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From product design to supply chain design : Which methodologies for the upstream stages of innovation?

Brunelle Marche

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DOCTEUR

DE

L'UNIVERSITÉ DE LORRAINE

Spécialité : GENIE DES SYSTEMES INDUSTRIELS

De la conception de produit à la conception de filière :

Quelles méthodologies pour les étapes amont de l'innovation ?

From product design to supply chain design:

Which methodologies for the upstream stages of innovation?

Brunelle MARCHE

École doctorale SIMPPE (Sciences et Ingénierie des Molécules, des Produits, des Procédés et de l'Energie) - Université de Lorraine

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To R.,

“Si on me presse de dire pourquoi je l’aimais, je sens que cela ne peut s’exprimer qu’en répondant :

« Parce que c’était elle, parce que c’était moi, parce que c’était nous »“

(Inspiré de Montaigne)

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GENERAL INTRODUCTION

The thesis that we support is based on a joint and complex vision of the product and its supply chain. We present a new perspective on innovation engineering by taking into account the simultaneous design of the product and the corresponding supply chain. The industrial objective is to increase the success rate when launching an innovative product on the market. During this research, collaborations with innovative companies have been managed in order to confront the theoretical contributions with reality.

A “Nielsen Breakthrough Innovation Report” study about 12,000-product launches across Western Europe between 2011 and 2013 shows that 76% of new product launches fail in their first year, approximately three out of four products. Johan Sjöstrand, Managing Director of Nielsen Europe’s innovation practice and co-author of the study, points out that “*innovation success is never just a remarkable coincidence*”¹. Thus, a study of the key success factors for innovation stemming from in reference books in innovation management was carried out. A first observation appears: the launch and the conditions of launching of a product are not mentioned in success factors studies (Kahn, 2013; Tidd and Bessant, 2013; Trott, 2008). (Tidd and Bessant, 2013) briefly discusses the network concept, (Trott, 2008) points out network and supplier relations and (Kahn, 2013) includes a paragraph on the supply chain in the chapter dedicated to the network supporting innovative products. So, the organization of the supply chain during the launch of an innovative product does not seem to be considered as a key success factor. Based on our experience, this lack of integration of the shape of the supply chain during the launch of the innovative product represents a serious limitation. Thus, in this thesis, one of the major industrial challenges is to anticipate the design of the supply chain for an innovative product in order to define, at the design stage, an adapted supply chain able to support this new product. Therefore, based on a robust and original theoretical framework, we propose a methodology for designing and adjusting the supply chain when a new product is developed by a manufacturing company. Manufacturing companies are defined as companies engaged in the manufacture of goods by assembly (manufacture of machinery, equipment, computer products, and electronic products, automobile and so on). These companies produce goods that can be mechanically dismantled or broken down. The strategic business unit of this thesis is on innovative products with a mechanical character.

1. Thesis Approach

For this research, we focus exclusively on innovative products. Our basic assumption assumes that product design has to integrate another scale that of the supply chain, i.e. that anticipating changes in the innovative company supply chain influences the emergence of the innovative product. This assumption leads to reflect on the possibility of generating a methodology that facilitates the modeling and design of the supply chain associated with a product. To answer this problem, it is important to study in depth (theoretically and empirically) the concept of the supply chain and the relationships between the product, the company and the supply chain. This thesis seeks to better understand these joint evolution, particularly through case studies. In this document, these case studies focus on either innovative SMEs (two study

¹ “Nielsen cracks the DNA of ‘breakthrough innovation’ success, following study of 12,000 product launches across Europe” 09/09/2014.

cases) or larger innovative enterprises whose products are a component of the final product (two study cases). From this study stems an engineering design of the supply chain. One specific case is analyzed in order to validate the coherence and adaptability of the engineering. Finally, the results obtained are discussed from a theoretical and then pragmatic point of view.

The product/supply chain system is a part of a larger Technology Innovation System, containing both social and technical components, all of which need to be aligned: product price and performance, production, complementary product/service, stakeholders (subcontracting, supply, manufacture, distribution, sales...), customers, institutions, knowledge technology and application, financial, human and natural resources, economic, strategic or socio-cultural context, unexpected events among others. Hence, supply chain design is a vast subject, so this research has a precise scope: the product performance, the production, the complementary product, the stakeholders and the strategic context.

The approach to develop this thesis is illustrated on figure 1.

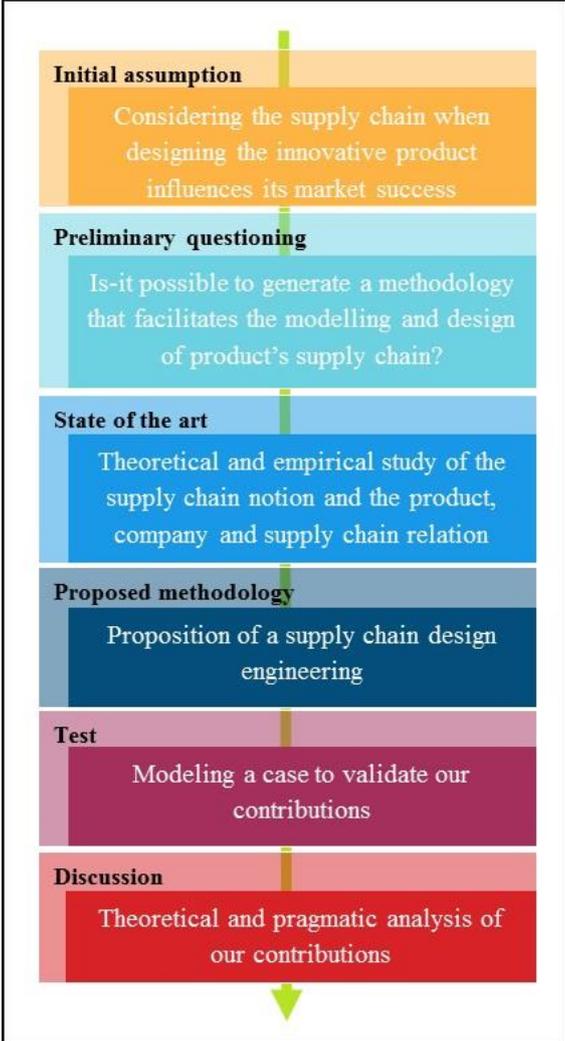


Figure 1: Thesis approach

2. Thesis structure

The document is structured in four parts: **the context and research positioning (part 1)** which help to lay the foundations of our research; **the state of the art (part 2)** which help to deepen the key concepts of this research and to delimit the conditions and environment in which our work is developed; **the methodological contributions (part 3)** which consist in developing supply chain design engineering and finally **an implementation and validation of our contributions (part 4)** which allows us to test engineering on a real case and to discuss all our results. The structure of this document is illustrated in figure 2.

	<i>Field of investigation</i>		
	INNOVATION AND INNOVATIVE PRODUCT	SUPPLY CHAIN	ADJUSTMENT
Introduction	General Introduction		
Part I: RESEARCH POSITIONING	Chapter 1: Context and research positioning		
Part II: STATE OF THE ART	Chapter 2: Innovation and Supply Chain – Definitions of concepts		
		Chapter 3: Related theory to describe the product, company and supply chain relation	
		Chapter 4: Agile supply chain and Supply Chain Agility	
	Chapter 5: Empirical analysis based on industrial cases		
Part III: METHODOLOGICAL CONTRIBUTION		Chapter 6: Proposition of an instantiated supply chain model	
	Chapter 7: Proposition of supply chain design engineering		
Part IV: IMPLEMENTATION AND VALIDATION OF OUR CONTRIBUTION	Chapter 8: Design of an innovative product supply chain		
	Chapter 9: General discussion of our research		
Conclusion	Overall conclusion		

Figure 2: Schematic structure of the PhD thesis

Each part is composed of chapters whose contents are summarized as follows:

The **first part** aims to position our research.

Chapter 1: In the literature, the organization of the supply chain during the launch of an innovative product is still little considered as a key success factor, which, in our opinion, represents a serious limitation. In this chapter, we present the context of our research and the initial findings that will serve as the basis for our research. These initial results lead to our research problem.

The **second part** explains and justifies the theoretical positioning of the research.

Chapter 2: Innovation has become fundamental for company development and sustainability. However, nowadays, it seems appropriate to anticipate the sequence of companies that will be responsible for manufacturing and distributing this innovation. In this chapter, we present and link the different concepts at the heart of our research: innovation, the innovative product and the supply chain. This chapter highlights that there is a functional link between the product and the supply chain.

