic approaches such as complex adaptive system and social network analysis where the level of detail is important, and complex behaviours and relationships between different elements are considered in a complex environment. Applying this approach to a large environment such as a logistic web context involves a large quantity of data, enormous number of computing operations, and many variables interacting together. Comparing scenarios through a quantitative approach by creating experience plans and running many replications (Law, et al., 2000) is not currently achievable, because the normal variability and the level of uncertainty inherent in the real world logistic web systems are already highly complex to control. According to Pathak et al. (2007), the impact of uncertainties within a many-entity environment may overwhelm the limited robustness of small-scale globally optimal solutions. This means that even if the variability of the simulations is kept to its minimum level, leaving only the variability of the real system, the number of replications required for any comparison will be very important, as each replication would take a significant execution time. Also, a key purpose of the logistic web simulating is to allow the users to follow closely the evolution of the simulation through visual interfaces.

The logistic web simulator is designed to allow users to grasp the complexity of logistic web contexts and to support them in making decisions in these contexts. The focus is on the dynamics, the interactions, and the mutual impacts occurring in logistic webs. The logistic web simulation platform helps the users understand the impact of various logistic web elements on their operations and businesses, as well as assess the real impacts of these decisions on the internal operations, external partners and the rest of the logistic web.

The logistic web visualization aspect acquires an important role in order to support the purpose for which the logistic web simulator was designed. Users need to follow the progress of the simulation visually through comprehensive and dynamic sets of interfaces. They also need to track the evolution of different metrics and KPIs to achieve a clear understanding. The logistic web simulator core itself is not equipped with tools that provide these capabilities but its features are enhanced through the integration of the logistic web tools as mentioned earlier.

The multi-screen and multi-focus characteristics provided by the monitor allow different levels of analysis. They allow managers to follow the states of specific elements such as the inventory level of a product in certain sites or to monitor complex elements such as the product logistics process from plants to stores. It can allow cross-department collaboration by bringing together managers from different perspectives, such as marketing, supply chain management, and finance, to work jointly in a boardroom to unify their visions and develop common strategies. In the case of cross-organization collaboration, actors from different organizations can create scenarios involving a global strategic vision and jointly follow and study the simulation and its results. Users have the possibility to increase and decrease the simulation speed or temporary stop it. They can zoom in and out dynamically through different sections of the logistic web and closely assess multiple KPIs.

While the monitor provides the possibility to observe the simulation in real time, the mapper and playback allow studying the simulation from its beginning until its current time. The mapper provides static multi-dimension visualization, mining, and assessment of any selected logistics context and its performance at any desired depth through product, organization, time, and logistics dimensions. For example, a user can focus on the supply chain of a product by finding the produced quantity, the sold quantity globally or in a specific site, the quantities exchanged among organizations or among sites at any desired time span. The playback lets users replay back the simulated past as many times as they need while the simulation is still running, stopped, or after it ended. Users can dynamically visualize, assess and mine the simulated past of a logistic web context and its performance by replaying the past evolution of the simulation and dynamically following various KPIs.

Local Optimizations and Logistic Web Simulations

While the logistic web simulator is not designed for optimization, it is a powerful tool to test the impact of local optimizations on different components of the logistic web. Some logistic web sections can be optimized, outside the simulator, by using optimization procedures such as mathematical programming, metaheuristics or meta-models. The obtained result is then used to parameterize the configuration, as well as the functioning and/or the behaviour of certain logistic web elements. The resulting configuration and/or behaviour are implemented into the profile of the corresponding elements in a logistic web simulation. The logistic web simulation, in this case, provides two advantages. First, instead of testing these sub-systems in isolated environments by injecting random input data, the simulator provides a realistic testing environment that takes in consideration the interactions of different elements in a virtual logistic web context. Second, since local optimizations do not necessary guarantee a global optimization (Eschenbächer, et al., 2003; Capari, et al., 2004), the logistic web simulator allows studying the impact of a local optimization on the entire business context, on external partners and on the extended logistic web in a dynamic monitored environment.

It is also important to emphasize that each agent in a simulation can be modeled with a very complex behaviour involving local optimization through decision rules, heuristics, and even mathematical programming, when deemed appropriate by the users to represent reality adequately. For example, a shop scheduler may exploit scheduling algorithms and heuristics. This requires more processing and memory storage for these agents so as not excessively slowing down the overall simulation. Ultimately, the agents may use the exact same software tools as the real actors in the logistic web.

Synthesis

Logistic Webs are complex environments in which complex relationships between supply networks, organizations, sites, and humans occur. Changes in a part of a web can create waves of changes that reach distant actors. Managers need to evaluate the impact of their decisions on their internal operations, on relationships with their partners and on their environment. They need also to understand the impact of external actions on the internal operations and on their businesses. In this subsection, we introduced the logistic web simulation platform as a tool in a series of logistic web decision systems that support decision making in the context of logistic webs.

The platform consists of a logistic web simulation database and a multi-agent simulator. Two types of multi-agent applications are found in the simulator. The synchronization application ensures the chronological logic within the virtual world created by the simulator. The organization applications represent the companies interacting in the virtual web environment. The simulator offers advance agent behaviour to reproduce environments as close to the reality as possible. Different abstraction levels of organizations, sites, and agents are provided to allow full understanding of managerial implications, to focus on important sections of the logistic web and to consider all elements of the web context without gross aggregations and simplifications. The logistic web simulation platform features are enhanced by connecting the platform to logistic web tools through the database. These systems allow dynamically visualizing, monitoring, mining and assessing the virtual web contexts and their performance.

Future research is needed on rendering the platform more generic, easily customizable, and applicable for various industrial contexts. Agent behaviour modeling is a rich area for further research, allowing on one side to accelerate the creation and edition of original and variant models, and on another side to represent more realistically the behaviour of various types of agents regularly encountered in logistic webs. Logistic Web visualization is yet another rich avenue for further research, designing new viewing capabilities and assessing their value added. Further research should involve extensive win-win collaboration with industry, to further advance and validate the logistic web concepts, methodologies and technologies.

Demand Generation for Supply Web Simulations[12]

Among the environmental data (see Figure 43) required by the logistic web simulator is the daily market demand received by stores. However, the consideration of multiple interacting companies results in a complex circulation of demand along supply networks and in many case detailed POS demand is not exposed to all actors of a retailer's supply network. Sometimes, some of these actors can be interested in studying and understanding the impact of the POS demands on their specific supply network. Nevertheless, these actors have and own detailed daily data about the orders received from their clients and the shipments to these clients' sites. This section presents a methodology to be used by an actor to estimate the demand of its products in retail stores belonging to its customers and for

[12] This section was presented in Hakimi, D., Montreuil, B., & Labarthe, O. (2010a). Retail Store Demand Generation For Supply Network Simulation. *Proceedings of 8th ENIM IFAC International Conference of Modeling and Simulation, Hammamet, Tunisia, May 10-12*

which the POS data is not available. The methodology exploits the actor's transactional data and knowledge about the market of its products to gradually distribute its global estimated demand over each logistics echelon existing between the actor and the retail stores. The resulting store demands are distributed over the weeks and then over the days to generate daily store demands. This demand can be used as an input for logistic web or supply network simulations to allow companies to take advantages of their knowledge about the market and investigate the dynamics within their networks and the networks of their partners. Capabilities for simulation based experimentation of scenarios and alternatives can (1) enable assessing the impact of collaboration within supply networks, (2) facilitate engaging other members of the supply network into collaborative initiatives, and (3) increase decision-making capabilities in a complex logistics context.

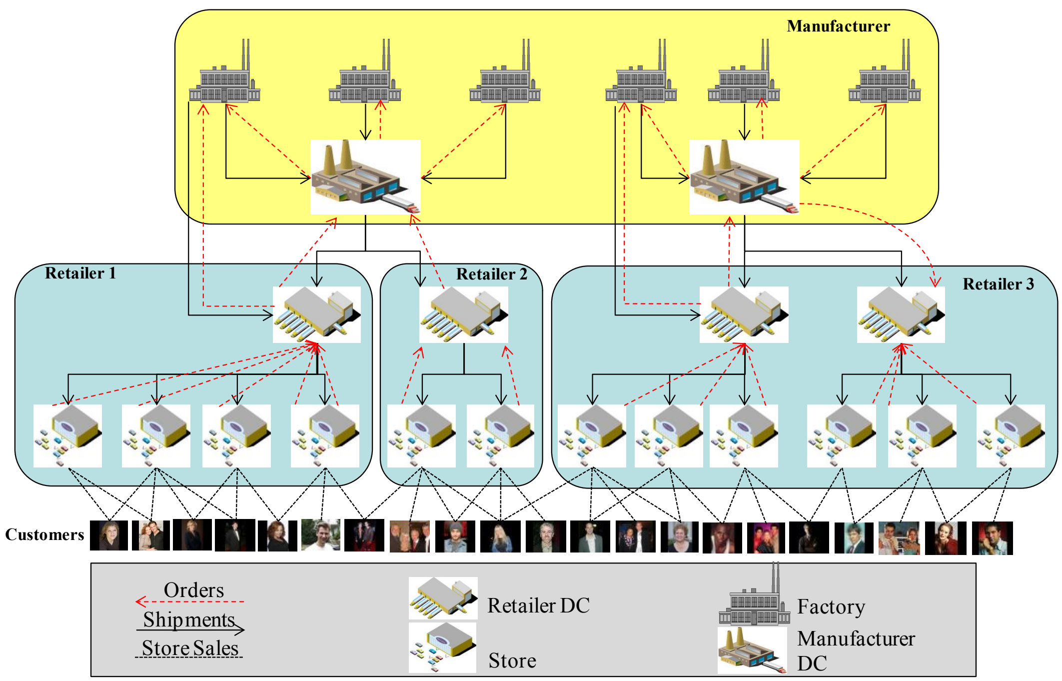


Figure 48: Illustrative network of a manufacturer supplying a retail network

Figure 48 depicts an illustrative supply network typology used to expose the store demand generation approach from a manufacturer perspective. The manufacturer, which is operating many factories and distribution centers (DCs), deals with retailers owning multiple DCs and retail stores. The order flow is directed upstream from the stores to the retailers' DCs, from the retailers' DCs to the manufacturer's DCs, and from the manufacturer's DCs to the manufacturer's factories. The shipment flow is directed downstream, starting at the factories and ending at the stores. The overall flow allows shortcuts for large orders so that retailers' DCs can send direct orders to the manufacturer's factories and receive direct shipments from them.

There is no deep collaboration between the manufacturer and the retailers. They do not share their demand knowledge with the manufacturer. For example, the manufacturer does not have access to POS data, intra-retailer ordering data, inventory data, and shipment data. This implies the need of estimating each of its products' daily demand disseminating through the retail network, starting at each store, as it occurred in the last few years and projecting it in the future through alternate demand scenarios. To do so, the manufacturer wants to capitalize on (1) historical data of the transactional information resulting from the supply operations with the retailers' DCs and stores, and (2) on its knowledge about how the retailers operate. The demand estimations must reflect weekly and daily seasonality, demand trends over planning periods, and be consistent with the precise retailer orders received by the manufacturer in the past.

The remaining of this section is structured as follows. The first subsection proposes a focused literature review on simulation models in retail contexts. Subsection two presents the proposed approach for demand generation. Subsection three explains how to obtain the coefficients defined in the proposed approach. Subsection four concludes with a summary of the contributions and potential research avenues.

Literature review

Decision-makers perceive demand estimation as one of the main elements in strategic, tactical, and operational activities. When it is used appropriately, the point of sale (POS) demand exposure over the supply chain acquires a competitive advantage to all members of the supply chain (Croson, et al., 2003). In a logistic web context, demand apprehension acquires even more strategic importance and the extension of the decisional boundaries forces managers to position the demand of their products in larger and more complex systems. It is not only important for a supplier to estimate the demand of the adjacent client but also to understand how this demand is generated at the point of sales (POS) and carried to the upmost suppliers.

In the retail industry, the supply activities are governed by direct interactions with final consumers. The impacts of demand chain management on manufacturing performance are presented in Frohlic *et al.* (2002). As demonstrated in Tenn *et al.* (2008), product availability can significantly bias the results of aggregate demand models. Two approaches are generally used to estimate the demand by simulation in the retail context. The first approach is based on consumers' behavioural definition while the second approach focuses on demand simplification.

According to the consumer approach, the behaviour of a consumer is represented by a utility function or by detailed demand behaviour. Davis (2000) proposes three components in order to elaborate a parametric demand system for a differentiated product demand model in retail markets. These components are: (i) a parametric model of consumer preferences based on a utility function, (ii) the consumer preferences variation, and, (iii) the distribution of consumer types in the population. Montreuil *et al.* (2006) extend this approach by modelling in the simulation each consumer as an autonomous and pro-active decisional agent characterized by behavioural specifications determined through collaboration with the customer behaviour and marketing teams.

When using a demand simplification approach, the consumer behaviour is limited to emitting an order. Demand is defined as an input parameter, generally a distribution function, to simulate the behaviour of a complex system. This approach is used in various research works. Nair *et al.* (2006) examine the retail performance of a short lifecycle product in different contexts of demand variability (low and high). Evaluation of the supply chain performance is based on the costs related to the coordination of operational policies and pricing markdowns. Fleisch *et al.* (2005) use the demand simplification approach in their simulation study of a retail supply chain in order to assess the impact of inaccurate inventory information on the supply chain performance. In their study, the information of the generated end-customer demand is propagated in real-time to the supplier. Zhang *et al.* (2007) similarly use the approach in their simulation study aiming to quantify the benefit of sharing demand information in a supply chain composed of two retailers, a distributor, and a supplier. Ryu et al. (2009) also use it in their simulation study analyzing the supply chain performance in terms of throughput, inventory level and service level, subject to two distinct types of information sharing methods, the planned demand transferring method and the forecasted demand distributing method.

All the research works reported above, as exploiting the demand simplification approach, limit their investigations to the same simple supply chain structure. Each study involves a three-echelon network generally composed of one retailer, one distributor, and one supplier. This linear structure determines the informational and physical flow circulation. The flow of orders is linear: (i) from end-customer to retailer, (ii) from retailer to distributor, and, (iii) from distributor to supplier. The flow of products is also linear in the opposite direction.

As previously introduced, many reasons can lead organizations to restrain data sharing and the majority of studies focus only on evaluating the impacts of different information sharing methods across the echelons and not on estimating missing information. In the field of demand management, sales forecasting has attracted 80% of the total research works (Ko, et al., 2010). None of the research works propose a model in which a member of a supply chain or supply network can estimate the retail store demand on the basis of historical transactional data with direct clients.

Daily Stores Demand Generation Approach

This subsection presents the approach suggested for generating daily stores demands. It highlights the modeling assumptions, defines the flow of orders and shipments, explains the general used approach, and finally details the adopted methodology.

Modelling Assumptions

Because of the complexity of the context considered and the lack of information due to the limited data sharing between the manufacturer and the retailers, a set of assumptions is adopted in order to offset the information shortage and to exploit the general knowledge about the market, the products and retailer operations. The objective is to beneficiate from, and to maximize the utility of, this informal knowledge that is rarely adequately used.

The following assumptions are maintained:

- The number of stores per retailer is known;
- The store locations and sizes are known;
- For any product, a store is supplied by a single retailer DC. However, many DCs can supply the store with different products;
- Stock-outs of products in stores result in lost sales;
- The product demand patterns feature week-of-year and day-of-week seasonality;
- The demand of each product is independent from other product demands;
- The demand of each retail store is independent from the demand of other retail stores;

Data required for the presented model, such as the number of stores per retailer and the store locations and sizes, is general information that can be obtained through public media without involving the concerned retailers. It can be gathered without the risk of violating any data confidentiality. In case some of this data is missing, it can be inferred by using different estimation techniques such as those presented in this section. The objective is to maintain model integrity as much as possible while being pragmatic about data availability.

Defining the flow of orders and shipments

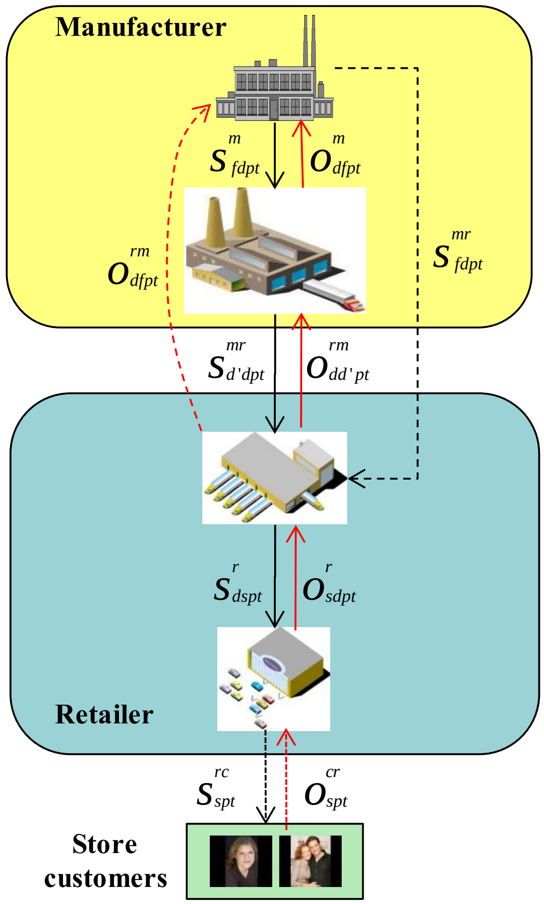


Figure 49: Flow of orders and shipments

Figure 49 depicts a supply chain example to illustrate and capture the flow of orders, the typology of shipments, and the exchanges occurring between typical multi-sited manufacturer and retailer. The stores and distribution centers are uniquely numbered, avoiding the need for retailer identification in the variables.

Identifiers (upper right of variable or parameter):

m:	manufacturer level
r:	retailer level
c:	customer level
w:	weekly level
t:	daily level

Indices and sets:

$f \in \mathbf{F}$, F= $\lvert \mathbf{F} \rvert$	Manufacturer's factory
$d \in \mathbf{D}$, D= $\lvert \mathbf{D} \rvert$	Distribution center (DC)
$d \in \mathbf{D^m}$, $D^m = \lvert \mathbf{D^m} \rvert$	Manufacturer's DC
$d \in \mathbf{D^r}$, $D^r = \lvert \mathbf{D^r} \rvert$	Retailer's DC

$s \in \mathbf{S}$, S= $|\mathbf{S}|$ Store
$p \in \mathbf{P}$, P= $|\mathbf{P}|$ Product
$w \in \mathbf{W}$, W= $|\mathbf{W}|$ Week
$t \in \mathbf{T_y}$ T_y= $|\mathbf{T_y}|$ Day in planning horizon
$j \in \{1, 2, \ldots, 7\}$ Day position in a week.

Data parameters:

O^{m}_{dfpt}: Quantity of product *p* ordered by manufacturer's distribution center *d* from factory *f* in day *t;*

S^{m}_{fdpt}: Quantity of product *p* shipped by factory *f* to manufacturer's distribution center *d* in day *t;*

$O^{rm}_{dd'pt}$: Quantity of product *p* ordered by retailer's distribution center *d* from manufacturer's distribution center *d'* in day *t;*

$S^{mr}_{d'dpt}$: Quantity of product *p* shipped by manufacturer's distribution center *d'* to retailer's distribution center *d* in day *t;*

O^{rm}_{dfpt}: Quantity of product *p* ordered by retailer's distribution center *d* from factory *f* in day *t;*

S^{mr}_{fdpt}: Quantity of product *p* shipped by factory *f* to retailer's distribution center *d* in day *t;*

Estimation variables:

O^{r}_{sdpt}: Quantity of product *p* ordered by retailer's store *s* from its distribution center *d* in day *t;*

S^{r}_{dspt}: Quantity of product *p* shipped by retailer's distribution center *d* to store *s* in day *t;*

O^{cr}_{spt}: Quantity of product *p* ordered by customers from store *s* in day *t;*

S^{rc}_{spt}: Quantity of product *p* sold to customers by store *s* in day *t.*

General approach

The generation of estimated store demands is done gradually through site and time disaggregation: from a total ordered quantity by a retailer distribution center to each store demand, from an estimated demand over the entire planning period to the daily demands, and from historic data to estimates and forecasts. The combination of these dimensions gives, at the end, the estimated daily forecasted demand for each product at each store. The estimation process is described in this subsection in a simplified way assuming one year of historical data with the aim of generating the estimated retail store demand for that year or for a future year based on a set of scenario building criteria. It can be readily extended to deal with multiple years of historical data and multi-year prospective scenarios. It is also presented using a single retailer and a single manufacturer. The approach can be readily enlarged for multiple retailers and manufacturers, as long as the underlying hypotheses are still appropriate.

The approach starts by estimating the total demand of each product at each retailer DC for the planning year. This total demand is then divided over the weeks of the year, and then weekly demands are divided into daily demands as shown in Figure 50. The approach consists of six consecutive steps. Each step uses the output of the previous step multiplied by a new factor or a set of fractions. In the first step, the product total ordered quantity placed by a retailer DC is computed by summing all the orders placed by the retailer DC to all manufacturer sites through the historical year. In the second step, the total ordered quantity is transformed to an estimation of the total demand by considering lost sales estimation. Step three provides an estimation of the estimated demand for the scenario by multiplying the estimated total historical demand by a trend factor. This factor expresses the expected changes in the demand of the resulting scenario. In step four, the estimated global demand is divided over the stores assigned to the considered DC. In step five, each store share of the estimated global demand is split over the weeks. Finally, in step six, each week's share is split over its days.

