An Information Model for Lean, Agile, Resilient and Green Supply Chain Management

Izunildo Fernandes Cabral

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Orientador: Professor Doutor António Bárbara Grilo

Composição do Júri:

Presidente: Professor Doutor Virgílio Cruz Machado

Vogais: Professor Doutor Henrique da Rocha O'Neill; Professor Doutor António Bárbara Grilo

FACULDADE DE CIÊNCIAS E TECNOLOGIA
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To my Mother Serafina Fernandes and my Sister Mª Helena Cabral …

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Resumo

Em ambientes empresariais modernos, uma eficaz Gestão da Cadeia de Abastecimento (SCM) é crucial para a continuidade dos negócios. Neste contexto, Lean, Agile, Resilient e Green (LARG) são identificados como paradigmas fundamentais para a competitividade da Cadeia de Abastecimento como um todo. De facto, a competição entre cadeias de abastecimento tem substituído a tradicional competição entre empresas. Para fazer uma Cadeia de Abastecimento mais competitiva, capaz de responder aos pedidos dos clientes com agilidade, capaz de responder de forma eficaz aos distúrbios inesperados, em conjugação com responsabilidades ambientais, e a necessidade de eliminar processos que não acrescentam valor, as empresas devem implementar um conjunto de práticas de Gestão da Cadeia de Abastecimento LARG e Indicadores-chave de desempenho para medir as suas influências sobre o desempenho da Cadeia de Abastecimento. No entanto, a selecção das melhores práticas LARG e indicadores-chave de desempenho é um problema de tomada de decisões complexo, envolvendo dependências e feedbacks. Por outro lado, qualquer tomada de decisão precisa ser apoiado por dados reais e transparentes. Por isso, esta dissertação pretende apresentar dois modelos integrados para auxiliar a gestão da informação e a tomada de decisão. O primeiro é um modelo de informação para apoiar uma Gestão de Cadeia de abastecimento LARG, permitindo a troca e armazenamento de dados/informação através de uma única plataforma de informação. Neste modelo três tipos de diagramas são desenvolvidos, Diagrama de Processos de Negócio, Diagramas de Casos de Uso e Diagramas de Classe para apoiar a modelação da plataforma de informação. O segundo é um modelo de tomada de decisão, designado "LARG Analytical Network Process (ANP)" para seleccionar as melhores práticas/indicadores-chaves desempenho de gestão de cadeia de abastecimento LARG a serem implementados nas cadeias de abastecimento. Ambos os modelos são desenvolvidos e validados numa cadeia de abastecimento automóvel, nomeadamente a Volkswagen Autoeuropa.

Palavras-chave: Lean, Agile, Resilient, Green, Supply Chain Management, Information Model ANP Model, Key Performance Indicators, automotive

Abstract

In modern business environments, an effective Supply Chain Management (SCM) is crucial to business continuity. In this context, Lean, Agile, Resilient and Green (LARG), are advocated as the fundamental paradigm for a competitive Supply Chain (SC) as a whole. In fact, competition between supply chains (SC) has replaced the traditional competition between companies. To make a supply chain more competitive, capable of responding to the demands of customers with agility, and capable of responding effectively to unexpected disturbance, in conjugation with environmental responsibilities, and the necessity to eliminate processes that add no value, companies must implement a set of LARG SCM practices and Key Performance Indicators (KPI) to measure their influence on the SC performance. However, the selection of the best LARG SCM practices and KPIs is a complex decision-making problem, involving dependencies and feedbacks. Still, any decision-making must be supported by real and transparent data. This dissertation intends to provide two integrated models to assist the information management and decision-making. The first is an information model to support a LARG SCM, allowing the exchange and storage of data/information through a single information platform. In this model three types of diagrams are developed, Business Process Diagram (BPD), Use Cases Diagram and Class Diagram to assist the information platform design. The second is a decision-making model, designated LARG Analytical Network Process (ANP) to select the best LARG SCM practices/KPI to be implemented in SCs. Both models are developed and validated within the automotive SC, namely in Volkswagen Autoeuropa.

Keywords: Lean, Agile, Resilient, Green, Supply Chain Management, Information Model, ANP Model, Key Performance Indicators, automotive

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List of Abreviations

SCM	Supply Chain Management
LARG	Lean, Agile, Resilient, and Green
ANP	Analytical Network Process
SC	Supply Chain
LARG SCM	Lean, Agile, Resilient, and Green Supply Chain Management
LARG SC	Lean, Agile, Resilient, and Green Supply Chain
KPI	Key Performance Indicators
BPD	Business Process Diagram
LARG ANP	Lean, Agile, Resilient, and Green Analytical Network Process
MIT	Massachusetts Institute of Technology
Pt	Portugal
EDAM	Engineering Design and Advanced Manufacturing
IT	Information Technology
BPMN	Business Process Modeling Notation
UML	Unified Modeling Language
LARG KPI	Lean, Agile, Resilient, and Green Key Performance Indicators
VW	Volkswagen
LM	Lean Manufacturing
NVA	Non-Value Added
VA	Value Added
TPS	Toyota Production System
JIT	Just in Time
FMS	Flexible Manufacturing Systems
GSCM	Green Supply Chain Management
TQM	Total Quality Management
JIS	Just in Sequence
ISO	International Organization for Standardization
R&D	Research and Development
AHP	Analytical Hierarchy Process
MCDM	Multi-criteria Decision Making
IBM	International Business Machines
WSM	Weighted Sum Model

WPM	Weighted Product Model
ELECTRE	ELimination Et Choix Traduisant la REalité
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
FAHP	Fuzzy Analytical Hierarchy Process
RFID	Radio Frequency Identification
FANP	Fuzzy Analytical Network Process
OMG	Object Management Group
BPM	Business Process Model
PO	Purchasing Order
RFQ	Request For Quotation
OOSE	Object-Oriented Software Engineering
E-R	Entity-Relationship
CD	Compact Disc
TV	Television
SC BPD	Supply Chain Business Process Diagram
EOQ	Economic Order Quantity
FG	Finished Goods
TPM	Total Productive Maintenance
UCD	Use Cases Diagram
ID	Identifier
SE	Super Entity
FF	Focal Firm
LARG UCD	Lea, Agile, Resilient and Green Use Cases Diagram
LARG SC	Lea, Agile, Resilient and Green Supply Chains
IS	Information System
G	Goal
C	Cost
SL	Service Level
T	Time
QofP	Quality of Product
L	Lean
A	Agile
R	Resilient
G	Green
1tS	1^{rst} tier Suppliers
1tD	1^{rst} tier Distributors
P	Practice
RIW	Relative Importance Weight
PWC	Pairwise Comparison
CR	Consistency Ratio

CI	Consistency Index
RI	Random Consistency Index
IC	Inventory Cost
OFR	Order fulfillment Rate
RUD	Responsiveness to Urgent Deliveries
NC	No Comparison
SS	Strategic Stock
SRR	System for Rapid Response
RMP	Reuse Materials and Packages

List of symbols

ω	Eigenvalue vector
λ_{max}	Maximum eigenvalue
n	Number of elements

Chapter 1 Introduction

1.1 Context

In recent years, the area of supply chain management (SCM) has become very popular. This is evidenced by market increases in practitioner and academic publications, conferences, professional development programs and university courses in the area (Burgess, Singh, & Koroglu, 2006). Within today's manufacturing circle, there is a rapid revolution due to many reasons, ranging from customer oriented products, shortening product life cycles, stakeholder requirements, local and international regulatory compliances, to competitions amongst players within industry (Olugu, Wong, & Shaharoun, 2010). The global market has imposed that competitiveness improvement requires collaborative work and partnerships across supply chains, motivating companies to make better decision to improve the Supply Chain (SC) performance. Collaboration between organizations, supported by flawless communication between their systems and applications, has been identified as key factors for enterprise success on a continuously changing global environment, enabling the companies to enforce their partnership and strengthen their business in the market (Jardim-Goncalves, Grilo, & Steiger-Garcao, 2006).

Organizations are looking for new methods of work and business relationships, and the exchange of information and documents with partners is often incapable of being executed automatically and in electronic format. This is mainly due to problems of incompatibility in the information representation and in the software application methods adopted (Jardim-Goncalves et al., 2006). From a Supply Chain Management point of view, any company should not work in isolation, but must collaborate with others entities in the chain to compete with other chains. So, if there is a platform that supports that exchange, it will be easier for enterprises to share data/information, allowing increasing the competitiveness of the supply chain and making timely decisions (Cabral, Grilo, Puga-Leal, & Cruz-Machado, 2011). But, having an information platform and a collaborative supply chain is not itself sufficient to meet the markets requirements.

Is thus an issue clearly the development of strategies to implement and evaluate scenarios for increasing the competitiveness of the supply chain and to assist decision-making in different management paradigms. Lean, Agile, Resilient and Green (LARG) paradigms are identified as the key paradigms to survive in the global market competition. The current challenge is to make the supply chain more competitive, capable of responding to unexpected disruptions (Resilient), responding quickly to changes in demands of customers in a market increasingly volatile and turbulent with agility (Agile), in conjugation with environmental responsibilities (Green), necessity to reduce cost, eliminate processes that add no value (Lean).

1.2 Objectives

The aim of this dissertation is to develop two models to support a Lean, Agile, Resilient, and Green SCM (LARG SCM). The first objective is a LARG information model that will support the creation of a LARG platform, which will support data/information exchange between all the companies in the considered supply chain. The second objective is to develop a decision making model that will assist managers in selecting the best practices, KPIs, and paradigms in different situations, in LARG context.

Those objectives are developed through literature review and case study development in automotive Supply Chain, using interviews and questionnaires with experts in automotive industry. The first objective (LARG information model) is achieved through the creation of three diagrams: Business Process Diagram (BPD); Use Cases Diagram; and Class Diagram. The BPD is developed to model core business processes, material, information, and financial flows of each entity in the supply chain. Use Cases diagrams are to represent the interaction between users and platform system. With the Class Diagram, is intended to show the static view of the system and the information to be stored.

The second objective (LARG ANP Model) is reached by developing an Analytical Network Process (ANP) that allows selecting the best factor (practices, KPIs, paradigms, enablers), by prioritizing all of them. To this purpose a set of clusters/elements are identified to compose the model and pairwise compared with respect to a given factor.

1.3 Research Methodology

This scientific research is part of the MIT Project, designated Lean, Agile, Resilient, and Green Supply Chain Management funded by Fundação para a Ciência e a Tecnologia da Faculdade de Ciências e Tecnologia (MIT-Pt/EDAM-IASC/0033/2008). The project has eleven tasks and each task can utilize the work of others. Namely in this task (six) designated "LARG SCM Information System", there are many contributions of previous tasks (task four – Metrics for Lean, Agile, Resilient, and Green SCM; task three - Assessment of Lean, Agile, Resileint, and Green SCM implementation practices; task two – Lean, Agile; Resilient, and Green paradigms attributes; task one – SCM characterization on Lean, Agile, Resilient, and Green).

The methodology employed to guide this research is summarized in Fig. 1. 1. To achieve the objectives proposed in the previous point an extensive literature review is made on Lean, Agile, Resilient, and Green Supply Chain Management, techniques for information system modeling and models for decision making. Much of the literature reviews are part of the work published in ambit of same project. With the literature review, is intended to get answers for the following questions: what is the context of each paradigm (Lean, Agile, Resilient, and Green); which are the characteristics of each paradigm in context of automobile SC; which are the core LARG practices that can be implemented in each level of the chain; which are the proposed LARG Key

Performance Indicators (KPIs) to measures the influences of LARG practices implementation; which are LARG SCM attributes; which are the models for decision making in SCM context.

As shown in Fig. 1.1, firstly a literature review on lean, agile, resilient, and green SCM (LARG SCM) is done. In this stage, the aim is to understand the concept of each paradigm and finding the potential tradeoffs and divergences between them and identify a set of LARG SCM practices and possible KPIs to evaluate the influence of practices implementation on SC performance. The practices and KPIs are connected directly to each SC level (distributors, focal firm, suppliers). Then, is identified the most appropriate diagrams to assist the information model development. This model development is supported by two standard language used in IT modeling fields, Business Process Notation Modeling (BPMN) and Unified Modeling Language (UML). Literature review is made in this stage to understand the potentiality of each language/diagram. In LARG information model development a Business Process Diagram is modeled to give a global vision of the material, information and financial flows of the automotive SC considered. Firstly, were created a BPD general, with contributions of a team of experts of the referred project, and in second stage was adapted to an automobile chain, with contributions of experts in automobile industry, namely professionals in logistics that work in focal firm. The same procedures are followed in use cases diagram and class diagram development.

Based on BPD developed, it will be possible to identify the core data/information associated to each organization/department and process that will be represented in class diagram. All data/information stored on structural component of LARG platform (class diagram) will be very important to assist the managers in decision making. The LARG platform will serve as support for decision making in ANP model, i.e., looking to a given KPI (metrics) value, is decided which practice should be implemented to improve these value.

Before development of the ANP model, a literature review was conducted to contribute to build a model to assist decision making in LARG context. In this stage is identified the clusters/elements to represent the ANP model.

Based on data collection in automobile industry and contributions of a team of experts, are eliminated the practices that are not implemented in automotive SC and is selected a set of implemented practices for making pairwise comparisons according to other factors (enablers, KPIs, paradigms, stakeholders), to validate the LARG ANP model. At the same time, is selected a set of KPIs to be pairwise compared according to other factors (practices, paradigms, stakeholders, enablers). To make pairwise comparisons between clusters/elements of ANP model, some questionnaires were made in the logistics department of a focal firm (Autoeuropa). The questionnaires were directed to the responsible of logistics department.

The BPD is developed using the ActiveModeler Avantage software, and the design of UML diagrams (use cases and class diagram) are done using the Argo UML software. Finally, the ANP model is implemented by the Super Decisions and Excel.

Literature review on Lean, Agile, Resilient and Green SCM

- SCM characterization on Lean, Agile, Resilient and Green (understand LARG SCM context)
- Identification of LARG practices and KPIs (performance)
- Identification of LARG attributes (to class diagram development)
- SCM characteristics

⇓

Literature review on techniques for information system modeling

- Select and study the techniques
- Understand the linking between the techniques

⇓

Literature review on models for decision making

- Select and study the models
- Understand the application of each model

⇓

Selection and linking of practices and KPIs

- Selection of LARG SCM practices in automotive industry context
- Selection of LARG KPIs to evaluate LARG SCM practices implementation
- Connect LARG practices and KPIs to each entity (level of the chain)
- Identification and selection of macro indicators (enablers)

⇓

LARG Information system modeling

- Mapping automotive SC Business Processes Diagram - BPD (using BPMN)
- Use cases and use cases diagram development (using UML)
- LARG class diagram development (using UML)

⇓

Development of ANP model to select best LARG practices and KPIs

- Identification of clusters/elements to represent the model
- ANP conceptual model (linking between clusters/elements)
- Questionnaires/interviews to eliminate no implemented LARG practices and no used KPIs
- Questionnaires to make pairwise comparisons between clusters/elements
- Data collection (in Autoeuropa VW)
- Data processing and analysis of results

Figure 1.1 Research methodology.

1.4 Research contribution of this dissertation

Firstly this dissertation intends to review the existing research on LARG SCM, namely characteristics, attributes, practices, performance indicators and existing models. That literature reviews aims to support the LARG SCM information system development and ANP model. This dissertation has also carried out a review of major LARG SCM practices and KPIs and finding the potential relationships between the practices and the KPIs, situation where the implementation of a practice can improve the value of a given KPI.

The key research contribution of this dissertation is the introduction of an information system model to assist SC managers on decision-making. Three types of diagrams have been developed in this research to support an LARG platform system that will improves the exchange of information between all actors in the SC. Information sharing through this proposed platform system is crucial for effective SCM, mainly in SCs as automobile where the frequency of information exchange should be very high. The business process diagram developed represents a powerful toll to understand the link of processes in different level of the chain or inside the organizations, processes to be improved, points where interoperability problems exist, and fundamentally data/information associated to each organization/department and process. The uses cases developed have an important contribution in this research since they represent all system requirements, i.e., the potential interactions between the users (agents of considered SC) and the system. The importance of class diagram is that allows storing all data/information required to a LARG SCM.

Other interesting contribution of this research is the introduction of a fictional “super entity” that is responsible for managing the chain as a whole. This “super entity” is an external entity that seeks SC competitiveness by improving SC performance as a whole. The main function of this “super entity” is to make SC entities working in collaboration to achieve a unique result: SC competitiveness.

Another key contribution of this thesis is that offer an ANP model to support the decision-making, on selecting the best practices to be implemented in the automotive SC. This model, also allows testing other scenarios as select the best KPI to measures performance of a given entity, enabler most appropriate to achieve competitiveness and the paradigm more suitable to a given entity or supply chain. This model is very flexible since allows managers to prioritize the best factor according to other given factor.

1.5 Structure of the dissertation

The dissertation is organized in 7 chapters. This first chapter does a brief introduction, namely as regards the scope of study, objectives, methodology, and contribution of this research.

Chapter 2 does a literature review on Lean, Agile, Resilient and Green Supply Chain Management, characteristics, attributes, practices and KPIs.

Chapter 3 and 4 are also a literature review. In chapter 3 a brief description of models for decision-making is done, and in chapter 4 is described the techniques to model the business process and information system.

Chapter 5 presents the diagrams developed to assist LARG information system modeling, namely: Business Process Diagram (BPD), use cases and class diagram.

Chapter 6 applies the developed model to select the LARG SCM best practices.

In chapter 7 a case study in automobile SC is presented to show the results of ANP model.

The conclusions and a critical analysis of the results obtained are presented in chapter 8. Future research work is also suggested to develop as a result of the study now presented.

Finally the thesis ends with the bibliography used in literature review and annexes. The annex is about the questionnaires used to do data gathering in chapter 7.

Chapter 2 Supply Chain Management (SCM)

Supply chains encompass the companies and the business activities needed to design, make, deliver, and use a product or service (Hugos, 2006). Businesses depend on their supply chains to provide them with what they need to survive and thrive. Every business fits into one or more supply chains and has a role to play in each of them (Hugos, 2006).

According to (Stevens, 1989), a Supply Chain (SC) can be described as a chain that links various agents, from the customer to the supplier, through manufacturing and services so that the flow of materials, money and information can be effectively managed to meet the business requirements. A supply chain, in other words, extends from the original supplier or source to the ultimate customer (Blanchard, 2010). There are basically three types of flows in a SC: material flow (direct flow and reverse flow), information flow and financial flow. Currently there is the assumption that SC's compete instead of other SC's (Martin Christopher & Towill, 2000). So, the competitiveness or failure of supply chains is determined by the way that the entities manage and integrate their process. It is in this context that the term Supply Chain Management (SCM) appears. Then, what is Supply Chain Management? According to (Hugos, 2006), the SCM can be defined as the things that can be done to influence the behavior of the supply chain and get the desired results. In literature, there are many definitions of SCM. Following is presented some definitions:

- Hugos M. in his book (Essentials of Supply Chain Management, 2006), refers to SCM like "the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served".
- The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer et al., 2001).
- Strategic factor for increasing organizational effectiveness and for the better attainment of organizational goals such as enhanced competitiveness, better customer service and increased profitability (Gunasekaran, Patel, & Tirtiroglu, 2001).
- Is the set of business processes and resources that transforms a product from raw materials into finished goods and delivers those goods into the hands of the customer. Supply chain management (SCM) has been defined as "the management of upstream and downstream relationship with suppliers, distributors and customers to achieve greater customer value-added at less total cost" (Wilding, 2003).

All these definitions have many concepts in common: strategic collaboration, business process management, production and inventory management, value-added for final customer.

Often there is some confusion between the concept of SCM and logistics. According to (Hugos, 2006), there is a difference between the concept of supply chain management and the traditional concept of logistics. According to him, logistics typically refers to activities that occur within the boundaries of a single organization and supply chain refer to networks of companies that work together and coordinate their actions to deliver a product to market. Also, traditional logistics focuses its attention on activities such as procurement, distribution, maintenance, and inventory management. Supply chain management acknowledges all of traditional logistics and also includes activities such as marketing, new product development, finance, and customer service (Hugos, 2006).

And what is the SCM objective? According to (Groznik & Maslaric, 2010), the objective of supply chain management is to provide a high velocity flow of high quality, relevant information that enables suppliers to provide for the uninterrupted and precisely timed flow materials to customers. To (Susana G. Azevedo, Carvalho, & Machado, 2010a), the supply chain objective is to delivering the right product, in the right quantity, in the right condition, to the right place, at the right time, for the right cost. Since customer requirements are continuously changing, supply chains must be adaptable to future changes to respond appropriately to market requirements and changes.

2.1 SCM characterization on Lean, Agile, Resilient and Green

2.1.1 The Lean Paradigm

Lean Manufacturing (LM), was developed by Taiichi Ohno at Toyota Motor Company in the 1950s (Motwani, 2003). The term “Lean” means a series of activities or solutions to eliminate waste, reduce Non-Value Added (NVA) operations, and improve the Value Added (VA) process (S. Wu & Wee, 2009). The word “Lean” or “Lean production” was developed from the Future Car Investigation by MIT, to interpret Japan’s new production system, particularly the TPS (Toyota Production System) in order to distinguish it from mass production (Conti, Angelis, Cooper, Faragher, & Gill, 2006; MacDuffie & Helper, 1997; Womack, Jones, & Ross, 1991). The literature offers many definitions of lean philosophy, but all of them share most of the same principles (Susana G. Azevedo, Carvalho, & Machado, 2010b). According to Womack and Jones (1991), the lean paradigm is an approach which provides a way to do more with less (less human effort, less equipment, less time and less space), while coming closer to customer requirements (Womack et al., 1991).The lean paradigm is a systematic approach to identify and eliminate all non-value-added activities through continuous improvement (Susana G. Azevedo et al., 2010b).

According to (Motwani, 2003), LM is an enhancement of mass production. Getting the product right the first time, continuous improvement efforts, quality in products and processes, flexible production, and minimizing waste of any kind are the enhancements that produce LM. LM involves changing and improvement processes, the attack upon the system, i.e., re-engineering the whole process, so that the common causes are much reduced (Motwani, 2003).

The importance of the lean paradigm is highlighted by (Gunasekaran et al., 2001), in the following affirmation: “The viability of a firm now largely depends on how well it can respond to customer requirements while becoming lean”. The lean approach has essentially focused on the elimination of waste (Ashish Agarwal, Shankar, & Tiwari, 2007) and responsiveness to change (Motwani, 2003).

The core content of lean manufacturing lies in Just in Time (JIT), reducing the inner waste of resources with the smallest investment achieving the biggest output (H. M. Wu, 2009).

2.1.2 The Agile Paradigm

The concept of agile manufacturing was presented in 1991, by the Iaccoca of Lehigh University, which focus on the ability to respond rapidly to changes in demand, both in terms of volume and variety. The origins of agility as a business concept lie in Flexible Manufacturing Systems (FMS) (Fan, Xu, & Gong, 2007). According to (Fan et al., 2007), flexibility is one of the key characters of an agile organization. This concept can be extended to a supply chain. To (M. Christopher, 2000), business agility embraces organizational structures, information systems, logistics processes, and, in particular mindsets.

Given the objective of supply chain, the agile supply chain intends to create the ability to respond rapidly and cost effectively to unpredictable changes in markets and increasing levels of environmental turbulence, both in terms of volume and variety (Ashish Agarwal et al., 2007). To (Baramichai, Zimmers, & Marangos, 2007), “an agile supply chain is an integration of business partners to enable new competencies in order to respond to rapidly changing, continually fragmenting markets. The key enablers of the agile supply chain are the dynamics of structures and relationship configuration, the end-to-end visibility of information, the event-driven and event-based management”. According to Christopher (2000), the agile supply chain characteristic is market sensitive. To him, market sensitive means that the supply chain is capable of reading and responding to real demand.

Agile manufacturing works well where demand is less predictable and the requirement for variety is high (M. Christopher, 2000). To (Fan et al., 2007), the aim of the agile supply chain is to carry inventory as generic as possible (postponement concept).

Since the first introduction (1991), this paradigm has been receiving an increasing attention by both researchers and industrial communities (Bottani, 2009). Currently accepted definitions relate agility to the ability of companies to respond quickly and effectively to (unexpected) changes in market demand (Brown & Bessant, 2003; Fliedner & Vokurka, 1997; Sharifi, Colquhoun, Barclay, & Dann, 2001), with the aim to meet varied customer requirements, in terms of price, specification, quality, quantity, and delivery (Prince & Kay, 2003). Agile enterprises react quickly and effectively to changes markets, driven by customized products and services (Bottani, 2009). Furthermore, agility directly affects company’s capability to produce and deliver new products in a cost-efficient way (Swafford, Ghosh, & Murthy, 2006).

Decrease in manufacturing costs, increased customer satisfaction, removal of non-value added activities and increased competitiveness (Lin, Chiu, & Chu, 2006) are among benefits that can be achieved through agile strategies. It is recognized as fundamental strategies for survival in turbulent and volatile markets and to help companies to deliver the right product at the right time to the customers (Ashish Agarwal et al., 2007; Lin et al., 2006; Yusuf, Sarhadi, & Gunasekaran, 1999).

2.1.3 The Resilient Paradigm

To increase profits margins, many companies develop strategies to seek out low-cost solutions. This can be a big problem because today's marketplace is characterized by higher levels of turbulence and volatility. According to (S. Azevedo, 2008) the risk to business continuity has increased as result of supply chain vulnerability to disruption. Today the objective in supply chain design has to be upon resilience, whereas in the past was cost minimization or service optimization (Tang, 2006). Resilient supply chains may not be the lowest-cost supply chains but they are more capable of coping with the uncertain business environment (H. Carvalho & Machado, 2009).

To (H. Carvalho & Machado, 2009), resilience refers to the ability of the supply chain to cope with unexpected disturbances. Supply chain resilience is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failure modes. The goal of supply chain resilience analysis and management is to prevent the shifting to undesirable states, i.e., the ones where failure modes could occur. In supply chain systems, the objective is to react efficiently to the negative effects of disturbances (which could be more or less severe) - (H. Carvalho & Machado, 2009). According to (Haimes, 2006), the aim of resilience strategies has two manifolds:

- To recover the desired values of the states of a system that has been disturbed, within an acceptable time period and at an acceptable cost;
- To reduce the effectiveness of the disturbance by changing the level of the effectiveness of a potential threat.

The ability to recover from the disturbance occurrence is related to development of responsiveness capabilities through flexibility and redundancy (Rice & Federico, 2003). Flexibility is related to the investments in infrastructure and resources before they actually are needed. Examples of flexibility are multi-skilled workforce, designing production systems that can accommodate multiple products and real-time changes (Rice & Federico, 2003). Redundancy is concerned to maintaining capacity to respond to disruptions in the supply network, largely through investments in capital and capacity prior to the point of need. Examples of redundancy include excess of capacity requirements, committing to contracts for material supply (buying capacity whether it is used or not), and maintaining a dedicated transportation fleet (Rice & Federico, 2003). These authors differentiated flexibility from redundancy in the following way: redundancy capacity may or may not be used; it is this additional capacity that would be used to replace the capacity loss caused by a disruption. Flexibility, on the other hand, entails restructure previously existing capacity. Christopher and Peck (Martin Christopher & Peck, 2004) have taken care to avoid some of the pitfalls of synonyms; in particular they distinguish between "resilience" and "robustness". For them, robust mean "strong or sturdy in physique or construction". Here the emphasis is on physical strength. In IT terminology "robustness" is "the ability of a computer system to cope with errors during execution". A robust process may be desirable, but does not itself equate to a resilient supply chain. They define resilience as "the ability of a system to return to its original state or move to a new, more desirable after being disturbed.

The ability to avoid the failure modes, after a disturbance occurrence, is vital for the supply chain success - it is a supply chain resilience property. In this sense, resilience can be a strong source of competitive advantage. However, resilience is not always desirable; for instance, systems states that reduce profitability can be highly resilient. The organizations difficulties in escaping from these undesirable states, even when reengineering programs are implemented, is emphasized by the relatively low success rate of business process reengineering (Al-Mashari, Irani, & Zairi, 2001).

2.1.4 The Green Paradigm

The green supply chain management was raised firstly by Manufacturing Research Association of Michigan State University in 1996, which is added the thought of green manufacturing and environmental management based on the traditional SCM in order to heighten the utility rate of resource and energy and reduce the environmental influence which was produced by some product (Jia & Bai, 2009). Environmentally sustainable green supply chain management has emerged as organizational philosophy to achieve corporate profit and market share objectives by reducing environmental risks and impacts while improving ecological efficiency of these organizations and their partners (Rao & Holt, 2005). Changes in government policies, such as the Waste Electrical and Electronic Equipment directive in European Union (Barroso & Machado, 2005) (Gottberg, Morris, Simon, Mark-Herbert, & Cook, 2006), making the industry responsible for post-consumer disposal of products, forces both manufacturers and researchers to implement sustainable operations across the supply chain (Zhu, Sarkis, & Lai, 2008). The increased pressure from community and environmentally conscious consumers had lead to rigorous environmental regulations, forcing the manufacturers to effectively integrate environmental concerns into their management practices (Rao & Holt, 2005).

According to (Srivastava, 2007) green SCM is an integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the customers as well as end-of-life management of the product after its useful life. The objects of GSCM add the waste handler and logistic agent based on the traditional SCM which includes material supplier, component supplier, manufacturer, distributor, retailer and customer to form a bidirectional logistic which is based on the reuse, remanufacture and recycle and to height the utility rate of the resource and emerge and reduce or eliminate the environmental influence (Wang, Zhang, Liu, Liu, & Zhang, 2005), i.e., suppliers, manufacturers and customers should work together towards the reduction of environmental impact from production processes and products (Vachon & Klassen, 2008). The schematic of the material flow and the echelons involved in a green supply chain is presented in Fig. 2.1. The goals system of GSCM is consisted of price, quality, cost, service, resource and environment (Guo, Zhao, & Wang, 2008). The content of GSCM includes green design, green material, green manufacture, green marketing, green packing, green consumption and green recycle (Denf & Wang, 2008; Guo et al., 2008; X. Z. Li & Wang, 2008).

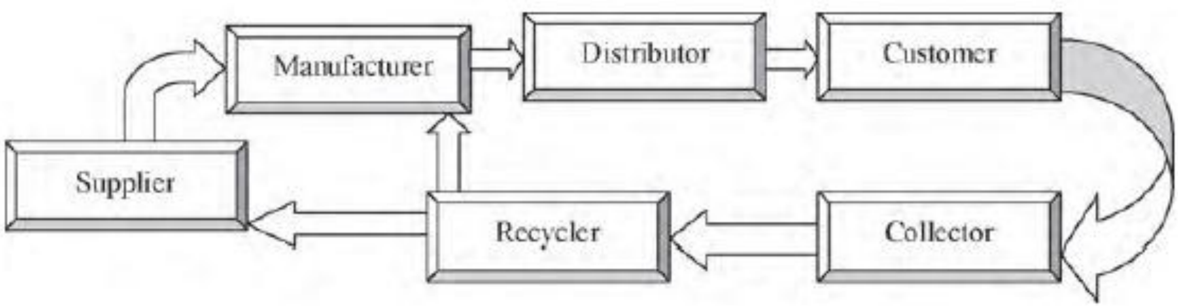


Figure 2.1 Green supply chain (Olugu, Wong, & Shaharoun).

According to (Srivastava, 2007), green supply chain management can reduce the ecological impact of industrial activity without sacrificing quality, cost, reliability, performance or energy utilization efficiency; meeting environmental regulations to not only minimizing ecological damage, but also leading to overall economic profit.

2.1.5 Lean, agile, resilient and green paradigms comparison

(H. Carvalho & Machado, 2009), based on literature review, made a comparison of the four paradigm based on 7 drivers: purpose; manufacturing focus; alliance; organizational structure; supplier involvement; inventory strategy; lead time and; product design. Table 2.1, presents this comparison.

Table 2.1 Lean, agile, Resilient, and Green paradigms comparison (H. Carvalho & Machado, 2009).

Driver	Lean	Agile	Resilient	Green
Purpose	Focus on cost reduction and flexibility, for already available products, through continuous elimination of waste or non-value added activities across the chain	Understands customer requirements by interfacing with customers and market and being adaptable to future changes	System ability to return to its original state or to a new one, more desirable, after experiencing a disturbance, and avoiding the occurrence of failures modes	Focus on sustainable development - the reduction of ecological impact of industrial activity
Manufacturing focus	Maintain high average utilization rate. It uses just in time practices, "pulling" the goods through the system based on demand	Has the ability to respond quickly to varying customer needs (mass customization), it deploys excess buffer capacity to respond to market requirements	The emphasis is on flexibility (minimal batch sizes and capacity redundancies), the schedule planning is based on shared information	Focus on efficiency and waste reduction for environmental benefit and developing of re-manufacturing capabilities to integrate reusable/remanufactured components
Alliances (with suppliers and customers)	May participate in traditional alliances such as partnerships and joint ventures at the operating level	Exploits a dynamic type of alliance known as a "virtual organization" for product design	Supply chain partners join an alliance network to develop security practices and share knowledge	Inter-organizational collaboration involving transferring or/and disseminating green knowledge to partners and customer cooperation
Organizational structure	Uses a static organizational structure with few levels in the hierarchy	Create virtual organizations with partners that vary with different product offerings that change frequently	Create a supply chain risk management culture	Create an internal environmental management system and develop environmental criteria for risk-sharing
Approach to choosing suppliers	Supplier attributes involve low cost and high quality	Supplier attributes involve speed, flexibility, and quality	Flexible sourcing	Green purchasing
Inventory strategy	Generates high turns and minimizes inventory throughout the chain	Make in response to customer demand	Strategic emergency stock in potential critical points	Introduce reusable/ remanufactured parts in the material inventory; Reduce replenishment frequencies to decrease carbon dioxide emissions; Reduce redundant materials
Lead time focus	Shorten lead-time as long as it does not increase cost	Invest aggressively in ways to reduce lead times	Reduce lead-time	Reduce transportation lead time as long it does not increase carbon dioxide emissions
Product design strategy	Maximize performance and minimize cost	Design products to meet individual customer needs	Postponement	Eco-design and incorporation of complete material life cycle for evaluating ecological risks and impact

Based on Table 2.1 and literature review, is possible to conclude: the main objective of each paradigm is:

- Lean – cost reduction and elimination of waste.
- Agile – quickly response to changes in demand/market.

- Resilient – capacity to respond to unexpected disruption.
- Green – sustainable development and reduction of environmental impact.