Chapter 3: In order to understand the links between the different subjects of our research, i.e. the product, the company and the supply chain, we propose to rely on the work of different schools of thought. This chapter aims to explore from a “behavioral” point of view the product/supply chain link and the company-supply chain link in order to reveal their dynamic character. Our first theoretical contribution will come from the study of the product/supply chain link where we propose to consider product/supply chain design as a complex activity within the innovation process.

Chapter 4: The theories used in the previous chapter emphasized that the complexity of the product/enterprise/supply chain triptic required a managerial approach to understand it correctly. Indeed, the innovative company can implement strategies to fit the product and the supply chain or to adjust the current supply chain to obtain a more suitable supply chain. The literature suggests that an agile supply chain is better suited to an innovative product. Thus, an innovative company can seek to implement agility strategies in order to adjust the innovative product/supply chain couple and thereby increase the chances of success of its product on the market. This chapter supports our second contribution: a framework to implement an agility strategy based on observable phenomena from the literature.

Chapter 5: Innovation impacts the company but also its environment. This chapter considers several case studies to identify impacts of an innovation on companies’ external supply chain. The aim is to understand how characteristics of the innovation, such as new technology adoption or new market introduction, among others, influence the company supply chain structure and we seek to determine misfits between the initial supply chain and future supply chain. To reach these goals, implemented adjustments during past innovation projects of surveyed firms, were observed and analyzed in order to understand how companies act to meet the needs of the product in

terms of supply chain design. Thus, this chapter supports our empirical contribution: the emphasis of different phenomena to consider during the elaboration of a new supply chain to optimize the performance and ensure the success of the innovation.

The **third part** focuses on the development of a supply chain design engineering.

Chapter 6: In order to describe the organization of a supply chain, it is essential to consider all the elements that constitute it: stakeholders, flows, processes, value among others. Consequently, it seems appropriate to develop a model to facilitate data collection and analysis in order to understand the supply chain as a system. From a systematic review of the literature and case studies, this chapter presents a representation model for any supply chain. Thus, this chapter present our first methodological contribution: an instantiated supply chain model, which is confronted with several case studies to verify its pertinence.

Chapter 7: At present, there are few tools that enable companies to design a supply chain adapted to their innovative product. Consequently, this chapter presents our second methodological contribution: the Model-Based Supply Chain Engineering that we developed based on Harmony methodology. This engineering aims to model the different supply chain scenarios based on the data collected during product design. It integrates the instantiated supply chain model to collect data and the framework to implement an agility strategy to analyze the actions implemented by the innovative company.

The **fourth part** consists of the implementation and the validation of our proposition.

Chapter 8: In order to validate our contributions, a case study is selected and studied. This case concerns an ongoing innovation, i.e. the product is at the last steps of its development and not on the market when the supply chain analysis has been achieved. This chapter is a direct application of Model-Based Supply Chain Engineering and illustrates each step of the engineering process, from the product study to the modeling of a corresponding supply chain scenario.

Chapter 9: This chapter provides a discussion of our overall findings. From a methodological point of view, we highlight that the multi-functional nature of supply chain analysis for an innovative company. Indeed, coupled with other tools, its use proves to be relevant. From a scientific perspective, we emphasize the usefulness and limitations of all our contributions. Finally, from a pragmatic perspective, we discuss the contextual elements that influence the implementation of a supply chain.

PART 1: RESEARCH POSITIONING

INTRODUCTION OF PART 1:

In this first part, we present the scientific positioning of this research.

Nowadays, innovation goes beyond the boundaries of the company. Indeed, it is not the result of a single company, hence the need to focus on the concept of the supply chain. Therefore, our research focuses on two complementary notions: the innovative product and the supply chain.

This section describes the context of our study and leads to our research questions. To address our research topic, a paradigm shift is needed: a transition from a product to supply chain is occurring. For this reason, we propose to approach this subject in a theoretical, empirical and methodological approach.

CHAPTER 1 Context and research positioning

Introduction

In a constantly changing and evolving industrial context, this first chapter aims to present the context in which our research is positioned and to detail our first observations and research questions. Innovation is a concept that has become omnipresent both in literature and in the industrial world. However, nowadays, we have seen that innovation is the work of several companies. Therefore, it seems interesting to study it at the supply chain level.

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1.1 Context: innovation goes beyond the company's boundaries

The concept of innovation is directly related to that of a company (Giget, 2007). In a continuously changing industrial context, innovation contributes to the success and sustainability of companies (Galvez, 2015), which have the ability to design and commercialize new products or change the way these products are manufactured and delivered to customers. It is considered as the driving force of the company's development by creating a permanent dynamic based on novelty (Boly et al., 2016). It leads to competitive advantages: better performance, best prices, better adaptation to the needs among others. Indeed, innovation is a new way of creating value for customers, users and the innovative company itself (Garel and Mock, 2012). However, despite significant advances in its understanding and formalization, the mastery of the innovation process is far from being acquired (Toledo, 2014). Therefore, the success of an innovative product remains highly uncertain.

In addition, new products become more and more complex, involving an increased number of stakeholders. Consequently, innovation cannot always be carried by the company alone (Boly et al., 2016), it is often a collective and open process (Garel and Mock, 2012). Indeed, the new product often requires new resources, a new mode of delivery, and a distribution of tasks of realization between several companies. As a result, innovation occurs within wide collaborative systems between customers and suppliers (Maniak and Midler, 2008) or between final customers and companies (Garel and Mock, 2012). Thus, it is important to have a vision of the sequence of stakeholders involved in the launching of an innovation (Boly et al., 2016).

1.1.1 The supply chain: A full-blown object of study

A supply chain regroups all the companies involved in the production and distribution of a final product (B-to-C chain) or a finished/semi-finished one (B-to-B chain). The supply chain is considered by some authors as an object of study in itself (Christopher, 2000, 1998, 2016; Fisher, 1997; Fixson, 2005; Lee, 2002; Vonderembse et al., 2006). These authors study the characteristics of the supply chain, its functioning, and its evolution and so on. The notion of the supply chain is not fixed in time. Many definitions exist to describe this concept; they vary according to the dimension studied, which widens the search field on the notion of the supply chain. These definitions are presented further in chapter 2.

Nevertheless, a supply chain like a company is managed and has a strategic orientation. A supply chain is dynamic, it can evolve and adjust to the product that it supports in order to be effective and efficient. In fact, an organized and coordinated supply chain adapted to a particular product leads to a competitive advantage.

1.1.2 Product innovation and the supply chain

The emergence of a new product sometimes leads to changes in the environment of the company that innovates and impacts the organization of the supply chain: the relationship between the stakeholders change, stakeholders appear and others disappear, skills evolve...

The design of a new product requires anticipating these changes on the current environment and the way that it will modify the relationships of the main stakeholders (users, distributors, suppliers). Lack of awareness of these changes can threaten the development and future commercialization of the product (Boly et al., 2016). Knowing these changes and, above all, anticipating them becoming fundamental to the success of the new product.

1.1.3 Product and Supply chain: towards a shared vision?

Based on innovation, our research studies two closely related and interacting subjects: the product and the supply chain. Two complementary perspectives are taken into account. From a research perspective, we seek a better understanding of innovation processes at both the product and the supply chain system levels. From an industrial perspective, our special interest relates to the decisions the company takes about the position of its new product in a supply chain and to all decisions and actions to make the product fitting/matching with the supply chain.

Consequently, this research has the following objectives. First, it helps to better understand the links between an innovative product and the associated supply chain. Secondly, it highlights in what extent the adaptation of the supply chain to the product is a key factor of success. Thus, the supply chain has to adapt to the requirements of the final/finished product or the product has to be adapted to the former supply chain.

To carry out this research, a constructivist approach was chosen. A constructivist research differs from interpretativism in the sense that beyond understanding, it is oriented towards the goals. Observation and modeling are phases in the progressive construction of a research project, and the definition of new representations (Boly, 2000; Le Moigne, 1994). To collect and exploit data about the innovative product/supply chain couple, a multiple case study approach was used (explained in the chapter 5).

1.2 Research problematic

Considering the context and the literature presented in the previous section, this research reveals six statements:

- Any supply chain has specific components;
- Any supply chain is unique;
- Every product has its own supply chain and this couple is unstable and evolutionary;
- Innovation leads to modifications of the supply chains;
- Product/supply chain attest of a double dynamic influence;
- The product/supply chain couple has to adjust facing novelty.