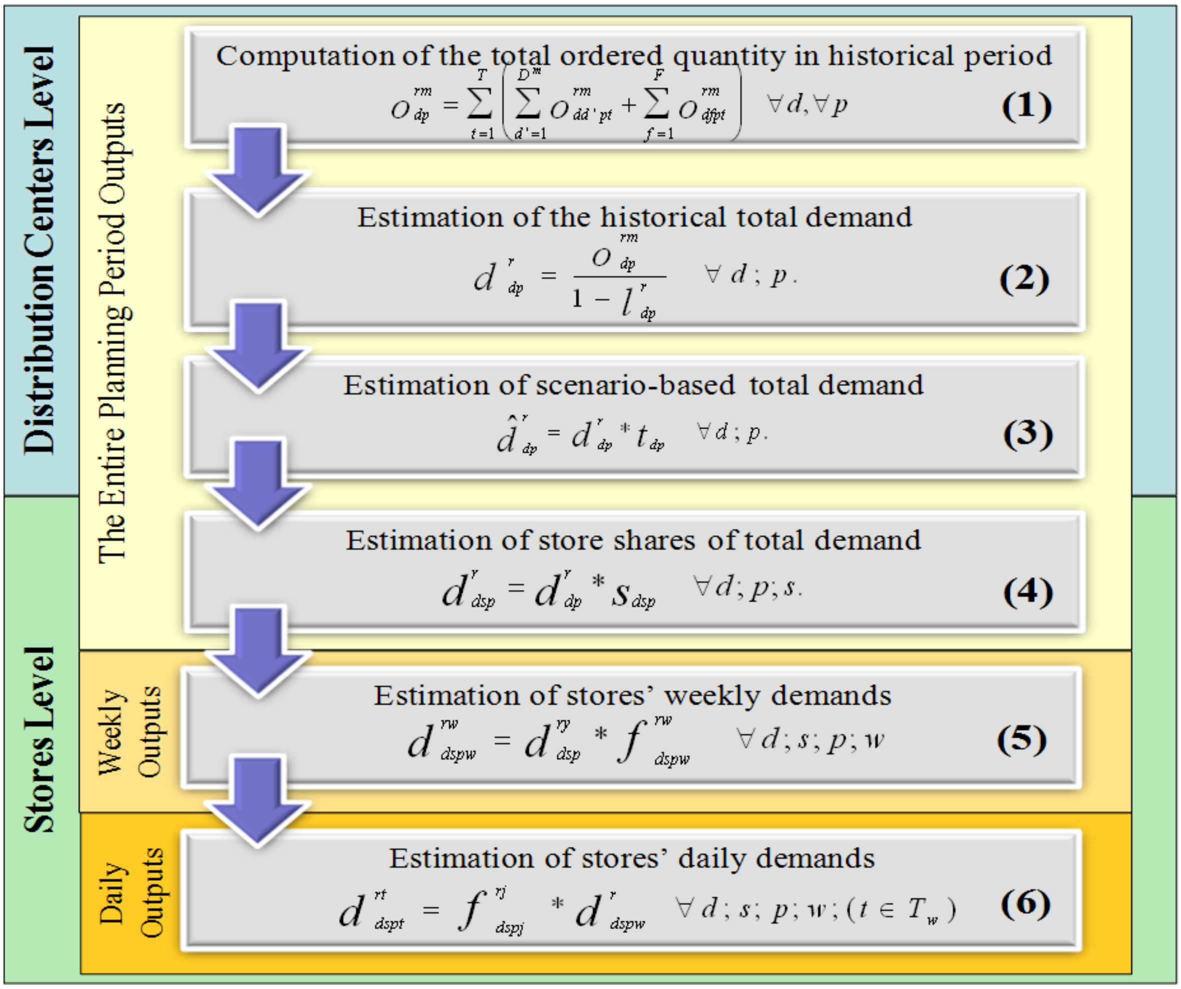


Figure 50 : Stores' Demands Based on Retailer's Orders

- For each retailer
  - For each retailer's Distribution Center (DC)
    - For each product
      - Computation of the total ordered quantity in historical period (eq. 1)
      - Estimation of the historical total demand (eq. 2)
      - Estimation of scenario-based total demand (eq. 3)
      - For each retailer's store assigned to the retailer's DC
        - Estimation of store shares of total demand(eq. 4)
        - For each week in the plan
          - Estimation of stores' weekly demands (eq. 5)
          - For each day in the week
            - Estimation of stores' daily demands (eq. 6)

Figure 51: Procedure for Daily Store Demands

The general procedure is presented in Figure 51. It generates the daily demand for every product of the manufacturer in every store of the retailer using embedded loops that integrate the equations provided in Figure 50 and detailed hereafter.

Detailing the methodology

- **Historical Total Ordered Quantities for each Retailer DC -Product Combination**

In the first step of the methodology, the total ordered quantities are computed based on the available historic data. The daily orders placed by a retailer DC to a manufacturer DC and to a manufacturer factory for each product are known as $o^{rm}_{dd'pt}$ and o^{rm}_{dfpt}. Summing these daily quantities for each combination of a retailer DC and a product enables to compute the historical total ordered quantity:

$$o^{rm}_{dp} = \sum_{t=1}^{T}\left(\sum_{d'=1}^{D^m} o^{rm}_{dd'pt} + \sum_{f=1}^{F} o^{rm}_{dfpt}\right) \quad \forall d, \forall p \qquad (1)$$

- **Historical Total Demand Estimation for each Retailer DC-Product Combination**

Stockouts of any product in any retail store in any day have the potential to result in lost sales. The manufacturer does not know when stock-outs occurred for each product in each retail store assigned to a retailer's DC, nor does it know which stock-outs resulted in lost sales. The approach compensates this lack of detailed information by estimates based on the experience of the management team of the manufacturer having responsibility for managing the retailer's account.

It exploits a lost sales factor l_{dp} defined as the fraction of demand estimated to have resulted in lost sales for product *p* in stores assigned to retailer's DC *d*. The determination of this factor is described in subsection 'Lost Sale Factor' below.

Using this factor, the historical total demand d^{r}_{dp} for every combination of retailer DC *d* and product *p* can be estimated using equation (2).

$$d^{r}_{dp} = \frac{o^{rm}_{dp}}{1 - l^{r}_{dp}} \quad \forall d; p. \qquad (2)$$

- **The Scenario-Based Total Demand Estimation for each Retailer DC-Product Combination**

If the objective is to create a prospective demand scenario differing from historical demand, then this step adjusts the historical total demand estimations obtained through equation 2 using a trend coefficient t_{dp} for each combination of product *p* and retailer DC *d*. The resulting $\hat{d}^{r}_{dp}$ will substitute d^{r}_{dp} in the equation 4. Subsection 'Trend Factor' below details how the trend coefficient is computed. The scenario-based total demand estimates can be computed using the trend coefficients as in equation 3:

$$\hat{d}^{r}_{dp} = d^{r}_{dp} * t_{dp} \quad \forall d; p. \qquad (3)$$

- **Estimation of Store Shares of Total Demand**

The objective of this step is to divide the estimated demand for product *p* of each retailer DC *d*, obtained in the previous step, among the stores assigned to *d*. This share is historically unknown to the manufacturer. However, it can be approximated through the exploitation of knowledge of the manufacturer's team assigned to the retailer's account. Subsection 'Store Demand Factors' below explains how stores can be clustered into groups, based on combinations of factors such as their size, leading to the estimation of a store demand factor s_{dsp} defined for each product *p* of each store *s* assigned to *d*. Equation (4) can then be used for estimating the scenario-based demand share of each store *s* assigned to the DC *d* for each product *p*:

$$d^{r}_{dsp} = d^{r}_{dp} * s_{dsp} \quad \forall d; p; s. \qquad (4)$$

- **Weekly Store Demands Estimation**

In this step, the time dimension is downgraded from the entire planning period to weekly periods. The objective is to divide each store demand estimates obtained in the previous step over the weeks constituting the scenario horizon. For each week *w* of the current plan *y*, the weekly demand factor f^{rw}_{dspw} estimates the percentage of the week's contribution to the total demand for product p in store *s* served by retailer's DC *d*. The estimation of this factor is detailed in subsection 'Weekly Demand Factors' below. Equation (5) estimates the demand share of each week *w* within the entire scenario horizon.

$$d^{rw}_{dspw} = f^{rw}_{dspw} * d^{r}_{dsp} \quad \forall d; s; p; w \qquad (5)$$

- **The Daily Store Demand Estimation**

In this step, the time dimension is again downgraded, this time from weeks to days. The objective is to divide each weekly demand obtained in the previous step over the days of the corresponding week. For each week *w*, the coefficient f^{rj}_{dspj} represents the contribution percentage of a day *j* belong to a week in the total demand of the store *s*. For example, the *j=Friday* factor estimates the contribution of Friday to a week's demand. Provided the daily demand factors estimated as shown in subsection 'Daily Factors' below, equation (6) estimates the demand share of each day *t* in each week *w* for the entire scenario horizon, which is the final estimation goal:

$$d^{rt}_{dspt} = f^{rj}_{dspj} * d^{r}_{dspw} \quad \forall d; s; p; w; (t \in T_w) \qquad (6)$$

Coefficients Computation

The methodology described earlier relies on a number of estimation coefficients. This subsection describes their nature and their computation.

Several of the coefficients are based on randomized generations according to various statistical distributions. The selection and parameter setting of these distributions are either induced from available transactional data or determined qualitatively by knowledgeable and experienced teams.

The following subsections sequentially focus on the lost sales factors, the trend factors, the store demand factors, the weekly demand factors and the daily demand factors.

Lost Sale Factors

For each product *p* of DC *d*, the aim is to estimate the percentage of lost sales that was incurred among all the stores served by *d* during the historical horizon, so as to enable the transposition of total order facts into total demand estimates.

Since there may be thousands of products, there is a need for a pragmatic approximation. The concept here used is based on two facts. (1) The overall product demand generally corresponds to a Pareto curve, as shown in Figure 52. (2) Lost sales are more prone to occur and relatively have more variance on lower demand products than on higher demand products. This is justified by the facts that lower inventories are kept for lower demand products and that less management attention is focused on low demand products.

So, the products are ranked into a number of Pareto groups. Figure 52 depicts a four-group clustering. For each product group *g*, three estimates are provided:

$\underline{l}_{dg}$: Optimistic lower bound on lost sales percentage for a product of group g served by DC *d*;

$\tilde{l}_{dg}$: Most probable lost sales percentage for a product of group g served by DC *d*;

$\bar{l}_{dg}$: Pessimistic upper bound on lost sales percentage for a product of group g served by DC *d*.

In Figure 5, the three parameters are estimated for each of the four product groups, with increasing mode and variance.

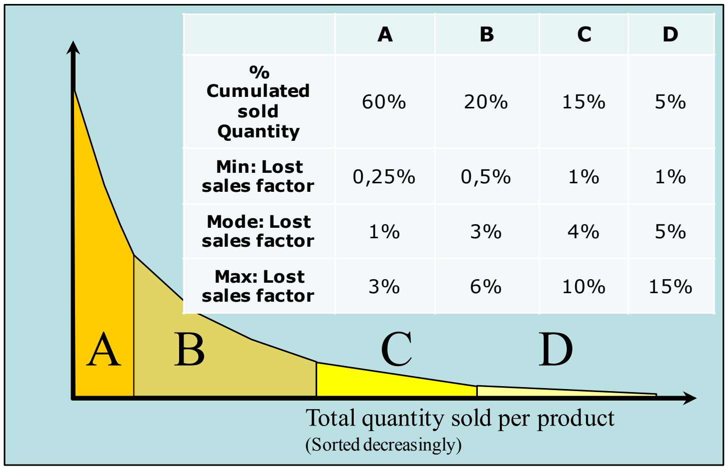


Figure 52: Lost Sales Factors Determination

For each product group, a statistical distribution must be selected, such as the smoother Beta (PERT) distribution or the simpler Triangular distribution (Law and Kelton, 2000).

Then the lost sales factor l_{dp} for each product p of group g_p in DC d can be generated for a given scenario as follows.

$$l_{dp} = L^{-1}\left(\underline{l}_{dg_p}, \tilde{l}_{dg_p}, \bar{l}_{dg_p}; u\right), \forall d, \forall p \qquad (7)$$

where

$L^{-1}(a,b,c;u)$: Inverse function of a selected distribution (e.g. Beta-PERT, Triangular) with lower, mode and upper parameters a, b and c; evaluated at u.

u~U(0, 1) : A pseudo-random number between 0 and 1.

This way, in each scenario the lost factors vary stochastically, as they vary from a product to another within the same group.

Trend Factors

The demand trend factors for all products *p* of every retailer DC *d* to be applied in a given scenario can be determined in a number of ways. They can be set to zero if the scenario is to represent the historical horizon. They can be approximately set to fit the trend estimates computed as part of a sales forecasting method used by the manufacturer to forecast product sales, even though sales are not identical to demands, when such trend estimates are available. They can be purposefully skewed for assessing crisis, out-of-the-ordinary demand situations.

When the above are deemed applicable, especially when there is minimal knowledge available about specific product demand trends, this subsection presents an estimation approach similar to the one used the computation of lost sales factors.

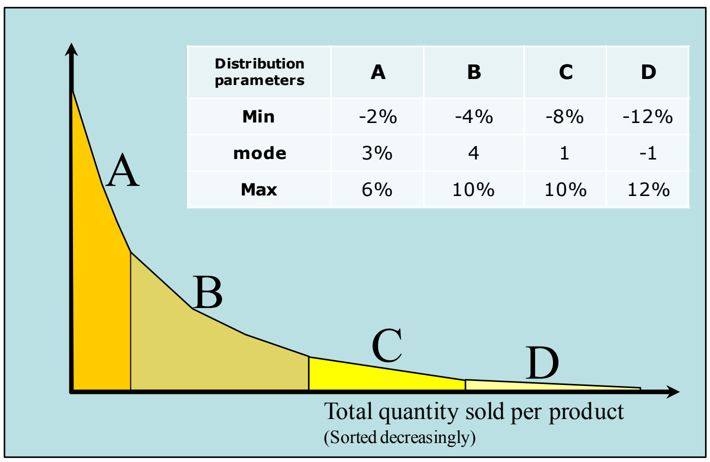


Figure 53: Distribution Parameter Definition for Trend Factors Determination

First, the products of a retailer DC are clustered into groups. Second, for each group, pessimistic, most probable and optimistic trend factors $\underline{t}_{dg}$, $\tilde{t}_{dg}$ and $\bar{t}_{dg}$ are estimated by knowledgeable and experienced teams. Third, the trend factor t_{dp} applied to each product of the group is stochastically determined using a user selected distribution such as the Beta-PERT and triangular distributions using equation 8. Figure 53 illustrates the essence of the approach with a simple case.

$$t_{dp} = L^{-1}\left(\underline{t}_{dg_p}, \tilde{t}_{dg_p}, \bar{t}_{dg_p}; u\right), \forall d, \forall p \qquad (8)$$

Store Demand Factors

Store demand factor s_{dsp} corresponds to the fraction of the total demand for product *p* stemming from the stores fed by retailer DC *d* estimated to be generated by the clientele of store *s*. This subsection introduces a four-step approach for estimating such factors particularly suited for large networks with minimal detailed information on specific product-store demand.

First, stores are clustered so that each group is estimated to have a homogeneous demand pattern, by the manufacturer's team responsible for the retailer's account. The team usually knows the retail stores assigned to each retailer's DC. This clustering can be based on a combination of attributes, including store size, type of location, and geographical region, as deemed best fit by the team based on available information and knowledge. An example with four groups is proposed in Figure 54, showing that in this case, the expected demand levels and ranges are estimated to be increasing from group 1 to 4.

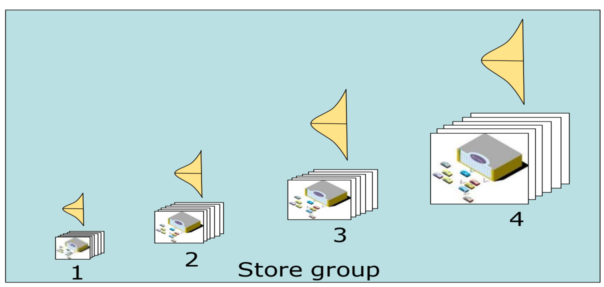


Figure 54: Grouping stores according to their size

Second, for each product *p*, or in a more aggregated way for each product group or for the overall set of products as most appropriate, the team estimates a relative store group demand factor mean $\hat{g}_{dgp}$ and standard deviation σ^{g}_{dgp} for each store group *g* fed by retailer's DC *d*. Table 6 provides an example of store group demand factors. For instance, group 2 has a mean of 30% with a standard deviation of 0,5%. The 30% means that it is estimated that collectively the stores of group two contribute to 30% of the overall demand. The sum of the means of all groups must equal 100%.

Store group		Demand Factor Generation Parameters (% per group)	
Group	Number of stores	Mean	Standard deviation
1	200	*34%*	0,59%
2	100	*30%*	*0,50%*
3	50	*23%*	0,48%
4	20	*13%*	0,38%
Total	*370*	*100%*	

Table 6: Illustrative Store Group Demand Factors

Third, in order to stochastically generate the store demand factor for a specific scenario, a statistical distribution has to be selected. The demand factor is generated using equation 9 for store s of group g_s fed by retailer's DC d, for product p, assuming a Normal Distribution:

$$r_{dsp} = N^{-1}\left(\left(\hat{g}_{dg_s p} \big/ n^{s}_{dgp}\right), \left(\sigma^{g}_{dg_s p} \big/ \sqrt{n^{s}_{dg_s p}}\right), u\right) \forall d, s, p \quad (9)$$

where

$N^{-1}(\mu,\sigma,u)$: The inverse function of a Normal Distribution with mean μ and standard deviation σ, evaluated at u;

n^{s}_{dgp}: Number of stores in group g of stores fed of product p by retailer's DC d;

In equation 9, the mean of the Normal Distribution for the store demand factors is simply equal to its group demand factor divided by the number of stores in the group. The standard deviation is computed by dividing the standard deviation of the group demand factor by the square root of the number of stores in the group.

The fourth step consists in normalizing the previously computed store demand factors so that their sum equals 100% for each combination of d and p.

Weekly Demand Factors

The weekly demand factors allow transposing the total demand into weekly demand, taking into consideration the seasonality of demand through the year, for each combination of retailer's DC *d*, retail store *s*, product *p* and week *w*. The factors correspond to the fraction of demand generated in week *w* within the overall year demand. Their sum for each (*d, s, p*) combination must equal 100%.

Depending on the level of available information and knowledge, the factors may be aggregated for combinations of products, stores and DCs. At the most aggregated level, a single series of weekly demand factors is used for all (*d, s, p*) combinations.

The method for generating these factors for a specific scenario relies first on providing an estimate of the mean $\hat{w}_{dspw}$ and standard deviation $\sigma(w_{dspw})$ of the weekly demand factors, as well as their distribution. There are many ways to obtain approximate values for these factors, each with its weaknesses. For example, many retailers provide manufacturers with aggregate product demand information through weeks of the year. When this is the case, it can be used to readily compute the weekly demand factors, with the negative impact of not differentiating among stores.

As another example, the manufacturer can determine the seasonal indices using product sale forecasting models. These indices can be similarly exploited to estimate the weekly demand factors. The forecasting models can be available by retailer's DC, yet they often reflect DC's demand rather than store demand, so when used they are bound to induce bias.

As a last example, the weekly demand factors may be estimated directly through the orders of the retailer DCs to the manufacturer. In such a case, the mean $\hat{w}_{dspw}$ can be estimated through equation 10 as the sum of orders gotten from the DC in week *w* over the total orders from the DC through the year.

$$\hat{w}_{dspw} = \sum_{t \in T_w} O_{dpt}^{rm} \Big/ O_{dp}^{rm} \qquad (10)$$

In such a case, instead of estimating directly the standard deviations $\sigma(w_{dspw})$, one can assume that all combinations share a similar coefficient of variation. This coefficient of variation can be grossly estimated by computing the standard deviation of the product specific factors for a (*d, s, w*) combination and dividing it by the mean of these factors. This estimated coefficient of variation can then be used to estimate the standard deviation $\sigma(w_{dspw})$ by multiplying it by $\hat{w}_{dspw}$.

Provided estimates for $\hat{w}_{dspw}$ and $\sigma(w_{dspw})$, the weekly demand factors can be generated for a given scenario using equation 11 when the Normal Distribution is used.

$$w_{dspw} = N^{-1}(\hat{w}_{dspw}, \sigma(w_{dspw}); u), \forall d, s, p, w \quad (11)$$

Note that it is straightforward to adapt equation 11 when users prefer to estimate coefficients of variation rather than standard deviations.

As with the store demand factors, the weekly demand factors obtained through equation 11 must then be normalized to sum 100% for each (d, s, p) combination.