There are some interesting conflicts between the paradigms, e.g., in respect to inventory strategic; lean supply chains typically have lower emissions due to reduced inventory being held internally at each company, but the frequent replenishment (due to low inventory level required in lean paradigm) generally tends to increase emissions. As distance increases, it is quite possible for lean and green to be in conflict (H. Carvalho & Machado, 2009; Venkat & Wakeland, 2006). With the increase of replenishment, supply chains are increasingly covering larger distances, consuming significantly more fossil-fuel energy for transportation and emitting much more carbon dioxide (Venkat & Wakeland, 2006). So, lean may be green in some cases, but not in others (H. Carvalho & Machado, 2009). Other conflict is between lean and resilient paradigm; lean require low inventory to minimize inventory cost, and in resilient paradigm is necessary a high inventory level due unexpected disturbance. The managers have to find the better strategies for their company or supply chains.

2.2 Lean, Agile, Resilient and Green SCM Practices

To improve SCM performance it is needed to implement a set of practices in the SC's entities and measure the impacts of these practices which can occur at the different entities. Following is presented some practices of each paradigm, in each level of the chain. The practices suggested are based in the literature review (S. Azevedo & Machado, 2009; Susana G. Azevedo et al., 2010a; Susana Garrido Azevedo, Carvalho , & Machado, 2010; Helena Carvalho, Azevedo, & Machado, 2010). Complete list are presented in annex 1. All practices should contribute to an effective supply chain based on lean, agile, resilient and green paradigm. According to (Susana G. Azevedo et al., 2010b), all these practices contributes to a supply chain with less waste (non-value-added activities), more responsive to the customer requirements, able to overcome disruption conditions and also to reduce environmental impacts. There are some practices that can belong to one or more paradigm, and have different impact on each paradigm.

2.2.1 Lean practices

Lean practices are all the practices that contribute to eliminate the waste and decrease the SC's cost. Table 2.2 shows a set of lean practices that can be implemented in different level in the chain.

Table 2.2 Lean SCM practices.

	Lean SCM practices
Distributor	Demand stabilization
	Milk run or circuit delivery for smaller distances
	Order/shipment tracking/notice
	To use third-party logistics for transportations
Focal Firm	Just in time (JIT) (focal firm → first tier customer)
	Pull flow control
	Total quality management (TQM)
	Supplier relationships/long-term business relationship
Supplier	Just in time (JIT) (first tier supplier → focal firm)
	Just in sequence (JIS) (first tier supplier → focal firm)
	Delivery materials directly to the point of use
	Single sourcing and lean purchasing

2.2.2 Agile practices

Agile practices are all the practices reflect the entity ability to respond rapidly and cost effectively to unpredictable changes. Table 2.3 shows some agile practices that can be implemented in different level in the chain.

Table 2.3 Agile SCM practices.

	Agile SCM practices
Distributor	First choice partner
	Ability to change quantity of supplier's order
	Ability to change delivery times of supplier's order
	Use of IT to coordinate/integrate activities in procurement
Focal Firm	Ability to change delivery times of supplier's order
	To use IT to coordinate/integrate activities in design and development
	Rapidly reconfigure the production process
	To increase frequencies of new product development
Supplier	Speed in adjusting delivery capability
	To capture information immediately
	Speed in increasing levels of product customization
	To alter delivery schedules to meet customer requirement

2.2.3 Resilient practices

Resilient practices are a set of practices that reflect the entity ability to cope with unexpected disturbances. Table 2.4 shows a set of resilient practices that can be implemented in different level in the chain.

Table 2.4 Resilient SCM practices.

	Resilient SCM practices
Distributor	Sourcing strategies to allow switching of suppliers
	Developing visibility to a clear view of upstream inventories and supply conditions
	Flexible supply base/flexible sourcing
	Committing to contracts for material supply (buying capacity whether it is used or not)
Focal Firm	Strategic stock
	Excess of capacity requirements
	Creating total supply chain visibility
	Developing collaborative working across supply chains to help mitigating risk
Supplier	Maintaining a dedicated transit fleet
	Flexible transportation
	Silent product rollover
	Developing visibility to a clear view of downstream inventories

2.2.4 Green practices

It is necessary to integrate the organizational environmental management practices into the entire supply chain in order to achieve a sustainable supply chain and maintain competitive advantage (Linton, Klassen, & Jayaraman, 2007; Zhu et al., 2008). The green supply chain management practices should cover all the supply chain activities, from green purchasing to integrate life-cycle management, through to manufacturer, customer, and closing the loop with reverse logistics (Zhu et al., 2008). Table 2.5 shows some green SCM practices.

Table 2.5 Green SCM practices.

	Green SCM practices
Distributor	Formal policy on green logistics/transport
	To invested in vehicles with reduced environmental impacts
	To work with customers to change product specifications
	To plan vehicles routes to reduce environmental impacts
Focal Firm	To reduce energy consumption
	To reuse /recycling materials and packaging
	Reverse logistics
	ISO 14001 certification
	Environmental collaboration with suppliers

Supplier	Green procurement/sourcing
	To work with product designers and suppliers to reduce and eliminate product environmental
	To use recyclable pallet to delivery materials

2.3 Lean, Agile, Resilient and Green SCM Performance Measurement

Performance measurement is crucial to better SCM (Cagnazzo, Taticchi, & Brun, 2010).To develop an efficient and effective supply chain, it is necessary to assess its performance. . Performance measures should provide the organization an overview of how they and their supply chain are sustainable and competitive (Reichhart & Holweg, 2007). With this task, the entities can check the impact of the strategies/practices implemented and potential opportunities in supply chain management (and points to be improved). Cost, service level (available in the right place at the right time), lead time (A. Agarwal, Shankar, & Tiwari, 2006; Martin Christopher & Towill, 2000; Mason-Jones, Naylor, & Towill, 2000) and quality (of product) may be used as key performance indicators. In each of KPIs we have different metrics that can be used in different levels of the chain. (Susana G. Azevedo et al., 2010b), provides an overview of operational and economical measures that can be used to evaluate the different paradigms on SC's performance (see Table 2.6).

Table 2.6 Supply chain performance measures (Susana G. Azevedo et al., 2010b).

	Metrics	***Measures***
Operational Performance	Quality	Customer reject rate
		In plant defect fallow rate
		Increment products quality
	Customer satisfaction	After-sales service efficiency
		Rates of customer complaints
		Out-of-stock ratio
	Delivery	On time delivery
		Delivery reliability
		Responsiveness to urgent deliveries
	Time	Lead time
		Cycle times
		Delivery lead time
	Inventory levels	Finished goods equivalent units
		Level of safety stocks
		Order-to-ship
Economical	Cost	New product flexibility
		Manufacturing cost
		Cost per operating hour

	Efficiency	Overhead expense
		Operating expenses
	Environmental revenues	Revenues from 'green' products
		Recycling revenues
		Cost avoidance from environmental action
	Environmental costs	Cost of scrap/rework
		Fines and penalties
		Costs for purchasing environmentally friendly materials
		Disposal costs
		Recycling cost = transport + storage costs
		R & D expenses ratio
Environmental Performance	Green image	Number of fairs/symposiums related to environmentally conscious manufacturing the organization participate
	Business wastage	Total flow quantity of scrap
		Percentage of materials remanufactured
		Percentage of materials recycled /re-used
		Hazardous and toxic material output
		Solid and liquid wastes
	Emissions	Energy consumption
		Green house gas emissions
		Air emission

2.4 LARG Supply Chain Management Practices vs. Performance

(Susana G. Azevedo et al., 2010b), proposed a conceptual model to explore the relationships between SCM practices and SC's performance measures. This model intends to find which practices can be implemented to improve LARG performance measures, as cost, inventory level, quality of products, customer satisfaction, time, business wastage, cash-to-cash cycle, environmental costs (Table 2.7).

Table 2.7 LARG SCM practices influence on manufacturing supply chain performance (Susana G. Azevedo et al., 2010b).

Supply chain performance / LARG supply chain practices	Operational performance				Economic Performance			Environmental performance
	Inventory levels	Quality	Customer satisfaction	Time	Cost	Environmental cost	Cash-to-cash cycle	Business wastage
Just in time	↓		↑	↓	↓		↓	
Supplier relationships	↓	↑		↓	↓			↓
Cycle/setup time reduction				↓	↓		↓	
Speed in improving responsiveness to changing market needs			↑	↓			↓	↓
To produce in large or small batches	↓		↑	↓				
Ability to change delivery times of supplier's order	↓			↓				
Developing visibility to a clear view of upstream inventories and supply conditions	↓	↑			↓			↓
Lead time reduction			↑	↓				
Demand- based management	↓		↑				↓	
Reduction in the variety of materials employed in manufacturing the products	↓				↓	↓		↓
To work with product designers and suppliers to reduce environmental impacts		↑				↓		↓
	7	3	5	7	5	2	4	5

2.5 Supply Chain Characteristics

According to (H. Carvalho & Machado, 2009), to evaluate the contribution of the paradigms practices in supply chain performance, it is necessary to establish the relationships between the supply chain characteristics changed by the paradigms (designated by "management characteristics") and their relationships with key performance indicators. They considered the following management characteristics: capacity surplus, replenishment frequency, information frequency, integration level, inventory level, production lead time and, transportation lead time. These characteristics can be altered to adjust the supply chain performance (H. Carvalho & Machado, 2009). Fig. 2.2 shows the diagram with the performance indicators and management characteristics relationships.

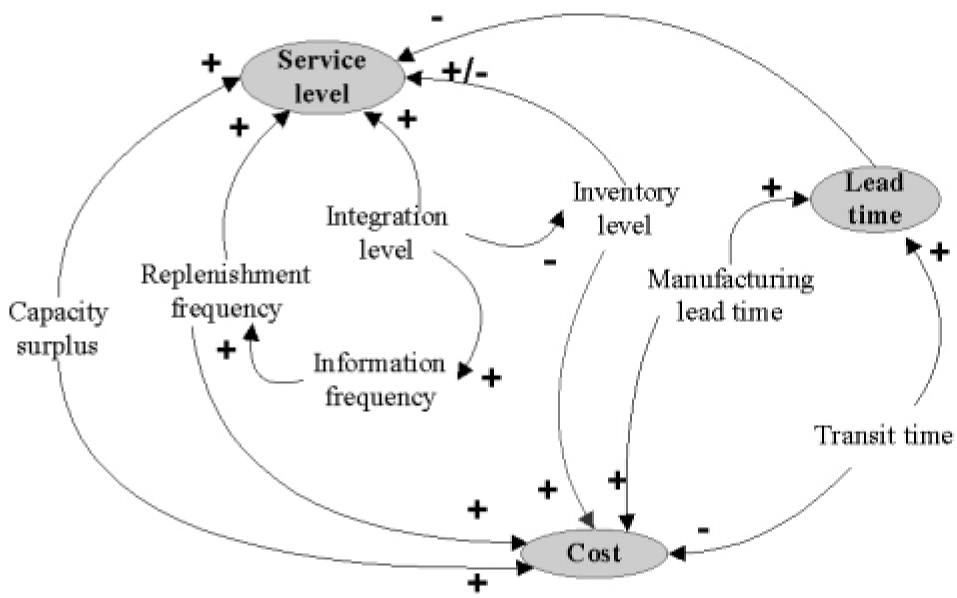


Figure 2.2 – Performance indicators and management characteristics relationships (H. Carvalho & Machado, 2009).

The causal diagram represented in Fig. 2.1 is used to capture the supply chain dynamics. With this causal scheme, it is possible to visualize how management characteristics affect the performance indicators. A positive link indicates that the two nodes move in the same direction, i.e., if the node in which the link start decreases, the other node also decreases (if all else remains equal). In the negative link, the nodes change in opposite directions, i.e., an increase will cause a decrease in another node (if all else remains equal) (H. Carvalho & Machado, 2009). Reading the diagram should be made as follows: for example, if production lead time increase, lead time and cost will increase (negative effect). There are some relationships between the management characteristics; an increased integration level will reduce the inventory level. This impact will reflect in Lean and Resilient paradigm and/or perhaps in Green. In lean paradigm we should have low inventory level to decrease the carrying cost; contrariwise, if a company has low inventory level, lose their capacity to respond to unexpected disruption. This challenge is be answered by developing the LARG ANP model, according to the enterprise strategies.

The tradeoffs between lean, agile, resilient, and green SCM paradigms must be understood to help companies and supply chains to become more efficient, streamlined, and sustainable. To this end, it is necessary to develop a deep understanding of the relationships (conflicts and commitments) between the lean, agile, resilient, and green paradigms (Fig. 2.1), exploring and researching their contribute for the sustainable competitiveness of the overs production systems in the supply chain, measured by its Cost, Lead Time, Quality (of product) and Service Level (H. Carvalho & Machado, 2009).

Table 2.8 (H. Carvalho & Machado, 2009) shows an overview of main synergies and divergences between the LARG paradigms. There are evidences that lean, agile, resilient, and green paradigms are complemented by each others. According to (H. Carvalho & Machado, 2009), the implementation of these paradigms in the supply chain creates synergies in the way that some supply chain characteristics should be managed, namely, “information frequency”, “integration level”, “production lead time” and “transportation lead time”. However, the impact of each paradigm implementation in the characteristics magnitude may be different. For example, the lean paradigm seeks compulsively the reduction of production and transportation lead times to reducing the total lead time and minimizing the total waste. However, the resilient paradigm, although it prescribes this reduction in lead times, it is not so compulsive, since the objective is to increase the supply chain visibility and capability to respond to unexpected disturbance (H. Carvalho & Machado, 2009).

Table 2.8 Paradigms synergies and divergences overview (H. Carvalho & Machado, 2009).

	Lean	**Agile**	**Resilient**	**Green**	
Information frequency	↑	↑	↑	–	*Synergies*
Integration level	↑	↑	↑	↑	
Production lead time	↓	↓	↓	↓	
Transportation lead time	↓	↓	↓	↓	
Capacity surplus	↓	↑	↑	↓	*Divergences*
Inventory level	↓	↓	↑	↓	
Replenishment frequency	↑	↑	↑	↓	

Legend: ↑ increase; ↓ decrease; – without consequence;

Chapter 3 Models for Decision Making

Decision makers generally assume that logical thinking is the best and only way to make good decisions. In doing so they neglect to observe that our mind is both rational and emotional. The rational side is associated with logical and structured reasoning, whereas the emotional side is concerned with feelings intuitions and hunches (Zammori, 2009). According to the great mathematician Henri Lebesgue, making direct comparisons of objects with regard to a property is a fundamental mathematical process for deriving measurements (T. L. Saaty, 2008).

Many people including mathematicians whose thinking is grounded in the use of Cartesian axes based on scales of measurement believe that there is only way to measure things, and it needs a physical measurement scale with a zero and a unit to apply to objects (T. L. Saaty, 2008). We can also derive accurate and reliable relative scales that do not have a zero or a unit by using our understanding and judgments that are the most fundamental determinants of why we want to measure anything (T. L. Saaty, 2008).

Until the introduction of the Analytical Hierarchy Process (AHP) (T. L. Saaty, 1990) and its generalization to dependence and feedback the Analytical Network Process (ANP) (T. L. Saaty, 2005), there were no effective means to combine feelings (hunches) and rationale in a structured and formal mathematical way (Zammori, 2009). According to (Zammori, 2009), now it is possible to make better decisions relying on both spheres of our mind, because the AHP and the ANP are multi-criteria decision-making (MCDM) methods that combine intuition and judgments with reason emphasizing the role of inconsistency in the decision-making process. These methods are based on a multi-criteria measurement theory which provides a general framework to deal with decisions in a structured way (Hou & Su, 2007): (i) by rigorously structuring the problems as a hierarchy or a network of all the factors and the influences among them, and (ii) by establishing the intensities of the influence relations through pairwise comparison judgments. In this manner all the relevant knowledge and intuition that have bearing on a decision are “scientifically” gathered together and it is possible to discover the rationale behind the best choice to be made and understand how quantitative reasoning underlies and guides the decision (Zammori, 2009).

According to (T. L. Saaty, 2008), the paradigm of measurement has numerous practical implications because it makes it possible for us to deal with intangible factors alongside tangibles used in science and mathematics in a realistic and justifiable way. Among the many applications made by companies and governments, now perhaps numbering in the thousands, the AHP was used by International Business Machines (IBM) as part of its quality improvement strategy to design its AS/400 computer and win the prestigious Malcolm Baldrige National Quality Award (Bauer, Collar, & Tang, 1992). In (2001) it was used to determine the best site to relocate the earthquake devastated Turkish city Adapazari. British Airways used it in 1998 to choose the entertainment system vendor for its entire fleet of airplanes. A company used it in 1987 to choose the best type of platform to build to drill for oil in the North Atlantic (T. L. Saaty, 2008). Other interesting applications concern supplier selection (Gencer & Guerpinar, 2007; Hou & Su, 2007), maintenance analysis (Braglia, Carmignani, Frosolini, & Grassi, 2006), marketing analysis (Yuksel & Dagdeviren, 2007), supply chain management (C. L. Yang, Chuang, & Huang, 2009) and design optimization (T. S. Li, 2010).

In addition to AHP/ANP, several multi-criteria decision-making (MCDM) methods have been proposed in technical literature (T. L. Saaty, 2008). Among these one can cite the Weighted Sum Model (WSM), Weighted Product Model (WPM), the ELECTRE Method, and the TOPSIS Method, but many others exist and goods reviews can be found in (Curwin & Slater, 2008; Figueira, Greco, & Ehrgott, 2005; Sweeney & Martin, 2008). According to (Zammori, 2009), many comparisons [see for example (Bhutta & Huq, 2002; Triantaphyllou, 2002)] have revealed that both the AHP and the ANP possess a number of benefits over the other MCDC methods, such as: (i) they provide a realistic description of the problem, (ii) they support group decision-making, (iii) they soundly structure the decision-making process, (iv) they incorporate both quantitative and qualitative factors, (v) they clearly express the relative importance of factors, (vi) they allow the decision makers to focus on each small part of the problem, (vii) they facilitate the evaluation of alternative scenarios, by supporting what if and sensitivity analysis (Zammori, 2009).

3.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision support methodology, introduced by Saaty, in 1980. According to (T. L. Saaty & Vargas, 2006b), the AHP is a general theory of measurement and one of the widely used approaches to handle such a multi-criteria decision-making problem. To him, it is used to derive relative priorities on absolute scales (invariant under the identify transformation) from both discrete and continuous paired comparisons in multilevel hierarchic structures. To (Taylor, 2004), AHP is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria. With AHP, the decision maker selects the alternatives that best meets his or her decision criteria developing a numerical score to rank each decision alternative based on how well each alternative meets them (Özdagoglu & Özdagoglu, 2007). In its general form, the AHP is a nonlinear framework for carrying out both deductive and inductive thinking without use of the syllogism (T. L. Saaty & Vargas, 2006b).

The Analytical Hierarchy Process (AHP) is a flexible multi-criteria decision-making method which can be used to effectively synthesize the judgments given by a team of experts in order to make better decisions in complex settings, where both tangible and intangible criteria must be considered (T. L. Saaty, 1990). The application of the AHP to the complex problem usually involves four major steps (Cheng, Yang, & Hwang, 1999):

i. Break down the complex problem into a number of small constituent elements and then structure the elements in a hierarchical form;

ii. Make a series of pairwise comparisons among the elements according to a ratio scale;

iii. Use the eigenvalue method to estimate the relative weights of the elements;

iv. Aggregate these relative weights and synthesize them for the final measurement of given decision alternatives.

The AHP is a powerful and flexible multi-criteria decision-making tool for dealing with complex problems where both qualitative and quantitative aspects need to be considered. The AHP helps analysts to organize the critical aspects of a problem into a hierarchy rather like a family tree (Maurizio, D'Amore, & Polonara, 2004). The essence of the process is decomposition of a complex problem into a hierarchy with goal (criterion) at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. Elements at given hierarchy levels are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of the hierarchy (Pohekar & Ramachandran, 2004). A decision maker may use this vector according to his particular needs and interests (Özdagoglu & Özdagoglu, 2007).

According to (Ho, 2008), the AHP consists of three main operations, including hierarchy construction, priority analysis, and consistency verification.

3.1.1 AHP methodology

In particular it is based on the three following principles (T. L. Saaty, 2000):

(1) The experts define the elements of the problem (i.e. decision criteria) and arrange them in the form of a hierarchy of objectives with parent elements in a given level connected to their children elements in a level below. The top level of the hierarchy represents the goal of the problem, while the bottom level contains the alternatives that can be chosen to maximize the objective. The first and the last level are connected through a series of intermediate levels, which represent the sub-criteria and other concerns in which the goal is decomposed.

(2) The experts assess (i.e. weight) the relative importance of criteria, sub-criteria and alternatives with respect to the elements in the higher level to which they are connected.

(3) All the judgments throughout the structure are used to derive corresponding priority scales that are then synthesized to determine the overall priorities of the alternatives.

The experts express their judgments in the form of comparisons between two elements (of the same level of the hierarchy) using the fundamental scale of absolute numbers (T. L. Saaty, 2005) (that will be described in the next point).

3.1.2 The Fundamental Scale

When are used judgment to estimate dominance in making comparisons, and in particular when the criterion of the comparisons is an intangible, instead of using two numbers w_i and w_j from a scale (if we must rather than interpreting the significance of their ratio wi/wj) we assign a single number drawn from the fundamental 1-9 scale of absolute numbers shown in Table 3.1 to represent the ratio $(w_i/w_j)/1$. It is a nearest integer approximation to the ratio w_i/w_j. The derived scale will reveal what the w_i and w_j are. This is a central fact about the relative measurement approach and the need for a fundamental scale. This scale is derived from basic principles involving the generalization of comparisons to the continuous case, obtaining a functional equation as a necessary condition and then solving that equation in the real and complex domains (T. L. Saaty, 2008).

Table 3.1 The Fundamental Scale of Absolute Numbers (T. L. Saaty, 2008).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
1.1 – 1.9	When activities are very close a decimal is added to 1 to show their difference as appropriate	A better alternative way to assigning the small decimals is to compare two close activities with other widely contrasting ones, favoring the larger one a little over the smaller one when using the 1 – 9 values
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A logical assumption
Measurements from ratio scales		When it is desired to use such numbers in physical applications. Alternatively, often one estimates the ratios of such magnitudes by using judgment

(T. L. Saaty, 2008) has assumed that an element with weight zero is eliminated from comparison because zero can be applied to the whole universe of factors not included in the discussion. Reciprocals of all scaled ratios that are >= 1 are entered in the transpose positions (T. L. Saaty, 2008).

The comparisons are made on homogeneous elements that are close so the judgments would not be wild guesses. If they are not homogeneous, they are carefully selected to go into groups or clusters with a common element from one group to the next (Zammori, 2009).

For example, if A_1 is a decision criterion and A_{11} and A_{12} are two of its sub-criteria, the experts must assess the relative importance of A_{11} over A_{12} by answering the following question: "with respect to A_1, how much more important is A_{11} than A_{12}?" The assessment is made using an integer value from the scale unless A_{12} dominates A_{11}, in which case the integer is used for this comparison and its reciprocal value is used for the first comparison (Zammori, 2009). Using this process, which is called a "pairwise comparison" it is possible to improve the quality of the judgments because it is easier to concentrate on just two factors at one time and to provide a comparative value from the scale than a number off the top of one's head (Zammori, 2009).

To derive priorities, all possible pairwise comparisons on the children of each parent with respect to the common property it represents should be made. It is worth noting that it is possible to reduce the number of questions that must be answered by means of short cuts, yet this approach is not advisable because it can decrease the validity of the results obtained. The criteria are pairwise compared with respect to the goal, the sub-criteria with respect to each parent criterion, and the decision alternatives with respect to the last level of sub-criteria above them (Zammori, 2009).

To derive the weights of the elements of the hierarchy, each time a set of children nodes (i.e. sub-criteria) are pairwise compared with respect to a parent node, all the relative judgments must be arranged in a reciprocal comparison matrix A = (a_{ij}) where the generic *ijth* cell contains the value of the comparison of the *ith* element with respect to the *jth* one. Therefore all the elements along the diagonal are equal to one, while a generic element *aij* is greater than one if the *ith* elements is dominant over the *jth* one and is less than one otherwise. Furthermore, due to the reciprocity of the comparisons, the value of the a_{ji} elements must be equal to $1/a_{ij}$ (Zammori, 2009).

Fig. 3.1 shows an example of a AHP model (Zammori, 2009). This model was developed to predict the outcome of the most likely nominee for the Democratic party, by comparing Senator H. Clinton with Senator B. Obama in 2008 United States presidential election. After this process, the AHP was applied by comparing the Democratic winner with Senator J. McCain of the Republican party.

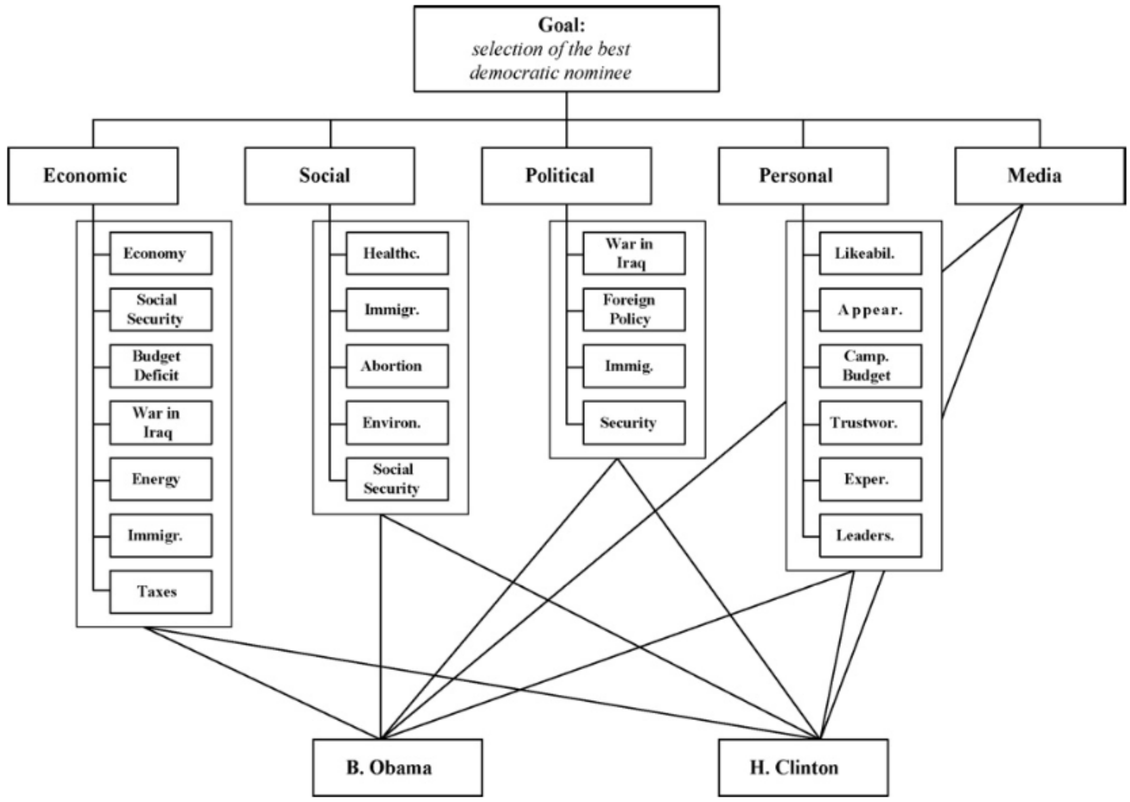


Figure 3.1 – The AHP model for the selection of the Democratic Nominee (Zammori, 2009).

In particular, the hierarchy shown in Fig. 3.1 was developed to synthesize all the interactions in a logical way that captures the priorities and preferences of the voters (Zammori, 2009).

3.2 Analytical Network Process (ANP)

The Analytic Network Process (ANP) is a multi-criteria approach [introduced by (Thomas L. Saaty, 2001)] that generalizes the AHP without making assumptions about the independence of higher elements from lower level elements in a hierarchy or about the independence of elements in the same level (as required in AHP). The difference between the two approaches is that while the AHP decomposes a problem into several levels in the form of a hierarchy of independent elements, the ANP replaces hierarchies with networks and makes it possible to structure a decision in the most general way conceivable (T. L. Saaty, 2005). The ANP captures the outcome of dependence and feedback between components of elements (Thomas L. Saaty, 2001). The ANP suggests a structured procedure where all relationships (influences) between the alternatives are assessed and synthesized into an overall outcome (Asan & Soyer, 2009). We apply ANP when we deal with complex interactions and indirect relationships existing between the elements of our problem. According to (T. L. Saaty, 2008), the ANP is our logical way to deal with dependence. To him, a hierarchy is a special case of network with connections going only in one direction.

A network has clusters of elements, with the elements in one cluster being connected to elements in another cluster (outer dependence) or the same cluster (inner dependence) (T. L. Saaty, 2008). The structural difference between a hierarchy and a network is illustrated in Fig. 3.2.

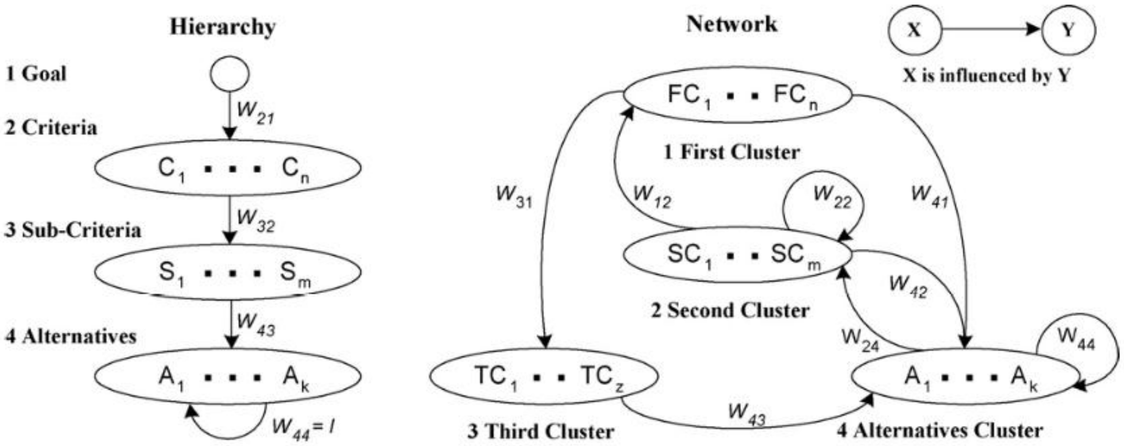


Figure 3.2 Comparison of a hierarchy with a network (Zammori, 2009).

As can be seen from Fig. 3.2, a hierarchy is a linear top down structure with no feedback from bottom to top levels. It is characterized by a goal cluster at the top and an alternatives cluster at the bottom Note that in Fig. 3.2, there is a loop in the bottom level of the hierarchy to indicate in a formal way that each element of that level depends only on itself (i.e. nodes are independent). A network does not require a strictly hierarchy organization for its clusters and can spread in any direction. In this way influences and inner dependencies can be transmitted from a cluster to another either directly or through one of the paths of the network (Zammori, 2009).

The components of the systems are represented as nodes, and two nodes are connected by an arrow if there is interaction between them. The orientation of an arrow shows the direction of the influences (i.e. interaction) between nodes (Zammori, 2009). As it seen from Fig. 3.2, $X \rightarrow Y$ means that the elements of a component Y depends on component X (Yu & Cheng, 2007) Loops denote inner dependencies among nodes of the same cluster. The strength of the dependencies is given by W_{ij}, which is a matrix containing numerical entries of the priorities of the strengths of influences of the *ith* cluster nodes on the elements of the *jth* cluster (Zammori, 2009).

According to (Zammori, 2009), the structure of a network is determined by its clusters, its nodes (i.e. elements) and the connections between them. Clusters contain elements that share common attributes and can be considered to be similar in some regard.

Connections represent the interdependency of two nodes and the arrow direction shows in which directions the influences flows. Thus, in an ANP network, two clusters are connected by an arrow when least one element in the first cluster is connected to one or more elements in the second cluster (Zammori, 2009). Fig. 3.3 illustrates an ANP model developed by (Gencer &

Guerpinar, 2007), where they consider supplier selection as a multi criteria decision problem. The proposed model of supplier selection was implemented in an electronic company.

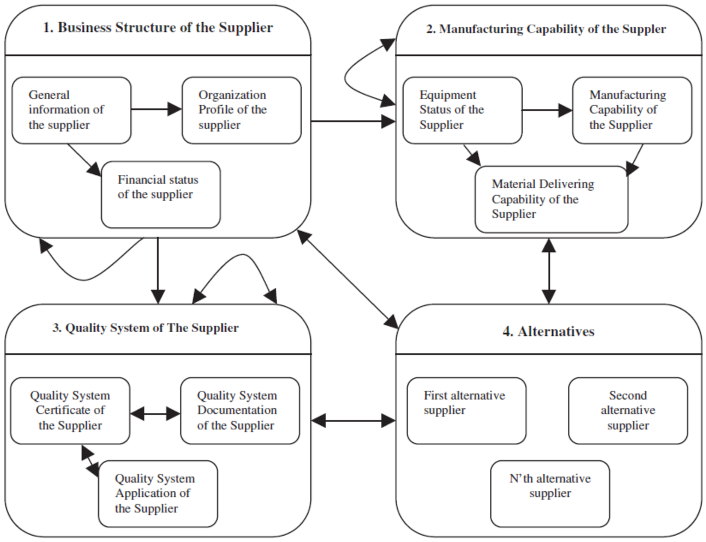


Figure 3.3 - An example of ANP model (Gencer & Guerpinar, 2007)

3.2.1 Outline of Steps of the ANP

To develop an ANP model we can follow a set of steps pointed by (T. L. Saaty, 2008). These steps may not be always followed rigorously, each decision makers can adapt to this problem. The steps are:

(1) Describe the decision problem in detail including its objectives, criteria and sub-criteria, actors and their objectives and the possible outcomes of that decision. Give details of influences that determine how that decision may come out.

(2) Determine the control criteria and sub-criteria in the four control hierarchies one each for the benefits, opportunities, costs and risks of that decision and obtain their priorities from paired comparisons matrices. If a control criterion or sub-criterion has a global priority of 3% or less, you may consider carefully eliminating it from further consideration. The software automatically deals only with those criteria or sub-criteria that have subnets under them. For benefits and opportunities, ask what gives the most benefits or presents the greatest opportunity to influence fulfillment of that control criterion. For costs and risks, ask what incurs the most cost or faces the greatest risk. Sometimes (very rarely), the comparisons are made simply in terms of benefits, opportunities, costs, and risks in the aggregate without using control criteria and sub-criteria.

(3) Determine the most general network of clusters (or components) and their elements that apply to all the control criteria. To better organize the development of the model as well as you can, number and arrange the clusters and their elements in a convenient

way (perhaps in a column). Use the identical label to represent the same cluster and the same elements for all the control criteria.

(4) For each control criterion or sub-criterion, determine the clusters of the general feedback system with their elements and connect them according to their outer and inner dependence influences. An arrow is drawn from a cluster to any cluster whose elements influence it.