1.2.1 Description of these six statements

1.2.1.1 Any supply chain has specific components

Every supply chain is composed of several stakeholders involved in different flows (financial, informational or material) and processes to transform the materials and to create value both for the actors of the supply chain and for the customer (Bidet-Mayer and Toubal, 2013; Christopher, 2016; Surana et al., 2005). Every product needs a particular and accurate sequence of stakeholders to be manufactured and sold to the market. This sequence follows the companies' characteristics (core business, skills, know-how, equipment and so on). All stakeholders of the supply chain have to contribute to the achievement of the product.

1.2.1.2 Any supply chain is unique

Each supply chain is unique. It is characterized by several aspects, such as:

- The individual behavior of each of its stakeholders;
- By the relation between them;
- By the relative influence of each other;
- By the commercial ambitions of each stakeholder.

The specificity of a supply chain is first due to the nature and the architecture of the product that impact the particular processes required to its production and distribution (Fixson, 2005). The specificity is also linked to the final market. Indeed, this later induces particular sale strategies and rules to the set of stakeholders involved in the supply chain (Fisher, 1997; Lee, 2002). The characteristics (skills, expertise, equipments, service...) of a company can be used to "typify" its supply chain and differentiate it from other supply chains supporting similar products. Thus, two similar products from a customer's point of view can have different supply chains, due to the companies and processes involved. Therefore, the links between a product and its supply chain are strong. The product/supply chain couple has to represent a consistent and dynamic whole so that the product can be manufactured, distributed and sold on the market.

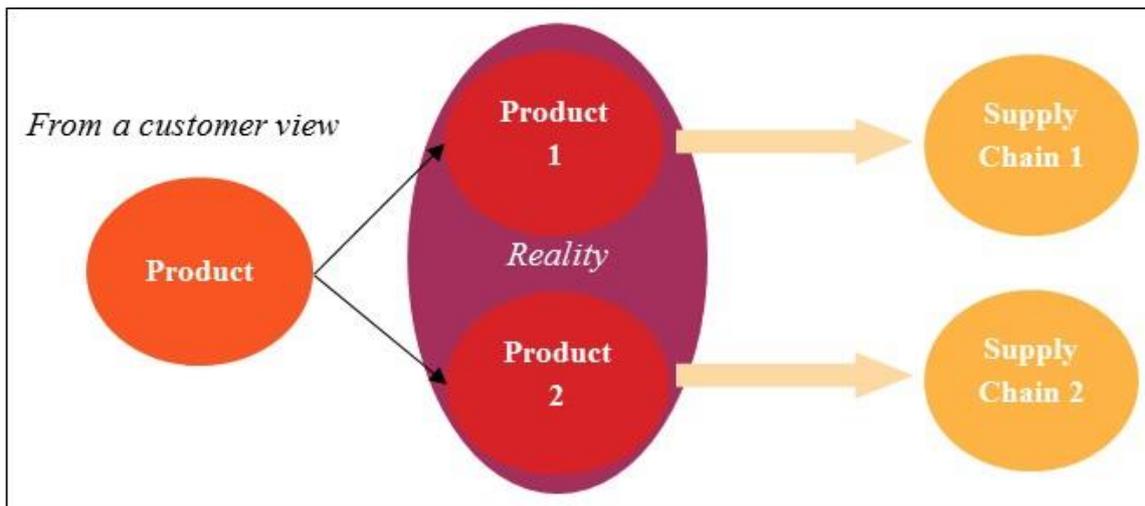


Figure 3: Any supply chain is unique

1.2.1.3 Every product has its own supply chain and this couple is unstable and evolutionary

The choice of a supply chain is directly linked to the expected results in terms of value creation. However, these expectations are evolving considering external constraints and internal objectives. Each supply chain evolves in an environment with external factors (political, economic, socio-cultural, technological, ecological and legal) that can change and so impact its operations (Marche et al., 2017a). Furthermore, each supply chain is characterized by the exchange between its stakeholders, by the mastering of processes (supplying, manufacturing, distribution) and by the individual and collective decisions (Fixson, 2005). Thus, the supply chain companies and their employees impact the global supply chain. Its functioning depends on the balance between all these components. Thus, the constitutive elements of a supply chain are unstable, undergoing the transformations (direct or indirect) of its environment (socio-cultural, political, normative changes among others) and basing its own behavior on the behavior of each company that composes it.

1.2.1.4 An innovation leads to a modification of the supply chain

Whatever the innovation is (product, service, processes, organization, way to sell...), the supply chain is impacted following the changes within the product. Consequently, a modification of the sequence of stakeholders or processes can be observed. An innovation can lead to consequential changes requiring a partial or complete reconfiguration of the supply chain (Marche et al., 2017a). These modifications may lead to the removal, the substitution or the integration of a company, flow or process into the initial supply chain.

1.2.1.5 Product / Supply Chain: A double dynamic influence

The supply chain has to meet the specification of the new product and vice versa. Indeed, the design of a supply chain depends on product characteristics (Fisher, 1997; Lee, 2002; Vonderembse et al., 2006), but the election of the supply chain is influenced by the technical choices made to manufacture the product (Blackhurst et al., 2005; Childerhouse et al., 2002). Thus, if the “optimal” supply chain is not found, the product has to be modified to ensure the launching. Conversely, a company will mobilize specific supply chain knowledge to modify

the design of a product, to facilitate its manufacturing, or to differentiate it from other similar products. Furthermore, the design of the supply chain gives information about the product manufacturing regarding:

- The existence or not of the manufacturing process on the current technological environment;
- Its easiness or not to be implemented;
- The skills availability or not to master it.

The design of the product/supply chain couple is a “subtle” balance between product requirements, expertise of supply companies and implicit expectations of the customers (Nuri et al., 2010). Indeed, the design of the product/supply chain couple has as main objective to satisfy end customers in order to guarantee the adoption of the product by the market.

1.2.1.6 The product/supply chain couple has to adjust facing novelty

Even if a change within the product can have a direct impact only on a specific component of the supply chain, the whole supply chain has to adjust to minimize the consequence of this impact to provide the right product to customers. Thus, the product/supply chain couple has to adjust to tend towards a more “optimal” supply chain for the innovative product (Fisher, 1997; Lee, 2002; Vonderembse et al., 2006). To overcome uncertainties caused by the innovative product, the product/supply chain couple has to be “co-managed” to foster the success of the product during its launch on the market (Nuri et al., 2010). However, the management of the product/supply chain couple is difficult to achieve. Indeed, the supply chain is composed of several stakeholders with their own interest and strategies. A company doesn't necessarily take into account the actions of other supply chain companies. The adjustment of the supply chain requires collective actions and a management that goes beyond the company's boundaries.

1.2.1.7 Illustration with a case study

Illustration with the Video on Demand case:

Video-on-demand (VOD) is defined as the provision, in a private context, of cinema or audiovisual works to the final consumer, at the consumer's request and at the time of its choice, by any electronic communications networks and for viewing on any reception equipment, from a catalogue of programs whose selection and organization is controlled by the publisher of this service².

Any supply chain has specific components

The VOD supply chain represents all the operations and stakeholders from production to content distribution. The marketing of VOD programs requires the establishment of economic relations between five types of stakeholders: producers, aggregators, publishers, distributors and equipment manufacturers (Lehmann-Ortega et al., 2016) to propose the most suitable offer for the final consumer.

Any supply chain is unique

² « Mission sur le développement des services de vidéo à la demande et leur impact sur la création » — Sylvie Hubac et le Centre National du Cinéma et de l'Image Animée (France) — décembre 2010

Within the VOD supply chain, five types of stakeholders are distinguished (Lehmann-Ortega et al., 2016):

- The producers who supply contents, mainly film producers.
- The equipment manufacturers who supply the IT media needed to visualize contents. These are legal download platforms, viewing terminals or game consoles with Internet access.
- The aggregators who create thematic or general offers for marketing and process digital content files. They are companies specialized in digital post-production or film distribution.
- The publishers who create a catalogue available to the public of the Internet. There are television channels, distribution networks or pure players.
- The distributors who manage the delivery, the customer database and means of payment. There are Internet service providers and mobile phone operators.

The sequence of stakeholders and processes and associated skills differ according to the desired final audiovisual content. From a consumer's point of view, a film is visible in VOD on different platforms, but each platform requires its own supply chain adapted to the technologies and formats used.