Daily Factors

As the store weekly demand factors were used to distribute the total demand among the weeks, the store daily demand factors are used to split the weekly demand over the days of the corresponding week. They reflect the daily seasonal effect by highlighting the variation of demand according to the day of the week.

At the weekly level, it made sense in eq. (5) to exploit the daily ordering flow from retailer's DCs to the manufacturer. Doing so here would induce tremendous bias as store supply orders are generally not in synchronization with daily consumer demand; since ordering is much more driven by internal policies of the retailer.

This is why the proposed approach relies on the manufacturer's team best knowing the consumer market of the retailer to explicitly provide estimate for the mean $\hat{j}_{dspw}$ and standard deviation $\sigma(j_{dspw})$ of day-within-week daily demand factors. These may be provided at the most aggregate level to be applied all across the store, or may be provided in a more granular fashion exploiting available knowledge about store groups, product types and seasonal variations. The only constraint imposed is that the sum of the provided factors to be applied to a (*p, d, s, w*) combination should equal one.

Table 7 provides an example of mean and coefficient of variation estimation for the daily demand factors. In the example, from Monday to Wednesday, the demand is generally low. Then it climbs to reach its peaks on Saturday and Sunday. The standard deviation of daily demand factors can be computed easily from the provided coefficients of variation.

Day-of-Week	Mo	Tu	We	Th	Fr	Sa	Su	Total
Mean factor	0,03	0,07	0,03	0,1	0,17	0,33	0,27	1
Coefficient of variation	0,15	0,15	0,15	0,2	0,2	0,3	0,2	

Table 7: An Example of the Estimation of the Normal Distribution Parameters for Daily Demand Factors

Provided the means, standard deviations and statistical distribution for the (*p, d, s, w*) combinations, the specific daily demand factors can be generated for every day within the scenario horizon. Equation 12 can be used when a Normal distribution is assumed.

$$j_{dspt} = N^{-1}\left(\hat{j}_{dspw_t}, \sigma\left(j_{dspw_t}\right), u\right), \forall d, s, p, t \qquad (12)$$

Then, as for the weekly demand factors, the daily demand factors must be normalized so that the sum of the factors within each week for a given (*p, d, s*) combination be equal to one.

Synthesis

This subsection has focused on a case where a manufacturer does not have access to a retailer's stores information and wants to estimate the demand of its own products in the multiple stores within the retailer's network. The introduced approach estimates the store demands by using transactional data with the retailer's DCs, without having access to the point-of-sales retail store sales or demand data. It exploits the market and product knowledge acquired by the manufacturer's team devoted to the retailer's account and interested in the store demand generation.

The suggested methodology for store demand generation follows a series of steps. It first estimates the global demand based on the orders received by the member. Then it disaggregates systematically this demand over the supply chain echelons up to the store level. The store global demands are then split over the weeks and finally over the days, resulting in scenarios of daily store demands. The procedure considers demand trends, week-within-year seasonality, and the day-within-week seasonality.

The methodology has been validated by the research team on the large scale of retail store demand generation in a partnership project with Procter & Gamble Canada. The prospective retail partner had over a thousand retail stores through Canada and several DCs. Procter & Gamble supplies to this retailer several hundred different products through a number of Canadian DCs and North American factories. The methodology has allowed the generation of demand scenarios, which have been fed into our logistic web simulation solution to simulate the supply networks of both parties. It has enabled the explicit treatment in the simulation experiments of highly distributed large-scale demand generated for each combination of store, product, and day within the simulated horizon.

Since demand behaviour generation is encapsulated in an autonomous application, which substitutes the “market” agent in the simulator, the “Store” agent-based applications are not influenced by how the demand is generated. The agents of a store are designed to make decisions according to the implemented managerial behaviours and in respond to external environmental changes such as the perception of new received demand. Thus, any change to enhance or adapt the demand generation module to new situations does not involve changing the simulator agents’ behaviour.

Future research avenues abound, as every fact of the methodology can be potentially enriched and improved by exploiting a variety of analytical and optimization techniques. Also, most of the imposed hypotheses can be challenged and relaxed. For example, product demand has been assumed to be independent between products. In practice, there are many situations where product substitutions are common when there are stock-outs of the primarily desired products. Research is needed on how to best tackle such a situation. There are also many settings where there is explicit competition even among a single manufacturer's products, and most often with other manufacturers and importers. Again, retail store demand generation in such a context is a captivating research avenue. Moreover, even if the daily store demands are not available, members can still obtain aggregated data about the store demands or other helpful data. The approach should allow integrating these data into the mathematical model in order to better beneficiate from different levels of data availability. Finally, an important research avenue is to develop approaches for validating such large-scale demand generation methodologies as the one presented in here, including the validation process for the selection of the different distributions and parameters.

Conclusion of the Chapter

Logistic Webs are complex environments in which complex relationships between supply networks, organizations, sites, and humans occur. Changes in one part of a logistic web can create waves of changes that reach distant actors. Managers must evaluate the impact of their decisions on their internal operations, on relationships with their partners, and on their environment. They also need to understand the impact of external actions on the internal operations and on their businesses. Since the logistic webs are complex systems that exist in dynamic environments, they can be considered as complex adaptive systems as suggested by the complexity theory. Approaching the logistic web concept from a systemic soft perspective requires tools, which consider the complexity inherent in logistic web systems, focus on the behavioural and relational aspects, and finely represent these systems. Four tools are presented in this chapter. The logistic web mapper and playback respectively help statically and dynamically visualize, mine, and assess the logistic web and its performance. The logistic web monitor is a real time business intelligence tool. Finally, the logistic web simulation platform is a simulating tool used to model complex logistic web environments finely.

The concept of static/dynamic/real time logistic web mapping and monitoring, enables the visualization, investigation, and mining of logistic webs according to multiple dimensions such as time, horizontal flow-driven structures, vertical organizational node structures, and product hierarchy. In addition, logistic web mapper, playback, and monitor prototypes exploit the concepts of schematization, simplification, data extraction, data mining, as well as historic and live mentoring.

The logistic web simulation platform consists of a logistic web simulation database and a multi-agent logistic web simulator. Two types of multi-agent applications are found in the simulator. The synchronization application ensures the chronological logic within the virtual world created by the simulator. The organization applications represent companies interacting in the virtual logistic web environment. The simulator offers advanced agent behaviour to reproduce environments as close to reality as possible. Different abstraction levels of organizations, sites, and agents are provided to allow full understanding of managerial implications, to focus on important subsections of the logistic web, and to consider all elements of the logistic web context without gross aggregations and simplifications. The logistic web simulation platform features are enhanced by connecting the platform to the logistic web applications through the database. This in turn allows dynamically visualizing, monitoring, mining, and assessing the virtual logistic web context and its performance.

These tools where tested using real world data and business knowledge provided by some key partners of the CIRRELT. The collaborative research project between our team with the Canadian division of the world-class consumer goods manufacturer *Procter & Gamble* provided a real world context for this applied research. P&G Canada is a complex manufacturing organization operating many factories and distribution centers. Each of its major clients is a complex large-scale retailer with many distribution centers and stores. Its plants ship to its distribution centers and to the clients' distribution centers and stores if full trucks are ordered. Each plant has a complex upstream-from-suppliers and a downstream-to-clients supply network can generate a complex supply network.

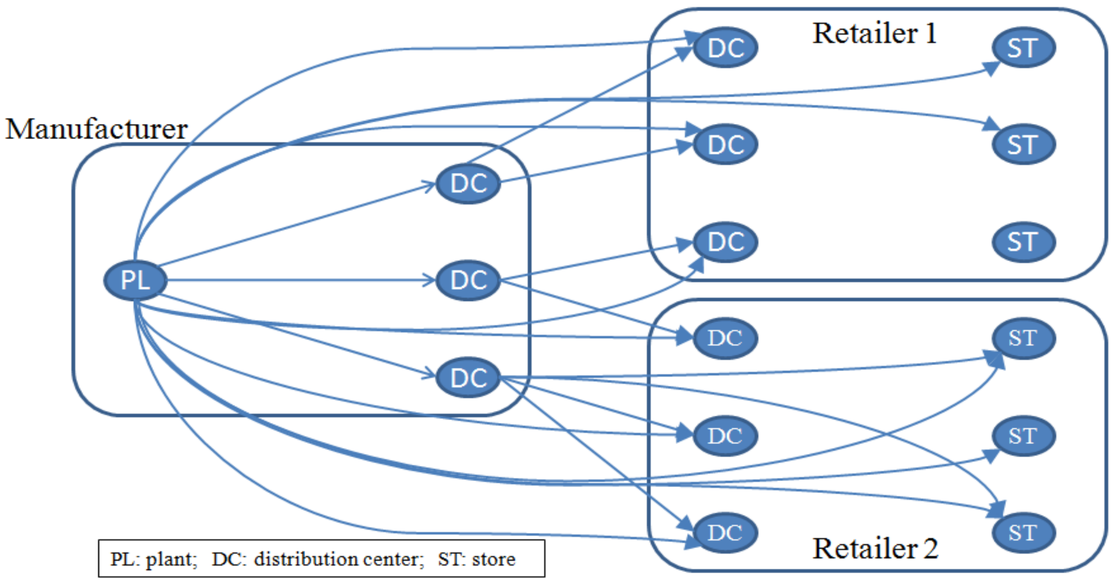


Figure 55: A Simplified Downstream Supply Network of a Plant of Procter & Gamble Canada

Figure 55 illustrates a simplified downstream supply network originating from one of the manufacturer's plants. Superposing the downstream networks generated by all the plants results in a logistic web composed of more than 80 sites (plants and distributions centers) owned or leased by the manufacturer, more than 70 retail distribution centers, and more than 6,000 stores during our joint project (Table 8).

Retailer	Number of stores	Number of Warehouses
A&P(Metro Inc)	+850	2
COSTCO	(77)	(68)
LOBLAWS	+1400	16
SDM	+1149	3
SOBEYS	+1300	18
WALMART	318	24
ZELLERS & HBC	279	7
Total	**+5373**	**+70**

Table 8 [13]: Illustrating the scale and scope of P&G Canada and its most important clients

P&G Canada supplied us with data about logistics operations, sales, inventories, orders, etc. This is extremely detailed data, which includes physical, informational, and financial

[13] For Costco, the warehouses are also consider as stores. For this reason, they are not considered in the total number of warehouses.

information about every operation or event in relation to logistics activities that occurred during a given time period. At that time, the logistic web involved more than 80,000 shipments per year from the manufacturer's sites in response to more than 200,000 client orders concerning more than 7,000 products (Table 9). In addition, the considered logistic web contains some of the top supply chains in the world. The AMR Research, a Gartner, Inc. company, ranked P&G supply chain second and Wal-Mart's fourth in its ranking of the supply chain top 25 for 2010 while stressing the fact the P&G was the only company that could site among the five top for six consecutive years[14].

P&G sites	81
Shipments form P&G sites per year	85000
Orders per year	224000
Products	7700

Table 9 : Some data about P&G Canada Shipments

In order to establish financial, marketing, and supply chain strategies, the manufacturer's managers needed to understand and evaluate the physical and financial flows occurring within its logistic web, between its sites and between these sites and the clients' sites. However, since the main plants and distribution centers operate as independent entities with different information systems, even the integration of the data within the manufacturer's organization is not a trivial task. The lack of integrated data results in defragmented non-connected information and the use of rough estimates rather than exact values for mapping flows. Even drawing a supply network for a specific product category feeding a particular major client was a huge undertaking that may require weeks of relentless work by analysts and managers.

Identifying Procter & Gamble's focused logistic web composed as the union of its downstream and upstream supply networks was by itself a significant conceptual achievement. Yet the main realization of the logistic web concept relevance came when our team got involved in supporting teams of this manufacturer that were studying the feasibility of undertaking major collaborative supply chain innovation initiatives with specific major retail clients. Assessing the feasibility of the proposed initiatives involved dealing concurrently and jointly with a specific large-scale supply network of the

[14] The AMR Supply Chain, Top 25 for 2010, Gartner, Inc., 2 June 2010.

manufacturer and the counterpart large-scale supply network of the major retail client, itself involving multiple distribution centers, more than a thousand stores and many suppliers. Without the engagement of both potential partners, the feasibility studies were limited to rough cut estimates while by developing a model of their joint logistic web, much more precise feasibility estimates were reachable. The sheer size and scope of the logistic web to be studied required novel logistic web technologies and modeling methodologies guaranteeing integrity to each actor. The unavailability of such readily usable logistic web technologies at that time was among the key reasons why the large-scale supply chain innovation initiatives did not get a green light and were then canned. This proved without a doubt (1) the mounting existence of supply chain innovation projects requiring a logistic web perspective and (2) the criticality of providing leaders of such logistic web innovation projects with technologies enabling them to perform feasibility studies requiring logistic web perspectives, to monitor ongoing logistic web innovation projects and to simulate projected logistic web innovations.

The provided data was crucial in validating the accuracy of domain and conceptual models. The produced domain and conceptual models provided the foundation for the design of the first prototypes of the logistic web application. The first versions of the logistic web prototypes were presented to different actors and potential users of P&G Canada and there was a very positive appreciation of the supported features and capabilities. Our approaches and technologies were also exploited in a European context as will be presented in the next chapter.

The research works presented in this chapter focus on enabling better visualization of the dynamics involved in the logistic web, on providing user-oriented logistic web solutions, and on activating real inter-organization collaboration. Future research is needed in order to render the tools more generic, easily customizable, and applicable for various industrial contexts. Agent behaviour modeling is a rich area for further research; on the one hand, accelerating the creation of original and variant models, and on the other hand, more realistically representing the behaviour of diverse types of agents regularly encountered in logistic webs. Supply web visualization is yet another rich avenue for further research, designing new viewing capabilities, and assessing their value added. Further research should involve extensive win-win collaboration with industry, to further advance and validate the logistic web concepts, methodologies, and technologies.

Toward Open, Reliable, and Interconnected Logistic Webs: The Case of Modeling and Simulating π-Enabled Logistic Web in France

In the previous chapter we looked at how to enhance and support the decision making process in the context of existing logistic web characterized by inter-organizational collaboration in the contexts of overlapping supply networks. The focus was on improving the performance of each supply network, supply chain, or company without major restructuration of the mobility, distribution, realization, and supply relationships and interactions. In the current chapter, and in order to stress the web dimension potentials, we are going to investigate a nonexistent form of logistic webs today that we can describe as open, interconnected, and reliable Logistic Webs. Specifically, we are going to look at the π-enabled Logistic Web introduced by Montreuil (2011) and its application within the project PREDIT: Simulation of the Physical Internet Contribution in Solving Logistics Problems: Application on Retail Industry in France. This project was conducted within the Physical Internet Initiative (www.physicalinternetinitiative.org) and it is a collaborative research endeavor of Mines ParisTech from France, EPFL from Switzerland and Laval University (CIRRELT) from Canada. The repartition of tasks among different teams is illustrated in Table 10.

The goal of this research is to study and quantify the expected impact of Physical Internet transformation in terms of economic, environmental, and social efficiency and sustainability. The project investigates the potential of transforming current distribution system of fast-moving consumer goods within France toward a logistics system enabled by Physical Internet through a set of comprehensive, fine granularity, holistic simulation based experiments. The experiment exploits logistics data from two distribution leaders in France, with their top 100 suppliers, in order to test a number of scenarios from current logistics to gradually more intensive Physical Internet enabled logistics (Ballot, et al., 2012).

Tasks	Mines ParisTech	EPFL	CIRRELT
1. π conception and project coordination	Leader	Contributor	Contributor
2. Models and data specifications	Contributor	___	Leader
3. π-network design optimization	Contributor	Leader	Contributor
4. Routing algorithms	Leader	Contributor	Contributor
5. Simulation model (national level)	Contributor	___	Leader
6. Simulation model (regional level)	Leader	___	Contributor
7. Reporting and valorization	Leader	Contributor	Contributor

Table 10 : Repartition of tasks among the teams of the PREDIT project

The real world data represents the product flows within a logistic web and was provided by a French association called Club Déméter (www.clubdemeter.fr). The data mainly consists of the weekly flow of fast-moving consumer goods across the logistic web of two major French retailers and their most important 106 suppliers. The database explicitly concerns grocery products excluding fresh food and covers the first 12 weeks of 2006. It was provided as an Excel spreadsheet containing several thousands of lines. Each line gives the information about the weekly quantity (in number of pallets) of certain product subcategory shipped from a source to a destination. The database provides the possibility to associate the product subcategories to one of the three upper level categories, and the sites (sources and destinations) to their geographic location and parent company in case of multi-sited companies.

The PREDIT project proposition document stresses out the targeted use of our logistic web simulation conceptual framework to design the simulation model and our logistic web mapper and playback technologies to visualize the outputs of the simulation scenarios.

Therefore and given the complexity and the scale of the systems to simulate, the conceptual framework for designing logistic web technologies along with the proposed architecture, presented in the previous chapter, were adapted to model, reproduce, and capture the details of the logistic web of the two French retailers and their suppliers.

This chapter is structured as follows. Section one provides a literature related to cooperative approaches in mobility and distribution. Section two presents the research objectives, and adopted methodology. Section three shows how the global architecture was adapted to meet the context of the PREDIT projects. Section four presents the simulation model. Section five details the behavior of the simulator's agents. Section six illustrates the simulator in action and reports on its performance using the results obtained within the PREDIT project for the case of the mobility web of mass distribution in France. The chapter ends with a conclusion summarizing the main contributions.

Literature review

Logistics is in the midst of an unprecedented worldwide antagonistic situation between, on one hand, its current attractive performances in terms of rapidity, flexibility, frequency of deliveries and costs, and, on the other hand, the necessity to improve its environmental and societal impact. For example, in France, industry must gear to meet the expected mid and long term objectives of 20% reduction of CO_2 emissions by 2020 and a fourfold reduction by 2050 (Boissieu, 2006). Among the important avenues investigated by researchers are the collaboration and the sharing of resources. Here we look first at contributions dealing with the mobility then next with the distribution.

Toward Open Mobility

Transportation is an important part of the logistics systems. With the increase of gas prices, low profit margins, high competitiveness and increasing environmental standards, the industry is required to increase its efficiency and use more environmental friendly solutions. Traditional consolidation strategies are not anymore enough to face the new challenges (Ballot, et al., 2010a). The truck industry for example is said to be still perform a substantial percentage of empty travels (Montreuil, 2011). Many authors believe that the substantial efficiency of the transport industry can be achieved by adopting more open and co-opetition approaches among the shippers and carriers (e.g. (Montreuil, 2011), (Schwind, et al., 2011)). This section revues some of the existing and innovative mechanisms of collaboration and transportation sharing that aim at reducing empty travels, increasing the transportation efficiency, and reducing the environmental impact of the industry.

Horizontal Cooperation in Transportation and Logistics

According to Cruijssen et al. (2007), while the horizontal cooperation is well addressed in maritime and aviation shipping, it is still in its infancy in the landside transportation. Focusing on the road transportation, Cruijssen et al. (2007) view logistics horizontal cooperation as “cooperation between two or more firms that are active at the same level of the supply chain and perform a comparable logistics function on the landside”. After a review of the existing research, the authors conclude that while they believe horizontal cooperation can result in economies of scale that could limit the increase of transportation costs, congestion, and emissions, they pinpoint the lack of conceptual classifications necessary to guide practitioners in implementing horizontal cooperation.

Horizontal transportation cooperation seems to acquire a special attention for researchers interested in the transportation of logs from forests to mills. In general, trucks travel empty in their way to the forest. Filling the trucks as much as possible during the back travels is therefore highly desired and the horizontal cooperation seems to help reaching this goal. Using a simulation approach, McDonald et al. (2001) compared pooled/shared and privately owned trucking systems for log transportation from a forest to a set of mills. They found that for the same number of trucks, pooling increased the volume of delivered wood and reduced the average trailer waiting time. Murphy (2003) focused on the reduction of the number of trucks on the road and obtained through a 0/1 integer linear program a decrease of up to 50% of the truck fleet sizes of two medium-sized New Zealander forest companies. In a Chilean tamper transportation context, Weintraub et al. (1996) report a 32% reduction in the fleet size. Frisk et al. (2010) estimate a 14.2% (8 million Euros/year) transportation cost saving and 20% emissions reduction resulting from a collaboration of eight southern Sweden forest companies. In the furniture industry, Audy et al. (2008) study the impact of benefit sharing in a coalition of four Canadian companies shipping to the USA market.

In the context of horizontal cooperation among a larger number of actors, Pan et al. (2009) studied the notion of logistics network pooling. This notion is based on the idea of using selected warehouses or distribution centers of some members as hubs used to consolidate shipments having similar destinations in order to fill trucks as much as possible. They report a reduction of around 25% of CO2 emission in a combination of two French retailers' supply networks involving 100 suppliers with a total of 164 warehouses and 59 distribution centers.

Since horizontal logistics cooperation is a contractual relationship that involves a predetermined set of actors sharing resources, it poses the problem of benefit sharing (see Hajdukova (2006); Audy et al. (2008); Nagarajan et al. (2008) and Frisk et al. (2010)).