(5) Determine the approach you want to follow in the analysis of each cluster or element, influencing (the preferred approach) other clusters and elements with respect to a criterion, or being influenced by other clusters and elements. The sense (being influenced or influencing) must apply to all the criteria for the four control hierarchies for the entire decision.

(6) For each control criterion, construct the super-matrix by laying out the clusters in the order they are numbered and all the elements in each cluster both vertically on the left and horizontally at the top. Enter in the appropriate position the priorities derived from the paired comparisons as sub-columns of the corresponding column of the super-matrix.

(7) Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to (outer dependence) or on elements in their own cluster (inner dependence). In making comparisons, you must always have a criterion in mind. Comparisons of elements according to which element influences a given element more and how strongly more than another element it is compared with are made with a control criterion or sub-criterion of the control hierarchy in mind.

(8) Perform paired comparisons on the clusters as they influence each cluster to which they are connected with respect to the given control criterion. The derived weights are used to weight the elements of the corresponding column blocks of the super-matrix. Assign a zero when there is no influence. Thus obtain the weighted column stochastic super-matrix.

(9) Compute the limit priorities of the stochastic super-matrix according to whether it is irreducible (primitive or imprimitive [cyclic]) or it is reducible with one being a simple or a multiple root and whether the system is cyclic or not. Two kinds of outcomes are possible. In the first all the columns of the matrix are identical and each gives the relative priorities of the elements from which the priorities of the elements in each cluster are normalized to one. In the second the limit cycles in blocks and the different limits are summed and averaged and again normalized to one for each cluster. Although the priority vectors are entered in the super-matrix in normalized form, the limit priorities are put in idealized form because the control criteria do not depend on the alternatives.

3.3 Additional considerations of AHP and ANP

ANP is a comprehensive decision-making technique that has the capability to include all the relevant criteria, which have some bearing, in arriving at a decision. AHP serves as the starting point of ANP (Thomas L. Saaty, 2001). Generally speaking, the ANP is more accurate and gives better results than the AHP (Zammori, 2009). Moreover, the ANP provides a general framework to deal with decisions without making assumptions about the independence of higher level elements from lower level elements, i.e., the ANP makes possible to deal with all kinds of dependence and feedback in a decision system (Bayazit, 2006; Zammori, 2009). Therefore, anytime there are dependences between criteria and/or alternatives, if one tries to model the problem as a linear hierarchy, the risk of getting an inconsistent result (i.e. an unsound ranking) is considerably high (Zammori, 2009).

According to (Zammori, 2009), turning a hierarchy in a network (in order to capture the most number of possible influences between factors), significantly increases the complexity of the model. An example is provided by Saaty in this work (T. L. Saaty, 1999), where a hierarchy is converted into a network and it is shown that the number of judgments increases from 79 to 624. Another disadvantage of the ANP is that the comprehension of a network is not as intuitive as that of a linear hierarchy. In other words, when the problem is structured in a hierarchy of decision criteria the flow of influence is clear, as it proceeds outright from the top level (i.e. the goal of the problem) to the bottom level (i.e. the alternatives) moving through a series of intermediate levels , which represent the sub-criteria in which the goal is decomposed. The same is not true for a network, for in this case there is not an origin and neither an end, and the relative influences between clusters and/or node are confounded and less detectable. Thus, making pairwise comparisons becomes more difficult and requires a deeper understanding of how the network has been built. As a consequence, whether the AHP permits one to develop the model before presenting it to a panel of experts (to gather the necessary judgments and for validation purposes), in the case of the ANP these two steps (i.e. building and validation) cannot be easily detached, and it is advisable to involve the experts from the very beginning of the development of the network (Zammori, 2009).

(T. L. Saaty, 2008), cite five types of criticisms of the AHP. One is the concern with illegitimate changes in the ranks of the alternatives, called rank reversal, upon changing the structure of the decision. It was believed that rank reversal is legitimate only when criteria or priorities of criteria or changes in judgments are made. The second concern is about inconsistent and their effect on aggregating such judgments or on deriving priorities from them. The third criticism has to do with attempts to preserve rank from irrelevant alternatives by combining the comparison judgments of a single individual using the geometric mean (logarithmic least squares) to derive priorities and also combining the derived priorities on different criteria by using multiplicative weighting synthesis. The fourth criticism has to do which people trying to change the fundamental scale despite the fact that it is theoretically derived and tested by comparing it with numerous other scales on a multiplicity of examples for which the answer was known. The fifth and final criticism has to do with whether or not the pairwise comparisons axioms are behavioral and spontaneous in nature to provide judgments.

Interestingly, the AHP/ANP provides a way to make complex decisions in the most general structures encountered in real life (T. L. Saaty, 2008). AHP should be used instead of the ANP whenever there are not evident dependencies between decision elements (or one can assume that such mutual influences are negligible) and when the problem can be soundly structured in the form of a linear hierarchy (Zammori, 2009).

Both AHP and ANP have been used separately or in conjunction with fuzzy in different areas, such as: management, manufacturing, industry, political, government, personal decision making, social, education, sports, tourism, service, military, etc. The pairwise comparison is done using the same fundamental comparison scale (1 – 9).

3.2 Some applications of AHP/ANP

Research articles	Contributions	Applications	Specific areas
(Zammori, 2009)	The analytic hierarchy and network processes: Applications to the US presidential election and to the market share of ski equipment in Italy	Politics/Marketing	Presidential election/market share
(Asan & Soyer, 2009)	Identifying strategic management concepts: An analytic network process approach	SCM	Strategic management concepts
(Sagir & Ozturk, 2010)	Exam scheduling: Mathematical modeling and parameter estimation with the Analytic Network Process approach	Educational systems	Exam scheduling
(Aragones-Beltran, Aznar, Ferris-Onate, & Garcia-Melon, 2008)	Valuation of urban industrial land: An analytic network process approach	Engineering	Industrial land
(Jharkharia & Shankar, 2007)	Selection of logistics service provider: An analytic network process (ANP) approach	Logistics	Service provider selection
(A. Agarwal et al., 2006)	Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach	SCM	Metrics modeling
(Gencer & Guerpinar, 2007)	Analytic network process in supplier selection: A case study in an electronic firm	Logistics	Supplier selection
(Yuksel & Dagdeviren, 2007)	Using the analytic network process (ANP) in a SWOT analysis – A case study for a textile firm	Marketing	SWOT analysis
(C. W. Chang, Wu, & Chen, 2009)	Analytic network process decision-making to assess slicing machine in terms of precision and control wafer quality	Quality	Control quality
(Z. H. Yang & Zhang, 2006)	Environmental performance measurement for green supply chain: An ANP-based approach	GSCM	Green performance measurement
(Troutt & Tadisina, 1992)	The Analytic Hierarchy Process as a model base for a merit salary recommendation system	General	Salary processing

3.4 Fuzzy set theory

In most of the real-world problems, some of the decision data can be precisely assessed while others cannot (Özdagoglu & Özdagoglu, 2007). Fuzzy logic/ fuzzy set theory has been introduced by Zadeh in 1965, when he extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms.

Unlike two-valued conventional (Boolean) logic, fuzzy logic is multi-valued. It deals with degrees of membership degrees of truth. Fuzzy logic uses the continuum of logical values between 0 and 1. Instead of just black and white, it employs the spectrum of colors, accepting that things can be partly true and partly false at the same time. In other words, fuzzy logic is a superset of Boolean logic that has been extended to handle the concept of partial truth-values between completely true and completely false (Bezdek, 1993).

Two major different kinds of uncertainties that exist in the real life, ambiguity and vagueness, are addressed by fuzzy logic. While ambiguity is associated with one to many relations, that is, situations in which the choice between two or more alternatives is left unspecified, vagueness is associated with the difficulty of making sharp or precise distinctions in the world; that is, some domain of interest is vague if it cannot be delimited by sharp boundaries (Inuiguchi & Ramik, 2000).

From the modeling point of view, fuzzy models and statistical models also possess philosophically different kinds of information: fuzzy memberships represent similarities of objects to imprecisely defined properties, while probabilities convey information about relative frequencies. Thus, fuzziness deals with deterministic plausibility and not nondeterministic probability (Topaloglu & Selim, 2010).

Fuzzy set theory has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specially designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many decision problems. Fuzzy set theory implements classes and grouping of data with boundaries that are not sharply defined (i.e. fuzzy). The major contribution of fuzzy set theory is its capability of representing vague data (Chan, Kumar, Tiwari, Lau, & Choy, 2008).

In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of these linguistics can be developed as quantitative data, this type of data set is then refined by the evaluation methods of fuzzy set theory (Özdagoglu & Özdagoglu, 2007).

According to (Chan et al., 2008), the fuzzy set is characterized by a membership function, which assigns to each object a grade of membership ranging between 0 and 1. In this set the general terms such as “large”, “medium” and “small” each will be used to capture a range of numerical values (Chan et al., 2008).

3.5 Fuzzy AHP

Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting (Kulak & Kahraman, 2005). Essentially, the uncertainty in the preference judgments gives rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences (Leung & Cao, 2000).

Basically Fuzzy AHP (FAHP) is the fuzzy form of AHP. It has the ability to extract the merits of both approaches to efficiently and effectively tackle the multi-attribute decision making problems (global supplier selection: a Fuzzy-AHP approach). The Fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP (Özdagoglu & Özdagoglu, 2007).

The AHP is one of the extensively used multi-criterion decision making methods but it has been generally criticized because of the use of a discrete scale of one to nine which cannot handle the uncertainty and ambiguity present in deciding the priorities of different attributes (Chan et al., 2008). That is the reason that many authors suggest the use Fuzzy AHP to solve this limitation and other suggest no application of fuzzy in AHP because they consider that the AHP is too vague and ambiguous. Table 3.3 shows some recent applications of Fuzzy AHP.

3.3 Some applications of Fuzzy AHP.

Research articles	Contributions	Applications	Specific areas
(Chan et al., 2008)	Global supplier selection: a fuzzy-AHP approach	Logistics	Supplier selection
(Srdjevic & Medeiros, 2008)	Fuzzy AHP Assessment of Water Management Plans	Water distribution	Water Management
(Cebeci & Kilinc, 2007)	Selecting RFID Systems for Glass Industry by Using Fuzzy AHP Approach	Glass Industry	System RFID
(Karimi, Mehrdadi, Hashemian, Bidhendi, & Moghaddam, 2011)	Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods	Environmental management	Wastewater treatment
(Kilincci & Onal)	Fuzzy AHP approach for supplier selection in a washing machine company	Logistics	Supplier selection

3.6 Fuzzy ANP

If all the attributes and alternatives are connected in a framework that involves interactions and dependencies at various levels, the need for a holistic approach like ANP is essential. The characteristics of conventional ANP include the pairwise comparisons at each level using a nine-point Saaty scale (Guneri, Cengiz, & Seker, 2009). Some of the disadvantages of conventional ANP include crisp decision making, unbalanced judgment scale, imprecise ranking and subjective judgment. In order to overcome the vagueness and uncertainty associated with the judgment of decision makers and to overcome the crisp pairwise comparisons, techniques like Fuzzy ANP (FANP) are preferred (Vinodh, Gautham, Ramiya, & Rajanayagam, 2010). Due to the vagueness and uncertain decision making with conventional ANP, the concept of Fuzzy ANP is found to be advantageous. Fuzzy ANP replaces the hierarchies into a network structure, in which all elements are interlinked (Y. H. Chang, Wey, & Tseng, 2009).

3.4 Some applications of Fuzzy ANP.

Research articles	Contributions	Applications	Specific areas
(Vinodh et al., 2010)	Application of fuzzy ANP for agile concept selection in a manufacturing organization	SCM	Agile concept selection
(Vinodh, Ramiya, & Gautham, 2011)	Application of fuzzy analytic network process for supplier selection in a manufacturing organisation	Logistics	Supplier selection
(Guneri et al., 2009)	A fuzzy ANP approach to shipyard location selection	Logistics	Location selection
(Tuzkaya & Onut, 2008)	A fuzzy analytic network process based approach to transportation-mode selection between Turkey and Germany: A case study	Logistics	Transportation programing
(Özgen & Tanyas, 2011)	Joint selection of customs broker agencies and international road transportation firms by a fuzzy analytic network process approach	Logistics	Transportation

Chapter 4 Information System Modeling Techniques

Requirements capture is arguably the most important step in software engineering, and yet the most difficult and the least formalized one (Mili et al., 2010). Enterprises build information systems to support their business processes. Software engineering research has typically focused on the development process, starting with user requirements – if that- with business modeling confused with software system modeling (Isoda, 2001). Researches and practitioners in management information systems, have long recognized that understanding the business processes that an information system must support is key to eliciting the needs of its users [see e. g., (Eriksson & Penker, 2000)] but lacked of tools to model such business process or to relate such models to software requirements (Mili et al., 2010).

4.1 Information sharing

Prior to the 1980s, a significant portion of the information flows between functional areas within an organization, and between supply chain member organizations, were paper-based In many instances, these paper-based transactions and communications were slow, unreliable, and error prone. Conducting business in this manner is costly because it decreases firm's effectiveness in being able to design, develop, procure, manufacture, and distribute their products (Handfield & Nichols, 1998). Companies historically have considered information an asset to be hoarded and protected, rather than shared. Sharing information with suppliers, for examples, weakens negotiating positions (Groznik & Maslaric, 2010). Effective information sharing means that you no longer have to own all the pieces of the supply chain to effectively operate as a single entity (Sturim, 1999).

Information sharing is a key ingredient for any SCM system (Moberg, Cutler, Gross, & Speh, 2002). By taking the data available and sharing it with other parties within the supply chain, an organization can speed up the information flow in the supply chain, improve the efficiency and effectiveness of the chain, and respond to customer changing needs quicker. Therefore, information sharing will bring the organization competitive advantage in the long run (Groznik & Maslaric, 2010). Information should be readily available to all companies in supply chains and the business process should be structured so as to allow the full use of this information (Trkman, Stemberger, Jaklic, & Groznik, 2007). The information systems and the technologies utilized in these systems represent one of the fundamental elements that "link" the organizations of a supply chain into a unified and coordinated system (Handfield & Nichols, 1998).

The bullwhip effect, for example, is a consequence of lack or distorted information in the supply chain. According to (Lee, Padmanabhan, & Whang, 1997), distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies: excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules.

4.2 Business Process Modeling Languages

4.2.1 What is a Business Process

Business processes are at the core of today's business world. Most of the effort put into business processes in practice is either the task of designing a new process or the task of analyzing and improving an existing process. In both cases, visualizations of the process models support the user in achieving his objectives (Effinger, Siebenhaller, & Kaufmann, 2009). The world "process" is defined in the dictionary as "a series of actions, changes, or functions bringing a result" (Mili et al., 2010). (Curtis, Kellner, & Over, 1992) defined a process as a partially ordered set of tasks or steps undertaken towards a specific goal. (Hammer & Champy, 1993) define business processes as a set of activities that, together, produce a result of value to the customer. The workflow management coalition defines business process as "a set of one or more linked procedures or activities which collectively realize a business objective or policy goal, normally within the context of an organizational structure defining functional roles and relationships (Coalition, 1999).

4.2.2 Why Business Processes

In traditional view, a business is considered a hierarchical organization that reflects both the functional decomposition of the enterprise and the chain of command (Mili et al., 2010). Different departments specialize in specific business functions (e.g., marketing or production or accounting), and within each department, sub departments, teams, and individuals specialize in sub functions. The processing of a customer order generally cross the boundaries of various departments: sales (to take the order), planning (to plan the manufacture of the product or the replenishment of the inventory), production, shipping, and accounting (Mili et al., 2010). When we talk about "business process modeling", we must identify which processes we are interested in, at what level of detail, and what are the relationships between these processes, if any (Mili et al., 2010).

Assume that a company aims at increasing its market share for its products. There are several ways to achieve this goal, including product innovation, competitive pricing, targeted marketing, building customer loyalty, responsive customer service, and so on (Mili et al., 2010).

According to (Ould, 1995), business process modeling is useful for three basic reasons, which may in turn support several business goals.

(1) *Describing a process*. We model a process to be able to describe it. We could have different target audiences for these descriptions, for instance, humans, in which case understandability is important (Curtis et al., 1992), or machines, in which case formality is important (Mili et al., 2010).

(2) *Analyzing a process*. Simply put, process analysis consists of assessing the properties of a process. Process reengineering and improvement relies on an analysis of existing processes to identify redundant or suboptimal steps. If the process is described

formally, we can verify mechanically structural properties such as coupling and cohesion (Phalp & Shepperd, 2000) or dynamic properties such as the absence of deadlock, liveness properties, and so on (Mili et al., 2010).

(3) *Enacting a process.* We may enact a process for simulation purpose or to provide some level of support for process execution. Depending on the language, this support can take different forms: reacting to events triggered by the execution of the process, checking that specific constraints are satisfied, or driving the execution of the process (Curtis et al., 1992). Only formal languages make process enactment possible. Language designers may put the emphasis on one of these basic usages, often at the expense of others (Mili et al., 2010).

Because business processes are complex, language designers generally provide different modeling views, each focusing on one aspect of the process. Curtis identified four views, summarized here (Curtis et al., 1992):

(1) The functional view presents the functional dependencies between the process elements (activities, sub processes, etc.). These dependencies are typically embodied in the fact that some process elements consume (or need) data (or resources) produced by others. Typical notations used in the functional view include data flow diagrams.

(2) The dynamic (behavioral) view provides sequencing and control information about process, that is, when certain activities are performed (timing, pre-conditions) and how they are performed (e.g., by describing the control logic).

(3) The informational view includes the description of the entities that are produced, consumed, or otherwise manipulated by the process. These entities include pure data, artifacts, and products.

(4) The organizational view describes who performs each task or function, and where in the organization (functionally and physically).

4.2.3 Business Process Modeling Notation (BPMN)

Business Process Model (BPM) can be expressed in several different notations, one of the most important being Business Process Modeling Notation (Delgado, García-Rodríguez de Guzmán, Ruiz, & Piattini, 2010). Is an important tool for understanding the activities and information which are typically used to achieve business goals. So far it is a popular way of describing and improving business process. The aim of the business process modeling in the phase of analysis is to understand processes in a domain (Macek & Richta, 2009). BPMN is a notation for representing business. BPMN focuses on the dynamic aspects of business processes; it covers neither the functional view, the information view, nor the organizational view. Because its primary goal is human understanding, it is not executable. With BPMN, business processes are represented in business process diagrams (BPD). However, the standard does not specify an exchange format for BPMN diagrams (Mili et al., 2010). The execution of business processes usually involves expanding several actions or areas in single or even different organizations (Delgado et al., 2010).

Business process modeling is used to communicate a wide variety of information to a wide of audiences. BPMN is designed to cover many types of modeling and allows the creation of end-to-end business process. The structural elements of BPMN will allow the viewer to be able to easily differentiate between sections of a BPMN diagram. There are three basic types of sub-models within an end-to-end BPMN model [((OMG), January 2011)and (Mili et al., 2010)].

(1) *Private (internal) business processes*. These are the processes that are internal to an organization, and which may typically be implemented by a workflow management system;

(2) *Abstract (public) business processes.* This type of model represents interaction points between a process that is internal to an organization (private business process) and the outside world (another process or participant); it shows the public interface of an internal process in terms of the message(s) that trigger it, and the subsequent message exchanges between the outside world and the internal process; abstract processes are contained within a pool and can be modeled separately or within a larger BPMN diagram to show the message flow between the abstract process activities and other entities.

(3) *Collaboration (global) processes.* Such processes describe the interaction between two or more business entities, each of which has its own internal process. These interactions are defined as a sequence of activities that represent the message exchange patterns between the entities involved.

(Mili et al., 2010) illustrates the three kinds of models through a simple purchasing process example. Fig. 4.1 shows an example of a private business process occurring within an organization. A “user” needs some product – the start event. He or she fills out an order request, which goes to purchasing. Purchasing turns around and creates a “Request for Quotation” that it sends to a number of suppliers. After the suppliers respond, it selects a supplier, and then sends them a Purchasing Order (PO). When the product arrives, purchasing receives the product (ascertains that it is received in good condition), and forwards the invoice to accounts payable who pay the invoice. The arrows between the tasks are control sequences. The tasks were separated into swimlanes, one per role in the process. Here, we have three functional roles: the “User” who needs the product; the “Purchasing Department” which turns that need into a PO dent to a supplier for a specific product; and “Accounts Payable” which pays the bill (Mili et al., 2010).

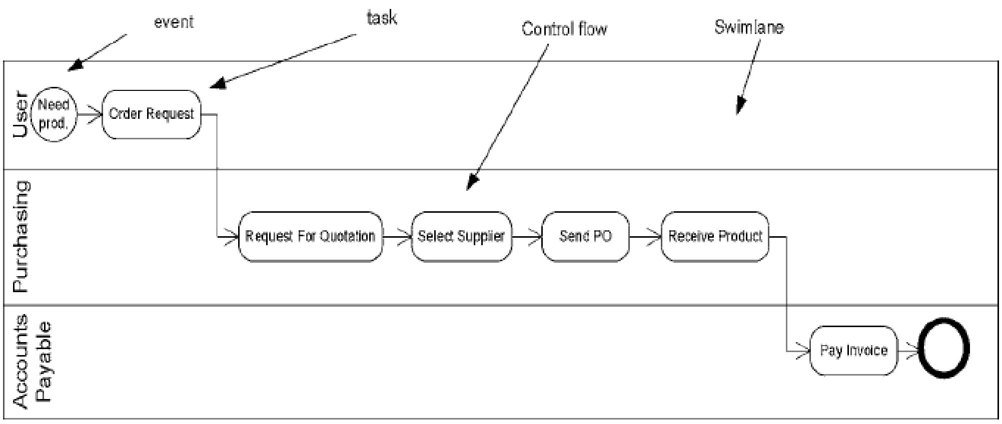


Figure 4.1 – A private business process using BPMN notations (Mili et al., 2010).

Fig. 4.2 shows the corresponding public process. Here, the focus is in the message exchanged with the outside world – in this case, the selected supplier. Only those tasks that send or receive messages are shown in the diagram (Mili et al., 2010).

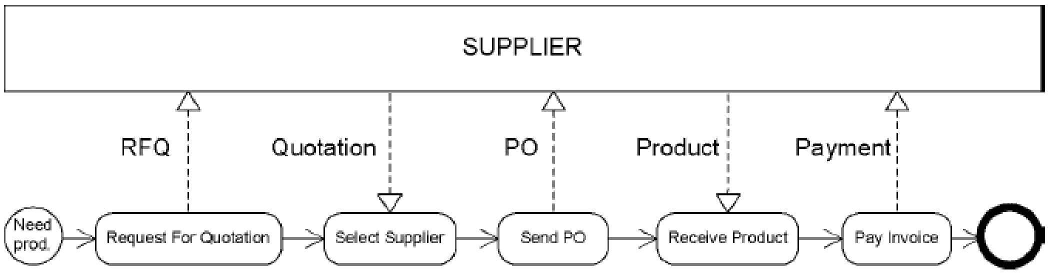


Figure 4.2 – The abstract public purchasing process (Mili et al., 2010).

A collaboration process is one involving two or more partners that show the messages exchanged between them to accomplish a joint goal. Collaboration processes involve the abstract public processes of the partners. Fig. 4.3 shows a collaboration process involving a buyer and a supplier. The difference between Fig. 4.2 and 4.3 is that is showed what happens on the supplier side this time. The difference between these kinds of processes is helpful to understand the relationships between the different standards in this space (Mili et al., 2010).

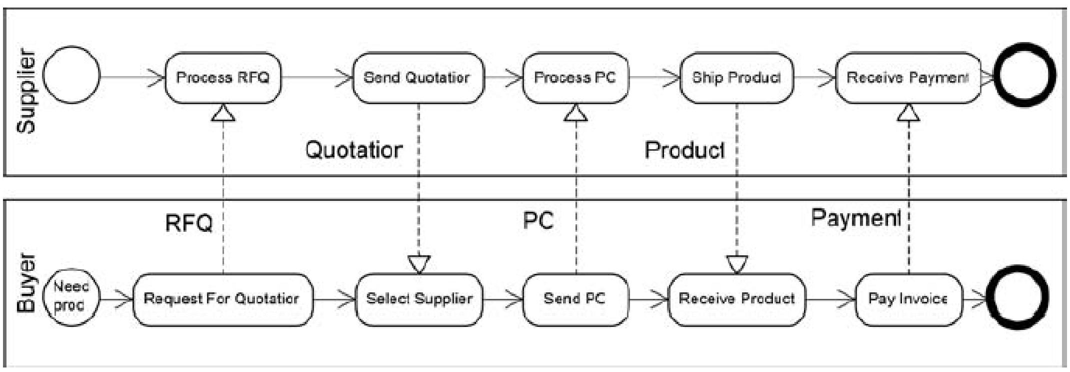


Figure 4.3 – The collaboration process (Mili et al., 2010).

4.2.4 Business Process Diagram (BPD)

BPMN provides a set of notations for modeling business processes. The four main groups defined in the standard are: flow objects, which are events, activities, decision/union nodes (split, join); connecting objects, which are sequences, messages and associations; swimlanes (pool, lanes) and artifacts (data, annotation, groups) (Delgado et al., 2010). Among the most important elements are flow objects, e.g. activities, events and gateways. The flow objects are connected by connecting objects, e.g. sequence flows or message flows. Additionally, BPMN models are structured by assigning flow objects to swimlanes and by adding artifacts, e.g. annotations, to connecting objects or flow objects (Effinger et al., 2009). A pool represents a process participant which is a business entity (enterprise, section) or a business role (seller, buyer), and a lane in a pool is a sub-partition used to organize activities (Delgado et al., 2010). For example, when we are modeling supply chain business process, the pool can be ever entity in the chain (Retailer, Distributor, Manufacturer, supplier) and the lane the departments of each entity (Sales, Marketing, Accounting, Production, Quality Control, Logistics, etc.).

(Hernández, Álvarez Rodríguez, & Martin, 2010) based on the Object Management Group (OMG) BPMN presented the following definitions for the notation elements:

i. *Event* – is something that "happens" during the execution of a business process. In order for an event to "happen" there must be a cause (Trigger), as a consequence there is an impact (Result). The event can be start, intermediate and end.
   - *Start* – indicates the starting point of a BPD. For example, in supply chain, the process can start with customer demand.
   - *Intermediate* – occur between a Start Event and an End Event. They will affect the flow of the process, but will not start or (directly) terminate the process ((OMG), January 2011).
   - *End* – indicates the end of a BPD, and they are usually triggered when the last step of the process has been completed.

ii. *Activity* – is a work that is performed within a BPD, it is carried out by a role (actor). An activity can be atomic (task) or non-atomic (sub-process).
   - *Task (atomic)* – is a work carried out by an actor in order to achieve an objective.
   - *Sub-process (Non-atomic)* – represents a set of activities (atomic tasks or other sub-processes), gateways, and its sequence flow.

iii. *Sequence flow* – shows the order of execution of activities within a business process, from start to end.

iv. *Gateway* – depicts the control of divergence and convergence of the sequence flow of the elements in a BPD. Can be parallel (AND), exclusive (XOR), inclusive (OR) or complex.
   - *Parallel* – represents the flow of parallel paths for the elements within a business process without checking any conditions.

- *Exclusive* – represents alternative flows of the elements within a BPD. For a given element of a BPD only one of the paths can be taken. A decision can be thought as a question that is asked at a particular point in the BPD.
- *Inclusive* – represents a branching point where alternatives are based on conditional expressions contained within outgoing sequence flow. However, in this case, the True evaluation of one condition expression does not exclude the evaluation of other condition expressions ((OMG), January 2011).

Fig. 4.4 illustrates the main relationship between core modeling elements in BPMN. To do it, (Rodriguez, Fernandez-Medina, & Piattini, 2007) have created the class know as Business Process Diagram (BPD) that allows to relate all BPD elements used to represent a specific business process. Table 4.1 present and describes a set of elements in which the Business Process Diagram (BPD) are based.

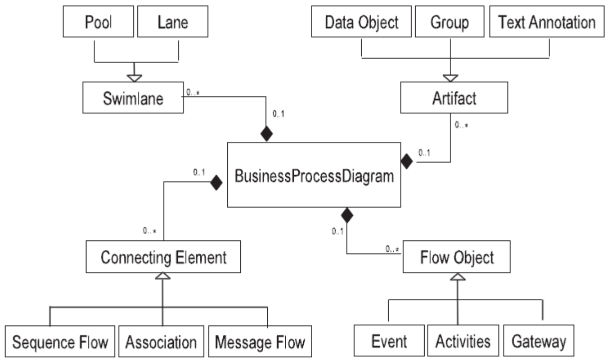
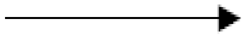
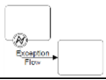
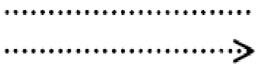
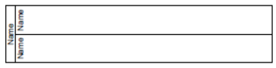
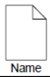
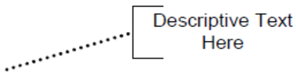


Figure 4.4 – Business process diagrams core elements (Rodriguez et al., 2007).

Table 4.1 Elements of a BPD.

Categorie	**Element**	**Type**	**Representation**
Flow Objects	Events	Start	
		Intermediate	
		End	
	Activities	Task	
		Process	
		Sub-process	
	Gateways	Exclusive	or X

		Inclusive	
		Parallel	
		Complex	
Connecting Objects	Sequence Flow	Normal flow	
		Uncontrolled flow	
		Conditional flow	
		Default flow	
		Exception flow	
	Message Flow		
	Association		
Swimlanes	Pools		
	Lanes		
Airtfacts	Data Object		
	Group		
	Annotation		

There are many notation elements in BPMN. But we must be aware that the objective of Business Process Modeling is to provide a simple and adoptable model to business analysts. The BPD must to be simples, not complex, and logically representing reality. Most business process is modeled adequately with the elements showed in the Fig. 4.5. These elements help understand how BPMN can manage the potentially conflicting requirement that BPMN provide to depict complex business processes and map to BPM execution languages ((OMG), January 2011).

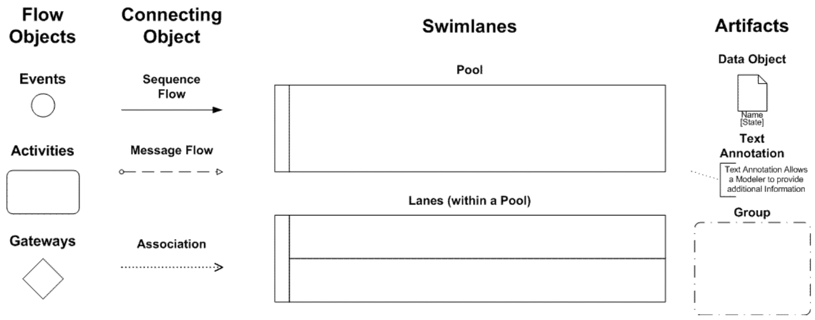


Figure 4.5 – core set BPMN elements (http://www.bpmn.org/Samples/Elements/Core_BPMN_Elements.htm - 28-02-2011)

4.3 Unified Modeling Language (UML)

Unified Modeling Language (UML) (Booch, Rumbaugh, & Jacobson, 1999a, 1999b) is a visual modeling language adopted as a standard for object-oriented modeling and design in software development by the industry body Object Management Group (OMG). It was created mainly based on three object modeling techniques and methods (Booch, 1994; Ivar Jacobson, Christerson, Jonsson, & Overgaard, 1992; Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991) that have been used in industry for many years (Liang, 2003). The UML standardizes the notations but it does not dictate how to apply the notations (T. A. Pender, 2002) . The UML includes specifications for nine different diagrams used to document various perspectives of a software solution from project inception to installation and maintenance. The Component and Deployment diagrams describe an implementation. The remaining seven diagrams are used to model requirements and design (T. A. Pender, 2002). One way to organize the UML diagrams is by using views. A view is a collection of diagrams that describe a similar aspect of the project. Fig. 4.6 illustrates the complementary nature of the three views and the diagrams that make up each view.

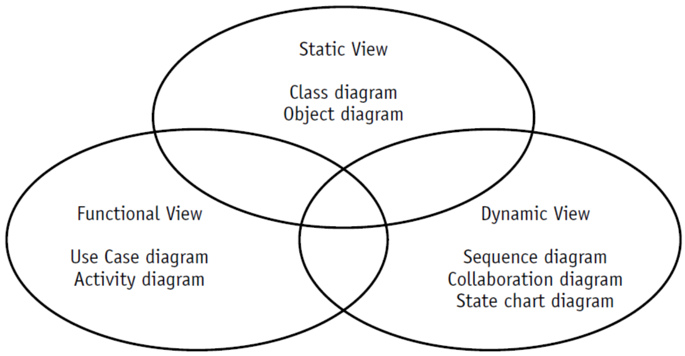


Figure 4.6 – Three complementary views or sets of UML diagrams (T. A. Pender, 2002).

To better understand this approach, Pender (T. A. Pender, 2002) gives an example based on the process of applying for a job. According to him, when we interview for a job, you can find out the job is about through a published description. A typical job description begins with a title and a brief definition of the job, usually in paragraph form. This would be the static part of the job description.

The job description is usually followed by a list of duties detailing what is expected of you in the performance of this job. We could think of the listed items as demands placed on us throughout the course of our job. This corresponds to the dynamic part of the job (T. A. Pender, 2002).

After getting job, there are often specific instructions on how to do our job (for example, policies and procedures to follow). These are the functional details of the job, for example, how to perform the job rather than what to perform (T. A. Pender, 2002).

In the Unified Modeling Language (UML), one of the key tools for behavior modeling is the Use Case Model, originated from the Object-Oriented Software Engineering (OOSE) (Almendros-Jimenez & Iribarne, 2005). In this research we just use the Use case Diagram and Class Diagram.

4.3.1 Software systems modeling

Software Systems Methodology is described classically as seven-stage process of analysis (Checkland, 1981), as summarized in Fig. 4.7. There are five stages associated with the so-called real world thinking: two of them for understanding and finding out about a problem station, and the other three for deriving change recommendations and taking actions to improve the problem situation. There are also two stages (below the dotted line) concerned with systems thinking, in which root definitions and conceptual models are developed. Each root definition provides a particular perspective of the system under investigation. A conceptual model defines activities necessary to achieve the perspective given in a root definition (Bustard, He, & Wilkie, 2000).

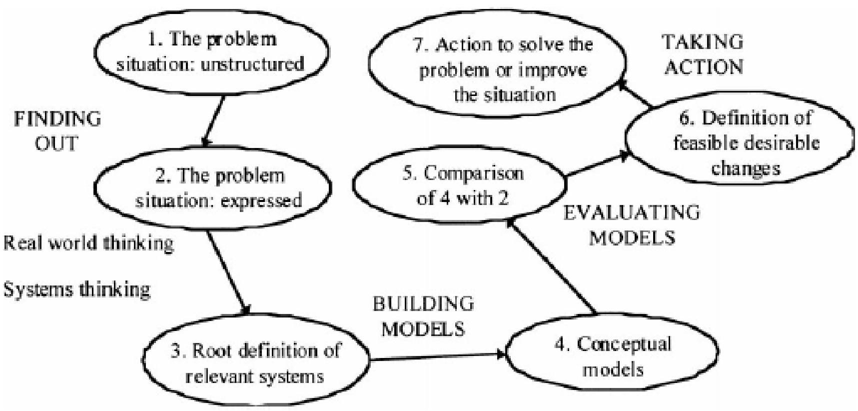


Figure 4.7 Checkland's seven-stage soft systems methodology (Bustard et al., 2000).