Every product has its own supply chain and this couple is unstable and evolutionary

The delivery of each VOD programs to final consumers requires the establishment of economic relations between all these stakeholders. Each content is the result of the choice of a type of producers (film producers, cinema distributors...), publishers (TV channels, networks of distributors or "*pure players*"), and distributors (Internet Service Provider or mobile phone operators) and depends on the equipment used by the consumers (legal downloading platforms, viewing terminals). However, the couple VOD/Supply chain can be threatened by the emergence of the new stakeholders. For example, the aggregators emerged with the appearance of the VOD and its role is growing with the expansion of VOD. New technology can lead to the emergence of new stakeholders. The implementation of a supply chain depends on several elements such as the profitability of the stakeholders or their negotiating power. Thus, any supply chain of content can be modified for non-technical reasons.

An innovation leads to a modification of the supply chain

Within the VOD supply chain, the way in which the digital content is distributed changes the supply chain in various places. At equipment supplier level: the technologies differ according to the way to delivery contents. At aggregator level: the digital file processing differs according to the way to delivery contents. At distributor level: the mobile phone operators delivery contents on specific sites on Internet or mobile phone while the Internet service providers delivery contents on specific channels for each editor on television (Lehmann-Ortega et al., 2016).

Product/Supply Chain: A double dynamic influence

Within the VOD supply chain, in order to make audiovisual work on the equipment of final consumers readable, the supply chain has integrated new stakeholders, the aggregators. The function of VOD aggregators is directly linked to the surge and the expansion of VOD services. As the VOD market itself, the role of aggregators is changing, evolving from a technical provider to a digital distribution consultant (Fontaine and Simone, 2017). With the expansion of video-on-demand, the supply chain has had to evolve to provide many complementary services: audio description, subtitles... Then, the

supply chain evolved accordingly, integrating new processes and skills mastered to a large extent by the aggregators.

The product/supply chain couple has to adjust

Within the VOD supply chain, given the proprietary technologies used by equipment manufacturers, compatibility problems may arise between the playback formats offered by these equipment manufacturers and those of content distributors (Lehmann-Ortega et al., 2016). To solve these problems, the content distributor can look for new equipment manufacturers whose technology is more suitable or ask current equipment manufacturers to modify their technology. If the desired technology does not exist, the distribution of content has to be reviewed.

1.2.2 Preliminary conclusion leading to research questions

These six statements highlight that:

- Our research is multi-scale and multi-actors;
- The relationships between the objects of our study (product and supply chain) are complex and dynamic.

In a context of innovation, the supply chain, the product and the company can evolve individually but also jointly. The triptic product/company/supply chain also evolves in order to respond to the novelty.

So, the interrelation between the innovative product and its supply chain is complex which justifies our interest. The changes in the supply chain caused by the emergence of a product are discussed. The previous findings lead us to suggest that the concept of impact seems too weak to really describe emerging statements. Indeed, as shown by statements 4 and 5, our main object of study, the supply chain, is constantly evolving and showing resilience to adapt. We consider that the notion of adjustment is more suitable to describe the way that the product influences the supply chain. The dictionary definition of this term supports our bias: an adjustment is the act of adapting something to something ³.

Considering all the previous point, our research question is formulated as follows:

How to model the **innovative product/supply chain interrelated couple** in order to identify the **adjustments to be implemented** within the supply chain by a manufacturing **company in a context of innovation**?

In order to answer our research question, we have to consider three dimensions:

³ Larousse

- A theoretical dimension:

How to better describe the interdependence between the characteristics of a product and those of the supply chain in the context of innovation? For a particular product, how to model the corresponding supply chain? How to match the type of supply chain required for a type of product? How can the adjustments required to transform/type the supply chain in the case of innovation be better understood?

- A methodological dimension:

How to anticipate (if possible) the future supply chain needed for innovation? From a specific product, how to design a future supply chain?

- An empirical dimension:

Are there generic phenomena within the supply chain caused by the emergence of an innovative product? Do these phenomena occur in both SMEs and large companies?

1.3 Positioning and contributions of research

1.3.1 Theoretical positioning: towards a paradigm shift

Simultaneous product and supply chain design is not addressed in the literature. This vision constitutes a different approach for the product design. Our research proposes to apprehend the innovation process on another scale: the supply chain.

This new approach requires among others to investigate the notions of performance and value. Compared to (Porter, 1986), the notions of performance and value change in scale, beyond the company's boundaries. These two evaluation dimensions can be measured at the level of each company as well as in the supply chain. This change of scale leads to a more collective vision.

Consequently, we pass from a "product-oriented vision" to a "supply chain oriented vision". The research is at the border of engineering (innovation engineering, specialty engineering) and business science.

1.3.2 Objectives and contributions

Based on a product/supply chain duality, our objectives are:

- A better visualization of the importance of the supply chain design during the product development;
- A contribution to the modeling of the future supply chain by taking into account the emerging data during the product design;
- An understanding of the limitations of anticipatory and predictive supply chain approaches incorporating innovation;
- A better understanding of the managers' and designers' practices, based on the concept of agility, leading to successful innovation combining supply chain and product transformation.

Consequently, this work contributes to scientific research through several aspects:

- A proposition to consider the product/supply chain design as a complex activity;
- A proposition of a framework to implement an agility strategy;
- The identification and description of in-situ phenomena following the emergence of an innovation;
- A proposition of a descriptive and instantiated supply chain model;
- A proposition of a supply chain design engineering for a specific product.

KEY FINDINGS OF THE CHAPTER 1

This chapter seeks to contextualize our research in order to understand the importance of the supply chain in product launching. It introduces several statements identified during our research:

- Any supply chain has specific components;
- Any supply chain is unique;
- Every product has its own supply chain and this couple is unstable and evolutionary;
- An innovation leads to a modification of the supply chain;
- Product/Supply Chain: a double dynamic influence;
- The product/supply chain couple has to adjust.

These statements lead to the research question:

How to model the **innovative product/supply chain interrelated couple** in order to identify the **adjustments to be implemented** within the supply chain by a manufacturing **company in a context of innovation?**

PART 2: STATE OF THE ART

INTRODUCTION OF PART 2:

This part explains and justifies the theoretical positioning of the research. In presenting the context, we found that a paradigm shift was needed to consider innovation on a scale. Consequently, it is essential to deepen the various concepts to be able to understand and answer the questions raised in our research.

The Chapter 2 seeks to present and links different concepts at the heart of our research: innovation, the innovative product and the supply chain in order to highlight the functional link between the product and the supply chain.

The Chapter 3 proposes to rely on the work of different schools of thought in order to understand the links between the different subjects of our research, i.e. the product, the company and the supply chain. This chapter aims to explore from a “behavioral” point of view the product/supply chain link and the company-supply chain link in order to reveal their dynamic character. It supports our first theoretical contribution.

The Chapter 4 highlights that a managerial approach can be used to understand the complexity of the product/enterprise/supply chain tryptic. Indeed, the innovative company can implement strategies to fit the product and the supply chain or to adjust the current supply chain to obtain a more suitable supply chain. This chapter supports our second contribution.

The Chapter 5 considers several case studies to identify impacts of an innovation on companies’ external supply chain. The aim is to understand how characteristics of the innovation, such as new technology adoption or new market introduction, among others, influence the company supply chain structure and we seek to determine misfits between the initial supply chain and future supply chain. This chapter support our empirical contribution.

CHAPTER 2 Innovation and Supply Chain—Definitions of concepts

Introduction

In a continuously changing industrial context, innovation contributes to the success and sustainability of companies (Galvez, 2015), which have the ability to design and commercialize new products or change the way these products are manufactured and delivered to customers. However, an innovation cannot always be carried by the company alone (Boly, Camargo, and Morel 2016) and requires the involvement of several companies in the manufacture and sale of the product. Thus, a vision of an innovative product supply chain can be beneficial to innovation.

The purpose of the chapter 2 is to propose a definition and clarification of the different concepts: innovation and supply chain. Innovation is a concept that has become omnipresent in both literature and industry. However, it's difficult to give a single and comprehensive definition of what innovation really is, given its inherent complexity. Similarly, the sequence of companies supporting the manufacturing and distribution of a product is defined by different appellations (Supply Chain, French *Filière* or Global Value Chain) depending on the context and its scope. Moreover, the supply chain concept is a recurring concept for scientific research. The variety of appellations and definitions demonstrates the complexity of this concept.

Chapter 2 clarifies and initiates answers to several research questions:

- How to better describe the interdependence between the characteristics of a product and those of the supply chain in the context of innovation?
- From a particular product, how to model the corresponding supply chain?
- How to anticipate (if possible) the future supply chain needed for innovation?