Transportation e-Marketplace

Electronic Transportation Marketplace (ETM) or auction is another form of transportation capacity sharing which involves larger communities than those of the horizontal collaboration. Goldsby et al. (2003) define them as "internet-based mechanisms that match buyers and sellers of transportation services with claims of reducing the administrative costs of transportation procurement to virtually nothing". Named also online freight marketplaces, they are portals where transportation capacity is bought and sold for short-term (spot market) and longer-term contracts (Nandiraju, et al., 2005). They are of three categories: clearinghouses where carriers and shippers post their requirements and carriers post their available capacity, auction houses where transportation capacity and demand are auctioned and freight exchanges where the online marketplace application matches at competitive price the posted shipper's demands to the announced carrier transportation capacities (Nandiraju, et al., 2005). It is believed that this type of markets can provide substantial economic and environmental benefits, but their potentials are still not fully exploited as they lack appropriate optimization (Regan, et al., 2003) and functionalities, and have limited number of users (Schwind, et al., 2011).

Travel Planning

Freight horizontal transportation cooperation, transportation pooling, and freight ETM generally focus on a single transportation mode at a time. A multimodal perspective of transportation integration is dealt with more when moving humans. For example, Yim et al.

(2004) proposes a multi-agent travel planning systems able to compare multimodal (train/plan) options. Moreover, some travel planning solutions provides more than just transporting passengers from sources to destination. For instance, Camacho et al. (2001) propose another multi-agent planning system that deals with the transportation from the origin to the destination, lodging and transportation at destination, and the return to the origin of the travel or other town. This system considers airplane, train, or bus as traveling options.

Physical Internet

It seems that the more a mobility system is open and the more actors it includes, the more efficient and sustainable it would be. Each of the concepts presented above has its limited scope of action even if the extend of this scope can vary in size from few actors to unlimited actors. Different standards, practices, and rules governing the actual systems of transportation make it challenging to conceive a global mobility system that can exploit the worldwide infrastructure. By exploiting the concept of universal interconnectivity of logistics networks and services, and the use of world-standardized containers, the Physical Internet proposes the notion of the Mobility Web as global and open system of mobility for physical objects, including humans, over the global multimodal network of transportation Montreuil (2011). This Web deals with moving physical objects within the global interconnected set of open unimodal and multimodal hubs, transits, ports, roads and ways promising thus an unprecedented saving of resources, energy, and money.

Toward Open Distribution

Montreuil (2011) emphasizes that logistics in its wide sense, encompassing transport, distribution, production, and supply chain networks, has become globally inefficient and unsustainable economically, environmentally and socially as currently performed. Numerous researchers are offering contributions toward solving this situation. Current research advocates designing logistics networks and supply chains characterized by improved flexibility (e.g. Beamon, 1999, Grigore, 2007, Winkler, 2009), agility (e.g. Christopher, 2000), responsiveness (e.g. Surie, et al., 2008), robustness (e.g. Klibi, et al., 2010), resilience (e.g. Christopher, 2005), adaptability (e.g. Surana, et al., 2005, Pathak, et al., 2007) and sustainability (e.g. Seuring, et al., 2008). Yet, these proposed solutions cannot address effectively, smoothly, and economically the global logistics challenge toward efficiency and sustainability (Peck, 2007, Montreuil, 2011, Sohrabi, et al., 2011).

On one hand, the supply, demand, energy, and labor global markets can dramatically shift over time resulting in non-optimal, inflexible, and slow-reacting supply networks and long zigzagging travels of goods between facilities and actors (Wilson, 2008). On the other hand, Montreuil (2011) affirms that when considering at any certain time the regional total space of all the storage facilities regardless of which companies they belong to, the overall storage capacity is far beyond the total required capacity of this region. This over capacity results from the fact that storage facilities are most of the time underused because of their closed proprietary nature coupled with demand seasonality and stochastic variability for the majority of products. In a scenario where every company can have access to the unused storage space of all the other companies, huge economic, social, and environmental impacts may occur as suggested by the Physical Internet (PI, π) concept (Montreuil, 2011).

As an illustration of the potential the Distribution Web, consider that in the USA alone there are about 535,000 warehouses and distribution centers while generally each company has access and exploits one or a few of these. The Physical Internet has the potential to enable each company to deploy its products across this wide set of distribution facility spread over all the USA at very advantageous conditions (Montreuil, 2011).

Using a network design optimization based methodology, Sohrabi et al. (2011) have recently demonstrated the potential of switching to an open distribution web. To do so, their study has contrasted three scenarios: (1) each company goes solo, designing and operating its dedicated proprietary distribution network, (2) a group of companies collaborate in order to design and operate a shared distribution web restricted to their joint usage, and (3) companies exploit an open distribution web, having access to a large number of open distributed facilities that they can use through short-term contracts without need to engage in large investments, long-term leasing, or strategic partnerships. In such a context, distribution networks can be dynamically redesigned within the Distribution Web in response to the business environment changes in an easy, cheap, and quick way.

Research Elements

This section focuses on positioning the research work presented here into its context and highlighting different aspects of the adapted research approach. It starts by the explanation of the characteristics and scenarios of the mobility and distribution webs to be simulated. The section explains also the methodology used to achieve the stated objectives and frames the expected contribution.

Research Objective

The goal of the research within the PREDIT project is to simulate a Physical Internet logistic web focusing on open mobility and open distribution to show that the efficient implementation and exploitation of Physical Internet solutions can result in worldwide economic, social, and environmental gains. The objective of this section is to present a methodology for developing logistic web simulators supporting studies of the impact of the mobility, distribution, and logistic webs. This is done in the France logistics case through the incorporation of Distribution Web and Mobility Web functionalities to a simulator that will be used to study the economic, environmental, and social impacts of implementing a large scale open logistic web for fast consumer goods distribution. The implications of this modeling will be studied from three design aspects: architecture, model, and agents' behavior.

The simulator is to support the daily shipments of thousands of orders and the deployment and inventory management of hundreds of products within a logistic web of hundreds of sites including plants, warehouses, distribution centers, unimodal and multimodal π-hubs (Ballot, et al., 2010b) and transits. The simulator should allow the contrast of the current mobility and distribution systems with different variants and levels of implementation of open distribution and mobility webs enabled by the Physical Internet.

Simulating Mobility Webs

Simulating the current way products are shipped involves manufacturers operating multiple plants and warehouses and shipping products in response to retailer site-specific orders. Products are usually packed on pallets and shipments are affected to trucks that cover the entire travel between the shipping sites of suppliers to the receiving sites of clients. There is generally no sharing of truckloads between different suppliers as a traveling truck only transports products of one supplier.

Simulating open mobility web alternatives involves submitting these actors to the same demand scenarios transposed into the same set of daily orders. In addition to the current set of players and sites, the simulation has to include the mobility web and its set of π-hubs and π-routes. Products are not anymore packed in pallets but in π-containers of modular sizes. These π-containers are the only unit loads allowed to be shipped on the simulated open mobility webs. In their way to a final destination, the π-containers can transit through π-hub where they can be transferred between transportation means and/or modes. The simulator should thus support the potential modes (truck-based road travel, train travel, etc.) and various types of unimodal and multimodal π-hubs. Transportation means are not anymore dedicated. They can carry π-containers of different actors. Since direct travels are not the rule in the open mobility webs, routing agents are responsible for determining the set of route segments and transportation means that containers will be affected to in order to reach final destinations. Road-based route segments can be restricted to be less than a few hours to allow most drivers to go back home in the same day. It should be possible to model different shipping and routing strategies in order to study the impact on the target objectives.

Simulating Distribution and Supply Webs

Currently, most companies use a limited number of private storage facilities to store, deploy, distribute, or sell their products. They cannot afford to open and close distribution and storage facilities whenever and wherever they want because of the involved costs. However, if we assume that the cost per container per day of accessing and exploiting other companies' storage spaces is around the cost of operating the company's own space, possessing and opening new storage and distribution facilities everywhere becomes unjustifiable. In this case, and as stipulated by the notion of the Distribution Web, a company can theoretically store its containers in any open distribution facility in the world as long as this facility meets its container storage requirements.

An open distribution facility is a site whose storage space is available for exploitation by any user of the Logistic Web. It can be a warehouse, a distribution center, a plant, a hub or any other site with storage capacity. In order to be open, a site should:

- handle standardized π-containers. The operations related to open distribution involve only standard π-containers. Any other form of packaging, like pallets for example, is not allowed;
- provide access to its free space to other members of the logistic web;
- provide continuous information about available storage space capacities;
- provide continuous information about the state of its stored π-containers to the containers' owners.

Figure 56 contrasts an archetypical existing distribution system with an open distribution system. In the former, actors use only their facilities to store and supply products to the final clients. The orders go upstream to the next adjacent site, which fulfills them using its own inventory and it places orders to its supplier to maintain the adequate inventory levels. In the illustrative open distribution system, products are stored in open facilities that are not necessary owned by the actors of the supply chain. The orders are placed by the final customers directly to the plant. The plant managers fulfill the orders by requesting shipments from the appropriate open facilities. The inventories over the entire distribution web are managed in a way that makes products rapidly available to clients, reduces costs, and brings the focus on value-adding operations.

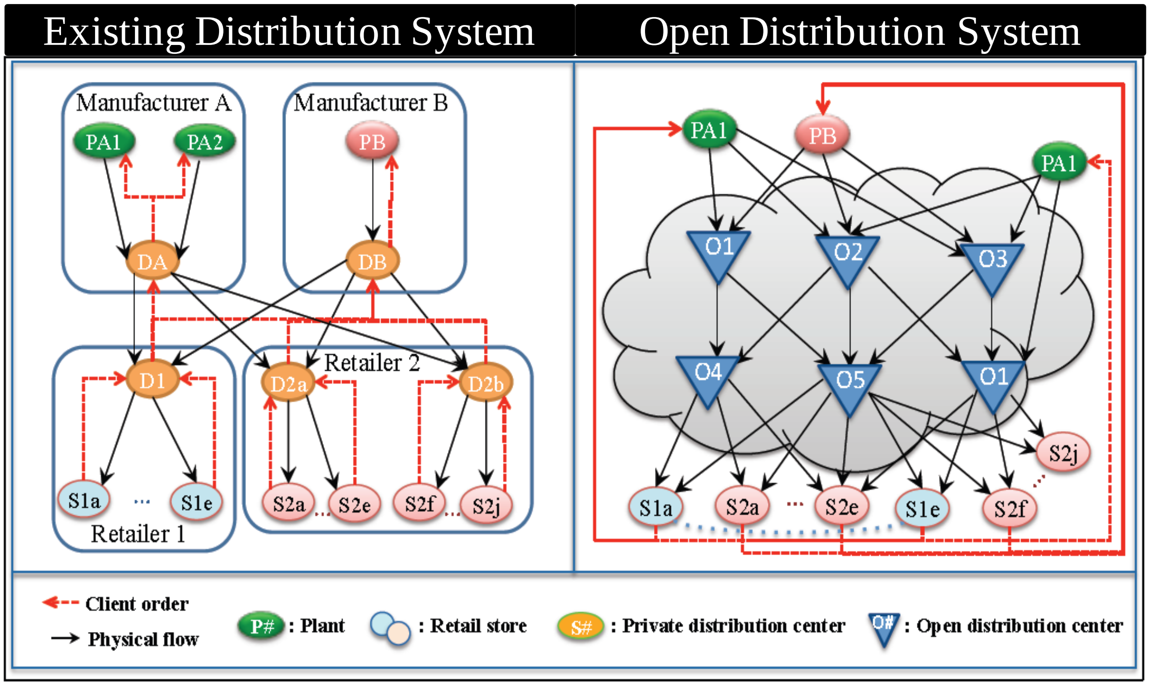


Figure 56: Contrasting the existing distribution system with an open distribution system

In addition to mobility scenarios, the simulator should support a variety of distribution system alternatives by providing easy and flexible configurable distribution networks and strategies. It should allow the simulation of the current distribution system, shared distribution networks, open distribution hubs, distribution webs, and any other combination of these systems. These scenarios are described below. All scenarios are Physical Internet enabled at different degrees except for the baseline scenario that reflects the current situation.

In each scenario, different distribution strategies can be adopted by the supply chain manager agents. It is important to remember that the hosting sites do not have to deal with or know the content of the containers. They deal with the containers as storage units. Only the supply chain managers of the companies owning or leasing the containers know what are in the containers so they can manage inventories and geographic repartition of their products over the logistic web.

In any type of open distribution, the sojourn price structure, the allowed durations-of-stay, the allowed container types, and the penalty modalities should be predefined for each open site as a part of its profile. These parameters may evolve during the simulation execution, but are set to predetermined values before the initialization.

Current Distribution System Scenario

In this scenario, each company relies only on its own sites to store and distribute its products. Suppliers store products in their warehouses and retailers in their distribution centers. The flow of products in the simulated logistic web reflects the customer orders fulfilled by suppliers. Products are packed in pallets for shipping. The objective of this scenario is to validate that our modeling approach and assumptions adequately reproduce the current reality and to provide a solid base for comparison with other scenarios.

Shared Distribution Network Scenario

This is the case of a distribution system open amongst collaborative supply network partners. The members of the same network open their facilities to store products of other members. Within a specific supply network, a member can use the available storage space of other partners to store and distribute its owned products regardless of whether these products belong to the company owning the storing facility or not. Only standard π-containers are allowed as a form of packaging (no pallets) in this scenario and any other scenario which does not involving the current distribution system.

This scenario is a midway toward a complete distribution web. It aims to provide an understanding of the implications of a closer collaboration among the members of the same supply network and can serve as guidance for the first real implementations of collaborative distribution.

Web of Open Distribution Hubs Scenario

In this scenario, open distribution hubs located at strategic geographic positions, such as close to the intersection of main highways, are dispatched over the served territory, corresponding for example to the France territory in the PREDIT project. These hubs do not necessarily belong to the members of the simulated logistic web. They can belong and be managed by private or public sector as third-party logistics providers. They offer storage space and distribution services. The advent of these open hubs results in an open distribution web that can be exploited by any actor as an extension of its storage and distribution space.

The mobility web already supports open mobility hubs that act as open crossdocking areas where containers can shift transportation means to continue their travel. The objective is to enable these hubs to support storage and distribution capabilities by allocating and managing container storing and handling capacities.

The objective of this scenario is to show, on one hand, the potential of exploiting openly accessible hubs that are widely distributed over the modeled geographic territory and, on the other hand, the excepted economic, social, and environmental efficiency and sustainability outcomes from the public and private sector investments in enabling the Physical Internet.

Distribution Web Scenario

In this scenario, any site belonging to any company is an open facility that makes available its unused storing space to all companies exploiting the logistic web. Members can dynamically decide where to store their containers according to a variety of distribution strategies and the information about storage areas (price structure, allowed durations-of-stay, container specifications, etc.) is made available by the open facilities.

The aim of this scenario is to investigate the claim that if an open distribution behavior is adopted by every actor in the Supply Web, major positive economic, environmental, and social impacts will be achieved, provided that the Physical Internet be put in place.

Other Distribution Scenarios

A variety of scenario can be designed and tested by using different combinations of the previous listed scenarios. In order to facilitate the design of different scenarios, an open-behavior variable is associated with each simulated site as a profile parameter. This way, the configuration of any combination would be possible. The scenario generator will serve to automate and support the user in designing scenarios.

Methodology

The general methodology consisted in using our approaches and platforms as a base for developing and exploiting the new simulator and then performing a gap analysis to identify what is required to meet the targeted objectives of the PREDIT project and how to implement the identified requirements. This process was applied for the general architecture, the design of the databases, the development of the simulator, and the linkage between the simulator and the logistic web tools.

Regarding the methodology used for modeling the simulator itself, we maintained the same methodology described in section 4.4 for developing the logistic web simulator. As it was highlighted before, this approach seeks to capture the complexity and dynamicity of logistics contexts by mapping software agents with real world decision-making actors or systems through three stages: a domain model, conceptual model, and operational model. In addition, as the decision mechanism is distributed over all the agents of the simulated environment, and because each agent encapsulates its own decisional behaviors, the objective is to develop, adapt and change the behaviors of each agent from one simulation to another in order to contrast different ways of doing, multiple mobility web options, and various management strategies and tactics.

The development of the simulation solution was expected to follow two main steps. The first steps objective is to develop a first version of the logistic web supporting the main supply functions and the Mobility Web. The second step upgraded this version to support in addition the Distribution Web. Currently, the first version is achieved along with the conceptual model for the second version. However, the project ended before completing the integration of the distribution functionalities into the simulator.

Global Architecture for Developing the Logistic Web Simulator

We have presented in 4.4.1 a conceptual framework for designing an agent-based logistic web simulation platform. Here, we exploit and adapt this framework in order to develop the Logistic Web simulator. Figure 57 illustrates the proposed architecture resulting from this adaptation. Since our focus in this stage is about simulating logistic web minimum efforts was dedicated to enhance the logistic web solution to become a real logistic web solution.

Therefore, the main changes to this part of the architecture consist in making sure it is correctly linked to the simulation solution. The latter, however, is the part that received the major changes to reflect the new logic inherent to logistic webs and Physical Internet. In the case of our prototype, the logistic web Simulator was even redeveloped using a different software platform technology and the simulation database was migrated to another database system.

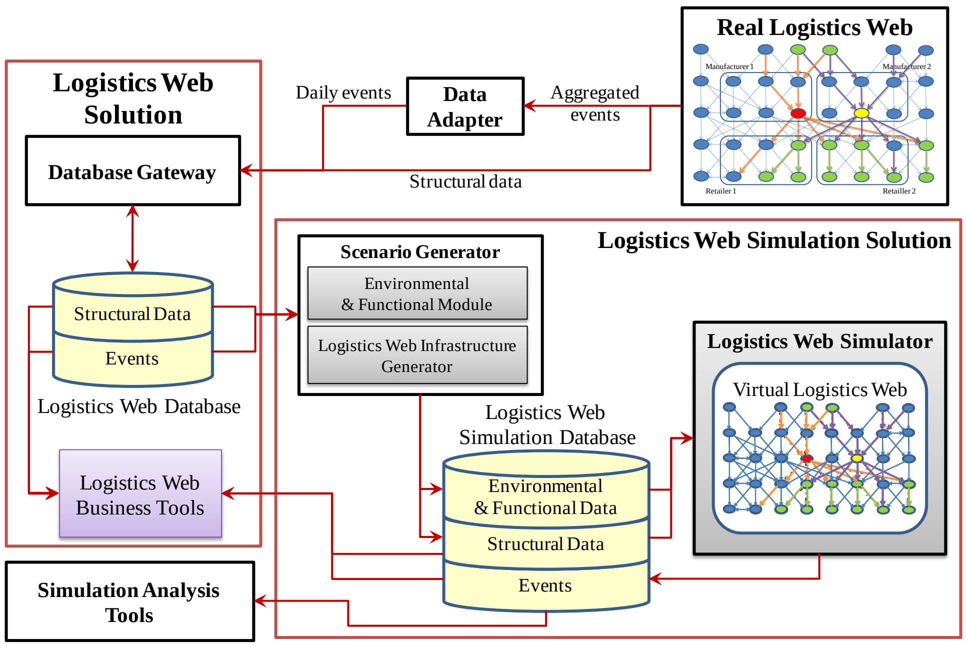


Figure 57: General architecture for developing the Logistic Web Simulation Platform

The scenario generator, developed by the team in EPFL, creates, through goal based heuristic optimization, the logistic web alternatives by producing a configuration consisting of a mobility web and distribution web based on the existing logistic web of the real companies' sites to be included in the simulation. The scenario generator is upgraded to helps users create mobility web alternatives to be experimented using the mobility web simulator. At the core of the generator lies an optimization engine. Specifically, in the France-based project, alternative networks were designed using a metaheuristic optimization engine that generated networks of interconnected unimodal and multimodal π-hubs and π-ways (roads and highways, railways, etc.) according to user defined economic, environmental, and societal goals. The scenario generator also generate, in addition to the mobility web, a distribution web by allocating storage capacity to the existing facilities or adding new distribution hubs. The scenario generator exploits the content of the logistic web database, including geographic information and the available transportation infrastructure, to generate the environmental, functional, and structural data required by the simulator.

The simulator is adapted to support the simulation of mobility and distribution aspects according to the Physical Internet principles. Based on a set of input parameters defined by the user, the simulator produces a virtual logistic web by exploiting the environmental data to generate the simulation environment, the structural data to configure the simulated supply, distribution, and mobility webs, and the functional data to determine the behavior of the agents and other components. As the simulation is running, the virtual world generates supply, distribution, and mobility events that are uploaded to the simulation database. This database is adapted to hold more information about the profiles of different entities such as agents, facilities, and product inventories as well as the new event data related to mobility, storage, and inventory.

Adapting the data to the simulation purposes is of paramount importance. For example, since the data available in the context of the PREDIT project is about the weekly flows of products, it was necessary to generate daily orders by repartitioning the weekly flows over the weekdays. This is done using the data adapter of which the development was inspired by the approach described in section 4.4.3 (Demand Generation for Supply Web Simulations).

Simulation analysis tools are mainly spreadsheets used to reduce the manual processing of the simulations' result. They exploit the content of the simulation database and the result of different scenarios to study the behavior of multiple Key Performance Indicators (KPIs) in order to determine the performance of scenarios based on the user input parameters.