A root definition, in general, identifies or implies six particular pieces of information, as described in Table 4.2.

Table 4.2 – General components of a root definition (Bustard et al., 2000).

Components	Meaning
Customers	The beneficiaries or victims of a system
Actors	The agents who carry out, or cause to be carried out, the main activities of the system
Transformation	The process by which defined inputs are transformed into defined outputs
Weltanschauung	A viewpoint, framework, image or purpose, which makes a particular root definition meaningful
Owner	Those who own a system (have the power to close it down)
Environment	Influences external to a system that affect its operation

4.3.2 Use cases and Use cases Diagram

The functional requirements of a software system can be captured and documented in use cases, which determine the functional scope of the objects in the system (Anda & Sjoberg, 2005). Use case modeling was first presented as part of the Object-Oriented Software Engineering (OOSE) methodology for software development (Ivar Jacobson, Ericcson, & Jacobson, 1995). Use case modeling is concerned with system description. With use case modeling, however, there are several levels of system that might be considered. Use case analysis was developed initially for computing systems, but can also be applied to the information system within a business, or to the business itself (Bustard et al., 2000). Use cases are a fundamental starting point of object oriented analysis and design (Hilsbos, Song, & Choi, 2005).

The functional requirements of a software system can be captured and documented in use cases, which determine the functional scope of the objects in the system (Anda & Sjoberg, 2005). The key concepts associated with the use cases model are actors and use cases. The users and any other systems that may interact with the system are represented as actors. The required behavior of the system is specified by one or more use cases, which are defined according to the needs of the actors. Each use case specifies some behavior, possibly including variants, that the system can perform in collaboration with one or more actors (Almendros-Jimenez & Iribarne, 2005).

A use case is a description of system usage, documenting transactions or sequences of interrelated events initiated by an actor. The complete functionality of the system from an external perspective is described by the set of use cases thus developed (Bustard et al., 2000). Use case diagrams show the interaction of the system with external entities, the so-called actors and describe the functionality of the system as a black box, without revealing its internal structure (Back, Petre, & Paltor, 1999).

Use case modeling is a requirement engineering techniques that similarly leads to the identification of system activities, but is driven more by needs of the system's "users" than those of the system itself. According to (I. Jacobson, 1987) a use case is a sequence of transactions in a system, whose task is to yield a measurable value to an individual actor of the system. In the same reference it is said "the set of use case descriptions specifies the complete functionality of the system. There are many different definitions of use cases, but all of them have their roots in Jacobson's or Cockburn's notation (Zelinka & Vranic, 2009). To (Arlow & Neustadt, 2005), a use case describes a coherent functionality that provides some result of value to a user. The main advantages one can get by creating use cases are (Back et al., 1999):

- Capturing the externally-required functionality of the system.
- Identifying the different goals for individual actors.
- Identifying candidate objects for the problem domain.
- Gaining an understanding of the problem domain.
- Gaining an understanding of the proposed solution.

Another benefit of use cases comes from the fact they are accountable, i.e. they can act as a contract between the users and the developers. Still, use cases also have a number of shortcomings (Back et al., 1999):

- They are informal. This is an advantage at an earlier stage in the development process, but later on, informal requirements can be easily misinterpreted.
- It is difficult, if not impossible, to check whether the system provides the functionality expected by the actors. To put it in another way, it is difficult to ensure that the actors can achieve their goals by using the system.
- They are essentially functionally in character, even though in UML, they are used to develop object-oriented systems. There is a missing link between functional use case diagrams and object-oriented class diagram.

There are six elements that make up the use case diagram: systems, actors, use cases, associations, dependencies, and generalizations. Fig. 4.8 shows these elements.

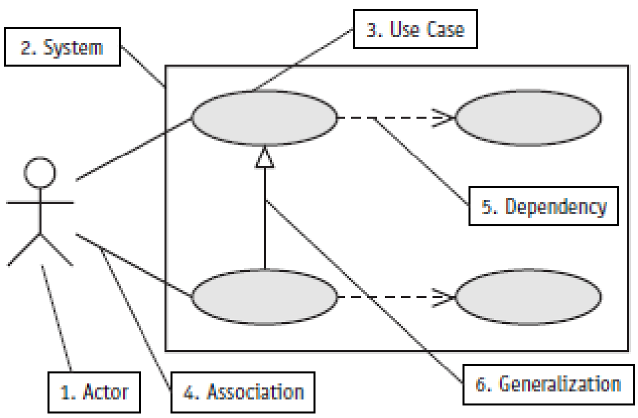


Figure 4.8 Elements of a use case diagram (T. A. Pender, 2002).

(1) System: sets the boundary of the system in relation to the actors who use it (outside the system) and the features it must provide (inside the system) (T. A. Pender, 2002).

(2) Actor: According to (Arlow & Neustadt, 2005), actors are roles adopted by external entities that interact with the system directly. Typically, actors are user roles, but systems, subsystems, or even time can all perform as actors. Each actor can participate in many use cases and each use case can embrace several actors. It is often distinguished between primary and secondary actors. Primary actors participate in a use case to satisfy their goals, while secondary actors help the system satisfy goals of primary actors (Zelinka & Vranic, 2009). Users in the classic sense are people who use the system. But users can also be other systems or devices that trade information (T. A. Pender, 2002).

(3) Use case: identifies a key feature of the system. Without the features, the system will not fulfill the user/actor requirements. Each use case expresses a goal that the system must achieve, and is named using a verb phrase that expresses a goal the system must accomplish, for example, deposit money, withdraw money, and adjust account. Although each use case implies a supporting process, the focus is on the goal, not the process (T. A. Pender, 2002).

(4) Association: identifies an interaction between actors and Use Cases. Each association becomes a dialog that must be explained in a Use Case narrative. Each narrative in turn provides a set of scenarios that function as test cases when evaluating the analysis, design, and implementation of the Use Case (T. A. Pender, 2002).

(5) Dependency: identifies a communication relationship between two use cases (T. A. Pender, 2002).

(6) Generalization: defines a relationship between two actors or two use cases where one use case inherits and adds to or overrides the properties of the other (T. A. Pender, 2002).

Other important term in use case diagrams is “flow of events” – or simply just flows (known also as scenarios). This represents every possible outcome of an attempt to accomplish a use case goal (T. Pender, 2003). A flow is a sequence of interactions between an actor and a system. The interactions start from the triggering action and continue until the goal is delivered or abandoned (Ivar Jacobson & Ng, 2005).

According to (T. A. Pender, 2002), by defining use cases in this manner, the system is defined as a set of requirements rather than a solution, i.e., the approach is not to describe how the system must work but describe what the system must be able to do. The use cases describe only those features visible and meaningful to the actors who use the system (T. A. Pender, 2002).

Use case relationships

After defining the system, actors, and use cases, is necessary to associate each user with the system features through the relationships. Use case relationships are a part of the use case description even though they are not explicitly present in most of the use case templates

(Zelinka & Vranic, 2009). UML offers two standard relationships between use cases called **include and extend**.

Include relationship defines that a use case contains the behavior defined in another use case (Object Management Group. OMG unified modeling language). The purpose of this relationship is to reuse existing behavior or extract identical behavior. The behavior of the included use case is simply inserted into the behavior described in the including use case (Zelinka & Vranic, 2009). The **extend relationship** is a relationship directed from the extending use case towards the use case being extended that specifies how and when the behavior defined in the use case can be inserted into the behavior defined in the use case being extended (Object Management Group. OMG unified modeling language). It is typically used to add optional or exceptional behavior without making changes to the behavior described in extended use case, which is similar to alternative flows (Zelinka & Vranic, 2009). The extend relationship is used in combination with extension points, which are named places in the flow of events where additional behavior can be inserted or attached (Meyer, 1997). Fig. 4.9 shows a use case diagram representing the actor, use cases and their relationships.

Association notation is a line connecting an actor to a Use Case represents an association, as shown in Fig. 4.9.The association represents the fact that the actor communicates with the Use Case (T. A. Pender, 2002).

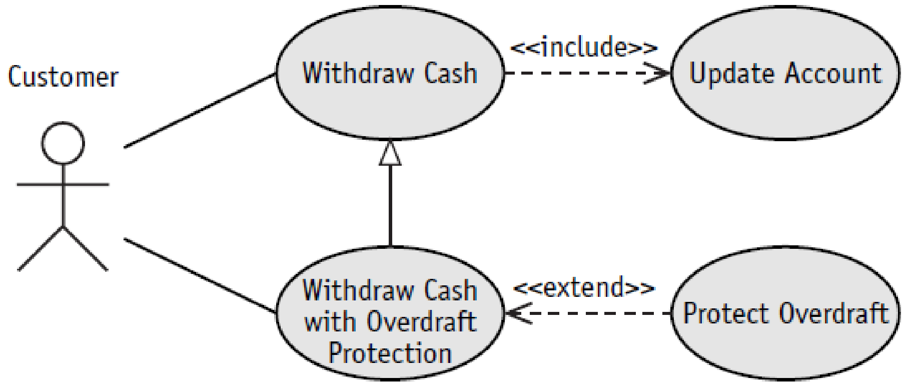


Figure 4.9 Example of use case diagram and their relationships (T. A. Pender, 2002).

4.3.3 Class Diagram

Class diagrams are part of the Unified Modeling Language (UML). Is one of six structure diagrams of UML (Haug, Hvam, & Mortensen, 2010).The Class diagram is by far the most used and best known of the object-oriented diagrams(T. A. Pender, 2002). The class diagram illustrates the structural component of the system and clearly identifies the classes, interfaces and their relationships within the system (António, 2008). According to (António, 2008), is the ideal diagram to represent concepts, classes and data types of the static structure of the system. Besides representing the concepts, the class diagram allows us to establish the relationships between classes (António, 2008). In the real relational database design, the E-R

(*Entity-Relationship*) methodology is the most used (Chen, 1976). Simple concepts (entities and relationships) enable an easy and intuitive modeling of real as well as abstract things and producing a conceptual model that can be easily transformed into relational database scheme by well-defined set of rules (Brdjanin, Maric, & Ieee, 2007).

The Class diagram represents classes, their component parts, and the way in which classes of objects are related to one another. A class is a definition for a type of object (T. A. Pender, 2002). (Booch, 1994) defines a class as a description of a set of objects that share the same attributes, operations, relationships and semantics (Booch, 1994). The Class diagram describes object classes and their relations, and is the most commonly applied UML diagram, and includes attributes, operations, stereotypes, properties, associations, and inheritance (T. A. Pender, 2002):

- Attributes - describe the appearance and knowledge of a class of objects (T. A. Pender, 2002). Booch (Booch, 1994) defines an attribute as a named property of a class that describes a range of values that instances of the property may hold. Attributes are shown below the class name and each compound word should begin with a capital with the exception of the first (e.g. produtionType). Some attributes will be mandatory, such as title, while others are optional, e.g. videoClip (Vidgen, 2003).
- Operations – define the behavior that a class of objects can manifest (T. A. Pender, 2002). An operation is the implementation of a service that can be requested from any object of the class to affect behavior (Booch, 1994). Operations are listed in the bottom compartment of the class box (Vidgen, 2003), how is shown in Fig. 4.8 (left).
- Stereotypes – help to understand this type of object in the context of other classes of objects with similar roles within the system's design (T. A. Pender, 2002). A stereotypes represents a variation of an existing type of model element (e.g. a class or a relation) (Haug et al., 2010).
- Properties – provide a way to track the maintenance and status of the class definition (T. A. Pender, 2002).
- Association – is just a formal term for a type of relationship that this type of object may participate in. Associations may come in many variations, including simple, aggregate and composite, qualified, and reflexive (T. A. Pender, 2002).
- Inheritance – allows to organize the class definitions to simplify and facilitate their implementation(T. A. Pender, 2002).

Classes represent things; relationships represent the connections between things (Vidgen, 2003). Generally, in UML there are five types of relationships between classes. These relationships are association, aggregation, composition, generalization, and dependence (António, 2008). The notation for the class elements and the most common relationship types are illustrated in Fig. 4.8. In addition, a navigability arrow can be used to show the direction of association, aggregation and composition relationships (Haug et al., 2010).

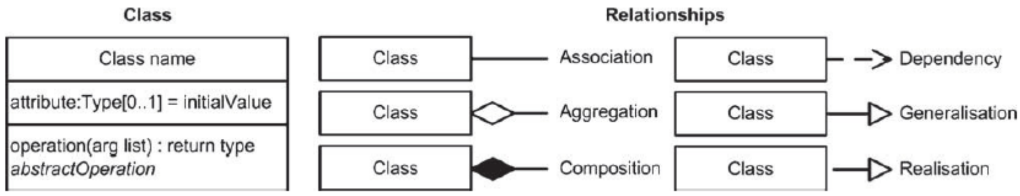


Figure 4.10 Elements of class diagrams (Haug et al., 2010).

Association – An association is a structural relationship between things showing that one can navigate from the instances of one class to the instances of another (and possibly vice versa). Associations are shown as solid lines that connect the same or different classes, and can be read in two directions (Vidgen, 2003).

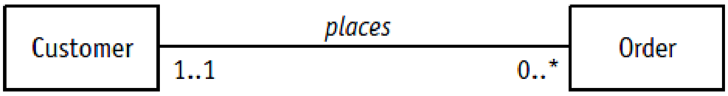


Figure 4.11 How to represent an association relationship in UML (T. A. Pender, 2002).

Aggregation – is a special type of association used to indicate that the participating objects are not just independent objects that know about each other (T. A. Pender, 2002). Represents the association that exists when an object contains other (António, 2008). The included class calls component and the class that include call compound, or container (António, 2008). Aggregation describes a group of objects in a way that changes how you interact with them (T. A. Pender, 2002). Aggregation is represented with a hallow diamond, how is illustrated in Fig. 4.10. In this example, is shown a aggregation relationship between the class "Team" and "Player"; players are assembled into a team; but if the team is disbanded, the players live on (depending of course on how well they performed) (T. A. Pender, 2002).

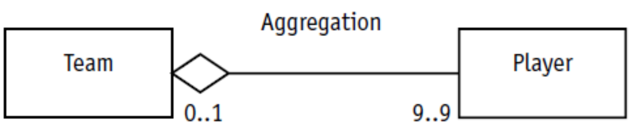


Figure 4.12 How to represent an aggregation relationship in UML (T. A. Pender, 2002).

Composition – is a special way of aggregation, with the restriction that the objects components belong, in fact, the object compound (António, 2008). Is used for aggregations where the life span of the part depends on the life span of the aggregate (T. A. Pender, 2002). The aggregate has control over the creation and destruction of the part. In other words, the member object cannot exist apart from the aggregation (T. A. Pender, 2002). Composition relationship is represented by the solid diamond how is shown in Fig. 4.11. A book is composed of chapters; the chapters would not continue to exist elsewhere on their own, they would cease to exist along the book (T. A. Pender, 2002).

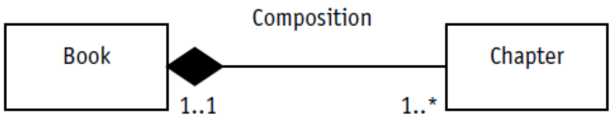


Figure 4.13 How to represent a composition relationship in UML (T. A. Pender, 2002).

Generalization – is the process of organizing the properties of a set of objects that share the same purpose. Generalization relates classes together where each class contains a subset of the elements needed to define a type of object (T. A. Pender, 2002). A generalization is represented as is shown in Fig. 4.12. Reading of the Fig. is: apple, watermelon, and orange, are three types of fruit; a red delicious is a type of apple, and an apple is a type of fruit (every red delicious object is an apple object and every apple object is a fruit object) (T. A. Pender, 2002).

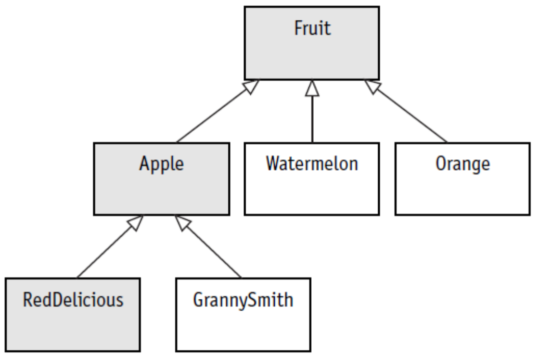


Figure 4.14 How to represent a generalization relationship in UML (T. A. Pender, 2002).

Dependence – the dependence relationships is used to describe situations in which a class depends on the other. An example of a situation where it makes sense to apply a dependency ratio is the description of the relationship with a class that is passed by parameter. The dependence is an association that is represented dashed (António, 2008).

Finally, is illustrated a class diagram example that includes the relationships presented previously (Figure 4.15). In UML classes are shown as rectangles. The class name should be a noun or noun phrase and begin with a capital letter. Classes can represent tangible things, such as the seats in a theatre, and intangible things, such as an account balance in an accounting system (Vidgen, 2003).

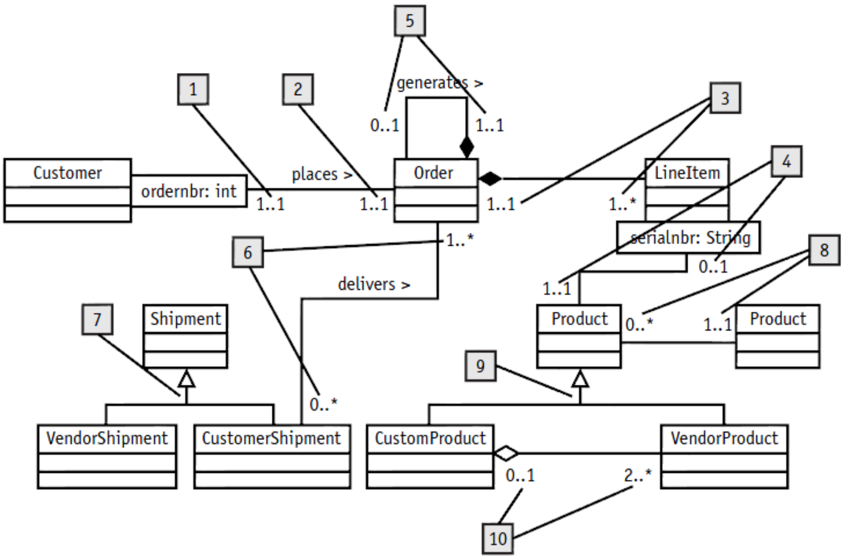


Figure 4.15 Class diagram example (T. A. Pender, 2002).

Figure legend (T. A. Pender, 2002):

1. On the “places” association between Customer and Order, the multiplicity of 1..1 means that every Order must be placed by a Customer. An Order cannot exist on its own.
2. On the “places” association between Customer and Order, some customers may not yet have placed any orders while others may have been doing business with the vendor for a long time. The Order multiplicity should be 0..*. But a Customer can use the order number as a qualifier to look up a specific Order (qualified association), so the multiplicity with the qualifier is 1..1.
3. An Order is constructed using one or more Line Items. Each Line Item includes information like a price and any applicable discount. But every Line Item exists only as part of an Order represented by composition and multiplicity of 1..1 on the Order. There must be at least one item on the Order so the LineItem multiplicity is 1..*.
4. Each Line Item is associated with a specific Product (1..1). The Line Item refers to the Product using a serial number as a qualifier (qualified association). A Product might not ever be ordered, so the multiplicity on the Line Item end is zero to one (0..1). In other words, a Product might not yet be associated with a Line Item.
5. An Order that is not filled completely will generate another Order that it refers to as a backorder (role name) and that backorder is associated with the Order that generate it (reflexive composition). Each backorder refers to exactly one other Order, its source (1..1). But each Order may or may not generate backorders (0..*).
6. The Order is shipped to the Customer via a Customer Shipment. When the Order has not yet been shipped, the multiplicity on the Customer Shipment is zero (that is, there is no Shipment associated with the Order). When more than one Shipment is needed to fill the Order (for example, the items are being shipped from multiple locations or are restricted by shipping requirements), the multiplicity is “many.” Hence the complete

multiplicity range is 0..*. A shipment may contain products from many orders, resulting in an Order multiplicity of 1..*.

7. Customer Shipment is just one type of Shipment (generalization). Another type of Shipment is the incoming Vendor Shipment referred to in the receiving process. CustomerShipment and VendorShipment are specializations of Shipment and so inherit all the properties of Shipment.
8. Many Products or no Products may be in a given Location (0..*). But in order for you to record a Product into inventory, you have to assign it to a Location. So there will never be a Product that is not associated with a Location. This requires a multiplicity of 1..1 on the Location end of the association.
9. VendorProduct and CustomProduct are both types of Product (generalization), specializations of the class Product. Both can be ordered and shipped. But CustomProducts are configurations of VendorProducts and VendorProducts are standalone items that are ordered and shipped independently, not in a configuration of other Products.
10. It is possible to create custom products using VendorProducts; for example, a home entertainment system might consist of a receiver, CD player, speakers, TV, and so on (aggregation). Why is it aggregation and not composition? Because the VendorProducts, like the CD player, may exist and be sold separately from the entertainment system. The multiplicity on VendorProduct is 2..* because a CustomProduct is only a logic entity made up of a combination of at least two VendorProducts. A VendorProduct may be sold individually and does not have to be part of any CustomProduct configuration (0..1).

The literature review in two previous chapter, three and four, serves to help the researcher of this dissertation in understanding the core concept of two models that is developed in following sections, LARG information model and LARG ANP model. Basically, the objective is to find the tradeoffs of each tool and perceive how to apply the concepts acquired to LARG models development.

The following chapters focus primarily on the development of those two models to support a Lean, agile, Resilient, and Green SCM on automobile industry. For this purpose a case study in automotive SC is presented in chapter 7.

Chapter 5 LARG Information System Models

5.1 Methodology

This study includes a theoretical development to build a LARG information model. This task is entered in the field of software development. In software system modeling, systems requirements must be identified previously to facilitate the system development planning. The question is why the necessity of integrated information model? The first answer for this question is: offers SC managers an integrated platform that supports the exchange of information/data in real time between all intervenient of the system (supply chain). Another answer is that this platform helps overcome the problems of interoperability that may exist if each entity has their particular information system. With this platform, information is available to be consulted by any user system that has permission. With this information platform there will be improved security and compatibility of data/information exchange. To this purpose, it is used Business Process Modeling Notation (BPMN) and Unified Modeling Language (UML) to build the information model required. In UML, two business diagrams are developed, use case diagrams and class diagram. In BPMN, a Business Process Diagram (BPD) the aim is to provide global view of the automotive supply chain, material, information and financial flows. The use case diagrams represent the interaction between system and their users, i.e., the system requirements. Summarizing, with the use cases diagram is intended to do a list of previous functionality of the information platform to facilitate the class diagram design. If is known previously the functionality of the system, the identification of classes to store the needed data will be more easy. With the class diagram, the aim is to show the structural information components of the LARG information model and identify the most important classes of each paradigm (lean, agile, resilient, and green) and their relationships.

The main objective of this information system platform is to assist data/information exchange between all the companies in the considered supply chain. There is a fictional "super entity" that is responsible for the supply chain management as a whole, seeking the SC performance improvement and SC competitiveness. All LARG SCM practices are stored in LARG platform and the super entity can classify them according to paradigm, degree of importance and degree of implementation. In the LARG class diagram, there is a class "LARG practices" where is stored information about all these practices. The methodology for the LARG Information system design is shown in Fig. 5.1.

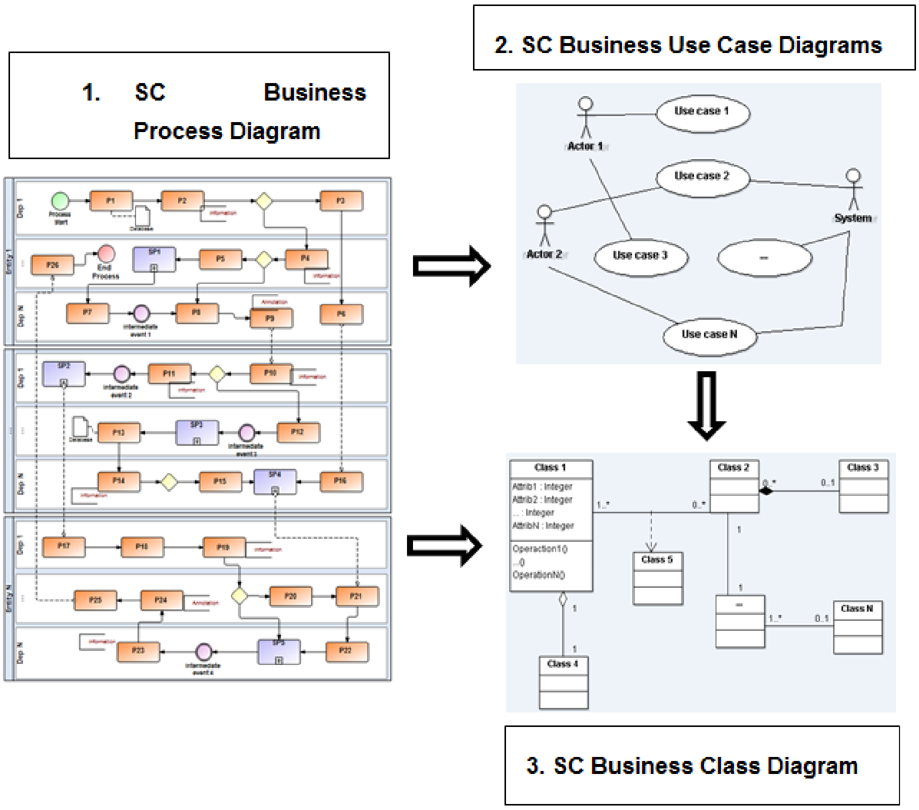


Figure 5.1 Methodology for LARG information system design.

With the design of information model is intended to provide a single information platform to assist decision-making in the considered SC. An effective decision-making should be based on data (reliable, real and transparent). However, if there is not a platform that meets global SC information, decision making about SC as a whole will be more difficulty.

The design of the LARG information model includes the contributions of a Delphi exercise with a panel of academics and professionals on automotive supply chain management. Firstly, a general business process diagram, different use cases diagram and a general class diagram were developed with these contributions. The class diagram development also has contribution of academics experts in database system. These diagrams were discussed with the panel of academics experts in supply chain management before their validation through a case study in focal firm. As is shown in Fig. 5.1, firstly is developed a BPD that will assist the development of use cases diagram and class diagram. Based on BPD developed, was identified with the professionals of focal firm the core data/information associated to each organization/department to be represented in class diagram. At the same time, was identified the previous functionality of the information system. Before developing the class diagram is necessary to understand the purpose of the information system. The system requirements have to be previously identified to facilitate the identification of data to be modeled. The previous identification of users also helps to identify data associated to each one. To frame our general BPD to the context of automobile industry, some process diagrams were consulted and discussed in focal firm, in order to identify the core business processes, material, information and financial flow of an automobile SC. The validation of the LARG information system diagrams was conducted finally in logistics department, through semi-structural interviews.

Before developing the class diagram is necessary to understand the purpose of the information platform. The system requirements have to be previously identified to facilitate the identification of data to be modeled. The previous identification of users also helps to identify data associated to each one.

5.2 The Business Process Diagram (BPD)

In this research, the BPMN is used because it offers a modeling technique that is quickly understood by all users of the business, from business analysts that make drafts of the processes to technical developers that are responsible for the technological implementation of those processes and finally business people that will manage and control those processes. Moreover, it creates a standardization that connects design with implementation of business processes.

The LARG Business Process Diagram will provide a holistic view of the supply chain in study, and identify points where can exist interoperability problems, processes to be improved, data associated to each entity and processes where the practices implementation influence the SC performance. Other advantage of the BPD development is that it helps in identifying the information/data that is necessary to model in LARG class diagram.

5.2.1 The proposed automotive SC BPD framework

The proposed automotive SC BPD describes and links a set of core business SCM processes in automotive supply chain, including the three main entities on the supply chain considered in this study (1^{rst} tier suppliers, focal firm, and 1^{rst} tier distributors) and their respective departments. There are three types of flows that are modeled: material, information, and financial flows.

In this phase, first is presented a global SC BPD containing only the entities considered is this research (Fig. 5.2). With the automotive SC BPD we intend to give a global view of the automotive SC core processes without going into details of what happens between departments. The global automotive SC BPD is illustrated in Fig. 5.3. The complete SC BPD containing the processes that occur within departments is shown in Fig. 5.4. Both diagrams developed include the three main entities level on the automotive supply chain (1^{rst} tier suppliers, focal firm, and 1^{rst} tier distributors). These BPD developed will represent a powerful toll in stage of LARG class diagram development, since allows identifying information/data that results from the SC business processes.

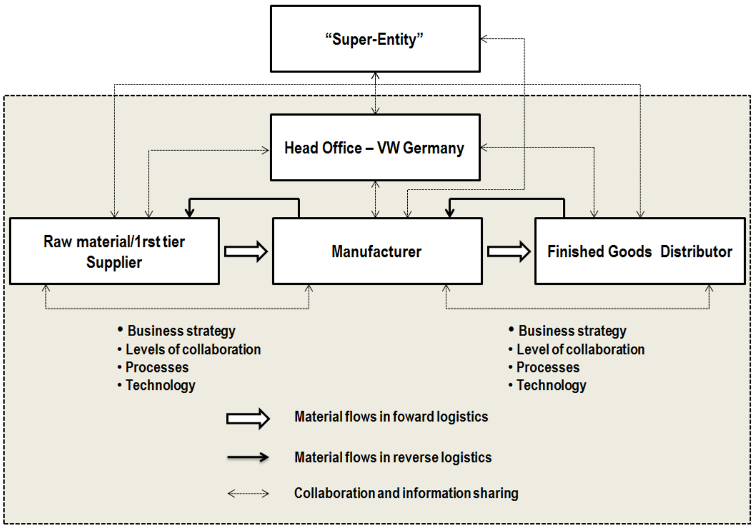


Figure 5.2 SC's entities of study.

Each of these three entities level presented on Fig. 5.2 is modeled on the BPD by a pool. Within each pool (entity), has been considered the most important departments of each entities, represented by a lane, namely Sales, Design & Engineering, Purchasing/Logistics, Production, Quality control, and Financial. In entity distributor is not considered the production department, since the production processes are not relevant in this entity as far as the SCM is concerned.

Especially in this automotive SC we consider a "Head Office" that is the main decision maker and responsible for the market study, final product design (design and engineering), selection of suppliers and distribute the final product to the finished good distributor. This entity will be represented by a pool and its major departments are: marketing (market study), design and engineering, sales, distribution and SC decision making. Is important to note that the producer/assembly company does not sales the final product directly to final customers and finished goods distributor. This process is assured by the Head Office. It means that any end user can make an order directly from the producer.

There are two types of suppliers on first tier. The first type is the traditional supplier that is responsible for produce/buy the components necessary to supply the manufacturer line. The second type is a logistic provider that is responsible for some pre-assembly and transportation of the components from suppliers to focal firm (assembly). The logistic provider is considered as a supplier, so will be represented as supplier's departments, by a lane. The core automotive business SCM process is modeled according to the three types of flow that exists in the supply chain, physic (material), information, and financial flow. In the first diagram, the financial flow is not represented as is shown in Fig. 5.3. The process begins with the customer order placement and end when the final product is received by the customer (distributor) that has requested the product.

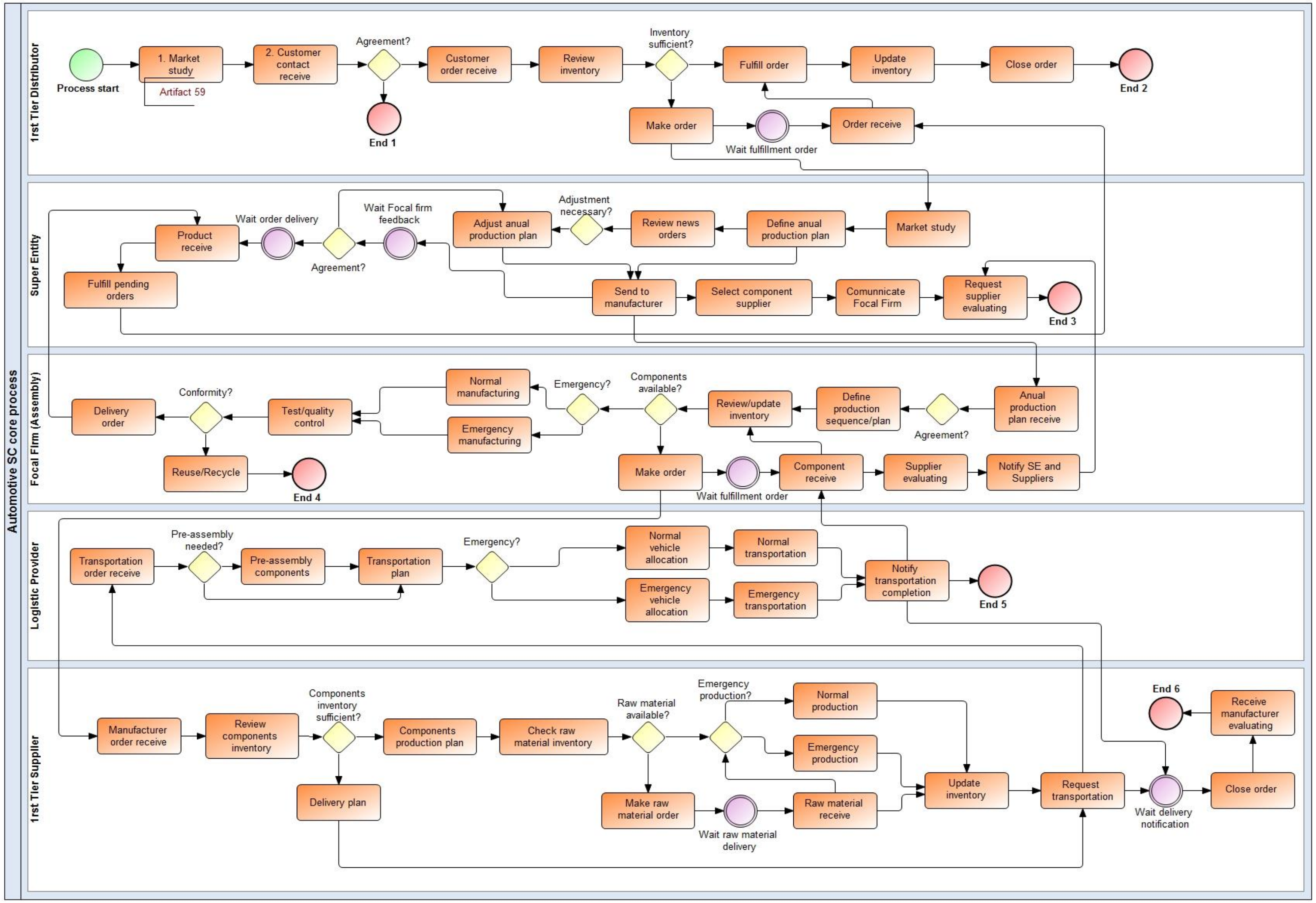


Figure 5.3 Global automotive SC Business Process Diagram developed.