Chapter 2 is divided into three parts. The first part consists of a clarification of the innovation concept and introduces our first object of study: the product. The second part proposes an in-depth study of our main focus: the supply chain. Finally, the third part introduces the link between the product and the supply chain.

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2.1 Innovation and innovative products

2.1.1 Innovation: a complex process

In a changing industrial context, the contribution of innovation to economic growth is well established. Nowadays, innovation is fundamental for the success, growth and sustainability of the companies to be performing on the market. However, it is sometimes difficult to know exactly what innovation is. The complex nature of this concept makes its definition difficult.

Renowned author in innovation, (Schumpeter, 1934) considers that innovations result from the introduction of a new good or service, a new production method, the opening of a new market, the generation of a new source of materials or the implementation of a new organization.

More recently, (Ben Rejeb et al., 2008) suggest that innovation is “the process of introducing a novelty into a system, thus allowing to consider changes on products, processes, markets, organizations and in addition to take into account an intensity of variable innovation”.

The “Innovation Management” standardization commission of AFNOR (2011) defines innovation as a “process that leads to the implementation of one or more product(s), service(s), process (es), organizational form(s), business model(s), new or improved, that can respond to implicit or explicit expectations and generate economic, environmental or societal value for all stakeholders”.

The aim is to introduce a novelty into a market (or a system, according to [Ben Rejeb et al., 2008]) in order to meet expectations and generate value.

2.1.2 Types of innovation

Through the Oslo Manual, the Organization for Economic Cooperation and Development defines innovation as “the implementation of a new or significantly improved product (good or service) or process, a new marketing method or a new organizational method in company practices, organization of the workplace or external relations” (OCDE, 2005)

In this definition, the OCDE implicitly considers four types of innovation:

- **A product innovation:** the introduction of a new good or service. This type of innovation also applies to products that change technical characteristics (components, materials, embedded software...) or mode of use.
- **A process innovation:** the development or the improvement of production method (the implementation of new machines, the use of more sophisticated software...) or the delivery (change in the chains of logistics of the company)
- **A marketing innovation:** the implementation of new method to open new markets or to better evaluate the company in relation to its competitors
- **An organization innovation:** the implementation of new method that aims to optimize daily practices and procedures of the company. This type of innovation is the result of strategic decisions.

These definitions emphasize that innovation may involve a product, service, process, organization or sales method.

Choice for this research: This research focuses on the product innovation as an entry point but we consider that organization, process and marketing are also considered from a supply chain point of view.

There are several types of innovation class (Booz et al., 1982) either new for the company, or for the market: new products in the world, new range of products, addition to an existing product line, improvement of existing products, repositioning, cost reduction. However, product launch is not synonymous with success: there are a lot of uncertainties during the innovation process.

2.1.3 Dimensions of the innovation process

The lack of a single definition of innovation highlights its complexity (Therrien et al., 2011). This complexity is due to:

- Its characteristics of uncertainty and variability (Boly, 2004);
- Its presence at several levels within companies: design activity, production lines, distribution networks, supply chain among others.

In its HCERES report⁴, the ERPI laboratory defines the five levels of innovation study (Figure 4).

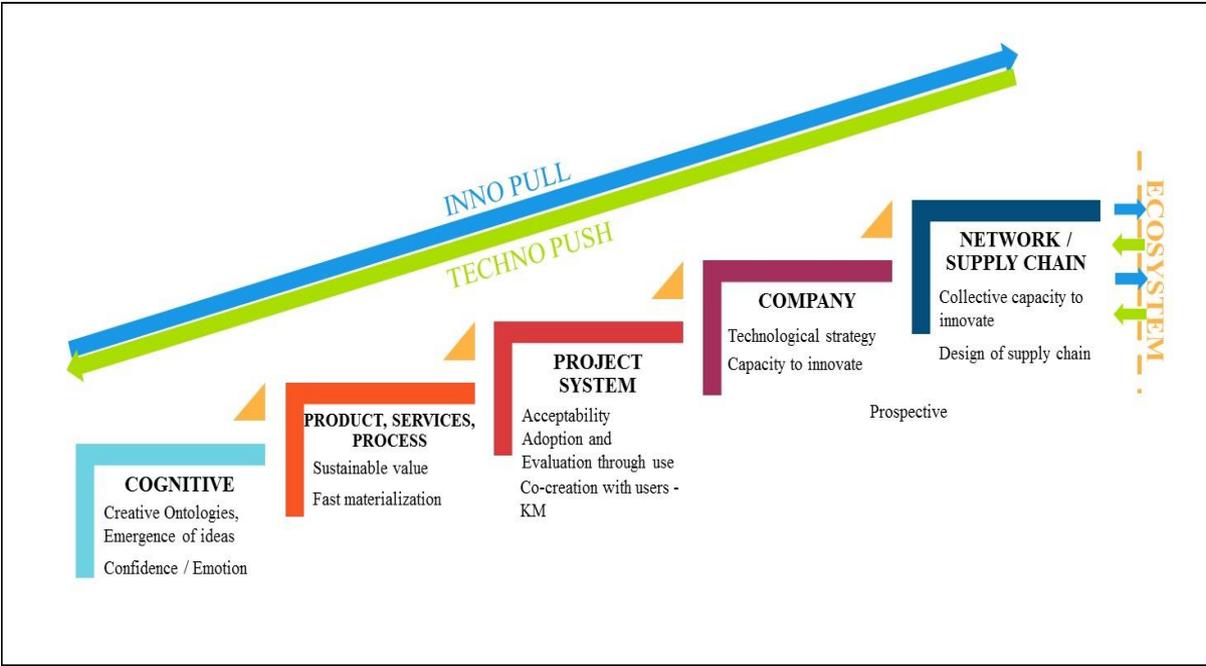


Figure 4: Five levels of innovation (ERPI HCERES report, 2016)

⁴ ERPI HCERES report, 2016

The cognitive dimension represents individuals, i.e. individual or collective cognitive and learning processes with the aim of generating new ideas, for example.

The dimension of the object represents different types of innovation: product, service, process, marketing... The object can take different forms over time: ideas, prototype, finished product... This dimension aims to promote fast materialization and create sustainable value.

The project dimension corresponds to a managerial level for the construction of the object. This dimension aims to privilege knowledge management, co-creation with users or acceptability, evaluation through uses.

The company dimension includes all activities impacted by innovation within a company. This dimension aims to consider a company's capacity to innovate and technological strategy.

The **network/supply chain dimension** concerns the external environment of the company. Innovation is part of a particular environment that must be taken into account at all stages of the development of the innovative project. This dimension aims to give priority to supply chain design and to promote a collective capacity to innovate.

In order to design a supply chain adapted to an innovative product, it is necessary to act at the product level and at the supply chain level by assuming that there is a Product/Supply chain design interface.

Thus, this research focuses on two levels:

- The network (considered here as a supply chain);
- The product in a context of innovation.

Therefore, this research aims to promote a **multi-scale optimization** of the innovation process.

2.2 What is a Supply Chain / Product couple?

2.2.1 Focus on the product: modeling pivot in innovation engineering

A product may be usefully viewed as a set of components that together provide utility to customers (Garud and Kumaraswamy, 1995). The complexity of the product stems primarily from the often-unknown nature and magnitude of interactions between different components of the product and their product performance implications. Indeed, a product is defined by components linked together through a set of interfaces: a product has an **architecture** (Henderson and Clark, 1990).

(Ulrich, 1995) defines the product architecture as “the scheme by which the function of a product is allocated to physical components”. It is characterized by “the structure of components and the interactions between them” (Pimmler and Eppinger, 1994).

Hence, the product architecture can be defined as an exhaustive description of a set of product characteristics, including the number and type of components, the number and type of interfaces between those components and represents the structure of the product.

There are three types of architecture (Sosa et al., 2003; Ulrich, 1995):

- A modular architecture, where the architecture can be broken down into sub-assemblies in such a way that each subassembly clearly impacts one or more components. This is consistent with the decoupled design concept, defined by (Suh, 1990). A module is an entity made up of a set of elements that are strongly interlinked and weakly linked to other elements external to the module (Baldwin and Clark, 2000);
- An integral architecture, in which all functions and components are strongly linked. This definition is consistent with the concept of coupled design, defined by (Suh, 1990). An integrator element is an element that interacts strongly in number or intensity with elements belonging to several modules. It creates the cohesion of the system as a whole (Baldwin and Clark, 2000);
- A hybrid architecture composed of modules (groups of elements) and integrators, an element can be a function, a component (Sosa et al., 2003).