The Simulation Model

The Logistic Web simulator is a discrete-event multi-agent application that reproduces an alternative reality to mimic a current or potential way of moving, distributing, storing, and supplying products within a logistic web by exploiting open or non-open logistics systems. It is developed using a simulation software tool such as AnyLogic (http://www.xjtek.com) that was used in the France-focused project. The class diagram of Figure 58 highlights the main classes related to the behavior of the functioning of the virtual supply, distribution, and mobility webs within the model and the relationships between them. Classes supporting the other functionalities of the simulation such as the computation of the KPIs and algorithms are not shown for the sake of simplifications.

The “Company” class represents the organizations that can be simulated in the model. It encapsulates the basic attributes of a company such as its name, unique identifier, main address and set of sites belonging to it. There is a variety of company types, such as a “Manufacturer”, a “Retailer”, a “Transporter”, “Distributing Company”, a “Transiting Company” or a “Routing Company”. The “Site” class represents physical centers that deal with physical objects or provide services. The “Site” class encapsulates the basic site methods and attributes such as the name, identifier, and geographic coordinates. Conceptually, as shown on the class diagram of Figure 58, any company can own any types of sites. However, in the context of the presented project, manufacturers have plants and warehouses, retailers own distributions centers and stores, transporters and routing companies have departments, and transit companies own unimodal road-based π-hubs and bimodal road-rail π-hubs. A site can be totally open meaning that it makes the excess storage space available to anyone, open only to the partners of the supply chain, or not open to external actors.

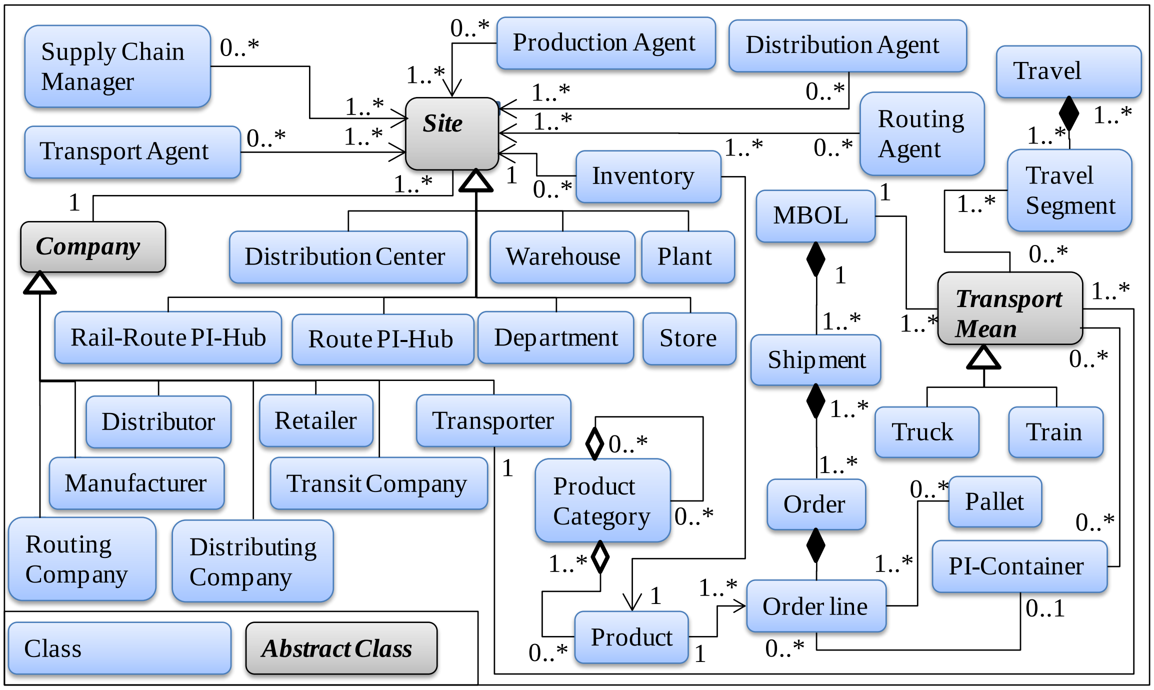


Figure 58: A Simplified class diagram of the Logistic Web simulator

All types of sites are directly involved in the manipulation of physical objects except for departments, which provide services such as determining routes and transportation means for π-container travel. Current plants, warehouses, distribution centers and stores can be components of both current and π-enabled logistic webs. They can be found in all scenarios. In π-enabled scenarios, they are assumed to be π-facilities (Montreuil et al. 2010) or at least have π-gateways enabling them to ship and receive π-containers. In π-scenarios, π-hubs have to be modeled, as they are distributed focal nodes where π-containers are transshipped to their next step in their route toward final destinations. The logistic web sites (plants, warehouses, distribution centers, and stores) carry the inventories of products they are dealing with. The products are classified under a hierarchy of product categories. A supplying site receives orders from its client sites. The orders consist of order lines, which specify the ordered quantity of the desired products.

In this research, the simulation focus is on the supply, distribution, and mobility webs, limiting the nodes of the realization webs to be sources for encapsulated shipped objects. Open realization webs are out of scope. For example, in the France-based project, the focus is on the first phase of the project in which the suppliers have their proprietary dedicated plants and warehouses, and the retailers have their proprietary dedicated distributed centers and stores.

In current non π-enabled context, customer orders are typically prepared in cases piled on pallets. The pallets to ship to the same destination are combined into a shipment. In road-based settings, a truckload is built from a set of shipments respecting the weight and volume constraints and then associated with a Master Bill Of Lading (MBOL) assigned to a truck ensuring direct delivery to destination. In a π-context, products of various orders are packed in π-containers, which are assigned to one or many transportation means that will transport them to intermediary nodes of the mobility web toward the final destination.

The model contains five main agent classes that are directly linked to the “Site” class to provide flexible modeling. The behavior of these agents is detailed in the next section. Different agents can be associated with any type of site and companies. This way, it is possible to generate specialized companies like routing companies owning departments that host routing agents, manufacturers, or retailers with their own routing departments, and even sites like plants or distributions centers with their own agents.

Agent Behaviours

As the class diagram illustrates, the proposed model features five types of agents responsible for decision-making. These agents are supply chain managers, distribution agents, production agents, transport agents and routing agents. Supply chain managers are the central and leading agents of the model. They initiate and drive core decisions involving supply chain operations. The role of the other agents is to assist the supply chain agents in applying these decisions in the best possible manners. A supply chain manager sends a request to its affiliated distribution agent to find and dispatch π-containers to specified regions or facilities. The supply chain manager delegates the distribution and the routing to the distribution agent, which handle the distribution part, and relies on the routing agent for containers routing. The transport agent replies to requests submitted by the routing agent. Generally, any requested agent sends feedbacks about the status of the query to the requesting agent. The transport agent also notifies the supply chain agents of the receiving sites about deliveries and those of shipping sites about pickups. Figure 59 show the direction and nature of the messages exchanged between the four main agents.

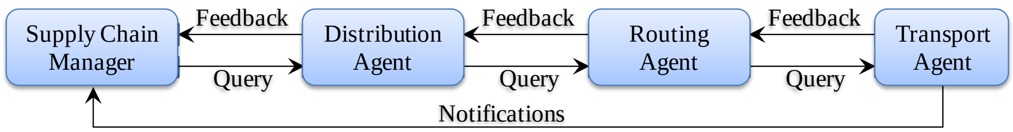


Figure 59: The communication between the simulator's agents

Each agent class is designed to allow the encapsulation of many variants of performing tasks so that agent instances can have customized behaviors within a simulation or from a simulation to another. This gives the possibility for implementing any combination of behaviors and results in the capability of simulating a large spectrum of scenarios featuring different levels of mobility and distribution openness, and targeting diverse optimization objectives. The behavior of each agent can be adapted to target economic, environmental, or social objectives or any level of trade-off between these three dimensions. Different inventory and distribution strategies will be integrated in order to study and determine the impact on supply, distribution, and transport costs, CO2 gas emissions, storage and transport capacity usage, etc. The costs used by the agent are not necessary monetary costs rather they are cost values that can be associated with distance, time, money, gas emissions or any other pertinent cost function that allows the computation of the economic, social, and environmental key performance indicators.

In the following subsections, typical agents and behaviors are presented in both a representative current context and a Physical Internet enabled context.

Supply Chain Manager

Supply Chain Managers (SCMs) have three main functions. First, managing and distributing the inventories over the simulated logistic web, second, placing orders to their suppliers, and, third, handling the clients' orders to ship. The following subsections discuss these functions.

Inventory and Distribution Managing

The initial inventories at each site are estimated using the historic data and provided to the simulation as input. In order to observe the condition of flow conservation, the inventories of subsequent suppliers are updated during the simulation based on each site received and shipped quantities. This role is ensured by the SCM for both physical and current non-PI enabled scenarios. Moreover, the consideration of inventories implies that the storage and handling capacity of each site should now be considered, estimated and added as a part of the site profile. These capacities are an important factor that will have economic and environmental impacts.

In current non-π-enabled scenarios, SCMs are assigned to plants, distribution centers, and warehouses. Supply chain managers manage the inventories of their sites using various inventory policies, estimations of expected demands, and received customer orders. In Physical Internet scenarios, supply chain agents of intermediary tier sites only deal with transiting π-containers of other companies because their sites are used as open facilities. However, the SCMs of the plants manage the inventory of their π-containers in these sites. To ensure a balanced exploitation of CPU and computation resources, each plant will have one or more SCMs based on the size of its activities. The intermediary sites will act as open facilities of which the storage space is dedicated in priority to the companies owing them than the excess space is available as an open storage to other companies.

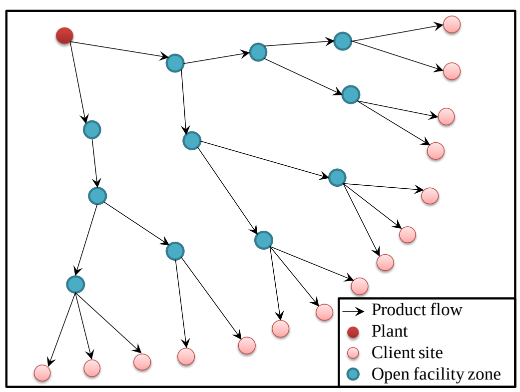


Figure 60: The default distribution network created by the plant supply chain manager

At the beginning of the simulation, the supply chain agent of the plant starts by setting the default distribution network based on the geographic repartition of their customers and their expected order quantities. Figure 60 shows an example of a default distribution network that will serve to supply the customers of a certain plant. The default distribution network server as a base for business as usual, but the supply chain agent can decide to ship its containers from any facilities to any other based on the evolution of the demand and inventory availability within the distribution channels. The design of the distribution network is beyond the scope of this work but it can take in consideration different design aspects found in the literature regarding the resilience, flexibility, lean, agile, leagile, decoupling point localizing, etc. However, it is import to note that in the context of π-enabled open distribution, the design of distribution networks is not anymore a strategic decision rather it is a tactic or even an operational decision. The reconfiguration of distribution networks is so inexpensive and easy that it does not justify long term or even mid-term commitments (Sohrabi et al., 2011).

The open facility zone (blue circles in Figure 60) can refer to a single facility, a set of potential predefined open facilities or a geographic zone where many potential open facilities are located. The SCM does not always need to define the exact site that will host its containers. For example, to serve customers of a certain city, the SCM may decide that the containers can be stored in any open facility within a circular geographic zone of twenty kilometers diameter from the center of the city. Once the open facility zones are determined, the SCM considers each zone as single fictive node in terms of management. For instance, the agent manages the inventory of a certain zone by applying regular inventory management policies (e.g. (s, S), (s, Q), (R, S)) to the total inventory in the open facilities within this zone. Also, the demand estimation is computed for the entire zone as if it was a single node. In fact, these fictive nodes are instances of the class “distribution center” created to facilitate the management of open facility zones.

Product Ordering

Daily demands are generated out of the simulator for each of the last supply chain tier sites and provided as input to the simulator. Every day, the SCMs of these sites determine the orders they place to their suppliers based on the received demand and on their inventory levels and policies. The agents of the upper stream members of the supply chain react and manage their operations according to the orders received from their clients. While all the SCMs place orders to their suppliers, those of the plants send their orders to the production agents, which ensure the production.

In π-scenarios, within any given supply network, the orders of the last tier sites are transferred directly to the first tier sites which are plants in the context of this research. The intermediary site will not order anymore; they are used only for open storage and distribution. However, the fictive node created by the plant SCMs will act as real sites of which the orders are placed to the upper stream fictive nodes or to the plant. This process is ensured by the SCM of the plant, which tries to regulate the flow of products over its distribution network by pushing inventories downstream in response to the orders of the final clients.

Client Orders Handling

On a daily basis, SCMs at the last tier sites try to fulfill the received demands for products carried in their facilities. If the demand is greater than the inventory level, lost sales occur. At the end of the day, the agent checks the inventories and places orders to its suppliers. The supplier in current non- π-cases is the adjacent upper stream member of the supply chain and in the π-cases is the plant. The received orders are sorted according to their delivery date.

In a current not-π-enabled context, the SCM agent organizes daily orders by destination and builds shipments from orders to be delivered to the same destinations while respecting the maximum allowed volume and weight of the targeted transportation means. In road-based transportation, shipments that are less than a truckload can be consolidated into MBOLs in order to maximize truck loadings. When either the volume or weight of an order exceeds truck capacity, the agent fractionates the order or its lines to fit in multiple MBOLs that respect weight and volume constraints. Once an MBOL is ready to be released, the SCM agent sends a notice to the transportation agent who assigns a truck to the MBOL.

In π-scenarios, the SCM shares the order handling procedure with the distribution agent. Product containerization and container consolidation into shipments is now delegated to the distribution agent. The supply chain agent defined for each order the open facility zone from which it should be collected and which site or open zone to which it should be shipped. The agent sends this information, along with the earliest and latest dates when the order should leave its origin and/or reach its destination, to the distribution agent, which tries to find the right solution. If no solution was found the distribution agent asks the SCM to relax some constraints or try other options. For example, if the supply chain had specified a fixed open facility for the pickup of the order, it can propose more facilities, an entire zone of open facilities, or even adjacent open facility zones. The process of constraint relaxation is done in a loop until a solution is found otherwise the shipment is postponed.

For π-containers that are only transiting through the facility of a SCM agent, the agent ensures the transshipment of these π-containers according to the specifications of the routing agents.

Upon receiving delivery of products they ordered, the SCM agents acknowledge these arrivals and update their inventory records.

Distribution Agent

Distribution agents are specific to distribution webs and assigned to the first tier sites (plants). They are not involved in non-π-enabled scenarios as their functions are not required in the current logistics system. In π-scenarios, distribution agents play for distribution, the same role played by the routing agents for routing. A distribution agent ensures the following main functions:

- Determines the origins of shipments and the containers to ship;
- Determines the exact destination site for each π-container to distribute when the SCMs don't predetermine specific hosting site for the π-container;
- Manage the excess of storage space in sites belonging to the company to which the agent is assigned.

Selection of π-Containers to Ship

The SCM sends a request to the distribution agent to ship orders from a certain zone to another. As it was mentioned before, a zone can be a precise site, a precise number of sites, or a geographic area where many potential sites exist. If the SCM did not specify the exact sites, the distribution agent starts by selecting the sites where the orders should be picked up based on the availability of the products in the sites and the eventual transportation costs. When the origin is defined, the agent proceeds with the containerization of the products into π-containers. This is normally the case when the origin is the production site of the products to ship or when the ordered quantities are fractions of the available containers. Otherwise, the agent selects the containers to ship among those available in the chosen sites. Then, the agent consolidates the orders into large π-containers to ship while observing the weight and volume loading requirements of used transport means.

Selection of π-Containers Destinations

At this point, the distribution agent has a set of π-containers to ship from specific sites to destination zones. For each of these π-containers, the agent will try to determine the exact destination site. There are three possible cases. The first case concerns the situation when the SCM has already defined the exact destination site. This can be the case when the order is shipped to a client site or because the supply chain selected a specific open facility. If the distribution agent can book a storage space in the target site for the π-container for the desired duration or if the π-container is shipped to a client site, the distribution agent sends a request to the routing agent to find the complete travel path for the container and when the path is determined, the transport agent ensures the shipment.

In the second case, the distribution agent should select a destination site for the π-container among a set of facilities provided by the supply chain agent. The distribution agent starts by eliminating the sites that cannot host the container because of a lack of space during the target storage duration or because they do not meet the container storage requirements. In the third case, the distribution agent has to select a destination site within a zone where many open facilities are located. The agent starts by finding all the open facilities of the desired zone, than eliminating those that cannot host the π-container in the same way as for the second case. After obtaining the list of potential sites having availabilities to host the π-container, the agent sends a request to the routing agent to evaluate the possibility to ship the π-container to each of the sites in the list. After assessing all the possibilities, the routing agent sends the result back to the distribution agent. The result indicates for each destination whether a travel was found and if yes, the expected costs. The distribution agent added transport cost to the storage cost for each destination and makes its final decision. Then, the agent confirms the booking of the storage space at the selected facility and informs the routing agent to confirm the corresponding travel.

In all cases, if there was no solution found to achieve hosting the containers in the target sites, the distribution agent informs the supply chain agent that should modify the shipping request as described upon the discussion of the supply chain agent behavior.

Management of the Excess of Storage Space

The distribution agents are responsible for managing the excess storage space of sites belonging to the company to which they are assigned. Periodically, the SCM determines the space it will need to store products or π-containers within each facility belonging to its company and provides this information to the distribution agent(s). The later freezes the required space for the company's activity and considers the remaining as open space available to host π-containers of external actors. The distribution agents of these actors can access the information about storage space availabilities on an announcement board of the facility. The board provides information about the categories of spaces available. For each space category, the board indicates the available size, type of containers to host, price, and earliest possible date for receiving and the latest date for dismissing the π-containers. This information is monitored and updated by the distribution agent based on data about the coming and leaving containers and the confirmed reservation.

Production Agent

Production agents have a very basic behavior in this version of the simulator since our focus is not on the production management. These agents exist in all scenarios and are affected only to plants. Their role is to generate products according to the quantities and time defined in the orders received from SCMs. At the defined moment, they inject the desired quantity into the inventory of the ordered product. Their behavior is not expected to encapsulate any operations scheduling or production management for now. Nevertheless, their behavior will gain more sophistications and their modeling will acquire a critical role upon the incorporation of the realization web into the simulator in subsequent versions.

Routing Agent

Routing agents need to be activated in π-enabled scenarios. Such agents are responsible for determining the path segments, π-hubs, and, depending on scenarios, transportation means, that containers will contract to iteratively reach the final destinations.

Routing agents support the distribution agent in selecting the origin and destination of π-containers among many possible origins and destinations when the SCM does not specify the exact sites. After determining the list of potential sites to store a π-container, the distribution agent send a request to the routing agent in order to assess the cost of transporting the π-container to each of these sites. For each possibility, the routing agent performs the appropriate routing algorithms to determine, segment-by-segment, the entire travel of a π-container, and then sends the results back to the distribution agent. The later choose the best travel and informs the routing agent about the final decision. Only then, the routing agent can proceed with the official reservation of transport means and transiting sites as it normally does.

Various π-container routing methods can be experimented. There are essentially static vs. dynamic methods, and a myriad of hybrids.

Illustrating the static group, a simple two-step method first assigns a fixed cost to each segment between nodes of the mobility web. The cost associated to each segment can be the distance, the expected average travel time, a monetary estimation, the expected greenhouse gas emission, or any other cost function. The second step executes a shortest path algorithm from a source to a destination over the graph whose vertices are the nodes of the mobility web and the edges are the inter-node segments.

Illustrating the dynamic group, a method searches to assign the π-container to a set of transportation means associated to a set of route segments that will ensure the entire travel between the source and the final destination. The method solves a time-phased shortest path problem from source to destination across the graph whose vertices correspond to a mobility web node at a given time (e.g. π-hub A at 9h00) and whose edges correspond (1) to time-phased inter-node segments (e.g. departing from π-hub A at 9:00 and arriving at π-hub X at 11:00) and (2) to sojourn times at node (e.g. flowing through π-hub A from 8:30 to 9:00). The costs associated with each inter-node edge and each intra-node edge can be set so that the shortest path algorithm minimizes for example the total cost incurred, the total greenhouse gas emission or time to final destination. The routing agent generates the set of potential inter-node edges by exploiting the travel schedules published by the transportation agents. It generates the set of potential intra-node edges by estimating the handling capacity of the hubs within the sojourn time window. If the algorithm is incapable of finding a feasible time-phased path from source to destination, the routing agent can request a customized travel from the transportation agent, re-try to route the container later, or route it to the an alternate intermediary destination. Then, the routing agent monitors the arrival of new travel availabilities that will iteratively lead the π-container to its final destination. As long as a complete source-to-destination path is not found, the agent dynamically keeps trying based on new published travels.

Various ways of combining the static and dynamic methods result in hybrid routing methods that can be applied by the agent to route π-containers. Moreover, in order to minimize the handling operations and costs, the agent can decide to group containers according to their final destinations, creating composite containers (Montreuil, 2011) that will then have to be routed to destination. Using such consolidation, the routing agent can prioritize the shipment of full-carrier-loads to be transported between π-hubs all the way from source to destination across the mobility web.