Based on customer demand and available stock, the distributor comes into contact with the super entity. If there is agreement the order is placed. However the super entity has already made its annual production plan and sends to manufacturer (focal firm). When there is a new order, is necessary to adjust the production plan that is not possible if the manufacturer and component's supplier does not have capacity. The manufacturer receive the production plan from the super entity and place order to 1rst tier suppliers to purchase the components necessary for the final product assembly. The delivery of components is made in Just in Time (JIT) and Just in Sequence (JIS). The first tier suppliers buy the raw material to produce the components and deliver to the manufacturer through logistic provider. Sometimes is necessary some pre-assembly before deliver the components on manufacturer. This activity can be done by a logistic provider. After receiving the components, the manufacturer makes the assembly, test and deliver to the super entity distribution center. Lastly the distribution center delivery the final product to the distributors. The supplier's evaluation is made by the manufacturer but the supplier's selection is done by the super entity, based on the manufacturer report.

Inside each entity, each department has their specific task to be modeled. In sales department for example, the main tasks are: manage customers list, manage customer orders, request credit approval, after-sales service, and complaints managing. The market study department is responsible for the market study and estimate the annual production. Design and engineering process is carried out by the department of Design&Engineering in super entity but should involves more entities, namely focal firm and first tier suppliers. These two entities have direct contact with production/assembly of components/final product and can add some value in design stage. Purchasing/logistics department has a set of core tasks, such as: control and update inventory level, plan purchasing, finished goods shipment, shipment notification, supplier's evaluation, contact suppliers, and make orders. In production department, the main processes are: material requirements planning, request material needed, plan and scheduling production, send finished goods to quality control, and carrying out maintenance. In quality control department, basically, the main tasks are: material (components/finished goods) quality control, testing finished goods (cars), measure nonconformities, send conform products to warehouse or production line. Processes like credit approval, invoice sending, and payment/receiving are carried out by the financial department. Logistics provider is responsible for transporting.

As is shown in Fig. 5.4, there are many processes in different departments/companies that are associated. Basically, these associations represent the link in material/information/financial flow within the same company or between two or more companies. Annotations has been used to represent all the perform indicators that results from the SCM business process or some information important for the ready of the diagram. Information as order date, Economic Order Quantity (EOQ), lead time, material cost, number of returns, number of nonconformities, delivery date, inventory level, setup time, maintenance cost, quantity reused/recycled, etc., are represented by annotations in automotive BPD. Fig. 5.4 just shows part of the conceptual automotive BPD developed.

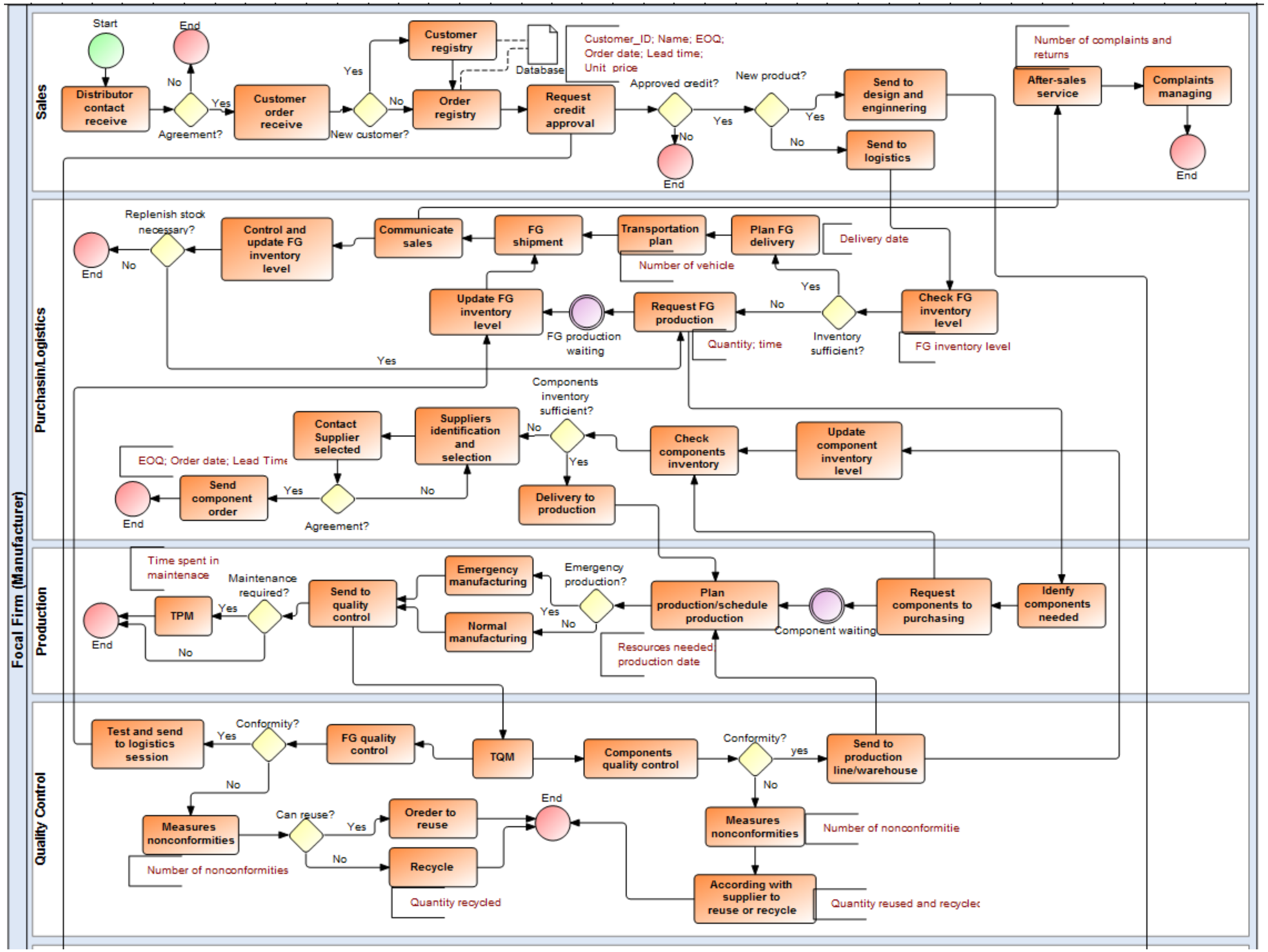


Figure 5.4 Stretch of the conceptual BPD developed.

The information flow is an important issue in the proposed automotive BPD. The availability of information is crucial for the successful management of the supply chain and decision making. Thus, all information must to be available and realistic in a given system/database. To design the database system it is important that there are identified previously which data will be modeled. With the BPD is possible to identify all the data that results of the supply chain business process. For example, associated with the process “order registry” and “customer registry”, we have important information to save, such as: customer name, quantity ordered, order date, lead time, price of item, etc. Other important information can be the number of nonconformities detected on the quality control process.

5.3 LARG Use Cases Diagrams

5.3.1 Identification of the actors of the system

The users of the LARG information system are the fictional “super entity”, suppliers, focal firm, distributors or other external entities that have permissions. Different use cases can be created to shows the interaction between the system and their users. The system users are all SC’s entities (managers) and a fictional “super entity” that is the SC manager. They are the system users because the system is modeled to assist their decision making and their information storage. Within each company, there are many users, namely the employees of each department. Basically the system users are all the employees of the different entities because they are the ones will work with the system. All users should share the required information for an effective SCM. The function of others users is to provide information, consult, update, delete, depending on their permissions. It is important to define permissions for each user previously. For example, the focal firm cannot alter the annual production plan or select suppliers. Also exist various types of users with various permissions: those who can insert, alter and consult information, i.e., can perform any action on the system; those who can only insert and consult information; and those who only can consult the information available.

In this research it is proposed the introduction of a fictional “super entity” that is responsible to manage the supply chain as a whole, seeking to make the chain more competitive and tries to find solutions to satisfy the final customers within the context LARG. The challenge of this fictional “super-entity” is to make a collaborative management, improving performance of each entity without prejudice the SC competitiveness. This “super-entity” has an important function in managing the conflicts of interest that may exist in the chain. Strategic decisions to enhance SC competitiveness should be performed by him.

Especially in the SC in the case study, there is a “super manager-Head Office” that is Volkswagen (in Germany). In context of this study, this “super manager” cannot be considered as “super entity” since he looks only for performance improvement in focal firm, distributors and not in other important level of the chain as 1^{rst} tier and 2nd tier suppliers. Sometimes, performance in focal firm is not the desired because entities in upstream do not have a good performance. The main challenge of the “super entity” is to seek the SC performance improvement and SC competitiveness. So, the information must be available, actual, and consistent allowing better decision-making.

5.3.2 Use cases diagrams proposed

The use cases are created with the purpose of showing the potentiality of the system, i.e., the managers need the LARG information platform for what. Several interaction scenarios (use cases) can be created to illustrate the interaction between the system and their users. The use cases diagram developed are divided into two groups: LARG use cases diagram and general use cases. LARG use cases diagram are those that relate to the scope of Lean, Agile, Resilient or Green SCM. For example, use cases diagram to know inventory level, degree of resilience, quantity of materials reused or recycled of global SC or each entity in particular, capacity of each entity, number of disturbances occurred, losses due to disturbances, demands not fulfilled, number of stop line, number of nonconformities, number of demands fulfilled in time, can be considered as LARG use cases diagram. Note that, to respond to these use cases diagram (requirements), is required a class diagram to store data/information to be consulted and processed.

General use cases diagrams do not relate to any paradigm, such as: use case to registry and login, generate annual production plan, consult information, supplier evaluating. Following is presented some use cases relating to LARG paradigms, developed in this study.

Use case diagram 1: Registry and login – this is the first requirements of the system. It is not a LARG use cases diagram but is necessary because all users must have a login to access the system. Before, is necessary to registry and getting login and password. Only users with permission can log into the system. In this use case, the user request a login, inserting the necessary data and wait for the login (user and password). After receiving the login the user can do login and after logout. This process is shown in Fig. 5.5. There is an especial case of generalization on use case “get login” that includes “get user” and “get password”. For all the subsequent use case diagrams, is necessary to login.

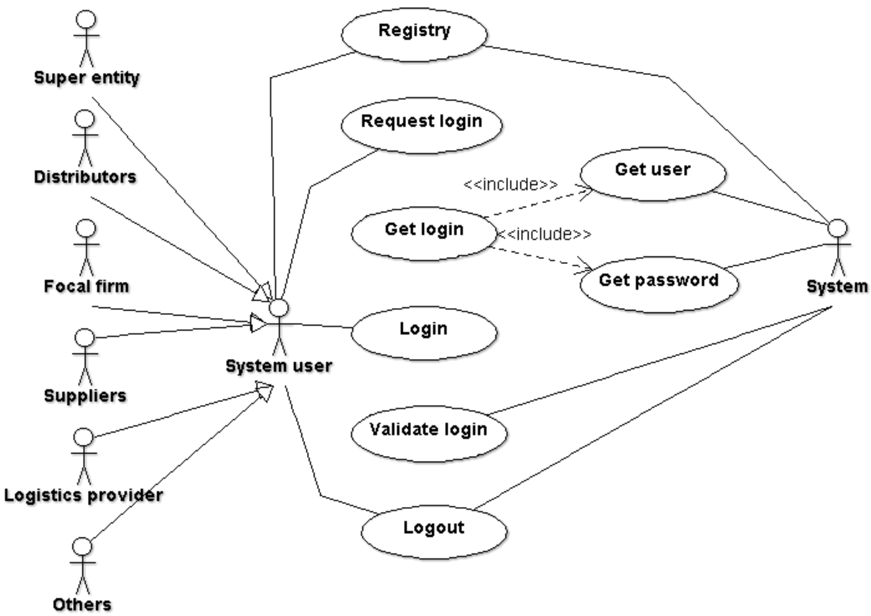


Figure 5.5 Use cases diagram to registry, login and logout.

Use cases diagram 2 (resilient UCD): calculate degree of resilience in SC (by super entity) – In this UCD, the main actor is super entity. He will interact with the system to calculate a global degree of resilience in the SC. Firstly, is necessary to define the criterion that will be used and a calculation formula. After, is obtained data from the system, and selected the entities that comprise this calculation. Finally, the system calculi the requested computation and shows the results. Note that it is an important UCD, since allows understanding how resilient is the chain and the necessity of news resilience strategies. Fig. 5.6 shows this use cases diagram.

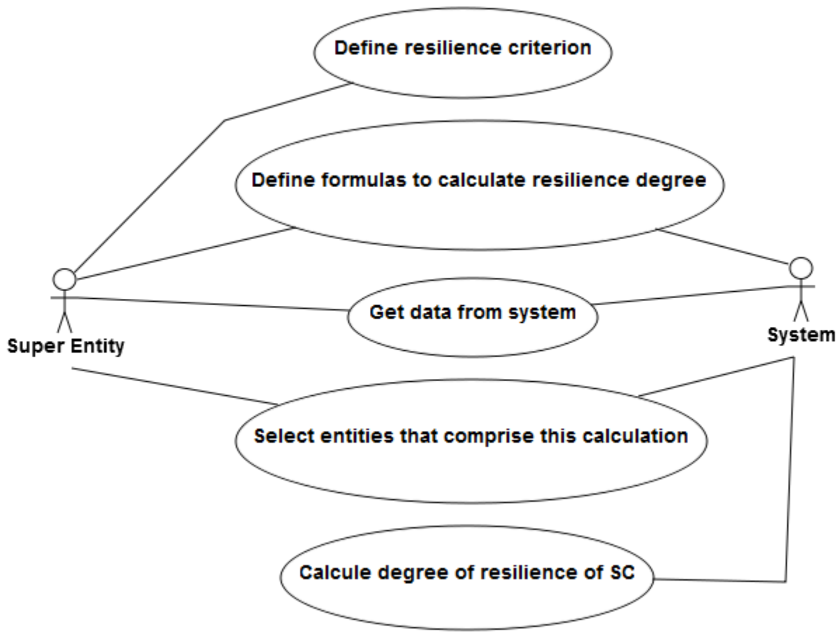


Figure 5.6 Use cases diagram to calculate the degree of resilience in the chain.

Use cases diagram 3 (lean UCD): to know the number of line stop in focal firm (by super entity) – to develop better strategies to avoid the stop of line, super entity can use the platform to know the number of occurred stop in focal firm. With this information, is possible to estimate a cost (due to interruption in production line). To this purpose, he needs to insert the ID of focal firm, define a period, search for desired information and request computation of results. Figure 5.7 illustrates this use cases diagram.

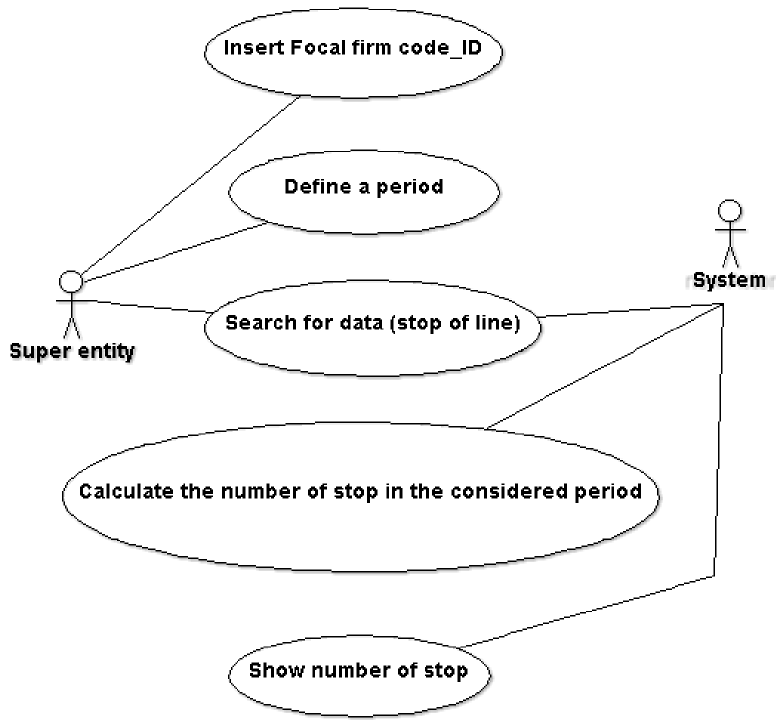


Figure 5.7 Use cases diagram to calculate the number of stop line in a given period.

<u>Use cases diagram 4 (green UCD):</u> <u>to estimate the quantity of recycled in global SC (by super entity/Head Office)</u> - in this use cases diagram, the main objective of super entity/Head Office is to have a perception about the quantity of materials recycled in a given period. It is necessary to search the quantity of recycled in each organization in particular and after calculate the global value for the SC. By comparing the quantity of each entity, it will more easy to develop specific strategies for the company with low level of recycled. Fig. 5.8 shows this use cases diagram.

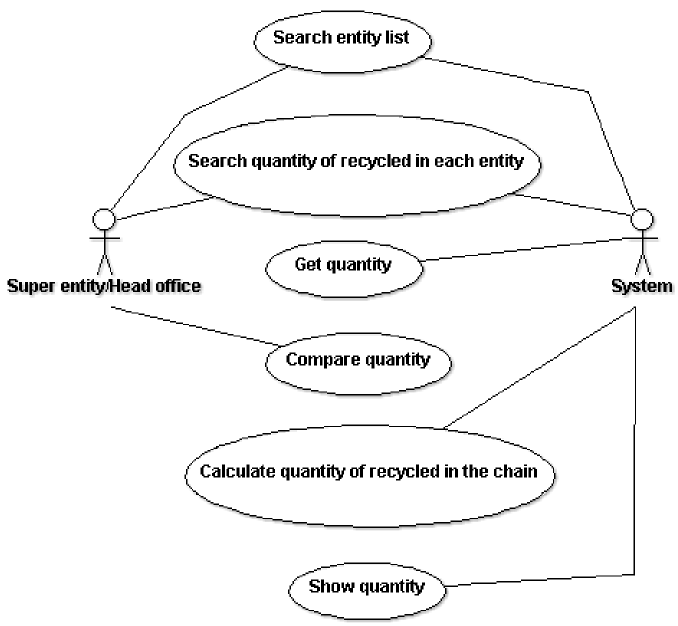


Figure 5.8 Use cases diagram to calculate the quantity of recycled in the SC.

Use cases diagram 5 (agile UCD): number of demands fulfilled in time (By super user or focal firm) – in this use cases diagram, the main user can be super entity or focal firm. This use cases diagram is important for both. Firstly is defined the supplier that will be consulted. After getting order info of the selected supplier is compared the data order date, lead time and date of delivery to find if order was delivered in time. Finally is estimated the number of times that delivery occurred out of time. An entity that has a high number of deliveries out of time means that is not agile. Still, this information can be used to evaluate the suppliers. Fig. 5.9 shows this use cases diagram.

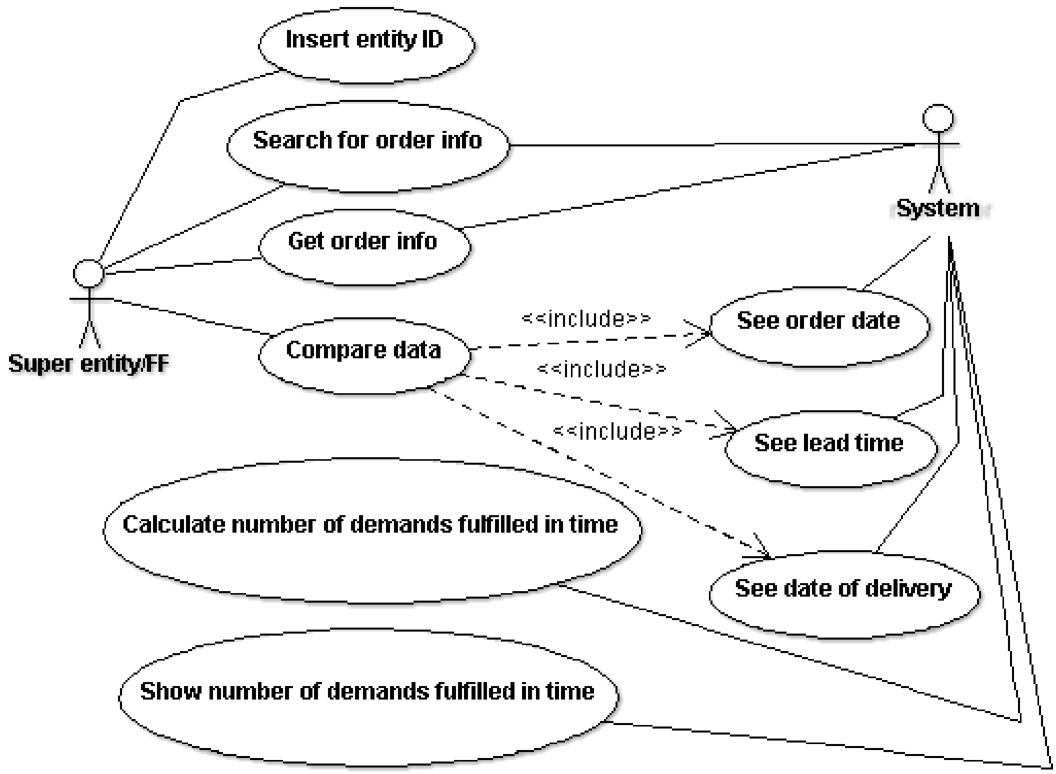


Figure 5.9 Use cases diagram to calculate the number of order fulfilled in time.

Use cases diagram 6 (LARG UCD): to calculate LARG performance (by suppliers/focal firm) – in this use cases diagram, the main users are suppliers and focal firm. The aim of this use cases diagram is to know how much their entity is LARG and develop some strategies to improve LARG performance. For this purpose, the supplier/focal firm will insert their ID code, search for LARG indicators, access and select the LARG indicators, define the calculate formulas, and finally calculate the LARG performance. Fig. 5.10 shows this use cases diagram.

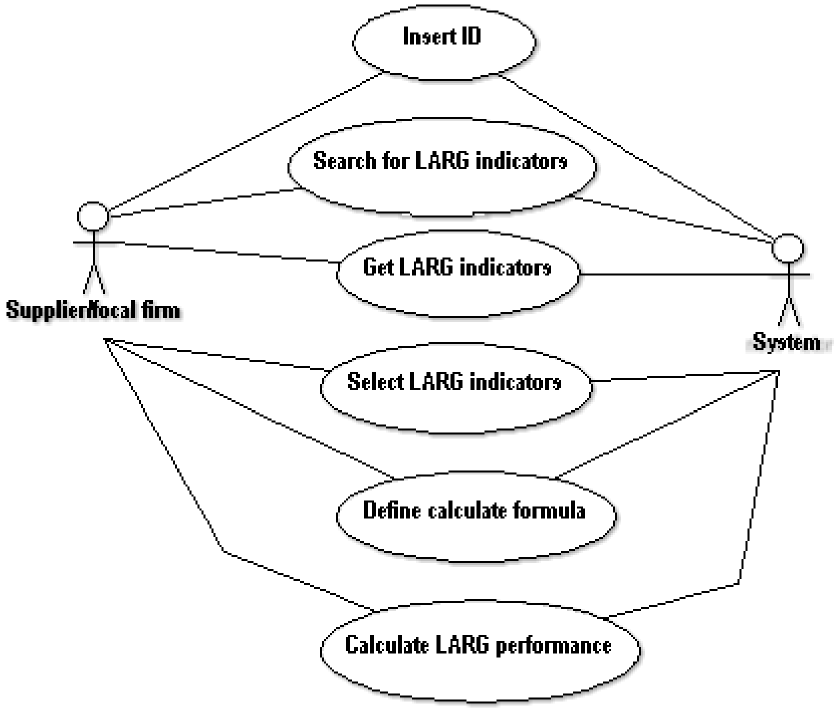


Figure 5.10 Use cases diagram to calculate the LARG performance of a supplier or focal firm.

Use cases 7: SC performance measurement (by super entity) – in this use cases diagram the main actor is the super user. The other entities managers can interact with the system for the same purpose. To measures the supply chain performance, it is necessary some data that the system can provide for this purpose. In this case, the super entity (or other entity interested in SC performance measuring) must interact with the system how is shown in Fig. 5.11. Since the platform will be available in web, any user can introduce the information that may be used by others. The first step of this process is to search the list of SC entities and get the specific data necessary to measures each KPI (cost, service level, lead time, and quality of product). Before the final measures, is necessary to define the weights of each entity and each KPI.

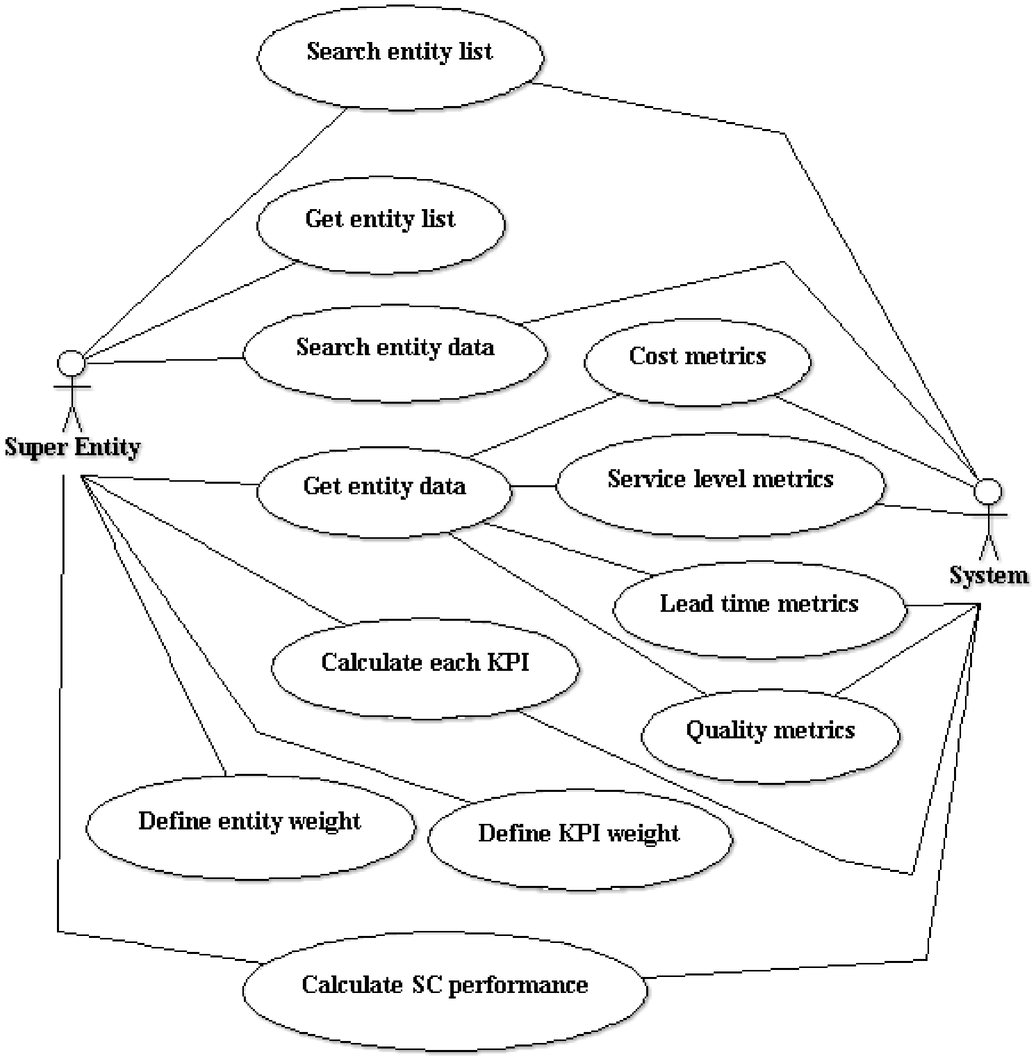
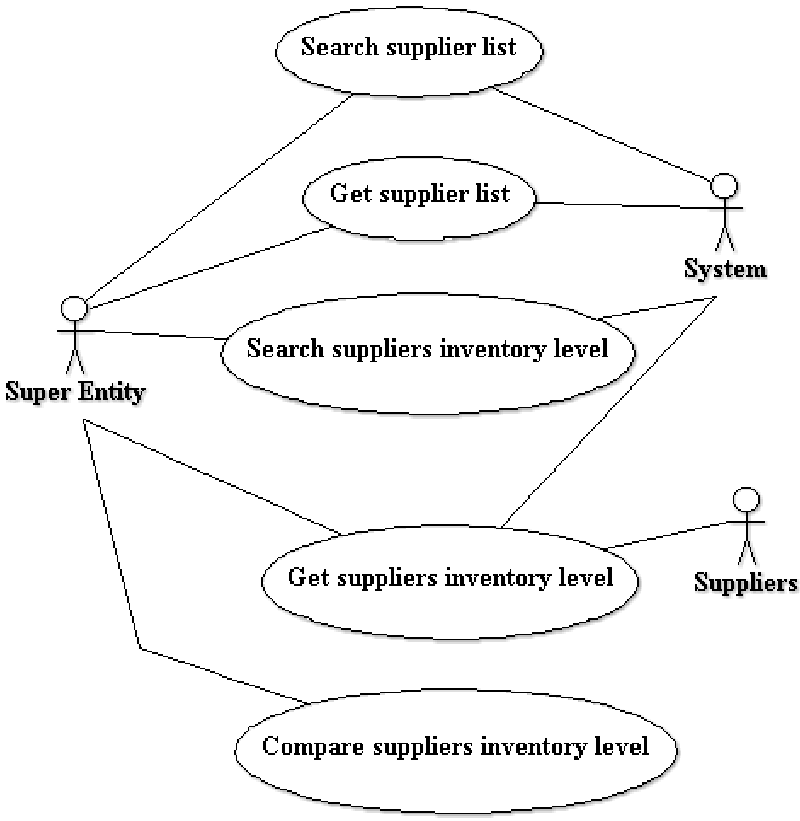


Figure 5.11 Use cases to evaluate the SC performance.

Use cases 8 (lean/resilient UCD): consulting and comparing the supplier's inventory level (by the focal firm) – in this case, the focal firm or the super entity is interested in consulting and comparing the supplier's inventory level to better develop their orders strategy. The steps to this use cases is to search the supplier's list, get their inventory level, and after compare their inventory level, as is shown in Fig. 5.12.



5.12 Use case diagram to check supplier's inventory level.

<u>Use cases 9 (agile UCD)</u><u>: status order consulting (Super entity/customer)</u> – sometimes is important to know the order status. The use case diagram for this purpose is shown in Fig. 5.13. The procedure here is: the entity interested in consulting the status order introduce the Order ID, access to the order status, view the entity that placed the order, and can access to all order information.

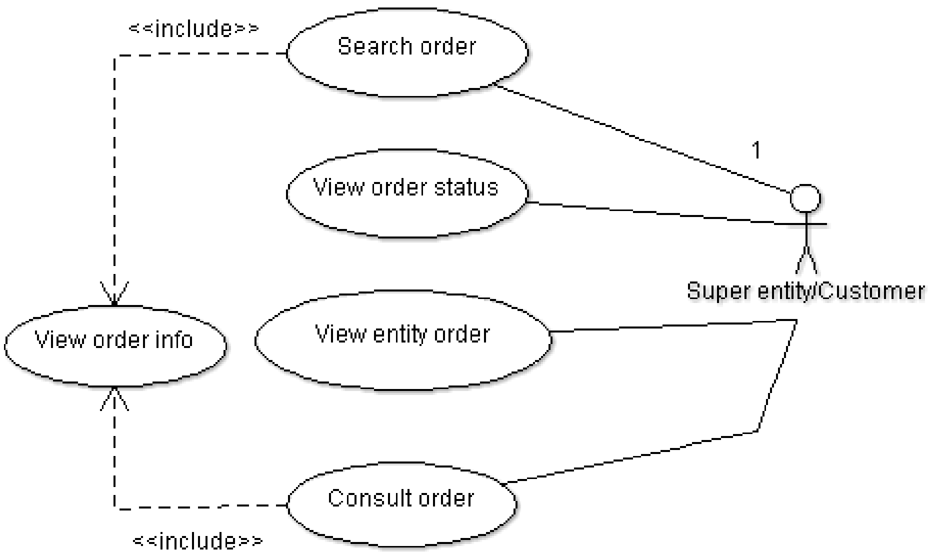


Figure 5.13 Use case diagram to check order status.

Use case 10: entity/order info managing: in this case the responsible for the system will interact with the system, managing the entity or order information. When there is any alteration of data regarding the entity or order, this information must be updated. In this use case diagram, the super entity can insert information about new entity, remove an entity, or simply update the existing information. The procedure to manage order info is the same. Fig. 5.14 shows this use case diagram.

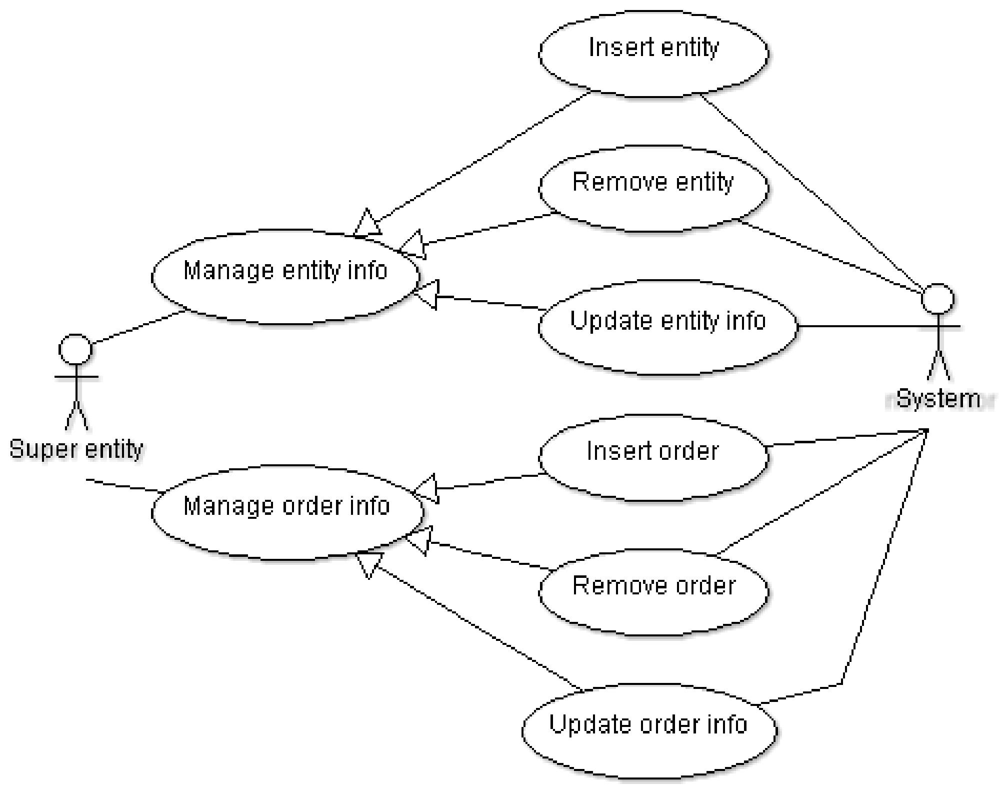


Figure 5.14 Use case diagram to manage entity/order info.