While there can be several ways of designing products' architectures, complex products are often designed with modular design logic (Baldwin and Clark, 2000; Ulrich, 2003).

Product architecture is particularly relevant because architectural decisions are made during the early phase of the innovation process (Ulrich, 1995). The product architecture is a design decision (Posen and Ethiraj, 2013), the type of the architecture influence decisions about the design and manufacturing: what sequences of activities? What actors? What equipment? What skills?

Consequently, the manufacture of a product mobilizes a set of companies, constituting a supply chain.

2.2.2 Focus on the supply chain

In the literature, several notions characterize the industrial sector associated to companies involved in the development and market introduction of a new product, this includes: supply chain, global value chain (an extended value chain) or even the French concept of *filière*. In the absence of consensus on a common definition, we seek to clarify the supply chain concept and to describe precisely its constituent elements.

2.2.2.1 Description of each concept

Several concepts were introduced above, most of them requiring further explanation and positioning to understand the need for a systematic study of this system: the *filière*, the supply chain and the Global Value Chain. The choice of these concepts are motivated because, they refer to the itinerary of the product during its design, manufacturing and distribution.

a. The French *Filière*

The term *filière* is used only in the francophone literature and does not have a proper English translation (Hugon, 1992; Koulytchizky, 1985; Rainelli, 1988). In the international literature, francophone authors mostly use the term supply chain. A *filière* highlights all the companies involved both in the design and the production of a product intended for a final consumer.

Originally appeared in the 1960s, a *filière* corresponds to a set of unitary operations necessary to move from raw materials to a final product (Bidet-Mayer and Toubal, 2013), it is therefore a way to visualize the itinerary of a product (Goldbert, 1962). These definitions emphasize the linear aspect of the *filière*. The concept of *filière*, emerged to describe the pathway of agri-food products and was often used to assess globally the performance of this politically and economically important sector. The study of the agriculture sector, and more particularly its transformation activities were, until this moment, considered separately by institutions involved with development and public financial supports. The concept of *filière* was at the basis of the search for coherence when giving subsidies, but also to structure public research activities and organizes quality and traceability management all along the supply chain.

The definition evolved over decades to respond to changes in the environment of companies and to broaden the spectrum of uses. The notion of stakeholders appeared gradually: the *filière* is constituted by agents concerned with a product, from its development, production up to its consumption and by the relations they maintain (Labonne, 1985). According to censuses carried out by professional organizations, companies belonging to the *filière* are described as been suppliers, manufacturing companies, service providers, institutions. As a result, each company is fully conscious of being part of a chain, in an interdependent whole (they depend on each other to determine the price of the product, its quality, traceability and image). If a problem occurs along the chain (contaminated meat for example), all the stakeholders will be impacted.

This definition is part of a systemic approach. The *filière* is defined not only by all the elements that compose it, in their diversity and complexity, but also by the relationship between them (Labonne, 1985; Trognon, 2005). The notion of flow is then added to focus on physical flows (raw materials, intermediary and final products) (Trognon, 2005).

b. The Supply Chain

The concept of supply chain stems from the extension of the logistics approach within the company to all the organizations upstream and downstream of it (Roy et al., 2006). This concept also underlines an input-output structure of value-added activities across companies, starting with raw materials and ending with the finished product (Gereffi et al., 2005). It proposes operational solutions for materials, information and financial flows management problems, to improve the system of delivery of products. Through it, an increase of the customer satisfaction is expected in terms of the cost, service and responsiveness (Temple et al., 2011).

The supply chain as a whole aims to improve performance by removing non-value adding steps. As a result, negotiations between stakeholders in the chain lead to the adjustment of the

flows so that it is in line with customers' expectations. Planning and forecasting tools help regulate flows within the supply chain. It is composed of transversal processes, involving a large number of different stakeholders (Surana et al., 2005). They are organized in a chain, upstream and downstream, that connect the different processes and activities (Christopher, 2016) to respond to a customer's request (Chopra and Meindl, 2012). These interconnected stakeholders, organizations geographically dispersed over several sites that cooperate (Génin, 2003), are bound by physical, informational and financial flows (Stadtler and Kilger, 2002). These definitions also highlight the systemic aspect of the supply chain. Recently, (Slack et al., 2016) define the supply chain as the relationships and the flows between a set of operations and processes that produce value in the form of a product to the ultimate consumer.

c. Global Commodity Chain or Global Value Chain

The concept of Global Commodity Chain (GCC) emerged in the United States to describe the network and production processes whose end result is a final product (Hopkins and Wallerstein, 1986) and to highlight the new forms of exchange between the hemispheres (Hopkins and Wallerstein, 1977). The GCC emphasizes the itinerary of the product between stakeholders vertically or horizontally integrated until obtaining the final product (Balambo and Haouari, 2010). Due to the globalization of trade this name has evolved towards the Global Value Chain (GVC), which involves rather multinationals (Balambo and Haouari, 2010).

The Global Value Chain is considered as an extended value chain, in connection with Porter's work (Porter, 1986). Porter described the processes within a company as a kind of value chain, whereas GVC considers processes across companies, which make it possible to systematically understand multiple mechanisms of creation and distribution along the chain (Balambo and Haouari, 2010; Gereffi et al., 2005).

The GVC connects activities of several stakeholders. It is therefore an inter-organizational network built around a product that connects households, businesses and states within the global economy (Palpacuer and Balas, 2010). The GVC focuses on the "commodification" of processes (Hopkins and Wallerstein, 1977). It emphasizes the simultaneous modification of the various stages of the product manufacturing processes and its consumption. In order to optimize the network function, the most important stakeholders in the chain often change suppliers, even if they select them outside the borders of the country. Indeed, in an internationalization approach, the choice of the stakeholders composing the GVC is made in such a way that all the components stand out as winners in terms of finances or market shares, for example. Thus, the way in which globalization is organized by geographical dispersion is highlighted (Temple et al., 2011). The GVC approach has a spatial dimension, represented by the territorial, geographical distribution of the stakeholders.

d. Conclusion about these concept

All terms detailed previously are relevant to talk about the product path, from the raw material to a finish product. However, they have a particular connotation: agri-food for the *filière*,

logistics for the supply chain and geographical for the Global Value Chain. The table 1 shows that the *Filière*, the Supply chain and the Global Value Chain.

Features of a supply chain				
	<i>A set of companies (Who?)</i>	<i>To develop a set of products (How?)</i>	<i>To create a holistic value (Why?)</i>	<i>To meet the customer needs (For whom?)</i>
French <i>Filière</i>	Companies, agents	Thanks to the design and the production of a product	To be a performing sector	A final consumer
Supply Chain	Organizations upstream and downstream of the focal company	Thanks to an input-output structure of value-added activities	To improve the operational performance by removing non-value adding steps	The customer
Global Value Chain	An inter-organizational network	Thanks to a “commodification” of the processes	To create value in a globalization context	The consumer

Table 1: Conclusion about the Filière, the Supply Chain and the Global Value Chain

Thereafter, we will use the term of “Supply Chain”. Here the supply chain creates value through a collaborative arrangement of companies who participate in the manufacture of an innovation for a specific market thanks to a succession of processes.

2.2.2.2 Perspectives considered in our research

Despite differences in describing the chain of activities leading to the development of a product, each notion considers the supply chain as a complex system involving actors, flows and processes. A supply chain is associated with a product (constituent element of a physical flow), activities or a valorization circuit (constituent part of a process) and operators and customers, representing the actors of the supply chain (Maudet-Charbuillet, 2009; Pimor, 2001). So, the supply chain includes the following three elements (Fleischmann et al., 1997; Gaucheron, 2000):

- The type of product to be treated, it has to correspond to a requirement specification;
- A succession of processes enabling the input to be valued;
- Stakeholders involved in the processes implementation.

These are key elements in our study, but other elements such as flows, skills or equipment among others also constitute the supply chain compounds. These elements can be studied from different perspectives:

- Stakeholders perspective: This perspective deals with the actors of the supply chain involved in the design and the manufacturing of the product. At the stakeholders level, innovation imposes a system composed of skills supported by companies. Innovation represents one of the effective competitive strategies in the market, it builds up competitive advantage and also sustains it (Tidd, 2001);

- Value perspective: This perspective considers the wealth created by the whole set of industrial and commercial activities within the system. The different forms of potential value must be considered (Boly et al., 2016);
- Process perspective: This perspective highlights the complexity of the system, consisting of a wide variety of components or elements with specialized functions: stakeholders, money, and customer requirements, among others. They are organized and linked by a wide variety of non-linear links (De Rosnay, 1975);
- Market perspective: In this perspective, the market is considered as the central subsystem of the environment. Strategies are adopted by top managers to match the product and the demand-side of the market, the final customers. This perspective is essential as the product has to meet the needs of final customers.