Transportation Agent

Transportation agents are part of the mobility web as they are exclusively concerned with mobility operations. These agents are responsible for managing the travels of transportation means belonging to their companies.

In a typical not-π-enabled context, once the transportation agent receives the notification about the availability of an MBOL from the supply chain agent, it schedules a truck for the specified shipping time. When the time is due, the agent decides on pallet loading associated to the MBOL into the vehicle, and then sends the vehicle toward the destination. The agent monitors all vehicles on the road, and when a truck arrives at destination, the agent initiates unloading operations and sends a notification to the SCM agent of the receiving site so that the latter acknowledges the receiving and updates its inventory.

In a π-context, the loads of π-vehicles and π-carriers are determined by routing agents instead of SCM agents. Therefore, the notification about the availability of π-containers to transport is coming from routing agents. In distributed road-based transport, trucks travel on segments of a few hours in order to allow most truck drivers to return home every day. When a full trailer load of π-containers has to travel over many segments before reaching its final destination, it will be pulled by a distinct truck along each segment. Changes of trucks are done at π-hubs and π-transits across the mobility web.

The transportation agent ensures the loading of π-containers in transportation means and the unloading at the π-hubs across the mobility web. Upon vehicle departure from a site, the transportation agent has to notify the appropriate routing agents if there was a schedule change. Upon vehicle arrival at a site, it has to notify the SCM agent about the delivery.

In addition, the transportation agent is responsible for managing the travel schedules of the transportation means and for publishing these schedules so that the routing agents can exploit them when establishing travel paths of π-containers. The transportation agent can adopt a variety of strategies to attract π-containers and maximize the loading of the transportation means. It may determine the travel schedules through various ways, for example exploiting information about the density of segment flows, weighing the importance of the served hubs, or estimating the potential business opportunities. Alternatively, there can be scheduled trips along π-routes at fixed frequencies within each day. Depending on the size of the set of π-containers ready to ship, the agent can decide to let the transporter depart, delay its departure until more π-containers accumulate, or cancel the trip and transfer the set of π-containers to another transporter-time combination. When regular services are not available, the transportation agent can also create customized trips upon request from the routing agent.

A Logistic Web Simulator Supporting the Mobility Web

This section illustrates the application of the methodology to the case of developing a simulator enabling the assessment of the potential impact of implementing a π-enabled open mobility web within the French territory to support fast moving goods distribution. For more details on the specific behaviours adapted by different agents and the exact routing and consolidation algorithms implemented in this version see (Ballot, et al., 2012; Sarraj, 2013a; Sarraj, et al., 2013b).

The developed simulator is capable of simulating mobility webs consisting of hundreds of sites exchanging millions of orders during years of the simulation time. The simulated virtual environment is a complex adaptive system that reproduces complex interactions between a large number of manufacturers, retailers, transporters, and routers. Each of these companies or departments acts as an autonomous entity managed by independent decisional agents that adapt their decisions according to the evolution of the global environment.

This section starts by explaining, in the first subsection, the steps for running the simulator. The second subsection contrasts the simulation of current non-π-scenarios vs. π-enabled mobility web scenarios. The last subsection shows how external applications can interact with the simulator for analysis and decision support purposes.

Running the Simulator

In order to run a simulation, the user starts by selecting the scenario, the scenario parameters and the input and output databases. When he launches the simulator, the following steps are performed:

1. The simulator starts setting the simulated environment by:
   a. Setting the simulation starting time;
   b. Loading the geographic information and maps;
   c. Loading companies and their sites, and localizing the sites on the maps. In π-scenarios, the π-hubs and their companies are included in the loaded data.
   d. Setting the mobility web by defining the possible links between sites. In the non- π-scenarios, supplier sites ship directly to their client sites. The mobility web consists of all the links resulting from the simulated flows. In π-scenarios, the mobility web is now considered open at various levels and is strengthened by adding the network of π-roadways and π-railways associated with the selected scenario. The result is a π-enabled open mobility web.
2. Each day
   a. The simulator loads the orders to ship and transmits them to the shipping sites;
   b. The SCM agents, the routing agents, and the transportation agents perform their task according to their prescribed behavior.
   c. KPIs are updated while the simulation is running;
   d. At the end of the day, the selected daily KIPs are inserted into the database;
3. At the end of the simulation, the selected global KIPs are inserted into the database.

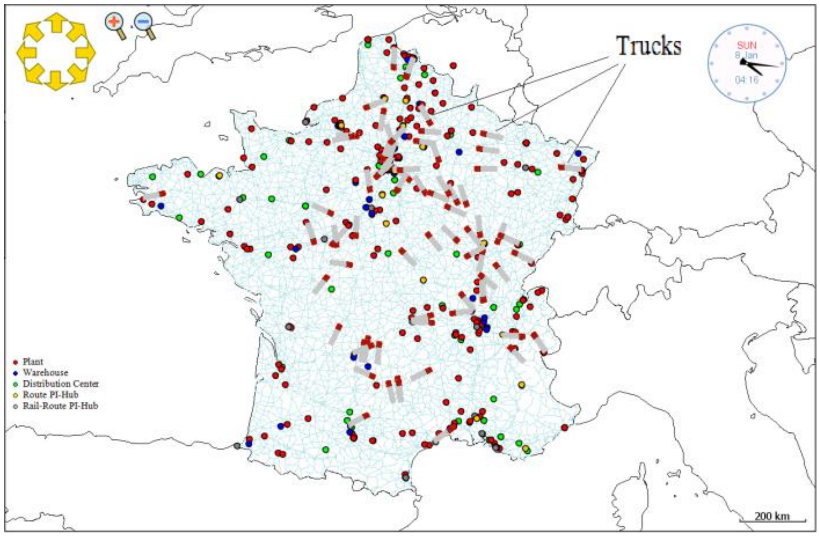


Figure 61: A screenshot of the main simulation view

As shown in Figure 61, while the simulator is running, it displays the geographical map of the investigated mobility web, the current time of the simulation and the transportation means that are traveling between sites along roadways and railways. The user can also consult the current values of many variables and all monitored KPIs.

Simulating Alternative Mobility Webs

Disaggregating the weekly flows into daily orders, using the data adapter, demand scenarios were generated. An illustrative scenario includes 282 381 order lines associated with 211 167 orders for 702 different products belonging to 53 product categories. These orders are moved within a logistic web encompassing, on one hand, 303 plants, and 57 warehouses belonging to the 106 manufacturers and, on the other hand, 58 distribution centers belonging to the two retailers (Table 11). To these, π-scenarios require adding a set of open π-hubs strategically distributed across France.

<table>
<tr><th></th><th colspan="2">Companies</th><th colspan="2">Sites</th><th>Product Categories</th><th>Product Hierarchy Levels</th><th>Products</th><th>Orders</th><th>Order lines</th></tr>
<tr><td rowspan="3">Number of Instances</td><td rowspan="2">Manufacturers</td><td rowspan="2">106</td><td>Plants</td><td>303</td><td rowspan="3">53</td><td rowspan="3">3</td><td rowspan="3">702</td><td rowspan="3">211 167</td><td rowspan="3">282 381</td></tr>
<tr><td>Warehouses</td><td>57</td></tr>
<tr><td>Retailers</td><td>2</td><td>Distribution Centers</td><td>58</td></tr>
</table>

Table 11 : The scale of the simulated case

	Route and Rail-Route PI-Hubs	Orders	Order lines	PI-Containers of 2.4*2.4*1.2 (m^3)	Transport Mean Travels	Total Travel distance (Km)
Number of Instances In a non π-Scenario	---	211 167	282 381	---	124 618	54 725 706
Number of Instances In a π-Scenario	38	211 167	868 093	677 551	270 623	43 735 190

Table 12: Contrasting mobility web scenarios

Table 12 provides a simple report contrasting two mobility web simulation scenarios that exemplifies the type of investigation enabled by the simulator. Firstly, the non-PI scenario represents the quo status described above, precisely matching real historical performance results. To distribute all the orders in the historical demand scenario, a total of 54 725 706 km were traveled by 124 618 transportation mean trips. The second scenario represents a π-enabled open mobility web where only small π-containers of 2,4m*2,4m*1,2m were considered. In order to be able to fulfill the orders, the SCM agents divided the original order lines into 868 093 smaller order lines that filled 677 551 π-containers. Each of these was routed, handled, and carried as an independent object. A total of 270 623 trips were required for a total travel distance of 43 735 190 km.

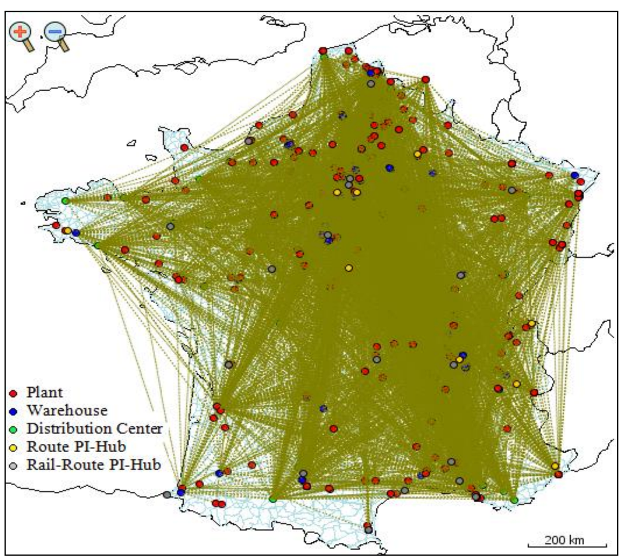


Figure 62 : The flow of goods in the existing mobility web

Even though the purpose of this section is not to report and analyze exhaustively the simulation based experiences performed in the case project, it is interesting to highlight some significant differences between the above scenarios. First, the number of trips in the π-scenario is much higher than in the baseline scenario: the distributed travel from π-hub to π-hub in the open mobility web of the π-scenario indeed creates more yet smaller hopping trips. Second, the overall travelled distance is significantly lower in the the π-scenario: the dynamic distributed consolidation of π-containers indeed increased the transportation means efficiency. The graphical display of inter-node flows in both scenarios provides visual evidence of the transformative impact of the switch from the current scenario to the Physical Internet enabled scenario. In Figure 62, the flow diagram of the current scenario is a dense spaghetti mess. In contrast, the flow diagram depicted in Figure 63 for the π – scenario reveals the structuring impact of consolidating travel through π–hubs in the open mobility web.

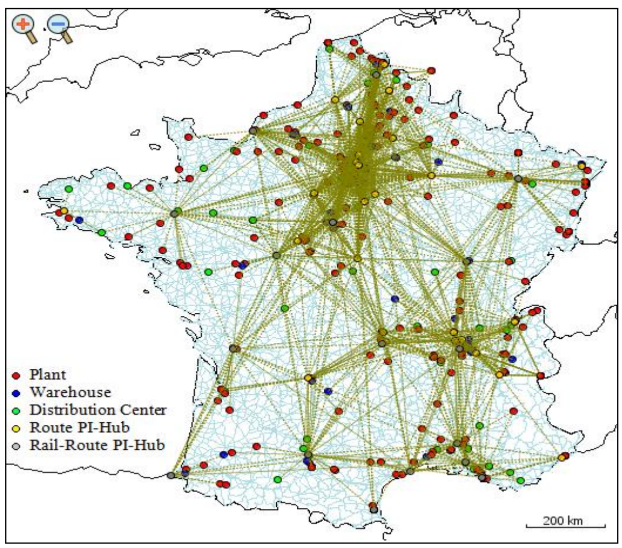


Figure 63 : The flow of goods in a physical internet enabled open mobility web

Connecting the Simulator to External Applications

While the simulator is running, it continuously generates and inserts event data into the logistic web simulation database (see Figure 57). These events along with other data are exploited by external applications for experimentation and decision support purposes. The simulation analysis tools are used for analyzing and studying the output of the scenarios of identified experiment plans. The logistic web business tools provide dynamic and static, visualization, monitoring, assessment, mining, and decision support for the simulated supply and mobility environment.

Currently, the logistic web mapper is adapted and able to connect to the output of the Logistic Web Simulator. This adaptation required connecting the mapper to the new database systems and structure and recognizing π-containers as unit loads. Whether it is connected to the output of a π or non-π-scenarios, the mapper provides all the features supported in the previous version. However, more conceptual and operational efforts are required to upgrade this application to be a Logistic Web mapper working according to Physical Internet principles.

Discussion and Conclusion

In order to demonstrate the large scale potential benefits of taking in account a logistic web perspective in dealing with the current global logistics situation which is economically, environmentally, and socially inefficient and unsustainable, we studied an open and interconnected Physical Internet enabled Logistic Web. The Physical Internet is a novel concept aiming to render the way physical objects are transported, handled, stored, realized, supplied and used throughout the world more economically, environmentally and socially efficient and sustainable. Physical Internet enables an open and interconnected global web called "Logistic Web" consisting of the Mobility Web, the Supply Web, the Realization Web, the Distribution Web, and the Service Web. Through the standardization of logistic web elements the high exploitation of connective technologies, as suggested by the Physical Internet, the concept will lead to more structuring in supply activities resulting in more automation of the decision process, more standardization of logistics operations, and easier and smoother resources sharing.

This chapter presented the conceptual model applied for developing a Logistic Web simulator supporting mobility and distribution webs simulations. The produced Logistic Web simulator supports for now the mobility web and future developments are expected to upgrade it to support the distribution web features. The simulator is a multi-agent application capable of reproducing large-scale virtual mobility webs consisting of thousands of actors and agents interacting together to mobilize shipments and π-containers over a connected network of sites, and unimodal and multimodal hubs. The simulator is exploited to study and compare simulations of various alternatives of existing mobility webs as well as open mobility webs enabled by Physical Internet.

The simulator was used for the investigation and the study of the impact of evolving from the current system of freight transportation toward a π-enabled logistic web in France. The results were promising since there was more than 15% increase in the truck fill rate, between 12% and 55% reduction in the CO2 emissions, and between 4% and 30% reduction in logistics costs (Ballot, et al., 2012; Sarraj, 2013a; Sarraj, et al., 2013b). These results can be seen as very conservative as the π-enabled scenarios used the actual product flows generated by the existing logistic web, whereas, it is expected that the actors will adapt their behaviour to make better usage of the opportunities presented by the π-enabled mobility web (Ballot, et al., 2012; Sarraj, 2013a; Sarraj, et al., 2013b).

These achievements testify to the huge potentials for adopting a web vision and moving from the current logistics system to an open, interconnected global Logistic Web. They are accomplished by a limited mobility web consisting of only two retailers' supply networks in one country. One can imagine that the extrapolation to a complete π-enabled global Logistic Web including all the Mobility, Distribution, Realization, Supply, and Service Webs can result in substantial benefits and change the face of logistics and supply chain management.

Conclusion

This chapter concludes this doctoral research work. Section one synthesises the research by providing a clear and concise summary of each of the five previous chapters. Section two highlights the main scientific contributions. The last section discusses limitations of this thesis and proposes further research opportunities.

Research Synthesis

This section provides a concise insight into the main ideas presented in the five chapters composing this thesis, as synthesized in Table 13.

The thesis begins by identifying the research question, stipulating that the existing paradigms overlook a predominant reality: companies are interacting in a web of overlapping networks rather than in independent closed networks. Thus, there is a need to consider the web dimension in supply chain management to support and address issues resulting from these kinds of web level interactions. Nevertheless, if the web dimension is integrated into supply chain management, then how should it, theoretically, fit into this field, what are the implications on the existing logistics systems, and how to design decision support systems that enable decision making at a web level?

Research Questions	Literature Study	Web Dimension in Supply Chain Management	Logistic Webs & Decision Support Systems	Web Dimension & New Perspectives
• **Definition of the research issue** • The need of the web dimension in supply chain management • **What are the implications of considering the web dimension in supply chain management?** • on SCM theories • on existing logistics systems • on decision support systems design • **What kind of results may be expected from open and interconnected logistic webs?**	• **What is the current scope of supply chain management?** • From the internal level to the network level • **Relevant contributions out of the network scope** • **Conclusions** • A need for new research beyond the supply network scope • The "web" dimension as the extension of the network dimension	• **Integration of the "web" dimension contributions into the knowledge body of supply chain management** • **Implications of considering the web dimension on supply chain management** • Impact on existing logistics webs • Inter-organisational collaboration • Decision-making • **Evolving toward new kinds of logistics systems** • Example of Physical Internet enabled Logistic Web	• **How to design decision support systems enabling the web dimension?** • Conceptual framework • Architecture • Prototypes • Demand generation for supply web simulations	• **Evolving toward open, reliable, interconnected logistic webs** • How to model and simulate these webs • What are the expected benefits • Case of simulating open mobility and distribution webs in France

Table 13: General Synthesis

Chapter two investigates the literature studying the evolution of the scope of supply chain management from internal operations, to dyadic relationships, then to supply chains, and finally to reach supply networks. The literature review also attests to the existence of limited research extending beyond the borders of supply networks, recognized today as the most advanced existing framework in supply chain management. The chapter emphasises that the consideration of internal operations, dyadic relationships, supply chain, and supply network levels is no longer enough to address the challenges faced by companies today, nor to provide a well-defined framework to address the complexity of the new logistics environments. It then concludes by proposing the web dimension as an extension of the network dimension in supply chain management.

Chapter three examines the dominant theories explaining and/or applied to supply chain management and identifies the way the web dimension can fit into the theoretical structure of the field. It then explores potential implications of integrating the web dimension into supply chain management on the existing logistic web from two facets: inter-organisational collaboration and decision support requirements. The chapter prospects the future of the logistics systems and the economic, environmental, and social potentials offered by the web dimension by studying the example of the Physical Internet enabled Logistic Web.

In chapter four, the main principles and general considerations that should guide the design of logistic web technologies are developed based upon a literature review, the expertise of our team, and our innovation. It details the criteria necessary to maintain for designing logistic web software applications capable of addressing the complexity of logistic web environments, and providing managers with smart and flexible tools for visualizing, assessing, mining, and monitoring logistic web contexts and their performance. These theoretical bases are exploited to prototype, at various degrees of implementation, first generations of web-dimension focused intelligence applications, which are the logistic web mapper, logistic web playback, logistic web monitor, and logistic web simulator.

Chapter five focuses on investigating the potential that can be obtained from applying a web vision through the example of the Physical Internet enabled logistic webs. It proposes a methodology for enhancing the simulation architecture proposed in chapter 4 to support the simulation of existing, as well as Physical Internet enabled mobility and distribution webs. It refers to the results obtained from the application of this methodology in the collaboration project PREDIT to demonstrate the substantial economic, environmental, and social expected benefits from adopting a web approach.

Main Contributions

This section details the main contributions of this thesis which can be summarized as follows: (1) extension of the scope of supply chain management to include the web dimension, (2) integration of the web dimension into the supply chain management theoretical structure, (3) proposition of a methodology, an architecture, and the design requirement for developing logistic web technologies and prototyping these elements in four applications, and (4) a design of a simulation platform for simulating physical internet enabled logistic webs.

Extending the Supply Chain Management Scope from the Network Dimension to the Web Dimension

The first major contribution of this thesis is the formal introduction of the web dimension as an extension of the network level in supply chain management and logistics. It stresses that supply chain management is still evolving and continues its evolution toward extending its scope from a network level to a networks of networks level that can be named the web level. The concepts of supply chain and supply network appear to be limitative in their representations of the complexity of physical, informational, and financial flows resulting from the interactions of the actors in overlapping networks. They also lack the theoretical foundations necessary to support and enclose contributions and concepts that reach beyond the limit of a single supply network, such as those dealing with transportation, e-market places, knowledge-based networks, selling networks, logistics pooling, and Physical Internet. The adoption of the web dimension in supply chain management is not only the solution to this issue, but it also guaranties significant new perspectives in the evolution of this field.

Integrating the Web Dimension into the Supply Chain Management Theoretical Structure

The second key contribution is the identification of the main theories and views applied to the different levels of supply chain management (internal level, dyadic relationship, chain, and network) and the integration of the web dimension into this theoretical structure. The web was added as the new dimension and associated with the theories and views having the potential to be applied to or to justify it. This was summarised in Table 5 reproduced here as Table 14.