Use case 11 (lean/resilient UCD): calculate the average inventory level in the chain – it is clearly a LARG use case diagram. The average inventory level in the supply chain is important information to the stakeholders, particularly the fictional “super entity”. With this information, the SC’s responsible can develop new strategies to manage the SC’s inventory. In this use case diagram, the first step is to search all entities that are inserted in the system. Following, is necessary to get the inventory level of each entity, compare these inventory level, and finally calculate the average inventory level. Fig. 5.15 shows this use case diagram.

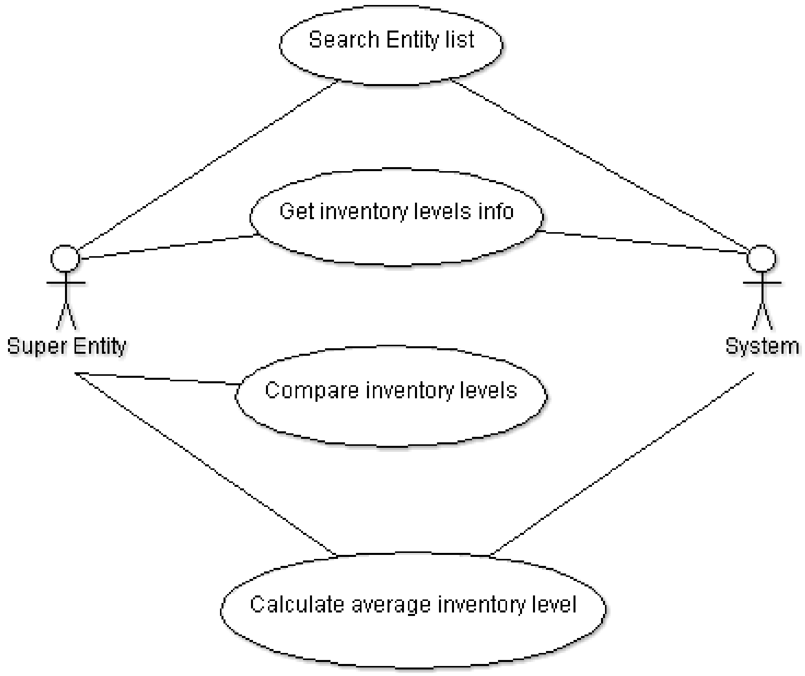


Figure 5.15 Use case diagram to calculate the average inventory level in the SC.

Use case 12 (LARG UCD): estimate how lean/agile/resilient/green is the entity/SC – this use case intends to estimate the performance of one entity or the supply chain according to a particular paradigm. For example, if the objective is to evaluate the lean performance, the information to search is about lean. If the objective is to evaluate the performance of one entity, after searching the entity list, the entity desired is selected. Following, is obtained the paradigm indicators info and their values. To calculate the paradigm weight, is necessary to select the KPIs that are included in measurement. Fig. 5.16 illustrates this use case diagram.

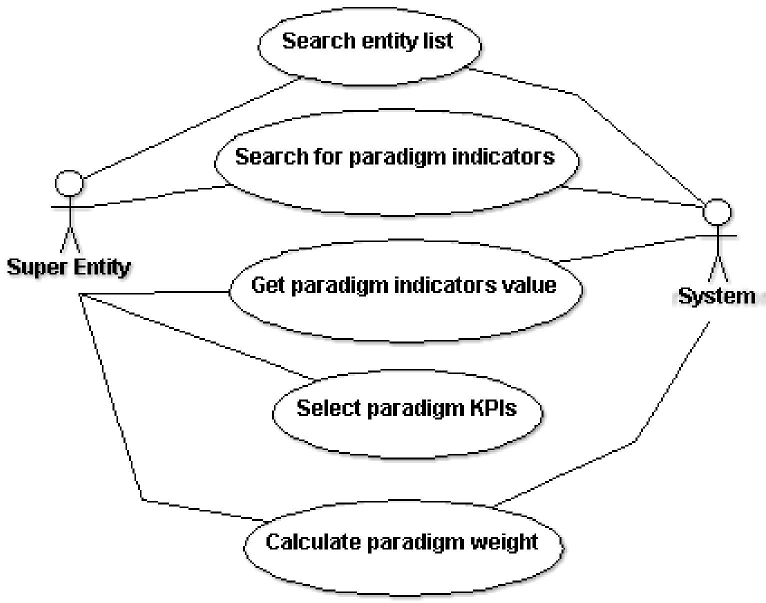


Figure 5.16 Use case diagram to estimate how lean/agile/resilient/green is the entity/SC.

Use case 13: <u>estimate the LARG SC performance</u> – this use case diagram is similar to previous. The difference is that in this case the indicators are selected regardless being lean, agile, resilient, or green. The super entity defines all indicators that are important for the measurement and estimate the LARG SC performance. This use case is shown in Fig. 5.17.

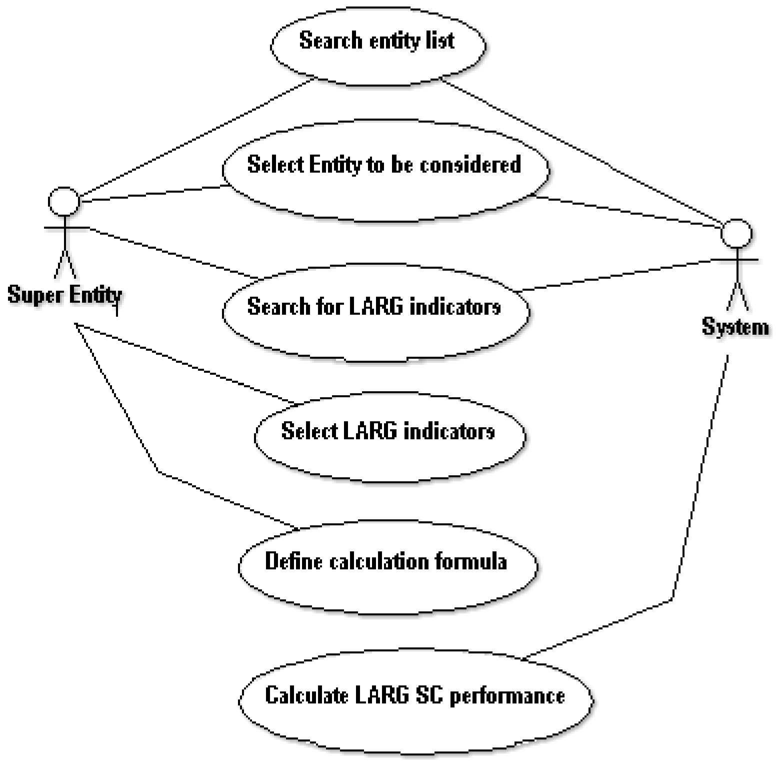


Figure 5.17 Use case diagram to calculate the LARG SC performance.

Use case 14: <u>supplier evaluating</u> – one of practices in the supply chain management is the supplier evaluating. Fig. 5.18 illustrates the way as the focal firm can evaluate their suppliers. The procedure here is to search the supplier list, select the supplier to be classified, define the evaluation criteria, find the weight for each criteria, calculate the rating and insert the rating in the system for others stakeholders. In the evaluation criteria definition, the suppliers may be involved.

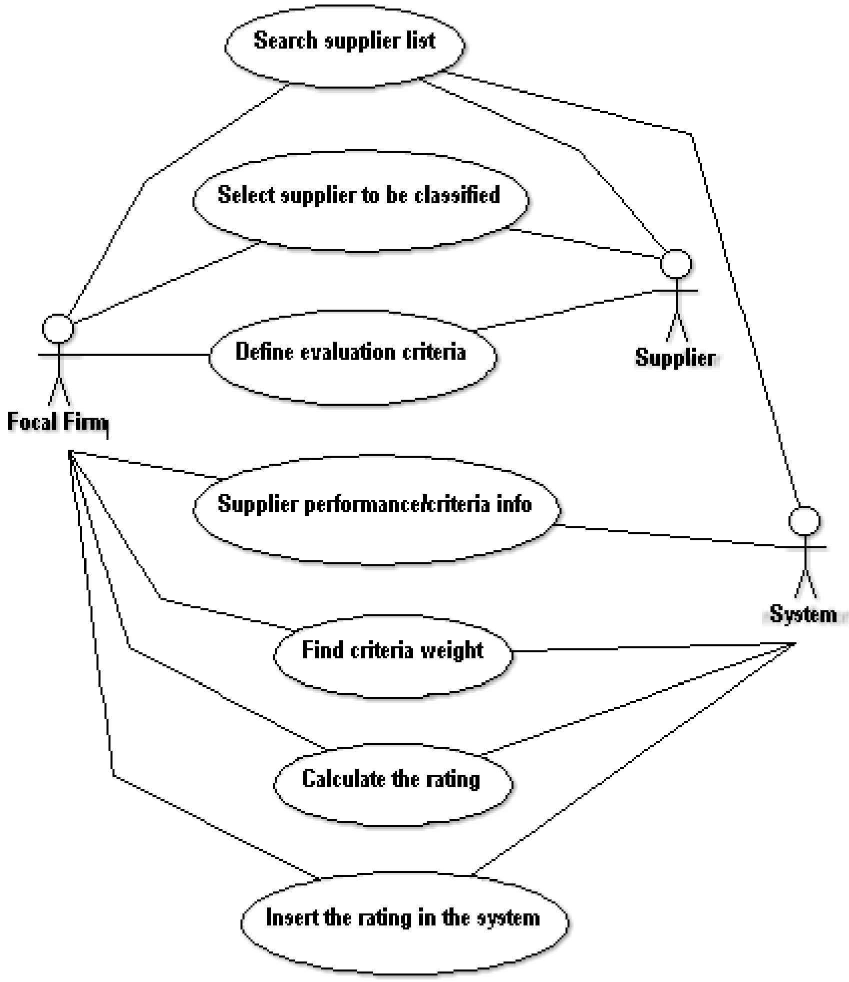


Figure 5.18 Use case diagram to evaluate a supplier.

The LARG platform information system is complex and can be used for many purposes. In the previous described use cases some possibilities were described. Still, the possible interactions between the system and their users are endless. In Table 5.1 is summarized the core use case diagrams developed in this research. Many others use cases diagrams can be created, according to the user requirements.

Table 5.1 Use cases diagram resume.

Identifier	Designation	Description	Actors
UCD1	Registry and login	The SC entities login into the automotive LARG SCM Information System to access the information	Entities/System
UCD2	Calculate SC degree of resilience	The super-entity will use information system to calculate the degree of resilience of the chain	Super-entity/System
UCD3	Know number of interruption of production line in focal firm	The super-entity estimate how many times the focal firm production line stopped in a given period	Super-entity/System
UCD4	Estimate quantity of recycled in SC	The super-entity will estimate a global value for materials recycled by comparing quantity of each entity	Super-entity/Head office/System
UCD5	Estimate the number of delivery out of time	Super-entity or focal firm will use the system to consult the number of out time delivery by a given entity.	Super-entity/Focal firm/System
UCD6	Calculate LARG performance	Suppliers or focal firm use the system to calculate their LARG performance	Suppliers/focal firm/System
UCD7	Consult and compare suppliers inventory level	Super-entity and suppliers use the IS platform to consult and compare inventory level of each supplier	SE/Suppliers/System
UCD8	Status order consulting	Super-entity or customer use the IS platform to consult the status order; order processing	Super-entity/Customer
UCD9	Calculate average SC inventory level	Super-entity need to know the SC average inventory level to make better decision and develop better strategies	Super-entity/System
UCD10	LARG estimation	Super-entity can use the IS platform to estimate how lean, agile, resilient, and green is the SC/entity	Super-entity/System
UCD11	Estimate the quantity of scrap in global SC	The super-entity/Head office can access the system to estimate the quantity of scrap resultant of the global SC	Super-entity/Head office/system
UCD12	Calculate the number of nonconformities detected in deliveries	Focal firm will use the system to know how many nonconformities has been detected in a given supplier delivery	Focal firm/system
UCD13	Estimate the number of recyclable pallet used to delivery materials	Suppliers and focal firm can use the system to know the quantity of recyclable pallet are used in material delivery	Suppliers/focal firm/system
UCD14	Estimate the consumption of hazardous/toxic materials	Suppliers and focal firm can use the system to estimate the consumption of hazardous/toxic materials in their entities	Suppliers/focal firm/system
UCD15	Estimate the energy consumption	Suppliers and focal firm can use the system to estimate the energy consumption inn their entities	Suppliers/focal firm/system
UCD16	Estimate the recycling workplace materials	Focal firm and Suppliers can use the system to know the quantity of materials recycled in workplace	Focal firm/suppliers/system
UCD17	Estimate the number of LARG practices implemented in each entity	Super-entity or Head office will use the system to know the LARG practices implemented in each entity	Super-entity/Head office/system
UCD18	Estimate the air emissions in global SC	Super-entity will use the system to estimate the air emissions in all SC entities	Super-entity/Head office/system

UCD19	Estimate the number of accidents in focal firm or suppliers	Super-entity and entities can use the system to know how many accidents occurred in a given period	Super-entity/focal firm/suppliers/system
UCD20	Estimate the customer reject rate	Suppliers can use the system to know the focal firm reject rate	Suppliers/system
UCD21	Estimate the delivery speed	Suppliers, focal firm and logistics provider will use the system to estimate the speed on delivering products	Suppliers/focal firm/logistics provider
UCD22	Estimate the obsolescence cost	Suppliers and focal firm can use the system to know the cost of obsolescence in their entities	Suppliers/focal firm/system
UCD23	Consult the setup time in focal firm	The super-entity can use the system to consult the setup time in the focal firm	Super-entity/focal firm system
UCD24	Consult the capacity of each entity	To define the annual production plan, the super-entity and Head office will use the system to consult the capacity of each entity	Super-entity/Head office/system
UCD25	Calculate the number of occurred disturbance in global SC	To define better resilience strategies the super-entity and Head office can base on the number of disturbance occurred in global SC or on a given entity	Super-entity/Head office/system

5.4 The Lean, Agile, Resilient, and Green Class Diagram

LARG platform modeling requires some perception about supply chain management fields and each paradigm. Information about orders, purchasing, delivery, production, maintenance, quality control, distribution, inventory management, material reused/recycled, needs to be stored. For example, when an entity makes an order, important information are EOQ (Economic Order Quantity), lead time, order date, entity that makes the order and entity that receives the order. Regarding to lead time, order date, date of delivery, we can evaluate the agile paradigm for example. By comparing these indicators it is possible to evaluate the agility on responding the customers demand. In quality control, the information relevant is the number of nonconformities detected in raw materials and finished goods. This is green information but can be lean information because nonconformities can result on waste, representing cost. For lean paradigm, some important information can be production cost, inventory cost, maintenance cost, quantity of resources, etc. Finally, for resilient paradigm, information about disturbances is necessary to assess how resilient is the entity/chain.

The proposed class diagram represents the structural information components of the LARG platform, and identifies the most important classes of each paradigm (Lean, Agile, Resilient and Green). The class diagram development methodology was to identify firstly the classes and their attributes with the contributions of academics experts on SCM and database system, and after finding their relationships. The methodology to identify the classes was to find which information are suitable to support LARG SCM, where many of those classes relate the three types of flow in the SC (material flow, information flow, and financial flow) Firstly was developed a general class diagram and after validated with professionals of logistics department in focal firm, through a case study. The conceptual class diagram for the LARG SCM system is shown in Fig. 5.19.

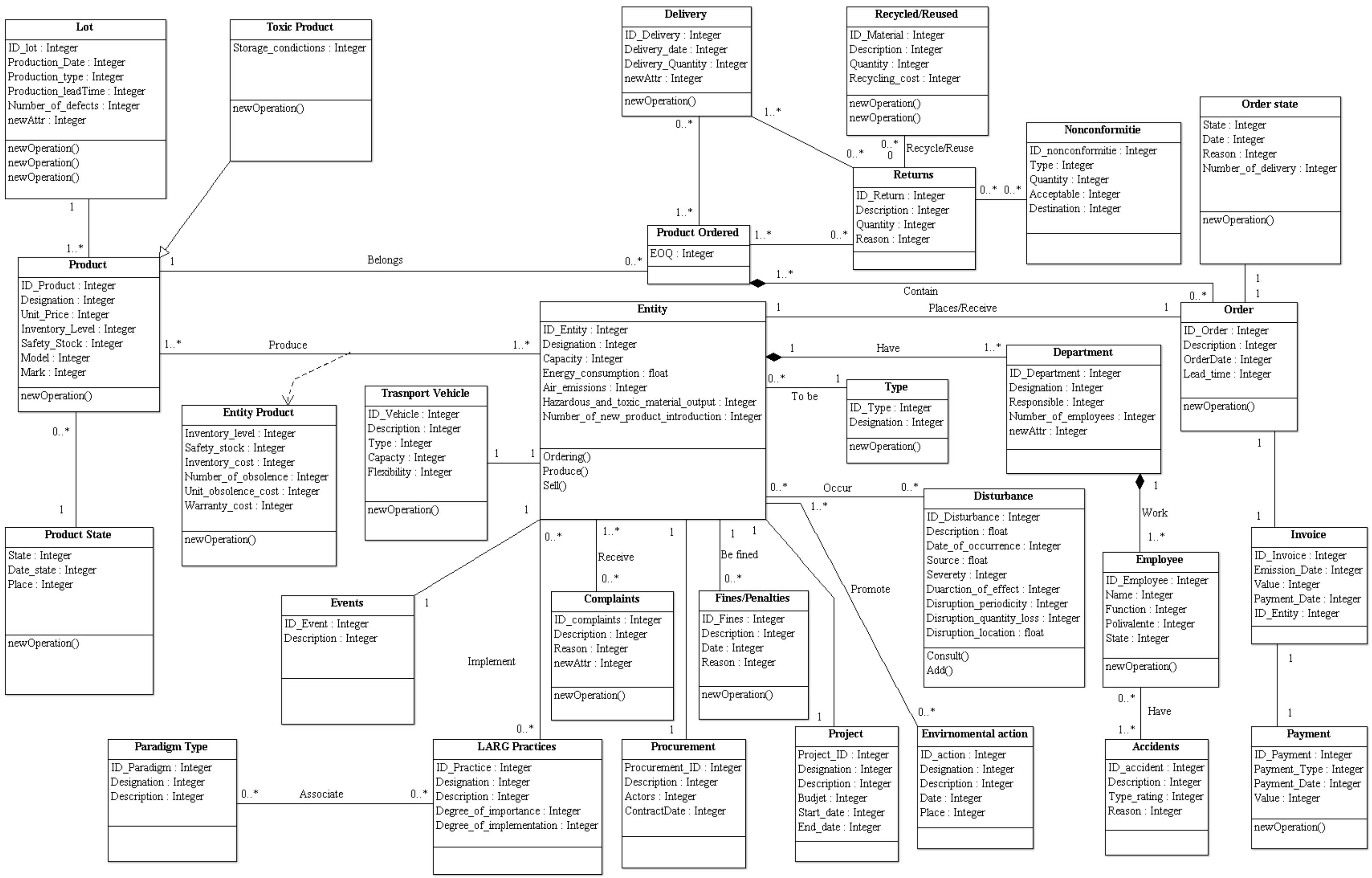


Figure 5.19 The Conceptual Class Diagram

5.4.1 Core Lean, Agile, Resilient, and Green classes and attributes

On the proposed LARG class diagram, the core classes identified to support LARG SCM are: entity, product, department, order, invoice, payment, employee, disturbance, order state, nonconformity, returns, reused/recycled, delivery/shipment, accidents, environmental action, fines/penalties, complaints, procurement, project, fairs/workshops (events), and transport vehicle, LARG practices and paradigm type. There are some classes that represent one or more paradigm and others that have no impact on the four paradigms.

The class “entity” represents the various entities in the chain. This class has been considered instead having a class for manufacturer, supplier, and distributor. In this class is possible saving information about lean, agile, resilient, and green paradigm. The core attributes of this class are: entity ID (unique entity identifier), designation (company name), type (depending on the level of the chain), capacity (installed), energy consumption and air emissions (important to assess lean and green performance), number of employees, hazardous and toxic material output. Capacity and energy consumption are lean attributes because allows to evaluate the cost; energy consumption is also a green attribute, as air emissions and hazardous/toxic material output. These are clearly environmental attributes; the attribute number of new product introduction, relate the agility of a company on responding to market needs, so is an agile attribute. Capacity is also a resilient attribute since allows to evaluate the capacity of a company to respond to unexpected occurrences.

“Disturbance” class is necessary because allows to save relevant information about the disturbance that occurs in the chain, and offers managers relevant information to define better resilient strategies. The main attributes in this class are: disturbance ID, description, date of occurrence, duration, source, severity, duration of effect, disruption periodicity, disruption quantity loss, disruption location. Disruption periodicity is the interval between the disruptions; disruption quantity loss is the difference between what an entity normally provides and which has been providing due to disruption; disruption location refers to where in the upstream supply chain the disruption event occur (disruptions can occur at the first, second, or third tiers of the chain). This class will be related to the entity class with a relationship many to many, i.e., an entity may have zero or more disturbance, and a disturbance can affect zero or more entities. Is not required that a disturbance affect an entity, i.e., if there are a contingency plan the entity may be not affected.

The class “Product” is other crucial class in the proposed class diagram. All companies have one or more products/services to satisfy customers’ orders. Thus is related to the class “Entity” with a relationship many to many, meaning that an entity may produce/sell one or more product and the same product can be produced by one or more entity. Is required that a product has a producer and a product does not exist if no exists a producer. The core attributes of this class are: product ID (identifier unique of each product; should not have two or more product with the same ID), designation, unit price, unit cost, inventory level, safety stock, model, and mark. Unit cost, inventory level, and safety stock are lean attributes since offers information about cost. Inventory level and safety stock are too resilient attributes because can relate the capacity of a company to respond to unexpected disturbances.

Associate to the class “Product”, exists the class “Lot”. The relationship is many to one, i. e., a product belongs to one lot and one lot may have many products (same products). The main attributes on this class are: lot ID, production date, production type (to stock or to order), and number of defects. This last attribute is clearly a lean and green attribute in simultaneous. When the number of defects is high, this represent a greater cost (lean) and more waste (green).

In “Delivery” class, it is possible to save all information about all shipment that process in the SC. It is clearly an agile class because from this class is possible to measures the delivery performance and evaluate the capacity to respond to the demands changes. The core attributes of this class are: delivery ID, delivery date, delivery quantity, and delivery place. By comparing the delivery date and delivery quantity with planned, is possible to evaluate the entity compliance rate. These two attributes can be lean and agile at the same time. If the delivery occur outside of the time, this represent cost and if occur in time planned mean that the entity is agile in responding to customers demands.

When a delivery is carried out, there may have some returns. That is why has been considered the class “Return”, allowing to save information about all returns that occur in delivery order. Thus this class is related to class “Delivery”. The main attributes of return class are: return ID, description, quantity, and reason. The attribute “quantity” returned represent lean and green attribute because may represent cost or waste.

Usually when there are some returns, is due nonconformities. So, is necessary to create and associate the class “Nonconformities” to the class “Returns”. Nonconformities class can be lean and green class. Their main attributes are: nonconformity ID, type, quantity, quantity acceptable, and destination. The attribute “quantity” represents lean and green attribute because it translates into cost and waste.

Other class associated to “Return” class is “Reused/Recycled”. When there are some returns, is important to decide what do with the returned item. To save information relating to the issue, there are considered the class “Reused/Recycled”. The core attributes on this class are: material ID, description, quantity (reused/recycled), and cost (of reuse/recycle). These two last attributes are clearly lean and green attributes.

Classes such “Fines/penalties”, “Events”, “Accidents”, and “Transport vehicle”, have been included on the proposed class diagram because there is possible to save important information on lean and green paradigms. Attributes such fines/penalties value, accident rating, and cost of event can represent lean and green attributes. On “Transport vehicle”, there are an agile attribute: flexibility of vehicle.

In the proposed LARG class diagram, there are some classes that do not represent any paradigm, such as: Invoice, payment, and employee. They are integrated in class diagram to complete the supply chain business process. For example, invoice and payment class are important to save financial information.

Note that there are considered two especial classes in LARG class diagram: LARG practices and paradigms type. A set of LARG practices will be saved in LARG platform and classified according to the respective paradigm. These practices are implemented by different entities in the chain. An entity can implement one or more practices and one practice can be implemented by one or more entities. Therefore, the relationship between classes entity and LARG practices is many to many. The class “LARG practices” has two important attributes: degree of importance and degree of implementation. These two attributes allows compare degree of practice implementation between two or more entities. The same practice can have different degree of importance in different entity. Related to class “LARG practices” is the class “paradigm type”. Each of those LARG practices can be classified in lean, agile, resilient or green paradigm. One practice can belong to one or more paradigm and one paradigm contains various practices. The aim of LARG practices implementation is to improve the value of the LARG KPIs. These KPIs are represented on the different classes in the LARG class diagram, so there is not a direct relationship between the class “LARG practices” other classes and their attributes.

5.5 Contribution of Information Modeling to Improve LARG SCM Performance

In this chapter has been proposed an integrated platform information system to support LARG SCM. Using this platform the entities can share information to improve their SC performance. Information sharing through the use of Information Technology (IT) is crucial for effective supply chain management, but the simply use of IT applications is not itself enough to realize the benefits of information sharing. Also, if each entity has its platform, the information sharing will be more difficult and the lack of compatibility problem will be present. The proposed platform intends to eliminate this problem, ensuring a safe and easy exchange of information.

This platform can be used by any entity on the supply chain. The main decision maker is then the super user, thus the main objective is to ensure him reliable and real data to perform their decision-making. The data stored on the platform is used to evaluate the supply chain performance in LARG context, by comparing the results of each company, obtained from perform indicators established previously. By comparing KPIs values from different periods, the super user can evaluate the effect LARG SCM practice implementation and identify measures to be improved.

The main barrier to this platform consists on the interoperability problem. There is some data/information that entities are not able to share because of privacy issues. The other question is how each company uses the platform to insert the information.

One of interoperability problems may be related to the practice implementation. This problem occurs on the practices that involves two or more entities (interoperable practices). Each practice has an ID and description as attribute. If the description is the same, it helps to overcome the semantic problems. Other problem of interoperability is the lack of compatibility that exists between the systems of each entity. For example, a problem that may exist is the problem of label and of inventories counting. The same product may have a code in the system of suppliers and other different in customers system. If exists a single platform this problem will be exceeded and the exchange of data/information is more effective and transparent.

Other important contribution of LARG platform system is that offers an extensive list of LARG practices to be implemented in different level of the chain. The selection of best practice is made according to LARG ANP model proposed in following chapter. The selection of best practices is done to improve the value of macro indicators (cost, service level, time, quality of product) and metrics (designated in this research KPIs). By combining values of a set of metrics stored in platform system is possible to calculate a value for each macro indicators. Regarding to metrics values, the managers can select the most appropriate paradigms to improve these values. Then LARG platform serves essentially to facilitate the data/information exchange between entities and assist decision making in selecting best practices, KPIs and paradigms performed by LARG ANP model presented in next chapter.

Chapter 6 LARG ANP: A Proposed Conceptual Model

The goal of this section is to propose a conceptual decision making model to assist SC' managers to select the best automotive LARG SCM practices in order to improve performance. There are a lot of models for decision making but on this research, Analytical Network Process (ANP), introduced by (Thomas L. Saaty, 2001) has been selected.

To achieve SC competitiveness, four management paradigms have been proposed in this research. In this research the selection of LARG practices and KPIs has been based on the identification of the most appropriate practices and KPIs in the automotive SC context. Firstly, is outlined a list of LARG practices (Annex 1), based on the literature (S. Azevedo & Machado, 2009; Susana G. Azevedo et al., 2010a; Susana Garrido Azevedo et al., 2010; Helena Carvalho et al., 2010), and then separated the practices by paradigm. To validate the LARG practices/KPIs identification a two-round Delphi exercise was conducted with 20 academic and professional experts. These experts identified the most appropriate LARG practices/KPIs in the context of automobile SC.

In order to select the best LARG SCM practices, a conceptual ANP model is proposed in this dissertation. Due to the mutual dependencies, inner dependencies and feedback effects on some clusters, the ANP can be used to systematically evaluate the most suitable LARG SCM practices. The traditional AHP method, also introduced by (R. W. Saaty, 1987) was not used because is not suitable for the problem under study. The AHP neglects the mutual effect of different conflicting levels in the SC network. The ANP, tolerates complex interrelationships between the criteria and decision levels and deal with dynamic problem (Tuzkaya & Onut, 2008). Thus, the LARG SCM practices selection problem can be effectively modeled by the judgments given by a set of enterprises managers in order to make better decisions in SC.

6.1 Why ANP?

Supply Chains are structured networks involving suppliers, manufacturers, distributors, retailers, and final customers. Within the Supply Chain there are complex decision-making involving all the actors with the overall objective of turning supply chains more competitive. Within this research work the main objective is to examine the potential of ANP model in helping managers to select the Lean, Agile, Resilient and Green best practices to be implemented. ANP was selected because of its ability to deal with mutual dependencies, inner dependencies, and feedback effects on some clusters that exist for systematically evaluating the most suitable LARG SCM practices. Indeed, (i) supply chains are complex networks with feedback and interdependence relationships between and amongst their actors; (ii) some KPIs and Practices can be used by one or more actor in the same or different ways at different level of the supply chain; (iii) some Practices can have direct influence on one or more enabler criteria (Cost, Service Level, Time, Quality of product); (iv) practices may have contradictory results.

Occasionally, in order to be Leaner, an entity must be less Resilient - for example, if the practice is “reduction of inventory level”, the entity will be leaner (reduction of inventory cost) and less resilient (no inventory stock to respond to a possible disruption); (v) there are some loops within the elements of the same clusters, for example in criteria cluster.

6.2 LARG ANP Methodology

The first step on the LARG ANP development is determining the clusters that comprise the network. Two particular cases of these clusters are “Alternatives” (LARG practices) and Subcriteria (KPIs). Literature review suggests many LARG practices and KPIs, but on these two clusters, (Thomas L. Saaty, 2001) suggests maximum nine elements. Thus, is necessary to select the core LARG practices and KPIs implemented on SC under study. To select LARG practices to comprises the model, is considered two publications (Susana G. Azevedo, Carvalho, & Machado, 2011; Helena Carvalho, 2011) by identifying the practices with a higher degree of implementation and rating. Due to limitations in obtaining answers from SC’ managers, in comparing nine practices and nine KPIs, it was necessary to further simplify and select the top three ranked practices and KPIs in order to reduce the number of pairwise comparisons. For example, if there are nine practices and nine KPIs, the number of pairwise comparisons for each dependency would be 351. The top LARG practices selected are: (P1) strategic stock; (P2) systems for rapid response in case of emergency and special demands; (P3) reuse materials and packages. The LARG KPIs selected are: (KPI1) inventory cost; (KPI2) order fulfillment rates; (KPI3) responsiveness to urgent deliveries. The various steps involved in LARG ANP model have been shown in Fig. 6.1

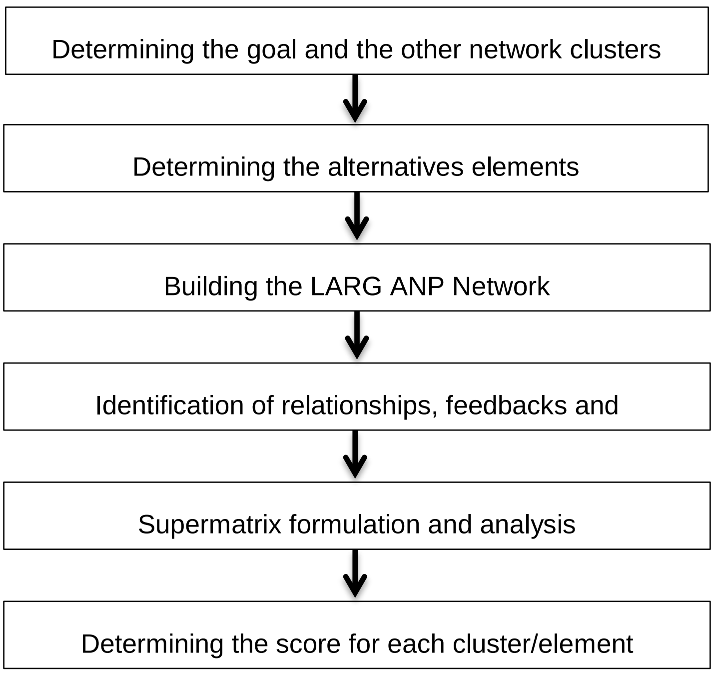


Figure 6.1 Various steps in LARG ANP model

In the application of ANP, software like, Ecnet, Super Decision, or mathematical program like Excel, Maple, Mathematica can be used. We chose to use Super Decision developed by William J. Adams of Embry Riddle Aeronautical University, Daytona Beach, Florida, working with Rozazann W. Saaty.

6.2.1 Application of LARG ANP methodology

LARG ANP best practices selection is a multicriteria problem. The first step in LARG ANP model is to construct the network by determining the clusters, elements and the relationships between them. In this research, LARG ANP model for prioritizing best LARG SCM practices comprises six clusters, as is shown in Fig. 6.2. Firstly is defined the main goal for LARG SCM best practices selection that meets the requirements of the decision-makers. The main criteria and sub-criteria are also identified at this stage by decision-makers. Following this identification, it is important to determine the alternative LARG SCM practices that can be included in the ANP model. Finally, the connection between the clusters is made.