All of which will be introduced in the next sections (a—b—c—d).

The Table 2 classifies all 80 collected papers of this content analysis with regard to supply chain approach to describe the product path, from the raw material to the final product. For each paper, we determine the studied supply chain and we determine which perspectives are highlighted.

Reference	Denomination	Perspective			
		Stakeholder	Process	Value	Market
(Goldbert, 1962)	Filière	*	*		
(Shaffer, 1973)	Filière		*		
(Wallerstein, 1974)	Global Value Chain		*		
(Montigaud, 1975)	Filière	*	*		
(Hopkins and Wallerstein, 1977)	Global Value Chain		*		
(Toledano, 1978)	Filière		*		*
(Malassis, 1979)	Filière	*	*		
(Parent, 1979)	Filière		*		
(Montfort and Dutailly, 1983)	Filière	*	*		
(Lauret, 1983)	Filière	*	*		
(Soulie, 1984)	Filière		*		
(Labonne, 1985)	Filière	*	*		
(Morvan, 1985)	Filière	*	*		
(Fourichon, 1986)	Filière	*	*		
(Ledent, 1986)	Filière		*		*
(Arena et al., 1991a)	Filière		*		*
(De Bandt and Humbert, 1988)	Filière	*	*		
(Duruflé et al., 1988)	Filière	*	*		*
(Rainelli, 1988)	Filière	*	*		*
(Laganier, 1988)	Filière	*	*		
(Lebailly, 1990)	Filière		*		
(Arena et al., 1991b)	Filière	*	*		*
(De Bandt, 1991)	Filière	*	*		
(Anderson and Narus, 1991)	Supply chain	*	*	*	
(Christopher, 2016)	Supply chain	*	*		
(Malassis and Ghersi, 1992)	Filière	*	*		*
(Lee and Billington, 1993)	Supply Chain		*		*
(Hines, 1993)	Supply chain		*	*	
(Moore, 1993)	Ecosystem	*	*		
(La Londe and Masters, 1994)	Supply Chain	*	*		*
(Ganeshan and Harrison, 1995)	Supply Chain	*	*		*
(Fleischmann et al., 1997)	Filière	*	*		
(Tchernev, 1997)	Filière	*	*		
(Tepend, 1997)	Filière	*	*		
(Christopher, 1998)	Supply Chain	*	*	*	*
(Tan et al., 1998)	Supply chain	*	*		
(Gaucheron, 2000)	Filière		*	*	*
(Fleischmann et al., 2000)	Filière	*	*		
(Lapide, 2000)	Supply chain		*		
(Mentzer et al., 2001)	Supply chain	*	*		*
(Gereffi et al., 2001)	Supply Chain / Filière / GVC	*	*	*	*
(Pimor, 2001)	Supply Chain	*	*		
(Stadtler and Kilger, 2001)	Supply chain	*	*		
(Rota-Frantz et al., 2001)	Supply chain	*	*		*
(Yuan et al., 2001)	Supply chain	*	*		

Table 2: Classification of collected papers according to the type of concept and the studied perspective

Reference	Denomination	Perspective			
		Stakeholder	Process	Value	Market
(Daviron and Gibbon, 2002)	Global Value Chain		*		
(Stadtler and Kilger, 2002)	Supply Chain	*	*		*
(Lenfle and Midler, 2002)	Filière		*		*
(Simatupang and Sridharan, 2002)	Supply chain	*	*	*	
(Min and Zhou, 2002)	Supply chain	*	*	*	*
(Génin, 2003)	Supply Chain	*	*		*
(Lummus et al., 2003a)	Supply Chain		*		
(Heeramun, 2003)	Supply chain		*	*	
(Lorino, 2003)	Supply Chain		*	*	
(Lysons and Gillingham, 2003)	Supply Chain		*	*	*
(Carbone, 2004)	Supply Chain	*			
(Paché, 2004)	Supply chain	*	*		
(Reiner and Trcka, 2004)	Supply chain				*
(Hohmann, 2004)	Supply Chain		*		*
(Gereffi et al., 2005)	Global Value Chain	*	*		
(Trognon, 2005)	Supply Chain	*	*	*	*
(Surana et al., 2005)	Supply Chain	*	*		
(Roy et al., 2006)	Supply Chain	*	*	*	
(Féniès, 2006)	Supply Chain	*	*	*	
(Lefaix-Durand et al., 2006)	Supply chain	*	*	*	
(Lorino and Tarondeau, 2006)	Supply chain		*	*	*
(Lunati, 2007)	Global Value Chain	*	*	*	
(Fabbe-Costes, 2007)	Supply Chain	*	*		
(Maudet-Charbuillet, 2009)	Filière	*	*		
(Palpacuer and Balas, 2010)	Global Value Chain	*	*	*	
(Balambo and Haouari, 2010)	Global Value Chain	*	*	*	
(Gereffi and Fernandez-Stark, 2011)	Global Value Chain			*	
(Temple et al., 2011)	Filière	*	*		*
(Fulconis et al., 2011)	Supply chain	*	*	*	
(Chopra and Meindl, 2012)	Supply Chain	*	*		
(Nepal et al., 2012)	Supply Chain	*			
(Tayur et al., 2012)	Supply chain	*	*		*
(Bidet-Mayer and Toubal, 2013)	Filière	*	*		
(Assogba and Klebaner, 2015)	Filière	*	*		
(Slack et al., 2016)	Supply Chain		*	*	*

Table 2: (Continued)

This classification shows that the process perspective is omnipresent in the definitions of the supply chain. Most of them describe the sequence of processes needed to manufacture and deliver a product. The human perspective plays an important role to talk about the supply chain, this allows to operate the processes. The value perspective is introduced to discuss the “performance” produced by the supply chain. Then, the market perspective helps to define the final goal.

All these perspectives are detailed below to better understand the supply chain, its composition and its functioning.

a. Human focus

The structural arrangement, corresponding to the organization of the stakeholders within the system, is therefore an essential element for the innovative product. The design of an innovative product leads to the acquisition of new skills, carried out by companies. Thus, capitalizing skills within the system is a major concern of the top management companies, members of the supply chain (Filipini and Martini, 2010). The management of human resources seeks a skills development process within companies to respond optimally to the specifications of the innovative product.

Innovation requires knowledge inside the supply chain. To fill knowledge gaps, new companies are integrated or modified in the stakeholders' network during the design of an innovative product.

This approach suits the special interest in determining the stakeholders' characteristic: the individual characteristics of the stakeholders and their internal or collective organizations. The individual characteristics of the stakeholders facilitate the determination of their typology and their position within the system. Structurally, the key variables are: the number of companies, the nature of their relationships and the sustainability of their relationships.

We can explain the human perspective through four points:

The typologies of stakeholders selected:

The position of the stakeholders within the system helps to create a stakeholder typology. All the stakeholders involved in the supply chain are classified from the first supplier to the ultimate customer of the product (Rota-Frantz et al., 2001), including suppliers, logistics providers, manufacturers, wholesalers and resellers (Kopczak, 1997). Then, the supply chain is composed of a wide range of companies including companies producing components and final products (Carbone, 2004).

To determine the typology of the stakeholders, a product can be decomposed into modules, components and then raw material. So, products are seen as hierarchical systems that are made up of modules, modules are made up of components, and each component is composed of raw materials (Arthur, 2009; Murmann and Frenken, 2006). Each manufacturing stage of a product can be assigned to one or several companies and thus is determined by the company position within the supply chain. As a result, a company intervening at the beginning of the chain will be considered as a supplier (of raw material or components) and a company intervening after the manufacture of the final product will be considered as a wholesaler or reseller. Once the final product is developed, the supply chain grows in terms of the number of interrelated companies (Nepal et al., 2012).

However, there are other typologies of stakeholders:

- Stakeholders working on the product and those managing the recyclability of the product

- Stakeholders specialized in a single supply chain, and those involved in several supply chains.