<table>
<tr><th>Dimension</th><th colspan="5">Theories and Views</th></tr>
<tr><td>Internal level</td><td>A prior period of development of management technique</td><td>Operational category</td><td rowspan="2">Creation era</td><td colspan="2">Transaction analysis and strategic choice theory</td></tr>
<tr><td>Dyadic relationship</td><td rowspan="2">1st Period : Resource-based view</td><td rowspan="2">Design category</td><td rowspan="4">Agency theory
Resource-based view
knowledge
Management view
Institutional theory</td><td rowspan="5">System theory</td></tr>
<tr><td rowspan="2">Chain</td><td rowspan="4">Integration era
Globalisation era</td></tr>
<tr><td rowspan="2">2nd Period: knowledge management perspective</td><td rowspan="3">Strategic category</td></tr>
<tr><td rowspan="2">Network</td></tr>
<tr><td>3th period: network collaboration period</td><td>Network perspective</td></tr>
<tr><td rowspan="2">Web</td><td>Overlapping networks period</td><td>Coopetition category</td><td>Web dimension awareness era</td><td rowspan="2">Web perspective</td><td>Complexity theory</td></tr>
<tr><td>Logistics Web period</td><td>Openness sharing of resources category</td><td>Global interconnectivity and opening era</td><td>Physical Internet</td></tr>
</table>

Table 14: Theoretical Integration of the Web Dimension into Supply Chain Management

Assessing the Implications of Adopting a Web Vision in Supply Chain Management

The third contribution is the identification of important implications for adopting a web vision on inter-organisational collaboration, decision-making, and new business model development. The objective is to demonstrate that without the web dimension, supply chain management overlooks important phenomena resulting from dynamic interactions occurring in overlapping networks, and is incapable of facing global challenges and stimulating innovations out of the network scope.

At the inter-organisational collaboration level, the web dimension offers supply managers a more global view of their supply environment, providing them with the possibility of enhancing collaborative relationships with their direct partners through the understanding of the impact of indirect partners or even the development of strategic alliances with these indirect partners.

At the decision-making level, web visibility allows supply chain managers to obtain a clearer understanding of the larger picture, and thus, the ability to make more accurate decisions. This thesis has analyzed the needs of supply chain managers in logistic web contexts and identified key issues in designing business intelligence and decision support systems that provide these managers with adequate assistance in dealing with the challenges and complexity presented by logistic web environments.

Finally, the web dimension has the potential of stimulating the creation of new business models, especially when exploiting open, interconnected, and reliable logistic webs.

Proposing Logistic Web Technology Development Methodology, Architecture, Design Requirements and Prototypes

The fourth contribution is the application of a multidisciplinary approach to propose a methodology, a global architecture, and design requirements for developing decision support systems enabling logistic web decision-making in the context of inter-organisational collaboration. With the desire to offer decision support systems for a field of study as large as supply chain management in logistic webs, it is necessary to combine concepts, methods and approaches capable of handling the complexity and the size of logistic webs, through a multidisciplinary approach. In this thesis key concepts core to designing innovative and powerful web-centric business intelligence tools are presented and discussed. The main concepts are complex adaptive systems, social network analysis, enterprise collaboration, multi-agent systems, business intelligence, visual analytics, Internet based solutions, and simulation. Melding these concepts into a consistent methodology around the design of decision support systems in the logistic web context, provides the opportunity to create, model, and build logistic web technologies having the potential to meet the needs of the manager in web contexts.

The introduction of logistic web technologies relies upon the development of functionalities for managers and engineers to help their companies thrive in fast-paced, rapidly evolving, and wide-reaching logistic webs. This research established basic elements for logistic web technology design: (1) a logistic web database system that standardizes and unifies the supply data of the logistic web members, and (2) a set of business intelligence tools supporting complex decision-making. Four tools have been designed and prototyped at various degrees of advancement. The logistic web mapper and playback respectively help statically and dynamically visualize, mine, and assess the logistic web and its performance. The logistic web monitor is a real time business intelligence tool, providing live monitoring of the dynamics and the states of a selected logistic web context. Finally, the logistic web simulation platform is an advanced multi-agent system for modeling and creating virtual complex logistic web environments. Combining the decision support scopes of each of these tools results in the incorporation of most decision-making aspects related to logistic web contexts. In addition, a methodology is proposed to generate market demand required by the logistics web simulator and turn it into the propagation of orders over the supply network. This methodology is used to estimate the demands at the points of sales based on product quantities that an actor of a supply network ships to its adjacent clients.

Designing a Simulation Platform For Simulating Physical Internet Enabled Logistic Web

The Physical Internet is a concept which aims to render the way physical objects are moved, stored, realized, supplied, and used throughout the world more economically, environmentally, and socially efficient and sustainable. In order to assess this claim, a large-scale, holistic simulator for simulating a Physical Internet enabled logistic web was built. The last main contribution of this thesis is a methodology for enhancing the design of the logistic web simulation platform to support simulating and contrasting existing logistic webs and Physical Internet enabled logistic webs. This methodology is applied to the development of the conceptual model for developing a logistic web simulation solution supporting the Distribution and Mobility Web simulations. The model illustrates how real mobility and distribution webs may operate and studies the implications of upgrading the Logistic Web simulation platform from three design aspects: the global architecture of the simulation technology, simulation model, and agent behaviors.

The mobility web simulator prototype developed was used to support the investigation and study of the impact of evolving from the current system of freight transportation toward an open logistic web in France. The simulator is a multi-agent application capable of reproducing large-scale virtual mobility webs consisting of thousands of actors and agents interacting together to mobilize shipments and π-containers over a connected network of sites, and unimodal and multimodal hubs. The simulator was exploited to study and compare simulations of various alternatives of existing mobility webs, as well as π-enabled open mobility webs.

Opportunities for Further Research

In general, while we believe that this thesis provides strong evidence of the validity and need for the web dimension in supply chain management, and it establishes solid theoretical and conceptual foundations for integrating the web dimension into the field, we do not pretend to cover all the aspects related to this subject. A key objective of this thesis was to increase the awareness of the web dimension. We trust that in the same way awareness of the chain and network dimensions drove subsequent important steps in the evolution of supply chain management, the consideration of the web dimension will lead to further major steps in this evolutionary process.

This reaches far beyond the mere content of one thesis or even a few research initiatives. It will be the contribution of a variety of actors such as researchers, practitioners, politicians, service providers, information technology companies, and anyone who sees the potentials of adopting the web vision. From a research perspective, it is clear that there is room for much work to be done around exploiting a web dimension approach in supply chain management. Addressing the field from a web standpoint has the potential for generating enormous contributions from various viewpoints whether they are from information systems, operation research, business administration, social sciences or other perspectives.

In terms of the specific contributions of this thesis, an important avenue for improvement would be to have the opportunity of investigating a large-scale implementation and adoption of the logistic web technology design framework and prototypes in a real logistic web. Such implementations will help pursue the iterative features improvement process, but will require logistic web partners willing to fund and fully support the testing of the integration of these solutions into their systems. A first thread along this direction was undertaken over a year with P&G Canada: this allowed the development, testing and validation of the first versions of the Logistic Web mapper and playback. These versions were also presented to the potential users of the company and to those of some of its partners who expressed great interest in using them, appreciating the ability to access global views while benefiting from the flexibility and ease in exploring various levels of details. Such partnerships have strong potential to move forward logistics web technology oriented research and innovation.

Another promising avenue is to enhance the proposed logistic web design, architecture, and prototypes to support the Physical Internet vision. Except for the simulation platform, the other prototyped technology components do not yet support decision making when assuming open, interconnected logistic webs. A more extensive investigation is necessary to identify whether to adapt the same framework, architecture, and technologies, to build new ones, or to construct different combinations.

Many research avenues stem from the introduction of the simulator of Physical Internet enabled environments. The Physical Internet is poised to have an important impact on transportation and supply chain management. New algorithms for managing supply operations, strategically deploying products over open distribution webs, and transporting and routing physical internet containers should be developed, simulated, and tested. The simulation of all the other components of the Logistic Web at even larger scales than what was considered in this work should be targeted to capture more of the potential impacts of the Physical Internet on economic, environmental, and social efficiency and sustainability.

Finally, developing a scientific approach to build and study new forms of webs is another research opportunity. In this thesis, we primarily focused on two forms of webs: the existing logistic webs and the open interconnected webs enabled by the Physical Internet. It is reasonable to think that other forms of webs can be conceptualized and studied. They may result in further changes to current visions and the ways of doing things, as well as leading to new perspectives and potentials.

References

Ackoff, R. (1960). Systems, Organizations and Interdisciplinary Research. *General Systems, 5*, 1-8.

Ahn, H., & Lee, H. (2004). An agent-based dynamic information network for supply chain management. *BT Technology Journal, 22*, 18-27.

Alarcon, F., Alemany, M., & Ortiz, A. (2009). Conceptual framework for the characterization of the order promising process in a collaborative selling network context. *International Journal of Production Economics*, *120*, 100-114.

Alemany, M., Alarcón, F., Ortiz, A., & Lario, F. (2008). Order promising process for extended collaborative selling chain. *Production Planning \& Control , 19*(2), 105–131.

Amaral, L. A., & Uzzi, B. (2007). Complex systems-A new paradigm for the integrative study of management, physical, and technological systems. *Management Science, 53*(1033–1035).

Amiguet, M. (2003). *MOCA : Un modèle componentiel dynamique pour les systèmes multi-agents organisationnels.* Tech. rep., Université de Neuchâtel.

Anderson, P. (1999). Complexity theory and organization science. *Organization Science*, *10*, 216–232.

Anon. (1999). Survey says supply-chain not meeting needs. *Modern Materials Handling, 54*, 27.

Audy, J., & D’Amours, S. (2008). Impact of Benefit Sharing Among Companies in the Implantation of a Collaborative Transportation System-An Application in the Furniture Industry. *Pervasive Collaborative Networks*, 519-532.

Ballot, E., & Fontane, F. (2010a). Reducing transportation CO2 emissions through pooling of supply networks: perspectives from a case study in French retail chains. *Production Planning \& Control, 21*, 640-650.

Ballot, E., Montreuil, B., & Thémans, M. (2010b). *contribution à la conceptualisation et à la réalisation d'un hub rail-route de l'Internet Physique. In: PREDIT (ed.). Paris: MEDDAT.* Tech. rep.

Ballot, E., Montreuil, B., Glardon, R., Sarraj, R., Pan, S., Hakimi, D., . . . Thémans, M. (2012). *Simulation de l'Internet Physique : contribution à la mesure des enjeux et à sa définition.* MEDDAT, Paris.

Ballou, R. (2006). The evolution and future of logistics and supply chain management. *Production, 16*, 375-386.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences, 13*, 1-14.

Bauer, B., & Odell, J. (2005). UML 2.0 and agents: how to build agent-based systems with the new UML standard. *Engineering applications of artificial intelligence, 18*, 141-157.

Beamon, B. (1999). Measuring supply chain performance. *International Journal of Operations \& Production Management*, *19*(3), 275-292.

Beamon, B. M. (1998). Supply chain design and analysis: Models and methods. *International Journal of Production Economics, 55*, 281–294.

Beniger, J., & Robyn, D. (1978). Quantitative graphics in statistics: A brief history. *American Statistician*, 1-11.

Biemans, W., & Brand, M. (1995). Reverse marketing: a synergy of purchasing and relationship marketing. *International Journal of Purchasing and Materials Management*, 29-37.

Bitran, G., Gurumurthi, S., & Sam, L. S. (2006). *Emerging Trends in Supply Chain Governance.* Tech. rep., Cambridge: MIT Sloan School of Management.

Boissieu, C. (2006). Division par quatre des émissions de gaz à effet de serre de la France à l’horizon 2050. *Division par quatre des émissions de gaz à effet de serre de la France à l’horizon 2050*.

Braha, D., & Yaneer, B.-Y. (2007). The statistical mechanics of complex product development: Empirical and analytical results. *Management Science*(53), 1127–1145.

Brock, D. (2001). The electronic product code (EPC)-a naming scheme for physical objects. *Auto-ID Center. Cambridge, USA, Massachusetts Institute of Technology*.

Bussmann, S., Jennings, N., & Wooldridge, M. (2004). *Multiagent systems for manufacturing control: a design methodology.* Springer-Verlag New York Inc.

Camacho, D., Borrajo, D., & Molina, J. (2001). Intelligent travel planning: a multiagent planning system to solve web problems in the e-tourism domain. *Autonomous Agents and Multi-Agent Systems, 4*(4), 387-392.

Camarinha-Matos, L., & Afsarmanesh, H. (2005). Collaborative networks: A new scientific discipline. *Journal of Intelligent Manufacturing, 16*, 439-452.

Camman, C. (2009). Le pilotage des démarches de Supply Chain Management : une approche constructiviste. *XVIIIèmee Conférence Internationale de Management Stratégique (AIMS 2009), Grenoble.*

Capari, I., Ulengin, F., & Reisman., A. (2004). A taxonomy for supply chain management literatur. *The 10th World Conference on Transport Research (WCTRS).*

Cavinato, J. (1992). Evolving Procurement Organizations: Logistics Implications. *Journal of Business Logistics, 13*(1), 27-45.

Chen, I., & A., P. (2004). Understanding supply chain management: critical research and a theoretical framework. *International Journal of Production Research, 42*(1), 131–163.

Childerhouse, P., & Towill, D. (2000). Engineering Supply Chain to Match Customer Requirements. *Journal of Logistics Information Management, 13*, 337-346.

Choi, T. Y., & Kim, Y. (2008). Structural Embeddedness and Supplier Management: A Network Perspective. *Journal of Supply Chain Management, 44*, 5-13.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management, 19*, 351-366.

Christiaanse, E., & Kumar, K. (2000). ICT-enabled coordination of dynamic supply webs. *International Journal of Physical Distribution \& Logistics Management, 30*(3/4), 268-285.

Christopher, M. (2000). The Agile Supply Chain:: Competing in Volatile Markets. *Industrial Marketing Management, 29*(1), 37-44.

Christopher, M. (2005). *Logistics and supply chain management: creating value-added networks.* Pearson education.

Christopher, M. G. (1992). Logistics and Suppry Chain.

Cook, D., & Swayne, D. (2007). *Interactive and dynamic graphics for data analysis with R and GGobi.* Springer Publishing Company, Incorporated.

Cooper, M., & Ellram, L. (1993). Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy. *International Journal of Logistics Management, 1*(3), 237-257.

Croom, S., Romano, P., & Giannakis, M. (2000). Supply chain management: an analytical framework for critical literature review. *European Journal of Purchasing \& Supply Management, 6*, 67-83.

Croson, R., & Donohue, K. (2003). Impact of POS data sharing on supply chain management: An experimental study. *Production and Operations management, 12*(1), 1-11.

Cruijssen, F., Dullaert, W., & Fleuren, H. (2007). Horizontal cooperation in transport and logistics: a literature review. *Transportation Journal, 46*(3), 22-39.

Davenport, T., & Brooks, J. (2004). Enterprise systems and the supply chain. *Journal of Enterprise Information Management, 17*, 8-19.

Davis, P. (2000). Empirical models of demand for differentiated products. *European Economic Review, 44*(4), 993-1005.

Dayal, U., Castellanos, M., Simitsis, A., & Wilkinson, K. (2009). Data integration flows for business intelligence. *Proceedings of the 12th International Conference on Extending Database Technology: Advances in Database Technology*, (pp. 1-11).

der Zee, D. V. (2006). Modeling decision making and control in manufacturing simulation. *International journal of production economics, 100*, 155-167.

Edwards, P., Peters, M., & Sharman, G. (2001). The effectiveness of information systems in supporting the extended supply chain. *Journal of Business Logistics, 22*, 1-28.

Ellram, L., LaLonde, B., & Weber, M. (1989). Retail logistics. *International Journal of Distribution and Materials Management, 19*(12), 29–39.

Eschenbächer, J., & Zwegers, A. (2003). Collaboration in value creating networks: The concepts of collaborative commerce. In *Collaborative Systems for Production Management.* IFIP.

Farmer, D. (1997). Purchasing myopia – revisited. *Journal of Purchasing and Supply Management, 3*(1), 1-8.

Fawcett, S., Osterhaus, P., Magnan, G., Brau, J., & McCarter, M. (2007). Information sharing and supply chain performance: the role of connectivity and willingness. *Supply Chain Management: An International Journal, 12*, 358-368.

Filippini, R. (1997). Operations management research: some reflections on evolution, models and empirical studies in OM. *International Journal of Operations \& Production Management, 17*(7), 655-670.

Fiol, C., & Huff, A. (1991). Maps for managers: where are we? Where do we go from here? *Journal of Managrmat Studies, 29*, 267–285 .

Fleisch, E., & Tellkamp, C. (2005). Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain. *International journal of production economics, 95*(3), 373-385.

Forget, P., D'Amours, S., & Frayret, J.-M. (2008). Multi-behavior agent model for planning in supply chains: An application to the lumber industry. *Robotics and Computer-Integrated Manufacturing, 24(5)*(5), 664-679.

Forget, P., D'Amours, S., Frayret, J.-M., & Gaudreault, J. (2009). Study of the performance of multi-behaviour agents for supply chain planning. *Computers in industry, 60*(9), 698-708.

Forrester, J. (1961). Industrial Dynamics. *MIT Press*.

Främling, K., Ala-Risku, T., Kärkkäinen, M., & Holmström, J. (2006). Agent-based model for managing composite product information. *Computers in Industry, 57*, 72-81.

Frayret, J.-M., D'amours, S., Rousseau, A., Harvey, S., & Gaudreault, J. (2007). Agent-based supply-chain planning in the forest products industry. *International Journal of Flexible Manufacturing Systems, 19*(4), 358-391.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., & Rönnqvist, M. (2010). Cost allocation in collaborative forest transportation. *European Journal of Operational Research, 205*(2), 448-458.

Frohlich, M. T., & Westbrook, R. (2002). Demand chain management in manufacturing and services: web-based integration, drivers and performance. *Journal of Operations Management, 20*(6), 729-745.

Fujimoto, T. (1999). *The Evolution of a Manufacturing System at Toyota.* New York, NY,,,: Oxford University Press.

Galbraith, J. (2009). Multidimensional, Multinational Organizations of the Future. *The Organization of the Future 2: Visions, Strategies, and Insights on Managing in a New Era*, 174.

Gaonkar, R., & Viswanadham, N. (2003). Robust supply chain design: A strategic approach for exception handling. *Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on, 2,* pp. 1762-1767.

Gardner, J., & Cooper, M. (2004). Strategic supply chain mapping approaches. *Journal of Business Logistics, 24*, 37-64.

Gaudreault, J., Frayret, J.-M., & Pesant, G. (2009). Distributed search for supply chain coordination. *Computers in Industry, 60*(6), 441-451.

Gaudreault, J., Pesant, G., Frayret, J., & D'Amours, S. (2012, Nov). Supply Chain Coordination Using an Adaptive Distributed Search Strategy. *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 42*(6), 1424-1438.

Gerber, A., Russ, C., & Klusch, M. (2003). Supply web co-ordination by an agent-based trading network with integrated logistics services. *Electronic commerce research and applications, 2*, 133-146.

Giunipero, L. C., Hooker, R. E., Joseph-Matthews, S., Yoon, T. E., & Burdvig, S. (2008). A Decade of SCM Literature: Past, Present and Future Implicactions. *Journal of Supply Chain Management, 44*, 66-86.

Goldsby, T., & Eckert, J. (2003). Electronic transportation marketplaces: a transaction cost perspective. *Industrial Marketing Management, 32*(3), 187-198.

Goodchild, M. (1998). Geographic Information Systems and Disaggregate Transportation Modeling. *Geographical Systems, 5*(1), 19-44.

Grigore, S. (2007). Supply chain flexibility. *Romanian Economic Business Review, 2*(1), 66-70.

Hajdukova, J. (2006). Coalition formation games: A survey. *International Game Theory Review, 8*(4), 613.

Hakimi, D., Montreuil, B., & Labarthe, O. (2009). Supply Web: Concept and Technology. *7th Annual International Symposium on Supply Chain Management, Toronto, Canada,.*

Hakimi, D., Montreuil, B., & Labarthe, O. (2010a). Retail Store Demand Generation For Supply Network Simulation. *Proceedings of 8th ENIM IFAC International Conference of Modeling and Simulation, Hammamet, Tunisia, May 10-12.*

Hakimi, D., Montreuil, B., & Labarthe, O. (2010b). Supply Web Agent-Based Simulation Platform. *Proceedings of the 3rd International Conference on Information Systems, Logistics and Supply Chain, ILS 2010 – Casablanca (Morocco), April 14-16.*

Hakimi, D., Montreuil, B., & Labarthe, O. (2011). A Conceptual Framework for Designing Non-Programmed Decision Support Systems in the Context of Supply Web. *Proceedings of International Conference on Industrial Engineering and Systems Management, Metz, France, May-25-27.* 2011.

Han, J., & Kamber, M. (2006). *Data mining: concepts and techniques.* Morgan Kaufmann.

Harland, C. M. (1996). Supply Chain Management: Relationships, Chains and Networks. *British Journal of Management, 7, Special Issue,,* S63480.

Harland, C. M., Lamming, R. C., & Cousins, P. D. (1999). Developing the concept of supply strategy. *International Journal of Operations \& Production Management, 19*(7), 650-674.

Harland, C., & Clark, J. (1990). Effectiveness framework for supply chain management. *Computer Integrated Manufacturing Systems, 3*, 196-207.

Harland, C., Zheng, J., Johnsen, T., & Lamming, R. (2004). A Conceptual Model for Researching the Creation and Operation of Supply Networks. *British Journal of Management, 15*, 1–21.

Hayes, R., & Wheelwright, S. C. (1984). *Restoring our CompetitiveEdge: Competing Through Manufacturing.* John Wiley, New York, USA.

Heckert, J., & Miner, R. (1940). Distribution Costs. *The Ronald Press Company*.

Helo, P., & Szekely, B. (2004). Logistics information systems. *Industrial Management and Data Systems, 105*, 5-18.