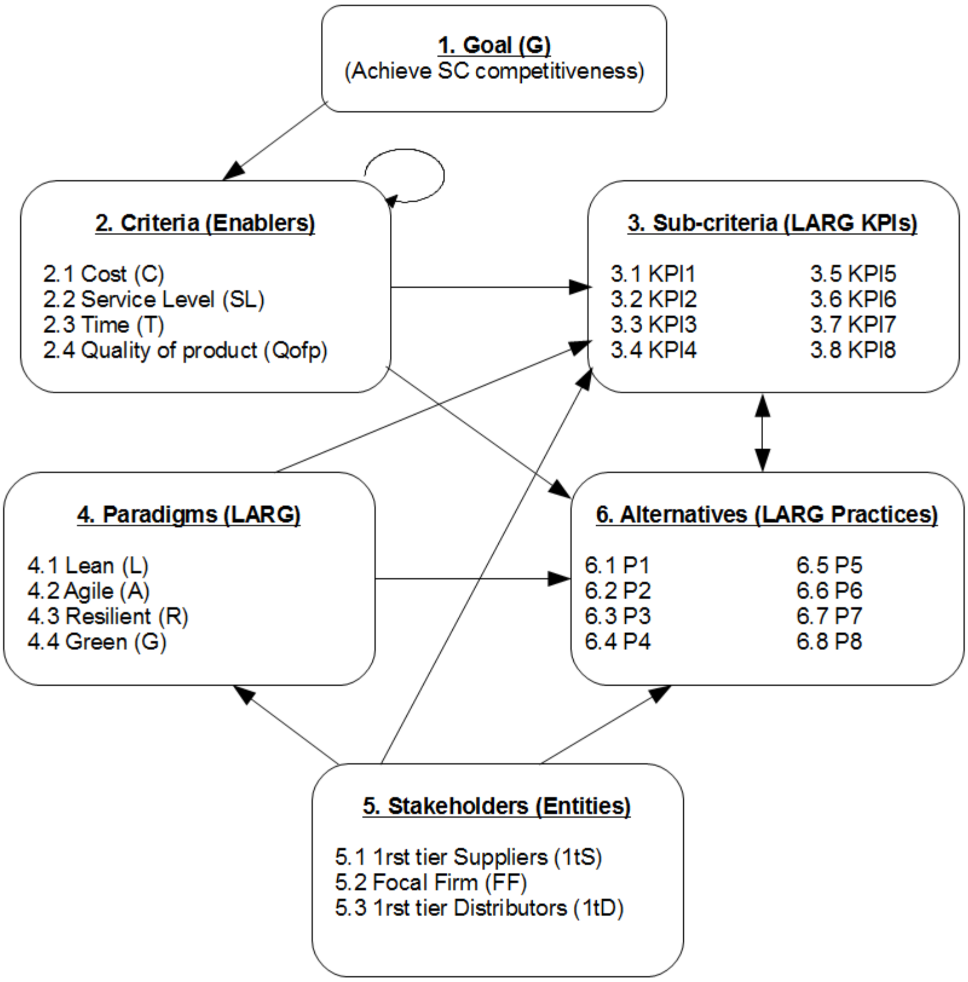


Figure 6.2 ANP model to select LARG best SCM practices.

As is shown in Fig 6.2, all clusters are connected by eight dependencies, one feedback and one inner dependencies. The main clusters are defined below:

(1) Goal (SC competitiveness) – this cluster contains only one element as the statement of the purpose for LARG SCM practice implies (i.e., refer to the objective of the SC). A supply chain must be competitive to survive in the global market and compete against other SCs.

(2) Criteria (enablers) – there are four main enabler criteria to assess the supply chain performance that have been included as nodes of this cluster: cost, service level, time, quality of product. The elements in this cluster represent the key enablers to achieve SC competitiveness. Each enabler contributes to the evaluation of the SC's performance, and a pairwise comparison is conducted between them in order to assess the relative importance of the criteria with respect to the goal (SC competitiveness). The connections to the goal cluster indicate that these four criteria will be used to evaluate the SC's performance. There are an inner dependencies in this cluster due to following the fact: if quality of product increases, the service level will increase and probably the cost of product will increase too; if an entity makes delivery outside of time, the service level will decrease and probably the cost increases too; if an entity introduces new product with high frequency, the service level can increases, but the quality of product can be not the desired; if a company respond rapidly and cost effectively to unpredictable changes, the service level increases and the cost may increases too.

(3) Sub-criteria (KPIs) – this cluster contains a list of potential LARG KPIs that can be used to measure the criteria of each of the enablers enablers. An inner dependency amongst the elements of this cluster can be also included, meaning that there are some KPIs that influence others. The three LARG KPIs identified in this cluster are: i) inventory cost; ii) order fulfillment rate; responsiveness to urgent deliveries.

(4) Paradigms (LARG) – this cluster comprises four SCM paradigms: Lean, Agile, Resilient, and Green. There can exist some inner dependency amongst elements of this cluster but it is not represented on the model due to study simplification. For example, the Lean paradigm requires low inventory level but the Resilient paradigm requires high inventory level. Being lean, with low inventory level, an entity can be green. If inventory levels are low, on the other hand, there will be fewer obsolete and/or out-of-date products.

(5) Stakeholders (Entities) – this cluster represents the three entity level considered in this study, "Supplier", "Focal Firm", and "Distributor". Is considered these to be the major agents in the automotive SC. This is an important cluster, as these agents are central to the decision-making process. Pairwise comparisons between these nodes can be undertaken to assess which entity is more or less important to the LARG SCM competitiveness. The connection with the practices/KPIs results from the fact that they have been implemented/used by companies contributing to improve the KPI value, and consequently the enabler's criteria. The same practice/KPI/paradigm can have different degrees of importance at each level of the chain. The connection with Paradigms cluster indicates that each entity can evaluate which paradigm is better.

(6) Alternatives (LARG practices) – this cluster includes the set of LARG SCM practices that can be implemented by the entities in the supply chain. The connection with Criteria cluster represents the effect of LARG SCM practice implementation on the enablers' criteria. The three main LARG SCM practices used for SC's performance evaluating, each with their own tradeoff and conflict, i) are strategic stock; ii) system of rapid response in case of emergencies and especial demands, iii) reuse materials and packages.

The arrows indicate relationships between elements in one cluster with elements in other clusters. In the Criteria cluster, especially, there are inner dependencies, because the elements within this cluster affect each other. Bidirectional arrow between Sub-criteria and Alternatives indicates feedback between these two clusters. The KPIs are used to evaluate the influence of practices implementation and the practices are implemented to improve the KPI values.

Validating the proposed conceptual LARG ANP model for selecting best practice/KPI/paradigm to improve SC competitiveness will be achieved by means of a case study in a real world automotive SC, presented in the next chapter.

Chapter 7 Case Study: Autoeuropa VW

The main objective of this case study is to validate the LARG ANP model proposed in previous chapter. The collection of data is conducted to this purpose. The validation of the proposed conceptual LARG ANP model for measuring and improving SC performance is achieved by development of case study in a real automaker, described below.

7.1 Volkswagen Group

The Volkswagen Group is one of the largest automakers in the world, with global headquarters in the city of Wolfsburg, Germany. This Group operates 62 factories around the world, and has 370.000 people involved on a daily basis in the production and/or delivery of more than 26.600 vehicles per day of more than 30 different models and different brands. The Volkswagen Group sells its products in over 150 countries and holds a top position in the global car market.

7.2 Volkswagen Autoeuropa

Volkswagen Autoeuropa (Autoeuropa VW) is a manufacturing company belonging to Volkswagen Group that works in Just in Time (JIT) system. It is located in the region of Palmela, Portugal, and began their effective production in 1995. The products of Volkswagen Autoeuropa are: VW Sharan (1995), SEAT Alhambra (1996), VW Eos (2006), VW Scirocco (2008), VW Sharan (2010), and the new SEAT Alhambra. Is important to say that Autoeuropa VW is one unit of production, i.e., does not sell the vehicles. In Portugal, who sells the vehicles are SIVA (importer of the mark Volkswagen in Portugal – for VW Sharan and VW Eos) and Seat Portugal (for SEAT Alhambra). VW scirocco is not sold in Portugal. The product design (car) is made in Germany, on Volkswagen AG.

The installed capacity is 197,800 vehicles per year, operating in three shifts per day. On average the production is 600 vehicles per day. VW Autoeuropa employed 3.207 people in 2010, with 2.000 these working at the industrial park in Palmela. The company has 671 suppliers (430 production suppliers and 241 logistics providers), of which 660 are European and 11, non-European – with the following geographical distribution: Portugal, Industrial Park (12); Portugal, other locations (67); rest of Europe (581); rest of world (11).

The production volume in last year (2010) is: VW sharan (23229 units), VW Eos (22775 units), VW Scirocco (45230 units) and SEAT Alhambra (10050 units). Most production is for external market, in 2010 for example, only 1,3% of production was destined to Portuguese market. The global sales volume of vehicles manufactured in Autoeuropa VW in 2010 was 1.646 (million €).

7.2.1 Data gathering for the model

In order to carried out the pairwise comparison between elements/clusters and determine the Relative Importance Weight (RIW) of these elements/clusters, a team of professionals in

Autoeuropa VW logistics department (the focal firm) was consulted. The objective was to profit from their perception of the LARG alternatives practices with respect to criteria and subcriteria targeting, SC' competitiveness. Data were gathered by means of semi-structured interviews in order to be able to discuss any doubts or misunderstandings about the questions and answers. Comprehensive questionnaires were used in this stage. Initially the objective was to involve other stakeholders (distributors and suppliers) in order to obtain their views and pairwise comparisons, but the accessibility to appropriate individuals among these stakeholders was extremely limited, and so the attempt was abandoned. An example of questionnaires used in this stage is presented in Annex 2.

Data were collected in logistics departments because such professionals are responsible for managing the entire SC from the perspective of the focal firm, meaning that these are the people who have insights into not only the focal firm, but also into distributors and suppliers. Other reason is that the collections of data in other tasks of the MIT Project, which the contributions were used in this thesis, were collected in the same department. So, the consistency is safeguarded.

The stage of data gathering was the most difficulty on the LARG ANP model because there are a lot of question to do. Often, the answers may not have time to respond calmly, so their judgments may not be the desired. After the data gathering, comparisons were carried out by the decision making team.

7.2.2 Pairwise comparison matrices between the elements and related weights

The next step is to conduct pairwise comparisons between clusters and elements. Pairwise comparison matrices are made according to the decision makers' answers by using the fundamental scale given in Table 3.1. The linguistic scale is used to compare two elements. The question exploring the pairwise comparisons is: with respect to a specific factor, which of a pair of factors is more important? After this question, is necessary to evaluate the degree of importance of the factor more important in relation to less important. For example, regarding SC competitiveness, which is more important, cost or service level? To what degree is the more important criterion of greater importance than the less important criterion? Pairwise comparisons are performed with respect to all the factors that have an impact on other factors within their own cluster or other clusters of the LARG network. Thus, the factors in a cluster are compared according to their influence on a factor in another cluster, to which they are connected, e.g., all factors in the cluster Criteria are compared according to their influence on the Goal cluster. To reflect interdependencies in the LARG network, pairwise comparisons among all the factors that influence others are conducted and these relationships are evaluated. As was done for the elements, the clusters that influence each other are pairwise compared to represent the weight of each cluster on the model. Table 7.1 and 7.2 summarize the overall information on pairwise comparisons, including all pairwise comparison matrices needed, the number of questions for each pairwise comparison matrix and an example question for each pairwise comparison for the elements and clusters comparison respectively.

All pairwise comparisons were performed by the responsible of logistics department, in focal firm.

Table 7.1 Overall information of elements pairwise comparison.

PairwComp of	With respect to	PWC matrices	Total PWC	Example PWC
1.Criteria elements	Goal	1	4(4 -1)/2 = 6	With respect to SC competitiveness, how much more important is cost when compared to service level
2.Criteria elements	Criteria	4	4*[3(3-1)] = 12	With respect to cost, how much more important is service level when compared to quality of product
3.Subcriteria elements	Criteria	4	4*[3(3-1)/2] = 12	With respect to cost, how much more important is inventory cost to measure cost when compared to responsiveness to urgent deliveries
4.Subcriteria elements	Paradigms	4	4*[3(3-1)/2] = 12	With respect to Lean paradigm, how much more important is KPI1 when compared to KPI2
5.Subcriteria elements	Stakeholders	3	3*[3(3-1)/2] = 9	With respect to Suppliers, how much more important is KPI1 when compared to KPI3
6.Subcriteria elements	LARG practices	3	3*[3(3-1)/2] = 9	To measure the influence of the implementation of P1, how much more important is KPI1 when compared to KPI2
7.Paradigms elements	Stakeholders	3	3*[4(4-1)/2) = 18	With respect to Focal Firm, how much more important is lean when compared to agile
8.Practices elements	Criteria	4	4*[3(3-1)/2] = 12	To improve the cost, how much more important is P1 when compared to P2
9.Practices elements	Subcriteria	3	3*[3(3-1)/2] = 9	To improve the KPI1 value, how much more important is P1 when compared to P3
10.Practices elements	Paradigms	4	4*[3(3-1)/2] = 12	With respect to Resilient paradigm, how much more important is P2 when compared to P3
11.Practices elements	stakeholders	3	3*[3(3-1)/2] = 9	With respect to Distributors, how much more important is P1 when compared to P3
Total		36	120	

As can be seen in Table 7.1, to carry out all LARG ANP pairwise comparison, would be necessary 36 matrices and 120 pairwise comparisons. The number of matrices and pairwise comparison would increase significantly if for example we increase the number of practices and KPIs. For example, if we had nine practices and nine KPIs, we would have more 12 matrices on the feedback connection between clusters LARG practices and LARG KPIs, more six for each cluster. The number of pairwise comparison for each dependency would be: 9*[9(9-1)/2] = 351.

The cluster pairwise comparison is made whenever there is more than one cluster influencing a given cluster. In LARG ANP model this situation occurs with three clusters: Criteria, Paradigms and Stakeholders.

Table 7.2 Overall information of clusters pairwise comparison.

PairwComp of	With respect to	PWC matrices	Total PWC	Example PWC
Criteria cluster	Criteria Cluster	1	1*[3(3-1)] = 3	With respect to criteria cluster, how much more influential is Subcriteria cluster when compared to LARG practices cluster
Subcriteria cluster				
LARG practices cluster				
Subcriteria cluster	Paradigms cluster	1	1*[2(2-1)/2] = 1	With respect to paradigms, how much more influential is Subcriteria cluster when compared to LARG practices cluster
LARG practices cluster				
Subcriteria cluster	Stakeholders cluster	1	1*[3(3-1)] = 3	With respect to stakeholders, how much more influential is paradigms cluster when compared to LARG practices cluster
Paradigms cluster				
LARG Practices cluster				
Total		3	7	

In evaluating the SC competitiveness, Cost (C), Service Level (SL), Time (T), and Quality of Product (QofP) were used as critical success factors. These four homogenous elements (Criteria cluster) have a link to Goal cluster indicating the influence they have on the SC competitiveness. Especially for Criteria cluster there are inner dependences, because the elements in this cluster affect each other; and there are two scenarios of pairwise comparisons in it. The first is with the Goal, to determine the relative influence that the criterion has in that regard, and the second is with the element in the cluster itself. Table 7.3 illustrates the pairwise comparisons between the four criteria with respect to Goal, judged by responsible of logistics department.

Table 7.3 Criteria pairwise comparison with respect to Goal.

Goal	(C)	(SL)	(T)	(QofP)
Cost (C)	**1**	1/7	1/8	1/4
Service Level (SL)	7	**1**	1	7
Time (T)	8	1	**1**	7
Quality of Product (QofP)	4	1/7	1/7	**1**

As can be seen in Table 7.3, for example, Service Level (SL) is judged “very strong” important than Cost (C), “equal” important than Time (T), and “very strong” important than Quality of Product (QofP). For each comparison matrix is necessary to derive the priorities of each element to find the eigenvalue vector (ω) and calculate the consistency ratio (CR).

The algorithm to estimating ω used in this research is synthesized as follows (C. W. Chang et al., 2009):

i. Sum the values in each column of the pairwise comparison matrix.
ii. Divide each element in a column by the sum of its respective column. The resultant matrix is referred to as the normalized pairwise comparison matrix.
iii. Sum the elements in each row of the normalized pairwise comparison matrix, and divide the sum by the n elements in the row. These final numbers provide an estimate of the

relative priorities for the elements being compared with respect to its upper level criterion. Priority vectors must be derived for all comparison matrices.

After this stage is necessary to calculate and assess the consistency ratio (CR). This ratio measures the logical inconsistency of the judgments and is calculated as follow:

$$CR = \frac{CI}{RI}$$

Where "CI" is consistency index and "RI" the random consistency index. CI (consistency index) of a matrix of comparisons is given by:

$$CI = \frac{(\lambda \max - n)}{(n-1)}$$

Where λ_{max} is the maximum eigenvalue and n is the matrix size. RI (random consistency index) is given by Table 7.4.

Table 7.4 Random consistency index (Thomas L. Saaty, 2001).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

Inconsistency may be considered a tolerable error in measurement and should be less than 0, 10 (10%) (T. L. Saaty, 2001).

Table 7.5 shows the relative priorities for the criteria pairwise comparison matrix with respect to the goal.

Table 7.5 Normalized criteria pairwise comparison matrix with respect to the goal.

Goal	**(C)**	**(SL)**	**(T)**	**(QofP)**	**Relative Weights**
Cost (C)	0,050	0,063	0,055	0,016	0,046
Service Level (SL)	0,350	0,438	0,441	0,459	0,422
Time (T)	0,400	0,438	0,441	0,459	0,434
Quality of Product (QofP)	0,200	0,063	0,063	0,066	0,098
Sum	1	1	1	1	1

As can be seen in Table 7.5, the criterion "Time" is more sustainable in achieving SC competitiveness with a score 0,434, followed by criteria "Service Level" with score 0,422 and Quality of Product (0,098). The criteria Cost has a low score (0,046) because the parameter is mainly controlled by Volkswagen headquarters in Germany, and the people in Autoeuropa VW do not recognize it as their main criterion. Also is Volkswagen that selects, for example, to which suppliers the focal firm should buy the components and at which cost.

To calculate the consistency index (CI), the normalized matrix has to be weighted. The resulting priorities vector is used to this purpose. The first element of this vector is multiplied by all the elements in the first column of that element, the second by all the elements in the second column and so on. To find the consistency vector, is necessary to sum the weighted elements in each row and divide it by the relative weights. Table 7.6 shows the weighted matrix with the consistency vector.

Table 7.6 Weighted criteria matrix and consistency vector.

Goal	(C)	(SL)	(T)	QofP	Sum	Relative Weights	Consistency vector
Cost (C)	0,046	0,060	0,054	0,024	0,185	0,046	4,022
Service Level (SL)	0,322	0,422	0,434	0,684	1,863	0,422	4,415
Time (T)	0,368	0,422	0,434	0,684	1,909	0,434	4,394
Quality of Product	0,184	0,060	0,062	0,098	0,404	0,098	4,133

The maximum eigenvalue (λ_{max}) is given by the average of the values of the consistency vector. In this case, λ_{max} is 4,241. The matrix size (n) is 4. The consistency random index (for n = 4) is 0,890. So the consistency index (CI) is given by:

$$CI = \frac{(\lambda \max - n)}{(n-1)} = \frac{(4{,}241 - 4)}{(4-1)} = 0{,}0803$$

$$CR = \frac{CI}{RI} = \frac{0{,}0803}{0{,}890} = 0{,}0902$$

The desired value of "CR" is less than 0,10, so the judgment in this matrix is consistency. Fig. 7.1 shows the computation results for this pairwise comparison matrix. As can be seen the results from the super decision software is very close to excel. Fig. 7.1 shows the relative priorities of criteria comparison with respect to "Goal", obtained on Super Decision Software.

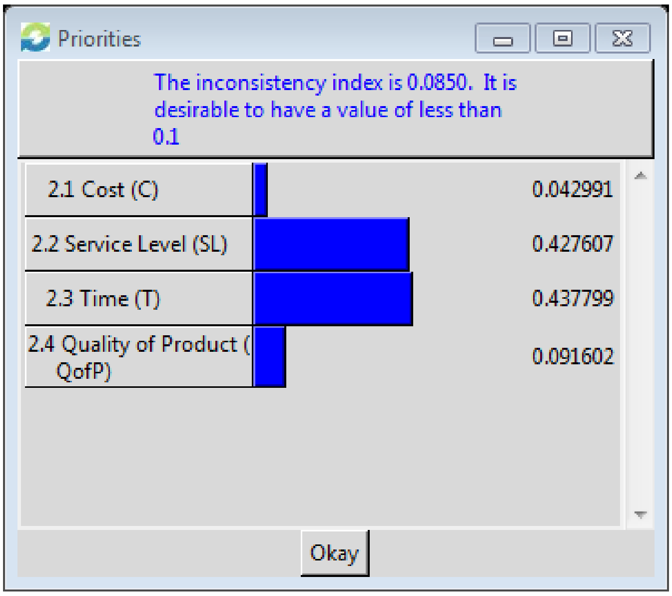


Figure 7.1 Priorities for criteria comparison with respect to "Goal", obtained on Super Decision.

By comparing the three sub-criteria (KPIs) based on each criterion, respondents were asked which KPI is more suitable to measure a given criterion. For example, to measure the SC cost, which KPI is preferred: Inventory cost or Responsiveness to urgent deliveries? As there are three KPIs, three pairwise comparisons are needed for each criterion (four matrices), totaling twelve (12) questions. Table 7.7 shows the sub-criteria pairwise comparison matrix with respect to Cost. Table 7.8 summarizes the priorities for the pairwise comparison matrices with respect to Cost, Service Level, Time and Quality of Product respectively.

Table 7.7 LARG KPIs pairwise comparison matrix with respect to cost.

With respect to Cost	IC	OFR	RUD	Priorities
Inventory cost (IC)	1	1/7	1/5	0,078
Order fulfilment rate (OFR)	7	1	1	0,487
Responsiveness to urgent deliveries (RUD)	5	1	1	0,435

λ_{max} = 3,013; CR = 0,0063

Table 7.8 LARG KPIs ranking with respect to each criteria.

Cost (C)		**Service Level (SL)**		**Time (T)**		**Quality of product (QofP)**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
OFR	0,487	RUD	0,646	RUD	0,689	NC	0,000
RDU	0,435	OFR	0,290	OFR	0,244	NC	0,000
IC	0,078	IC	0,064	IC	0,067	NC	0,000
λmax	3,013	**λmax**	3,074	**Λmax**	3,096	**λmax**	0,000
CR	0,0063	**CR**	0,064	**CR**	0,082	**CR**	0,000

NC = No Comparison

From Table 7.8, is possible to conclude that the KPIs “Order fulfillment rate” and “Responsiveness to urgent deliveries” score higher in measuring Cost, Service Level, and Time. None of these three indicators are appropriate to measure the Quality of product, so they are not comparable.

The next pairwise comparison matrix compares the cluster Sub-criteria (KPIs) with respect to each stakeholder (entities). Here, the objective is to find which KPI is more or less important to each entity. For example, with respect to the focal firm, which KPI is more suitable, “Inventory cost” or “Order fulfillment rate”? Table 7.9 shows the results of the pairwise comparison matrix for the sub-criteria (KPIs) with respect to focal firm. Due to limitations on obtaining responses from suppliers and distributors answers, only is presented the results for the focal firm.

Table 7.9 LARG KPIs pairwise comparison matrix with respect to focal firm.

With respect to focal firm	IC	OFR	RUD	Priorities
Inventory cost (IC)	1	1/5	1/7	0,074
Order fulfillment rate (OFR)	5	1	1/3	0,283
Responsiveness to urgent deliveries (RUD)	7	3	1	0,643

λ_{max} = 3,066; CR = 0,056

Analyzing the results of this matrix, the most important KPI in the perspective of focal firm is “Responsiveness to urgent deliveries”, with a score 0,643. “Inventory cost” continues to have a low score because focal firm does make stock - working, instead on a Just in Time (JIT) system.

The next pairwise comparison is between the clusters Sub-criteria and Paradigms. Here, the objective is to evaluate which KPI is more suitable in each paradigm. For example, with respect to Lean, which KPI is more important, “Order fulfillment rate” or “Responsiveness to urgent deliveries”? Table 7.10 summarizes the priorities of pairwise comparison between these two clusters.

Table 7.10 LARG KPIs ranking according to each paradigm.

Lean (L)		**Agile (A)**		**Resilient (R)**		**Green (G)**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
RUD	0,689	RUD	0,627	IC	0,455	NC	0,000
OFR	0,244	OFR	0,292	OFR	0,455	NC	0,000
IC	0,067	IC	0,081	RUD	0,091	NC	0,000
λmax	3,096	**Λmax**	3,095	**λmax**	3,000	**λmax**	0,000
CR	0,082	**CR**	0,082	**CR**	0,000	**CR**	0,000

NC = No Comparison

Looking at the results is possible to conclude that “Responsiveness to urgent deliveries” is the most important KPI for Lean and Agile paradigms, followed by “Order fulfillment rate”. “Inventory cost” is not important in the Lean paradigm because there is required zero inventories. On the contrary, in Resilient paradigm, “Inventory cost” is the most important KPI together with “Order fulfillment rate”. The KPI “Responsiveness to urgent deliveries” is the least important, since urgent deliveries are only necessary in the event of a lack of inventories or the planed order is not fulfilled.

To complete the pairwise comparison of Sub-criteria cluster, it is needed to compare this cluster to the LARG practices cluster. Table 7.11 shows the priorities of pairwise comparison between these two clusters.

Table 7.11 LARG KPIs ranking with respect to each practice.

Strategic stock		**SRR**		**RMP**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
IC	0,455	RUD	0,778	IC	0,778
OFR	0,455	OFR	0,111	OFR	0,111
RUD	0,091	IC	0,111	RUD	0,111
λ_{max}	3,000	λ_{max}	3,000	λ_{max}	3,000
CR	0,000	**CR**	0,000	**CR**	0,000

Analyzing Table 7.11 is possible to conclude that “Inventory cost” is the most appropriate KPI to measure the influence of practices “Strategic stock” and “Reuse materials and packages” with scores of 0,455 and o,778, respectively. On the contrary, it is the least important to “System of rapid response in case of urgencies and special demands” with a score (0,111). The best KPI to measure the influence of this practice is “Responsiveness to urgent deliveries”, score 0,778.

As is shown in Fig. 6.2 the LARG practices cluster (Alternatives) is influenced by the cluster Stakeholder making a pairwise comparison necessary between the alternatives (LARG practices) with respect to each entity. For example, in the perspective of the focal firm, which practice is more important to improve performance in given entity, “Strategic stock” or “System of rapid response in case of emergencies and especial demands”? Table 7.12 shows the results of pairwise comparison.

Table 7.12 LARG practices pairwise comparison with respect to focal firm.

With respect to focal firm	SS	SRR	RMP	Relative Weights
Strategic stock (SS)	1	1/3	5	0,283
System of rapid response in case of emergencies (SRR)	3	1	7	0,643
Reuse materials and packages (RMP)	1/5	1/7	1	0,074

λ_{max} = 3,066; CR = 0,056

According to the answers of the expert of the focal firm entity, the practice most important to the focal firm is “System of rapid response in case of emergencies and especial demands”, with a score of 0,643. Even though the focal firm does not work with inventories, some strategic stock is nevertheless needed in order to respond to unexpected disruptive shocks. Hence, “Strategic stock” is the second most important practice to focal firm, with a score of 0,283.

Next, the pairwise comparison is between the cluster LARG practices and Sub-criteria (LARG KPIs). This is a special relationship, as there is feedback between these two clusters. Thus, the pairwise comparison should be carried out in both directions. The first stage is to conduct pairwise comparison between the three practices with respect to each KPI. The question here is which practice is more suitable to improve a given KPI value, “Strategic stock” or “Reuse materials and packages? Table 7.13 shows the ranking of these pairwise comparisons. Pairwise comparison between the three KPI with respect to each practice is done.

Table 7.13 LARG practices ranking with respect to each KPI.

IC		**OFR**		**RUD**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
SS	0,455	NC	0,000	SRR	0,633
RMP	0,455	NC	0,000	SS	0,260
SRR	0,091	NC	0,000	RMP	0,106
λmax	3,000	**λmax**	0,000	**λmax**	3,039
CR	0,000	**CR**	0,000	**CR**	0,033

NC = No Comparison

The most important practices for improving “Inventory cost” are “Strategic stock” and “Reuse material and packages” (both with a score of 0,455). None of the practices is appropriate for improving “Order fulfillment rate”, so there is no comparison. To improve “Responsiveness to urgent deliveries”, the most important practice is “System of rapid response” (score 0,633), followed by “Strategic stock” (score 0,260).

Pairwise comparisons between the clusters “Criteria” and “LARG practices” are then performed. As is shown in Fig. 6.2 the Criteria cluster is influenced by the other entire cluster (LARG practices), meaning that the alternatives practices are compared with respect to all criteria (Cost, Service Level, Time, and Quality of product). The question is, for example: which practice is more important to improve the criteria cost, practice “Strategic stock” or “Reuse materials and packages”? Table 7.14 illustrates the priorities of these pairwise comparisons.

Table 7.14 LARG practices ranking with respect to each criteria.

Cost (C)		**Service Level (SL)**		**Time (T)**		**Quality of product (QofP)**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
SS	0,665	SRR	0,739	SS	0,723	SRR	0,777
SRR	0,231	SS	0,179	SRR	0,206	RMP	0,155
RMP	0,104	RMP	0,082	RMP	0,070	SS	0,069
λmax	3,087	**Λmax**	3,102	**λmax**	3,096	**λmax**	3,082
CR	0,075	**CR**	0,088	**CR**	0,083	**CR**	0,071

To improve Cost and Time, the best practice is “Strategic stock” (score 0,665), followed by “System of rapid response” (0,231). If the company has some strategic stock, it will respond to customer demand in less time and at less cost. Regarding Service level and Quality of product, the practice most appropriate is “System of rapid response” with scores of 0,739 and 0,777 respectively.

The next pairwise comparison is between clusters Paradigms and LARG practices. The question in this pairwise comparison is, for example: which practice is more important for lean, “Strategic stock” or “System of rapid response”? Table 7.15 shows the priorities of these comparisons.

Table 7.15 LARG practices ranking with respect to each paradigm.

Lean (L)		**Agile (A)**		**Resilient (R)**		**Green (G)**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
SRR	0,739	SRR	0,487	SS	0,689	RMP	0,818
SS	0,179	SS	0,435	SRR	0,244	SS	0,091
RMP	0,082	RMP	0,078	RMP	0,076	SRR	0,091
λmax	3,012	**Λmax**	3,013	**Λmax**	3,096	**λmax**	3,000
CR	0,088	**CR**	0,011	**CR**	0,082	**CR**	0,000

Analyzing the previous Table, the practice “System for rapid response” (score 0,739) is more Lean than both “Strategic stock” (score 0,179) and “Reuse materials and packages” (0,082). Note that “Strategic stock” is the second, only because is “strategic”. “Strategic stock” may allow minimizing Cost more than “Reuse materials and packages”. In the Agile paradigm, the most important is also “System for rapid response” with a score of 0,487. This is clearly an Agile practice. “Strategic stock” has a good score (0,435) when compared with “System for rapid response”, meaning that if a company has some stock, it will be able to respond more quickly to changes in demands. In the Resilient paradigm, the most important practice is clearly “Strategic stock” (score 0,689). The Resilient paradigm requires a high inventory level in order to respond to unexpected disruptive shocks. In this paradigm, “System for rapid response” (0,244) is more important than “Reuse materials and packages” (0,076). Finally, in the Green paradigm, “Reuse materials and packages” is the practice considered to be most important, with a score of 0,818.

Following, the pairwise comparison is between the cluster Paradigms and Stakeholders. The issue here is to determine which paradigm is more important to a given entity, for example, with respect to the focal firm, which paradigm is more important, Lean or Resilient? Table 7.16 shows the results of pairwise comparison between these two clusters.

Table 7.16 LARG paradigms pairwise comparison with respect to focal firm.

Focal firm	**(L)**	**(A)**	**(R)**	**(G)**	**Relative Weights**
Lean (L)	1	1/5	1	5	0,171
Agile (A)	5	1	5	7	0,606
Resilient (R)	1	1/5	1,0	5	0,171
Green (G)	1/5	1/7	1/5	1	0,051

λmax = 4,212; CR = 0,079

According to the responses of the expert, the most important paradigm in the focal firm entity is Agile, with a score very high relative to other paradigms (0,606). Lean and Resilient were considered to be of equal importance (0,171). The least important paradigm in the focal firm is Green (0,051).

Figure 6.2 shows that there are inner dependencies in the cluster Criteria, meaning that are needed pairwise comparison between the elements of this cluster with respect to his each element. The question here is, for example: with respect to cost, which criteria influences more, Service level or Time, Service level or Quality of product, Time or Quality of product? Table 7.17 summarizes the results for the inner dependencies pairwise comparison in the Criteria cluster.

Table 7.17 Criteria ranking of pairwise comparison with respect to each criteria.

Cost (C)		**Service Level (SL)**		**Time (T)**		**Quality of product (QofP)**	
Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities
QofP	0,746	QofP	0,467	SL	0,739	SL	0,633
SL	0,134	C	0,467	C	0,179	T	0,260
T	0,134	T	0,067	QofP	0,082	C	0,106
λmax	3,013	**λmax**	3,000	**λmax**	3,102	**λmax**	3,039
CR	0,011	**CR**	0,000	**CR**	0,088	**CR**	0,033

The criterion that influences Cost the most is “Quality of product” (0,746), followed by “Service level” (0,134), and “Time” (0,134). If the Quality of product increases, the Cost will increase too. Hence, if a client is not satisfied or if the supplier does deliver on time, it can represent additional cost. In Service level, the most important criterion is “Quality of product” (0,467), followed by Cost (0,467), and “Time” (0,067), meaning that a client will be more satisfied if the product has the desired quality than is cheaper on time. Looking at Time, the criterion that influences it the most is “Service level” (0,739), followed by “Cost” (0,179), and “Quality of product” (0,082). In Quality of product, the most important criterion is “Service level” (0,633), followed by “Time” (0,260), and “Cost” (0,106).

After conducting all pairwise comparisons in the model, it was developed the comparisons between clusters that influence a given cluster in order to establish the weights in a cluster matrix, seeking to calculate the weight priorities of their impact on each cluster. Weights derived from this process will be used to weight the elements in corresponding column blocks of the supermatrix corresponding to the control criteria. Clusters pairwise comparisons show how much clusters are influenced by each other. The process is the same when is compared the elements. Whenever there is more than one cluster that influences a given cluster, pairwise comparison is necessary. If there are not conducted this pairwise comparison, is assumed that all clusters have the same weight. Fig. 7.2 illustrates the cluster matrix with the relative priorities of all clusters pairwise comparisons, taken from the Super Decision software.

Super Decisions Main Window: LARG_ANP_Model_Super_Decision.mod: Cluster Matrix View

Cluster Node Labels	1. Goal (G)	2. Criteria (Enablers)	3. Sub-criteria (LARG KPIs)	4. Paradigms (LARG)	5. Stakeholders (Entities)	6. LARG practices
1. Goal (G)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2. Criteria (Enablers)	1.000000	0.188406	0.000000	0.000000	0.000000	0.000000
3. Sub-criteria (LARG KPIs)	0.000000	0.080975	0.000000	0.125033	0.333333	1.000000
4. Paradigms (LARG)	0.000000	0.000000	0.000000	0.000000	0.333333	0.000000
5. Stakeholders (Entities)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6. LARG practices	0.000000	0.730619	1.000000	0.874967	0.333333	0.000000

Done

Figure 7.2 Cluster matrix.

7.2.3 Supermatrix formulation and analysis

The values obtained from pairwise comparisons (in the preceding step) are used in the formation of the supermatrix structure. This matrix shows a local priority vector derived from the paired comparisons that represent the impact of a given set of elements within a component on another element in the system (T. Saaty, 2004). The supermatrix represents the influence of an element (on the left of the matrix) on another element at the top at the matrix. This matrix shows the interdependency and relative importance of each previously-defined element. The initial supermatrix must be transformed to a matrix in which of its columns sums up to unity (Promentilla, Furuichi, Ishii, & Tanikawa, 2008). For this reason, this matrix must be normalized using the weight of the cluster to achieve the unit columns (Özgen & Tanyas, 2011). In this way it is possible to achieve the stochastic or weighted supermatrix (T. L. Saaty & Vargas, 1998, 2006a).

The supermatrix is computed in three steps (Pangeran & Pribadi, 2010): the first step is the unweighted supermatrix created directly from all local priorities derived from pairwise comparisons among elements influencing each other. The second step, the weighted supermatrix is calculated by multiplying the values of the unweighted supermatrix with their affiliated cluster weights. The last step is composition of a limiting supermatrix, which is created by raising the weighted supermatrix powers until it stabilizes. Stabilization is achieved when all the columns in the supermatrix corresponding to any node have the same values. All the steps in LARG ANP model were conducted using Super Decision software. Fig. 7.3 –7.5 show the unweighted supermatrix, weighted supermatrix and limit supermatrix respectively.

Super Decisions Main Window: LARG_ANP_Model_Super_Decision.mod: Unweighted Super Matrix

	1.1 SC ~	2.1 Cos~	2.2 Ser~	2.3 Tim~	2.4 Qua~	3.1 Inv~	3.2 Ord~	3.3 Res~	4.1 Lea~	4.2 Agi~	4.3 Res~	4.4 Gre~	5.1 1rs~	5.2 Foc~	5.3 1rs~	6.1 Str~	6.2 Sys~	6.3 To ~
1.1 SC ~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.1 Cos~	0.04299	0.00000	0.46669	0.17135	0.10473	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.2 Ser~	0.42761	0.13360	0.00000	0.75041	0.63699	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.3 Tim~	0.43780	0.11939	0.06668	0.00000	0.25828	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.4 Qua~	0.09160	0.74701	0.46664	0.07825	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3.1 Inv~	0.00000	0.07783	0.06226	0.06434	0.33333	0.00000	0.00000	0.00000	0.06434	0.07796	0.45454	0.33333	0.33333	0.07193	0.33333	0.45454	0.11112	0.77778
3.2 Ord~	0.00000	0.48676	0.28505	0.23704	0.33333	0.00000	0.00000	0.00000	0.23704	0.28719	0.45454	0.33333	0.33333	0.27894	0.33333	0.45454	0.11113	0.11111
3.3 Res~	0.00000	0.43541	0.65269	0.69861	0.33333	0.00000	0.00000	0.00000	0.69861	0.63485	0.09091	0.33333	0.33333	0.64913	0.33333	0.09091	0.77775	0.11111
4.1 Lea~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.25000	0.16545	0.25000	0.00000	0.00000	0.00000
4.2 Agi~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.25000	0.62084	0.25000	0.00000	0.00000	0.00000
4.3 Res~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.25000	0.16545	0.25000	0.00000	0.00000	0.00000
4.4 Gre~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.25000	0.04826	0.25000	0.00000	0.00000	0.00000
5.1 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.2 Foc~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.3 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6.1 Str~	0.00000	0.67381	0.17136	0.73338	0.06579	0.45454	0.33333	0.25827	0.17136	0.43539	0.69861	0.09091	0.33333	0.27894	0.33333	0.00000	0.00000	0.00000
6.2 Sys~	0.00000	0.22554	0.75039	0.19907	0.78540	0.09091	0.33333	0.63700	0.75039	0.48679	0.23704	0.09090	0.33333	0.64913	0.33333	0.00000	0.00000	0.00000
6.3 To ~	0.00000	0.10065	0.07825	0.06754	0.14881	0.45454	0.33333	0.10473	0.07825	0.07782	0.06434	0.81819	0.33333	0.07193	0.33333	0.00000	0.00000	0.00000

Figure 7.3 Unweighted supermatrix.

Super Decisions Main Window: LARG_ANP_Model_Super_Decision.mod: Weighted Super Matrix

	1.1 SC ~	2.1 Cos~	2.2 Ser~	2.3 Tim~	2.4 Qua~	3.1 Inv~	3.2 Ord~	3.3 Res~	4.1 Lea~	4.2 Agi~	4.3 Res~	4.4 Gre~	5.1 1rs~	5.2 Foc~	5.3 1rs~	6.1 Str~	6.2 Sys~	6.3 To ~
1.1 SC ~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.1 Cos~	0.04299	0.00000	0.08793	0.03228	0.01973	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.2 Ser~	0.42761	0.02517	0.00000	0.14138	0.12001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.3 Tim~	0.43780	0.02249	0.01256	0.00000	0.04866	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.4 Qua~	0.09160	0.14074	0.08792	0.01474	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3.1 Inv~	0.00000	0.00630	0.00504	0.00521	0.02699	0.00000	0.00000	0.00000	0.00805	0.00975	0.05683	0.04168	0.11111	0.02398	0.11111	0.45454	0.11112	0.77778
3.2 Ord~	0.00000	0.03941	0.02308	0.01919	0.02699	0.00000	0.00000	0.00000	0.02964	0.03591	0.05683	0.04168	0.11111	0.09298	0.11111	0.45454	0.11113	0.11111
3.3 Res~	0.00000	0.03526	0.05285	0.05657	0.02699	0.00000	0.00000	0.00000	0.08735	0.07938	0.01137	0.04168	0.11111	0.21638	0.11111	0.09091	0.77775	0.11111
4.1 Lea~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08333	0.05515	0.08333	0.00000	0.00000	0.00000
4.2 Agi~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08333	0.20695	0.08333	0.00000	0.00000	0.00000
4.3 Res~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08333	0.05515	0.08333	0.00000	0.00000	0.00000
4.4 Gre~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08333	0.01609	0.08333	0.00000	0.00000	0.00000
5.1 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.2 Foc~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.3 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6.1 Str~	0.00000	0.49230	0.12520	0.53582	0.04807	0.45454	0.33333	0.25827	0.14994	0.38095	0.61126	0.07954	0.11111	0.09298	0.11111	0.00000	0.00000	0.00000
6.2 Sys~	0.00000	0.16478	0.54825	0.14544	0.57383	0.09091	0.33333	0.63700	0.65656	0.42592	0.20740	0.07954	0.11111	0.21638	0.11111	0.00000	0.00000	0.00000
6.3 To ~	0.00000	0.07354	0.05717	0.04935	0.10873	0.45454	0.33333	0.10473	0.06847	0.06809	0.05630	0.71589	0.11111	0.02398	0.11111	0.00000	0.00000	0.00000

Figure 7.4 Weighted supermatrix.

Super Decisions Main Window: LARG_ANP_Model_Super_Decision.mod: Limit Matrix

	1.1 SC ~	2.1 Cos~	2.2 Ser~	2.3 Tim~	2.4 Qua~	3.1 Inv~	3.2 Ord~	3.3 Res~	4.1 Lea~	4.2 Agi~	4.3 Res~	4.4 Gre~	5.1 1rs~	5.2 Foc~	5.3 1rs~	6.1 Str~	6.2 Sys~	6.3 To ~
1.1 SC ~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.1 Cos~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.2 Ser~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.3 Tim~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2.4 Qua~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
3.1 Inv~	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282	0.22282
3.2 Ord~	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797	0.11797
3.3 Res~	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921	0.15921
4.1 Lea~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.2 Agi~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.3 Res~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.4 Gre~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.1 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.2 Foc~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5.3 1rs~	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6.1 Str~	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173	0.18173
6.2 Sys~	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100	0.16100
6.3 To ~	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728	0.15728

Figure 7.5 Limit matrix.

7.2.4 LARG ANP model final priorities

After the limit supermatrix is achieved, the final task is to rank the elements in the LARG ANP model based on its priorities. As the result of the model, Fig. 7.6 illustrates the final score for each element considered. As can be seen, there are no inconsistency, meaning that all pairwise comparisons are consistent.

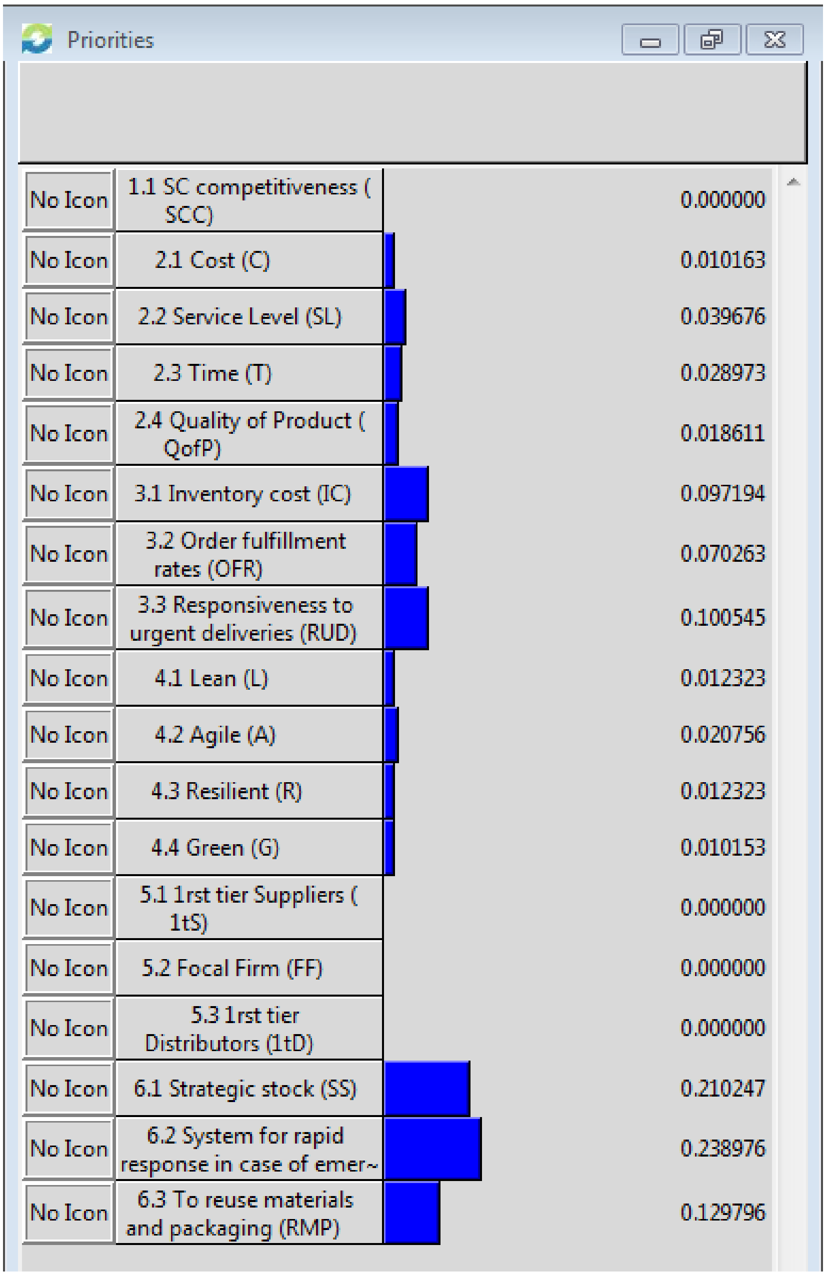


Figure 7.6 Experimental final priorities for LARG ANP model.

7.2.5 Discussion of the results of the LARG ANP model

Fig. 7.6, illustrates that in the Autoeuropa VW case study the most important criteria for achieving SC competitiveness is Service level, followed by Time, Quality of product, and finally, Cost. This means that in Autoeuropa VW's market, it is the customer base that defines the SC business process continuity. Customers' need is the most important factor, and these needs must be met. Furthermore, if customers are completely satisfied, it may signify that cost, time and quality of product are the desired. In sub-criteria cluster (LARG KPIs) the most important indicator is Responsiveness to urgent deliveries, followed by Inventory cost and Order fulfillment rates respectively. Responsiveness to urgent deliveries is in fact an important indicator in focal firm because there are many cases of difficulties and exceptional demands. Although the focal firm works in JIT, some "strategic stock" must be kept on hand in order to prevent losses resulting from possible SC shocks. Regarding paradigms, the most appropriate one is Agile (0, 020756), followed by Lean and Resilient (each with the same score of 0, 012323). Green is the least important paradigm (0, 010153). Due to increasing changes in marketplace and customer requirements, supply chains need to be increasingly Agile in order to gain competitiveness. The agile paradigm is associated with speed in responding to changes in demand, and it is a paradigm that is directly associated with customers. In today's business environment, customer satisfaction is a key factor. From the results of the model, the Service level and Agile paradigm lead the ranking, each one in their cluster, meaning that the results have some coherence. The Lean paradigm is an important one, but it is not in the first place in the ranking. This is likely due to the fact that of in an advanced SC, such as Autoeuropa VW, the processes are already highly standardized and that it is often difficult to realize considerable improvement regarding cost. However, processes that add no value must be continually eliminated. The Resilient paradigm was considered to have the same importance as Lean. For the same reason, i.e., due to standardization of SC processes, it is difficult to constantly address problems in the SC. The Green paradigm is the least important because supply chains and their entities consider it as a way to gain approval from the entities controlling the environmental impacts and society, and efforts usually target little more than minimum requirements. Many of the "Green" strategies that firms adopt are in fact implemented with the aim of reducing costs, and not in response to environmental issues or legislation.

Finally, for the LARG practices, "System for rapid response in case of emergencies and especial demands" was judged to be the most important, followed by "Strategic stock" and "Reuse materials and packages". Once again, it means that the results of the model are coherent, because SRR is an Agile practice and contributes customer satisfaction. "Strategic stock" appears in second place in the ranking of practices, as in the Resilient paradigm. This practice may also be considered as Lean only due to be "strategic".

7.2.6 Advantages and limitations of LARG ANP model

The LARG ANP model developed in this research is revealed to be an interesting approach for assist managers in decision-making with regard to Lean, Agile, Resilient and Green Supply Chain Management. It is possible to conclude that it is a dynamic and flexible model, as it allows practitioners to relate various factors at the same time and select the desired factor according to other factors, as illustrated in the Autoeuropa VW case study. However, it presents some limitations, derived mainly from the number of pairwise comparisons that are needed. Respondents complained that reply to all pairwise questionnaires was excessively time consuming and also that the process was mentally fatiguing. Another limitation is the (advised) constraint to have no more than nine elements in a given cluster, meaning that should not be compared more than nine practices and KPIs at the same time, which in turn implies an *a priori* selection of elements. A final limitation is related to the lack of consistency that may appear in pairwise comparisons. Judgments must then be reviewed by the respondent to solve this problem.

Chapter 8 Conclusions and Recommended Future Work

Effective supply chain management is one of the keys to survival in a market that is increasingly volatile and turbulent. In fact, the decision-making in selecting the appropriate strategies/practices/KPIs is a daunting challenge to SC managers. A poor decision can threaten the success of the chain. The LARG ANP model offers SC managers an excellent tool to assist their decision-making by selecting the best practice, KPI, paradigm, or competitiveness enablers.

This research attempts to cover the lack of an integrated information platform for lean, agile, resilient and green SCM paradigms. The design of a LARG Supply Chain consists in a strategic advance towards the global market but requires the ability to make decisions, adequate to the structure of the business and its business partners. The main objective is to give SC managers an integrated platform to assist the SCM. The LARG SCM information platform system has many advantages. First, it proposes a simple model to facilitate the data interchange between SC entities and within departments. Second, the languages used to model this information system are easy to be understudied by the business agents. Other important advantage of this system is that provides previously a static view of the system, the system requirements and the core SCM business process. In the use case diagrams, all potential users have been identified and the system has been modeled according to their necessity. It is noted that by having a LARG SCM information system does not mean that the competitiveness of the chain is better, is necessary an effective use of the system to get better results and performance improvement. Information sharing through the use of Information Technology (IT) and collaboration are crucial for effective supply chain management, but the simply use of IT applications is not itself enough to realize the benefits of information sharing. With the LARG platform, it is possible to store data to assist the decision-making in LARG ANP process.

Collaboration between entities in SC through the use of IT may be the key of success of SCs. In automotive SC as is this case, there is one supplier per component, is no reason for competition spirit, no collaboration and no sharing of information and knowledge.

In relation to the ANP, it proved to be a powerful decision-making method for prioritizing the best factors in the LARG context and coping with vagueness and ambiguity of its elaborated features and interrelatedness. The ANP approach developed in this research offers the ability to prioritize enablers, KPIs, practices and paradigms in complex situations, helping to overcome AHP limitations derived from ignoring feedbacks and inner dependencies. The main disadvantages of ANP are the large number of pairwise comparisons needed and the inconsistency problems. In this research, when the questionnaire was conducted some inconsistency was present. The judgments had to be reviewed by the respondent to solve this problem. After this review all matrix was consistency and the model computation was conducted.

In the case study of Autoeuropa VW, used for exploratory demonstration purposes of the LARG ANP model, according to the judgment of the focal firm professionals, “Service level”, “Responsiveness to urgent deliveries”, “System for rapid response in case of emergencies, problems or especial demands” and Agile have been advocated as the best elements, in each of their respective clusters.

Future work will be necessary to expand validations and to include more than three practices and KPIs. Also, is important to evaluate perceptions from various entities (first-tier suppliers and distributors) within the supply chain and compare the results.

Finally, it would be interesting to develop and validate the model in the context of other industries, such as aircraft manufacturing and ship construction/repair to compare those findings with the ones reported here. An interesting future work is to find the calculation formulas for each metric (KPI) and a calculation formulas for LARG index using the priorities of LARG ANP model.

Other future work is to apply the axiomatic theory design to develop a framework design toolkit for ICT-based platforms that deliver high levels of Business Interoperability that sustains product design, development and production in an industrial context of lean, agile and green industrial ecosystems.

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Annex

Annex 1 List of previous LARG practices identified

Annex 1.1 List of Lean practices

	LEAN PRATICES
First tier - supplier - focal firm	Geographical concentration
	Just-in-Time
	Outsourcing/Indigenous production
	Procurement consolidation
	Profit sharing
	Single sourcing and lean purchasing
	Supplier certification
	Supplier evaluation and rating
	Supplier involvement in product development
	Supplier relationship/long-term business relationship
	Supplier training and development
	supplier's in plant representative
	To delivery materials directly to the point of use
	To used EDI to share information
Focal Firm	Built-in quality system
	Cellular manufacturing
	Concurrent engineering
	Cycle/setup time reduction
	Design for manufacturability
	Frequent quick changeovers
	High-involvement work systems
	Innovative performance appraisal
	JIT
	Lot-size reduction
	Mass customization
	Multifunctional workforce
	Parts/work standardization
	Postponement
	Product modularity
	Production Scheduling improvement
	Pull flow control
	The level production and scheduling
	To use common parts
	To use of bar coding and Radio Frequency Identification (RFID)
	To used production planning and control technology (ERP)
	Total productive maintenance

	Total quality management
	Use of standard or bar codec containers
	WIP reduction
First tier - Focal firm - Customer	Cross-docking or compound delivery approach for great distances
	Customer relationships
	Delivery performance improvement
	Demand stabilization
	JIT
	Milk run or circuit delivery for smaller distances
	Order/shipment tracking/notice
	To capture the demand of the customers in real time (POS)
	To use third-party logistics for transportations
	To used EDI to share information
	Vendor Management Inventory (VMI)

Annex 1.2 List of Agile practices

	LEAN PRATICES
First tier - supplier - focal firm	Use of IT to coordinate/integrate activities in design and development
	Use of IT to coordinate/integrate activities in procurement
	Ability to change quantity of supplier's order
	Ability to change delivery times of supplier's order
	Speed in reducing development cycle time
	First choice partner
Focal Firm	Use of IT to coordinate/integrate activities in manufacturing
	Integrated supply chain/value stream/virtual corporation
	Centralized and collaborative e planning
	Rapidly reconfigure the production process
	To produce in large or small batches
	To accommodate changes in production mix
	To reduce manufacturing throughput times to satisfy customer delivery
	To reduce development cycle times
	To minimize setups times and product changeovers
	Organized along functional lines
	Facilitate rapid decision making
First tier - Focal firm - Customer	Use of IT to coordinate/integrate activities in logistics and distribution
	To alter deliver schedules to meet customer requirement
	To increase frequencies of new product introductions
	Speed in adjusting delivery capability
	Speed in improving customer service
	Speed in improving delivery reliability
	Speed in improving responsiveness to changing market needs
	Speed in increasing levels of product customization
	To capture demand information immediately
	Retain and grow customer relationships
	Products with substantial added value for customers

Annex 1.3 List of Resilient practices

	RESILIENT PRATICES
First tier - supplier - focal firm	Sourcing strategies to allow switching of suppliers
	Committing to contracts for material supply (buying capacity whether it is used or not)
	Flexible supply base/flexible sourcing
	Developing visibility to a clear view of upstream inventories and supply conditions
Focal Firm	Designing production systems that can accommodate multiple products and real-time changes
	Multi-skilled workforce
	Excess of capacity requirements
	Postponement
	Minimal batch sizes
	Strategic stock
	Make-and-buy trade-off
	Strategic disposition of additional capacity and/or inventory at potential "pinch points"
	Developing visibility to a clear view production and purchasing schedules
	Creating total supply chain visibility
	Lead time reduction
	Process and knowledge back-up
	Supply chain risk management culture
	Developing collaborative working across supply chains to help mitigating risk
First tier - Focal firm - Customer	Maintaining a dedicated transit fleet
	Flexible transportation
	Silent product rollover
	Developing visibility to a clear view of downstream inventories and demand conditions
	Demand-based management

Annex 1.4 List of Green practices

	GREEN PRATICES
First tier - supplier - focal firm	Certification of suppliers' environmental management systems
	Conducting joint planning to anticipate and resolve environment-related problems
	Environmental collaboration with suppliers
	Environmental monitoring upon suppliers
	Green procurement/sourcing
	Prequalification of suppliers
	Providing design specification to suppliers that include environmental requirements for purchased item
	Source materials from environmentally/ethically sources
	Suppliers' ISSO 14000 certification
	To communicate to suppliers environmental and/or ethical criteria for goods and services
	Second-tier supplier environmentally friendly practice evaluation
	To encourage suppliers to take back packaging
	To use green purchasing or logistics guideline
	To use recyclable pallet to delivery materials
	To work with product designers and suppliers to reduce and eliminate product environmental impacts
	Working with industry peers to standardize requirements (for suppliers and purchasing items)
Focal Firm	Applying life cycle assessment to conduct eco-reports
	Better use of natural resources
	Collaboration on products recycling with industry peers
	Cross-functional cooperation for environmental improvements
	Commitment of GSCM from senior managers
	Design of products for reduced consumption of material and energy
	Design of products to avoid or reduce use of hazardous of products and/or their manufacturing process
	Energy efficiency measures for lighting
	Environmental Management System (SEM)
	Environmentally friendly raw materials
	Filters and controls for emissions and discharges
	Green design (eco-design)
	Green innovation
	Green operations
	Internal recycling of materials within the production phase
	ISSO 14001 certification
	Investment recovery (sale) of excess inventories/materials
	Joining local recycling organizations
	Recycling workplace materials (toners, paper, packing wastes, water, solid wastes)
	Reduction in raw material (i.e. the use of recycled material) for product manufacturing
	Risk prevention systems to cover possible environmental accidents and emergencies
	Support for GSCM from mid-level managers
	Sale of scrap and used materials
	to decrease the consumption of hazardous/toxic materials

	To design products for dis-assembly
	To enhance environmental performance
	To integrate total quality environmental management (TQEM) into planning and operation processes
	To minimize waste
	To reduce energy consumption
	To reuse/recycling materials and packaging
	To use life cycle assessment to reduce the products environmental burden
	To use life cycle assessment for product design
	To use standardized components to facilitate their reuse
	Total quality environmental management
First tier - Focal firm - Customer	Cooperation with customer for eco-design
	Cooperation with customers for cleaner production
	Customers return our original packaging or pallet systems
	Discuss changes in current packaging with the customers
	Eco-labeling
	Environmental collaboration with the customer
	Environmental monitoring by the customer
	Environmentally friendly packaging (green packaging)
	Formal policy on green logistics/transport
	Reverse logistics
	To plan the vehicles routes to reduce environmental impacts
	To use of environmentally-friendly transportation
	To work with customers to change product specifications

Annex 2 Examples of questionnaires used in gathering data

Annex 2.1 Questionnaire of pairwise comparison of Criteria elements (enablers) according to SC competitiveness

Questionnaire 1 (comparison enablers/SC competitiveness)

This questionnaire has as objective assist a research that intend to study and compare a set of Criteria/enablers (Cost, Service Level, Time, and Quality of Product) aiming automotive SC competitiveness.

Your contribution is very important to development of this research. Please accept contribute by completing this questionnaire.

A - Enterprise characterization

1.0 Enterprise name: Volkswagen Autoeuropa

- 1.1 Country: Portugal
- 1.2 Business sector:
- 1.3 Number of employees:
- 1.4 Main product manufactured: Automobile (car)
- 1.5 Main customer (s) activities:
- 1.6 Position of person that complete this questionnaire: Logistics department responsible
- 1.7 Name of person that complete this questionnaire (optional):
- 1.8 Contact (e-mail):
- 1.9 How is positioned your firm in the automotive SC?

Fornecedor de 4ª linha	**Fornecedor de 3ª linha**	**Fornecedor de 2ª linha**	**Fornecedor de 1ª linha**	**Empresa Focal (Montadora)**	**Cliente de 1ª linha**	**Cliente de 2ª linha**
☐	☐	☐	☐	☒	☐	☐

B – Comparison of Criteria (enablers) according to SC competitiveness

Compare the criteria listed below, according to competitiveness of automobile SC.

B1 Which criteria is more important to competitiveness of automobile SC?

Cost	☐
Service Level	☐

B1.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which criteria is more important to competitiveness of automobile SC?

Cost	☐
Time	☐

B2.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which criteria is more important to competitiveness of automobile SC?

Cost	☐
Quality of Product	☐

B3.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B4 Which criteria is more important to competitiveness of automobile SC?

Service level	☐
Time	☐

B4.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B5 Which criteria is more important to competitiveness of automobile SC?

Service Level	☐
Quality of product	☐

B5.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B6 Which criteria is more important to competitiveness of automobile SC?

Time	☐
Quality of product	☐

B6.1 Evaluate the degree of importance of the most important criteria for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

Total: 6 (Questions)

Annex 2.2 Questionnaire of pairwise comparison of LARG practices according to paradigms

Questionnaire 2 (LARG practices/paradigms)

This questionnaire has as objective assist a research that intend to study and compare a set of LARG practices, according to four management paradigms (Lean, Agile, Resilient, and Green), in perspective of automotive SC.

Your contribution is very important to development of this research. Please accept contribute by completing this questionnaire.

A - Enterprise characterization

2.0 Enterprise name: Volkswagen Autoeuropa

2.1 Country: Portugal
2.2 Business sector:
2.3 Number of employees:
2.4 Main product manufactured: Automobile (car)
2.5 Main customer (s) activities:
2.6 Position of person that complete this questionnaire: Logistics department responsible
2.7 Name of person that complete this questionnaire (optional):
2.8 Contact (e-mail):
2.9 How is positioned your firm in the automotive SC?

Fornecedor de 4ª linha	Fornecedor de 3ª linha	Fornecedor de 2ª linha	Fornecedor de 1ª linha	Empresa Focal (Montadora)	Cliente de 1ª linha	Cliente de 2ª linha
☐	☐	☐	☐	☒	☐	☐

B – Comparison of LARG practices according to Lean paradigm

Compare the practices listed, according to Lean paradigm (in perspective of automobile SC).

B1 Which practice is more important according to Lean paradigm?

Strategic stock	☐
System of rapid response in cases of emergencies and exceptional	☐

B1.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which practice is more important according to Lean paradigm?

Strategic stock	☐
Reuse materials and packages	☐

B2.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which practice is more important according to Lean paradigm?

System of rapid response in cases of emergencies and exceptional	☐
Reuse materials and packages	☐

B3.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

Sub-total: 3 (Questions)

C – Comparison of LARG practices according to Agile paradigm

Compare the practices listed, according to Agile paradigm (in perspective of automobile SC).

B1 Which practice is more important according to Agile paradigm?

Strategic stock	☐
System of rapid response in cases of emergencies and exceptional	☐

B1.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which practice is more important according to Agile paradigm?

Strategic stock	☐
Reuse materials and packages	☐

B2.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which practice is more important according to Agile paradigm?

System of rapid response in cases of emergencies and exceptional	☐
Reuse materials and packages	☐

B3.1 Evaluate the degree of importance of the most important practice for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

Sub-total: 3 (Questions)

D – Comparison of LARG practices according to Resilient paradigm

Compare the practices listed, according to Resilient paradigm (in perspective of automobile SC).

B1 Which practice is more important according to Resilient paradigm?

Strategic stock	☐
System of rapid response in cases of emergencies and exceptional	☐

B1.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which practice is more important according to Resilient paradigm?

Strategic stock	☐
Reuse materials and packages	☐

B2.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which practice is more important according to Resilient paradigm?

System of rapid response in cases of emergencies and exceptional	☐
Reuse materials and packages	☐

B3.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

Sub-total: 3 (Questions)

E – Comparison of LARG practices according to Green paradigm

Compare the practices listed, according to Green paradigm (in perspective of automobile SC).

B1 Which practice is more important according to Green paradigm?

Strategic stock	☐
System of rapid response in cases of emergencies and exceptional	☐

B1.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which practice is more important according to Green paradigm?

Strategic stock	☐
Reuse materials and packages	☐

B2.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which practice is more important according to Green paradigm?

System of rapid response in cases of emergencies and exceptional	☐
Reuse materials and packages	☐

B3.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

Sub-total: 3 (Questions)

Total: 12 (Questions)

Annex 2.3 Questionnaire of pairwise comparison of LARG practices according to Focal firm

Questionnaire 3 (LARG practices/entities)

This questionnaire has as objective assist a research that intends to study and compare a set of LARG practices, according to each entity level in the automotive SC chain.

Your contribution is very important to development of this research. Please accept contribute by completing this questionnaire.

A - Enterprise characterization

3.0 Enterprise name: Volkswagen Autoeuropa

3.1 Country: Portugal

3.2 Business sector:

3.3 Number of employees:

3.4 Main product manufactured: Automobile (car)

3.5 Main customer (s) activities:

3.6 Position of person that complete this questionnaire: Logistics department responsible

3.7 Name of person that complete this questionnaire (optional):

3.8 Contact (e-mail):

3.9 How is positioned your firm in the automotive SC?

Fornecedor de 4ª linha	Fornecedor de 3ª linha	Fornecedor de 2ª linha	Fornecedor de 1ª linha	Empresa Focal (Montadora)	Cliente de 1ª linha	Cliente de 2ª linha
☐	☐	☐	☐	☒	☐	☐

B – Comparison of LARG practices according to Focal firm

Compare the practices listed, according to Focal firm (in perspective of automobile SC).

B1 Which practice is more important to focal firm, in perspective of focal firm?

Strategic stock	☐
System of rapid response in cases of emergencies and exceptional	☐

B1.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which practice is more important to focal firm, in perspective of focal firm?

Strategic stock	☐
Reuse materials and packages	☐

B2.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which practice is more important to focal firm, in perspective of focal firm?

System of rapid response in cases of emergencies and exceptional	☐
Reuse materials and packages	☐

B3.1 Evaluate the degree of importance of the most important practice for the least:

Equal		Moderate		Strong		Very strong		Extremely
1	2	3	4	5	6	7	8	9
☐	☐	☐	☐	☐	☐	☐	☐	☐

Total: 3 (Questions)

Annex 2.4 Questionnaire of pairwise comparison of paradigms (Lean, Agile, Resilient, and Green) according to Focal firm

Questionnaire 4 (LARG paradigms/entities)

This questionnaire has as objective assist a research that intends to study and compare a set of management paradigms (Lean, Agile, Resilient, and Green), according to each entity level in the automotive SC chain.

Your contribution is very important to development of this research. Please accept contribute by completing this questionnaire.

A - Enterprise characterization

4.0 Enterprise name: Volkswagen Autoeuropa

- 4.1 Country: Portugal
- 4.2 Business sector:
- 4.3 Number of employees:
- 4.4 Main product manufactured: Automobile (car)
- 4.5 Main customer (s) activities:
- 4.6 Position of person that complete this questionnaire: Logistics department responsible
- 4.7 Name of person that complete this questionnaire (optional):
- 4.8 Contact (e-mail):
- 4.9 How is positioned your firm in the automotive SC?

Fornecedor de 4ª linha	**Fornecedor de 3ª linha**	**Fornecedor de 2ª linha**	**Fornecedor de 1ª linha**	**Empresa Focal (Montadora)**	**Cliente de 1ª linha**	**Cliente de 2ª linha**
☐	☐	☐	☐	☒	☐	☐

B – Comparison of LARG paradigms according to Focal firm

Compare the paradigms listed, according to Focal firm (in perspective of automobile SC).

B1 Which paradigm is more important to focal firm, in perspective of focal firm?

Lean	☐
Agile	☐

B1.1 Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which paradigm is more important to focal firm, in perspective of focal firm?

Lean	☐
Resilient	☐

B2.1 Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which paradigm is more important to focal firm, in perspective of focal firm?

Lean	☐
Green	☐

B3. Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B1 Which paradigm is more important to focal firm, in perspective of focal firm?

Agile	☐
Resilient	☐

B1.1 Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B2 Which paradigm is more important to focal firm, in perspective of focal firm?

Agile	☐
Green	☐

B2.1 Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

B3 Which paradigm is more important to focal firm, in perspective of focal firm?

Resilient	☐
Green	☐

B3. Evaluate the degree of importance of the most important paradigm for the least:

Equal		**Moderate**		**Strong**		**Very strong**		**Extremely**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
☐	☐	☐	☐	☐	☐	☐	☐	☐

Total: 6 (Questions)