Helo, P., & Szekely, B. (2005). Logistics information systems: An analysis of software solutions for supply chain co-ordination. *Industrial Management \& Data Systems, 105*, 5-18.

Helper, S. (1991). *How much has really changed between US auto makers and their suppliers?* Sloan Management Review.

Herrington, J., McKenney, S., Reeves, T., & Oliver, R. (2007). Design-based research and doctoral students: Guidelines for preparing a dissertation proposal.

Hertz, S. (2002). Constraints and opportunities to change through overlapping supply chains networks. *Proceedings of the 18th IMP Conference in Perth, Australia.*

Hertz, S. (2006). Supply chain myopia and overlapping supply chains. *Journal of Business \& Industrial Marketing, 21*, 208–217.

Holmström, J., Främling, K., Tuomi, J., Kärkkäinen, M., & Ala-Risku, T. (2007). Intelligent product agents: The key to implementing collaboration process networks? *forthcoming in International Journal of Logistics Management*.

Huan, S. H., Sheoran, S. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management: An International Journal, 9*, 23-29.

Jagdev, H., & Thoben, K. (2001). Anatomy of enterprise collaborations. *Production Planning \& Control, 12,* 437-451.

Jankovic, M., Cardinal, S. L., & Bocquet, J. (2009). Management Tool by Integration of Collaborative Decision Making Process Knowledge and Information. *International Journal of Product Development, 8*, 109-121.

Johnson, T. (2007). Improving automation software dependability: A role for formal methods? *Control Engineering Practice, 15*, 1403-1415.

Johnston, R. (1994). Operations: From Factory to Service Management. *International Journal of Service Industry Management, 5*(1), 49-63.

Karageorgos, A., Mehandjiev, N., Weichhart, G., & Hammerle, A. (2003). Agent-based optimisation of logistics and production planning. *Engineering Applications of Artificial Intelligence, 16*, 335-348.

Kay, M., & Jain, A. (2002). Issues in agent-based coordination of public logistics networks. *24 September 2004] Available in World Wide Web*, 2000-9.

Keim, D. (2002). Information visualization and visual data mining. *IEEE transactions on Visualization and Computer Graphics*, 1-8.

Keim, D., Mansmann, F., Schneidewind, J., & Ziegler, H. (2006). Challenges in visual data analysis. *Proceedings of the Tenth International Conference on Information Visualization*, (pp. 9-16).

Kemppinen, K., & Vepsalainen, A. P. (2003). Trends in industrial supply chains and networks. *International Journal of Physical Distribution \& Logistics Management, 33*, 701-719.

Keskinocak, P., & Savasaneril, S. (2008). Collaborative procurement among competing buyers. *Naval Research Logistics, 55*, 516-540.

Keskinocak, P., Goodwin, R., Wu, F., Akkiraju, R., & Murthy, S. (2001). Decision support for managing an electronic supply chain. *Electronic Commerce Research, 1*(1), 15-31.

Ketchen, J., J., D., G., H., & M., T. (2007). Bridging organization theory and supply chain management: the case of best value supply chains. *Journal of Operations Management, 25*(2), 573-580.

Killen, K., & Kamauff, J. (1995). Managing Purchasing: Making the Supply Team Work.

Klibi, W., Martel, A., & Guitouni, A. (2010). The design of robust value-creating supply chain networks: a critical review. *European Journal of Operational Research, 203*(2), 283-293.

Ko, M., Tiwari, A., & Mehnen, J. (2010). A review of soft computing applications in supply chain management. *Applied Soft Computing, 10*(3), 661-674.

Kovalchuk, Y. (2009). *Multi-Agent Decision Support System for Supply Chain Management.* Tech. rep., School of Computer Science and Electronic Engineering, University of Essex.

Krafft, M., & Mantrala, M. (2006). *Retailing in the 21st century: current and future trends.* Springer Verlag.

Kumar, K., Dissel, H. V., & Bielli, P. (1998). The merchant of Prato-revisited: toward a third rationality of information systems. *MIS quarterly*, 199-226.

Labarthe, O. (2006). *Modélisation et Simulation Orientées Agents de Chaînes Logistiques dans un Contexte de Personnalisation de Masse : Modèles et Cadre Méthodologique.* Tech. rep., Université Paul Cézanne (Aix-Marseille III) et Université Laval.

Labarthe, O., Espinasse, B., Ferrarini, A., & Montreuil, B. (2007). Toward a methodological framework for agent-based modelling and simulation of supply chains in a mass customization context. *Simulation Modelling Practice and Theory, 15*, 113-136.

Lamming, R., Johnsen, T., Zheng, J., & Harland, C. (2000). An initial classification of supply networks. *International Journal of Operations \& Production Management, 20*, 675-691.

Lau, H., Wong, C., Pun, K., & Chin, K. (2003). Virtual agent modeling of an agile supply chain infrastructure. *Management Decision, 41*, 625-634.

Law, A., Kelton, W., & Kelton, W. (2000). *Simulation modeling and analysis* (3 ed.). McGraw-Hill New York.

Lazzarini, S. G., Chaddad, F. R., & Cook, M. L. (2001). Integrating supply chain and network analyses: The study of netchains. *Journal on Chain and Network Science, 1*, 7-22.

Lee, H., & Billington, C. (1992). Managing supply chain inventories: pitfalls and opportunities. *Sloan Management Review*, 65-73.

Lee, H., Padmanabhan, V., & Whang, S. (1997). Information Distortion in a Supply Chain: The Bullwhip Effect. *Management Science, 43*, 546-558.

Lee, J. H., & Kim, C. O. (2008). Multi-agent systems applications in manufacturing systems and supply chain management: a review paper. *International Journal of Production Research, 46*, 233-265.

LeMoigne, J. (1974). *Les systèmes de décision dans les organisations.* Presses universitaires de France.

LeMoigne, J. (1999). *La modélisation des systèmes complexes.* Dunod Paris.

Levinthal, D. A., & Warglien, M. (1999). Landscape design: designing for local action in complex worlds. *10*, 342-57.

Lewis, H. (1956). *The Role of Air Freight in Physical Distribution.* Boston,,,: Graduate School of Business Administration, Division of Research. , Harvard University.

Li, H., & Sun, F. (2007). A Parallel Multi-Agent Simulation Planning Approach to Complex Logistics System with Genetic Optimization. 4843-4846.

Lockyer, K. (1962). *Factory Management.* London,,,: Pitman.

Lowson, R. H., & Burgess, N. J. (2002). Supply network strategies and supply chain management for e-business. *Operational Research, 2*, 55-70.

Lummus, R. R., & Vokurka, R. J. (1999). Defining supply chain management: a historical perspective and practical guidelines. *Industrial Management \& Data Systems, 99*, 11-17.

Magretta, J. (1998). The power of virtual integration: an interview with Dell Computer's Michael Dell. *Harvard Business Review, 76*, 72-85.

McDonald, T., Taylor, S., & Valenzuela, J. (2001). Potential for shared log transport services. *Proceedings of the 24th Annual COFE Meeting*, (pp. 115-120).

Meredith, J., & Amoako-Gyampah, K. (1990). The Genealogy of Operations Management. *Journal of Operations Management, 9*(2), 146-67.

Miles, R. E., & Snow, C. C. (2007). Organization theory and supply chain management: An evolving research perspective. *Journal of Operations Management, 25*, 459-463.

Miles, R., & Snow, C. (1994). Fit, Failure and the Hall of Fame: How Companies Succeed or Fail. *Free Press*.

Miri-Lavassani, K., Movahedi, B., & Kumar, V. (2009). Developments in Theories of Supply Chain Management: The Case of B2B Electronic Marketplace Adoption. *The International Journal of knowlegge, culture, change and management, 9*.

Monostori, L. (2003). AI and machine learning techniques for managing complexity, changes and uncertainties in manufacturing. *Engineering Applications of Artificial Intelligence , 16*(4), 277–291.

Monostori, L., Vancza, J., & Kumara, S. (2006). Agent-based systems for manufacturing. *CIRP Annals-Manufacturing Technology, 55*, 697-720.

Montreuil, B. (2006). Facilities Network Design: A Recursive Modular Protomodel Based Approach. In *Progress in Material Handling Research, ed. By R. Meller et al.* (pp. 287-315). Material Handling Indsutry of America (MHIA), Charlotte, North-Carolina, U.S.A.

Montreuil, B. (2011). Toward a Physical Internet: meeting the global logistics sustainability grand challenge. *Logistics Research*, 1-17.

Montreuil, B., Frayret, J.-M., & D'Amours, S. (2000). A strategic framework for networked manufacturing. *Computers in industry, 42*(2), 299-317.

Montreuil, B., Labarthe, O., Hakimi, D., Larcher, A., & Audet, M. (2009). Supply Web Mapper. *Proceedings of International Conference on Industrial Engineering and Systems Management (ISEM2009).*

Montreuil, B., Meller, R., & Ballot, E. (2013b). Physical Internet Foundations. In T. Borangiu, A. Thomas, & D. Trentesaux (Eds.), *Service Orientation in Holonic and Multi Agent Manufacturing and Robotics* (Vol. 472, pp. 151-166). Springer Berlin Heidelberg. Retrieved from http://dx.doi.org/10.1007/978-3-642-35852-4_10

Montreuil, B., Rougès, J.-F., Cimon, Y., & Poulin, D. (2012, June). The Physical Internet and Business Model Innovation. *Technology Innovation Management Review*, 32-37.

Morel, G., Grabot, B., & Editors. (2003). Intelligent Manufacturing. *Special issue of Engineering Applications of Artificial Intelligence, 16*(4).

Moss, L., & Atre, S. (2003). *Business intelligence roadmap: the complete project lifecycle for decision-support applications.* Addison-Wesley Professional.

Movahedi, B., Miri-Lavassani, K., & Kumar, V. (2009). Transition to B2B E-Marketplace Enabled Supply Chain: Readiness Assessment and Success Factors. *The International journal of Technology, Knowledge and Society, 5*.

Moyaux, T. (2004). *Design, Simulation and Analysis of Collaborative Strategies in Multi-Agent Systems: The Case of Supply Chain Management.* Tech. rep., Université Laval.

Murphy, G. (2003). Reducing trucks on the road through optimal route scheduling and shared log transport services. *Southern Journal of Applied Forestry, 27*(3), 198-205.

Nagarajan, M., & Sosic, G. (2008). Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. *European Journal of Operational Research, 187*(3), 719-745.

Nair, A., & Closs, D. J. (2006). An examination of the impact of coordinating supply chain policies and price markdowns on short lifecycle product retail performance. *International Journal of Production Economics, 102*(2), 379-392.

Nandiraju, S., & Regan, A. (2005). Freight Transportation Electronic Marketplaces: A Survey of the Industry and Exploration of Important Research Issues. *Proceedings 84th Annual Meeting of the Transportation Research Board, Washington D.C.*

Negash, S., & Gray, P. (2008). Business intelligence. *Handbook on Decision Support Systems 2*, 175-193.

Nof, S., Morel, G., Monostori, L., Molina, A., & Filip, F. (2006). From plant and logistics control to multi-enterprise collaboration. *30*(1), 55-68.

Nooteboom, B., Berger, H., & Noorderhaven. (1997). Effects of trust and governance on relational risk. *Academy of Management Journal, 40*(2), 308-338.

Pan, S., Ballot, E., & Fontane, F. (2013). The reduction of greenhouse gas emissions from freight transport by pooling supply chains. *143*, pp. 86-94. Elsevier.

Paolucci, M., & Sacile, R. (2005). *Agent-based manufacturing and control systems: new agile manufacturing solutions for achieving peak performance.* CRC.

Pathak, S. D., Day, J. M., Nair, A., Sawaya, W. J., & Kristal, M. M. (2007). Complexity and Adaptivity in Supply Networks: Building Supply Network Theory Using a Complex Adaptive Systems Perspective. *Decision Sciences, 38*, 547-580.

Peck, H. (2007). Supply chain vulnerability, risk and resilience. *Global Logistics. New Directions in Supply Chain Management, 5*, 223-237.

Porter, M. (1985). Competitive Advantage. *The Free Press*.

Power, D., & Sharda, R. (2009). Decision support systems. *Springer Handbook of Automation*, 1539-1548.

Pramatari, K. (2007). Collaborative supply chain practices and evolving technological approaches. *Supply chain management: an International Journal, 12*, 210-220.

Regan, A., & Song, J. (2003). An auction based collaborative carrier network. *Transportation Research Part E: Logistics and Transportation Review, 2*.

Rosenbaum, F. A., & Kuglin, B. A. (2000). *The Supply Chain Network @Internet Speed: Preparing Your Company for the E-Commerce Revolution.* Hardcover.

Rosenburg, N. (1965). Adam Smith on the Division of Labour: Two Views or One? *Economica, 32*, 127-139.

Ryu, S.-J., Tsukishima, T., & Onari, H. (2009). A study on evaluation of demand information-sharing methods in supply chain. *International Journal of Production Economics, 120*(1), 162-175.

Rzevski, G., Skobelev, P., & Andreev, V. (2007). MagentaToolkit: A set of multi-agent tools for developing adaptive real-time applications. *Holonic and Multi-Agent Systems for Manufacturing*, 303-313.

Santa-Eulalia, L.-A., D'Amours, S., & Frayret, J.-M. (2007). Agent-based Simulation for Distributed Supply Chain Planning: Conceptual Modeling, Analysis and Illustration.

Sarraj, R. (2013a). *Interconnexion des reseaux logistiques : elements de definition et potentiel.* Tech. rep., Mines ParisTech.

Sarraj, R., Ballot, E., Pan, S., Hakimi, D., & Montreuil, B. (2013b). Interconnected logistic networks and protocols: simulation-based efficiency assessment. (pp. 1-24). Taylor \& Francis.

Schlegel, T., & Kirn, S. (2009). Interacting with the supply swarm: Towards an interactive and visual management of supply webs. *Industrial Informatics, 2009. INDIN 2009. 7th IEEE International Conference on*, (pp. 853-858).

Schwind, M., Stenger, A., & Aponte, S. (2011). Electronic transportation marketplaces: How can green-is help to promote sustainable logistics? *System Sciences (HICSS), 2011 44th Hawaii International Conference on*, (pp. 1-8).

Scott, C., & Westbrook, R. (1991). New Strategic Tools for Supply Chain Management. *International Journal of Physical Distribution and Logistics, 24*, 23-33.

Scott, J. (1988). Social network analysis. *Sociology, 22*, 109.

Seuring, S., & Muller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production, 16*(15), 1699-1710.

Shannon, R. E. (1998). Introduction to the art and science of simulation. *WSC '98: Proceedings of the 30th conference on Winter simulation* (pp. 7-14). IEEE Computer Society Press.

Shen, W., Hao, Q., Yoon, H., & Norrie, D. (2006). Applications of agent-based systems in intelligent manufacturing: An updated review. *Advanced engineering INFORMATICS, 20*, 415-431.

Shen, W., Norrie, D., & Barthès, J. (2001). *Multi-agent systems for concurrent intelligent design and manufacturing.* CRC Press.

Simon, H. (1996). *The sciences of the artificial.* The MIT Press.

Simon, H. A. (1960). *The new science of management decision.* Harper \& Brothers.

Sohrabi, H., & Montreuil, B. (2011). From Private Supply Networks and Shared Supply Webs to Physical Internet Enabled Open Supply Webs. *Adaptation and Value Creating Collaborative Networks*, 235-244.

Spekman, R. E., Jr, J. W., & Myhr, N. (1998). An empirical investigation into supply chain management. *International Journal of Physical Distribution \& Logistics Management, 28*(8), 630-650.

Spekman, R., Salmond, D., & Kamauff, J. (1994). At last purchasing is becoming strategic. *Long Range Planning, 27*(2), 76-84.

Stefanovic, D. (1999). Simulation and analysis of distribution system based on logistic principle. *Athens: 5th International Conference of the Decision Sciences.* Athens,,,.

Stefanovic, D., Stefanovic, N., & Radenkovic, B. (2009). Supply network modelling and simulation methodology. *Simulation Modelling Practice and Theory, 17*, 743-766.

Storey, J., Emberson, C., J., & Harrison, A. G. (2006). Supply Chain Management: theory, practice and future challenges. *International Journal of Operations and Production Management, 26*, 754-775.

Stuart, I., Deckert, P., McCutcheon, D., & Kunst, R. (1998). Case study: a leveraged learning network. *Sloan Management Review, 4*, 81-93.

Surana, A., Kumara, S., Greaves, M., & Raghavan, U. N. (2005). Supply-chain networks: a complex adaptive systems perspective. *International Journal of Production Research, 43*, 4235–4265.

Surie, C., & Wagner, M. (2008). Supply chain analysis. *Supply Chain Management and Advanced Planning*, 37-63.

Swaminathan, J., Smith, S., & Sadeh, N. (1998). Modeling Supply Chain Dynamics: A Multiagent Approach. *29*, pp. 607-632. John Wiley \& Sons.

Sycara, K., Paolucci, M., Velsen, M. V., & Giampapa, J. (2003). The retsina mas infrastructure. *Autonomous agents and multi-agent systems, 7*, 29-48.

Tan, K. C. (2001). A framework of supply chain management literature. *European Journal of Purchasing \& Supply Management, 7*, 39-48.

Telle, O. (2003). *Gestion de chaînes logistiques dans le domaine aéronautique : Aide à la coopération au sein d'une relation Donneur d'Ordres/Fournisseurs.* Tech. rep., École Nationale Supérieure de l'Aéronautique et de l'Espace.

Tenn, S., & Yun, J. M. (2008). Biases in demand analysis due to variation in retail distribution. *International Journal of Industrial Organization, 26*(4), 984-997.

Terzi, S., & Cavalieri, S. (2004). Simulation in the supply chain context: a survey. *Computers in industry, 53*, 3-16.

Theus, M. (2003). Interactive data visualization using Mondrian. *Journal of Statistical Software, 7*, 1-9.

Thomas, J., & Cook, K. (2005). *Illuminating the path: The research and development agenda for visual analytics.*

Towill, D., Naim, N., & Wikner, J. (1992). Industrial Dynamics Simulation Models in the Design of Supply Chains. *International Journal of Physical Distribution and Logistics Management, 22*(5), 3-13.

Unlu, A., & Sargin, A. (2009). Interactive Visualization of Assessment Data: The Software Package Mondrian. *Applied Psychological Measurement, 33*, 148-156.

von Bertalanffy, L. (1950). The Theory of Open Systems in Physics and Biology. *Science*(January), 13.

Vonderembse, M. A., Uppal, M., Huang, S. H., & Dismukes, J. P. (2006). Designing supply chains: Towards theory development. *International Journal of Production Economics*(100), 223–238.

Waldner, M., Lex, A., Streit, M., & Schmalstieg, D. (2009). Design considerations for collaborative information workspaces in multi-display environments., *9*.

Watson, H., & Wixom, B. (2007). The Current State of Business Intelligence. *Computer, 40*, 96-99.

Weintraub, A., Epstein, R., Morales, R., Seron, J., & Traverso, P. (1996). A truck scheduling system improves efficiency in the forest industries. *Interfaces*, 1-12.

Weiss, G. (2000). *Multiagent systems: a modern approach to distributed artificial intelligence.* The MIT press.

Wexler, M. (2001). The who, what and why of knowledge mapping. *Journal of Knowledge Management, 5*, 249-263.

Wilkinson, L., & Wills, G. (2005). *The grammar of graphics.* Springer Verlag.

Wilson, R. (2008). Economic impact of logistics. *Logistics Engineering Handbook, edited by GD Taylor, CRC Press, Boca Raton, Fl, USA*.

Winkler, H. (2009). How to improve supply chain flexibility using strategic supply chain networks. *Logistics Research, 1*(1), 15-25.

Womack, J., & Jones, D. (1996). *Lean Thinking: Banish Waste and Create Wealth in your Corporation.* New York, NY,,,: Simon & Schuster.

Womack, J., Jones, D., & Roos, D. (1990). *The machine that changed the world.* London.,,,: Macmillan, .

Wood, J. C., & Wood, M. C. (2003). *Henry Ford: critical evaluations in business and management* (Vol. 1). London,,,: Routledge.

Yim, H., Ahn, H., Kim, J., & Park, S. (2004). Agent-based adaptive travel planning system in peak seasons. *Expert Systems with Applications, 27*(2), 211-222.

Young, F., Valero-Mora, P., & Friendly, M. (2006). *Visual Statistics: Seeing Data with Dynamic Interactive Graphics (Wiley Series in Probability and Statistics).* Wiley-Interscience.

Zambonelli, F., Jennings, N., & Wooldridge, M. (2003). Developing multiagent systems: The Gaia methodology. *ACM Transactions on Software Engineering and Methodology (TOSEM), 12*, 370.

Zaraté, P., & Respicio, A. (2009). Technologies for Collaborative Decision Making. *International Journal of Decision Support System Technology, IGI Global, Hershey, 1*.

Zhang, C., & Zhang, C. (2007). Design and simulation of demand information sharing in a supply chain. *Simulation Modelling Practice and Theory, 15*(1), 32-46.

Zhang, J., Xu, J., & Liu, Y. (2009). Complex adaptive supply chain network: the state of the art. 5679-5683.