Number of stakeholders involved:

Each supply chain has a minimum number of members. According to (Stadtler and Kilger, 2001), it is defined as a system consisting of at least two different entities, linked together by flows. (Min and Zhou, 2002) consider the supply chain as a series of related firms: firms that buy the raw materials, transform them into components and finished products and distribute them to customers. Based on this description of the supply chain, which highlights the presence of an intermediary involved in product transformation, the supply chain can be considered as a set of at least three entities directly involved in upstream and downstream flows from a source to a customer (Mentzer & al., 2001).

Network organization:

A network is a set of explicit links between a company and preferential partners in order to acquire complementary resources (Maillat & al., 1993). Networks have their origin in strategic interactions between partners. The notion of a network is linked to the dynamic environment of a company. Each stakeholder is seeking an additional source of added value in exchanges of information and know-how. To take advantage of synergetic relations with other stakeholders, interdependence is widespread among the companies in the system (Maillat & al., 1993).

Many authors point out that supply chain companies are involved in networks (Christopher, 1998; Harland et al., 2004; Min and Zhou, 2002; Paché, 2004; Stadtler and Kilger, 2001) whose complexity increases with the number of interactions and interdependencies among different entities, processes and resources (Surana et al., 2005). This network is non-linear and scalable (Surana et al., 2005), the components of the supply chain are arranged in a complex way without following a defined rule: they can appear, disappear or be transformed throughout the life cycle of the product. The network is self-organizing to transfer information, products and finances among various suppliers, manufacturers, distributors, resellers and customers (Surana et al., 2005).

Skills mobilized:

The supply chain also represents a set of skills. Within each supply chain entity, human resources are taken into account to meet the needs of the product. These resources, with their own skills and know-how, influence the company's position within the supply chain. Hence, skills in raw material extraction are relevant upstream of the chain.

Two types of skills are differentiable: specific skills of each company adding value to the products (plastic injection molding for example) and transversal skills present in each company and sharing by several types of activities (intellectual, methodological, social or communication skills) (Le Boterf, 1994).

b. Value creation and performance focus

Performance:

Formulated in the past exclusively through a financial perspective (i.e. profitability), today's performance is multifaceted (Lakri et al., 2015). This vision has evolved by incorporating criteria such as cost, timeliness, quality, customer satisfaction, innovation among others (Dixon, 1990; Lebas, 1995).

Joseph Roussel, Supply Chain Expert at PwC France explains that “*The most successful companies invest in new generation, responsive supply chains in order to increase their profitability while satisfying their clients' needs in an increasingly difficult and competitive market.*”⁵ Thus, a well-designed supply chain is an undeniable lever for growth and a potential differentiating factor in the face of competition (Lakri, 2016). As a result, a well-designed supply chain is based on a company's ability to excel in three main activities (Roussel and Cohen, 2005):

- Determine how to structure the organization (see Chapter 4);
- Defining roles and responsibilities;
- Finding the right people with the right skills.

Currently, we have identified different points of view to determine the performance of a supply chain including:

- A network point of view: the supply chain performance can be defined by supply chain partners' ability to adapt to a dynamic environment (Vanderhaeghe and Treville, 2003);
- An organizational point of view: the supply chain performance is associated with the restructuring to reflect long-term changes in markets, technologies, and products (Whitten et al., 2012);
- A strategic point of view; the supply chain performance is associated with the alignment of strategies throughout the supply chain to meet the needs of the ultimate customers of the supply chain and to share costs and benefits equitably throughout the supply chain (Whitten et al., 2012);
- A financial point of view: the supply chain performance can be defined by the focus on the organization's profitability and ability to generate returns on investment and sales as compared to the industry average (Green Jr et al., 2005).

In our research, we will consider these different points of view but we also assume that the performance of a supply chain can also translate into the success of the innovative product on the market.

Hence, a supply chain will be efficient if:

⁵ <http://www.pwc.fr/global-supply-chain.html>—August 3, 2015 (Source : Lakri, 2016)

- The developed product is a success in the market. Sales or turnover indicators will be good means of assessing it;
- Its configuration is sufficiently responsive to adapt to perturbations of the environment. These perturbations can be a new product generation, the evolution of the product range, a transition within the product cycle life, a consideration of societal, economic or technical issues among others;
- It generates a better competitive advantage than the supply chain that supports a similar product. Sales or turnover indicators will be good means of assessing it.

Furthermore, performance is what contributes to improving value creation (Lorino, 2003).

Value creation:

Although the points of view are different, the three concepts emphasize that the transformation of the product along the supply chain follows a coherent path with a purpose appearing in the form of added value for each member of the chain.

The value added appears in different forms, as underlined (Boly et al., 2016). These authors identify eleven kinds of value that can be quantified.

- The value may be financial by analyzing the gross margin, return on investment or percentage of turnover of the new product;
- The value may be strategic. It evaluates itself by analyzing the number of competitors or its differentiation from the products available on the market;
- The value can emphasize the captive aspect of the client by calculating the percentage of clients under contract and their duration;
- The value may highlight the associated development opportunities. It evaluates by analyzing the number of possible markets;
- The value can be intellectual by analyzing the budget needed to protect the product;
- The value maybe commercial. It is assessed by considering market shares and geographical areas or the number of countries impacted;
- The value can be functional considering the number of functions that the product offers such as service rendered and ease of access;
- The value can underline the degree of novelty that can be assessed using (Garcia and Calantone, 2002) who identify the degree of novelty of the product by determining their impact on the micro scale (internal to the company) and macro scale (external to the company);
- The value may appear as notoriety, considering the percentage of customers who know the product;
- The value can be reflected in the number and motivation of candidates that apply for jobs in the company;
- The value can be sustainable and is then determined in terms of health, safety or environmental impact. It is evaluated using indicators.

The definition of a process shows that a process has to produce value for the beneficiary of this process (Hammer and Champy, 1993), the final customer of the supply chain.

The final value of a product is created by the network arrangement of a multiplicity of processes (Féniès, 2006), it is the result of a combination of activities and processes (Lorino, 2003). Behind the processes and activities are technologies, equipment, skills, and know-how to create value (Lorino, 2003).

The final value of the product supplied to the customer corresponds to the sum of the values contributed by each of the companies belonging to the supply chain. The value provided by a company results from a combination of activities, the value chain. It is the decomposition of the company into relevant activities in order to seize opportunities for value creation. Each activity in the value chain of a company contributes partly to the creation of the value appreciated by the end customer (Porter, 1986).

Despite its many forms, the concept of value remains subjective. Indeed, the value remains a reflection of a judgment mainly by the customer (Lorino, 2003). To estimate the value created, (Lefaix-Durand et al., 2006) proposes to perceive it as a measure of importance given by the relevant stakeholders. In other words, the value of a product proposed by a business is the amount that potential customers are willing to pay for that product (Lorino, 2003). This is valid throughout the supply chain, whether it is to acquire raw material, a component or the final product.

The concept of *filière* hardly addresses the notion of value, placing more emphasis on the notion of the process. The concepts of Supply Chain and Global Value Chain consider value as an essential element of the system.

c. Processes focus

This perspective highlights two elements.

Firstly, the process perspective, based on the links between the components of the system, the companies and the stakeholders, focuses both on structural and functional aspects. Indeed, it highlights the typology of flows (functional aspect) and their network arrangement (structural aspect) (De Rosnay, 1975). The concepts of the Global Value Chain and the Supply Chain are concerned with the systemic perspective in the form of a network whereas the concept of the *filière* deals with it from the point of view of a set of companies and humans. The concept of supply chain emphasizes a more functional aspect of the systemic perspective by talking about exchange of flows. The concept of *filière* fosters the structural aspect by privileging the notion of relationship.

Secondly, this perspective highlights the processes and activities transforming elements into output elements (Lorino, 2003), adapted to the customer's requirements. The concept of *filière* describes the process perspective by highlighting the notion of product itinerary relating to the operational sequencing required for product design. The supply chain concept approaches the process perspective more operationally by talking about product transformation. The supply chain is a process mapping how the value is gradually added to

the product delivered to the end customer (Lysons and Gillingham, 2003). Each process consists of an input like a raw material and an output like a component or a finished product (Féniès, 2006). Finally, the concept of Global Value Chain is more concerned with the extension of activities outside the company: logistics, manufacturing or distribution are managed by different companies distributed internationally.

Flows:

Relationships can be of a different nature which impacts the nature of flows: the nature can be social or economic (Evers and O’Gorman, 2011), personal or digital (Harris and Wheeler, 2005) or can take the form of a formal partnership (Kontinen and Ojala, 2011), a gentleman’s agreement, and so on. The nature of the links can be contractual, episodic or permanent, but also combined (product and money) or singular (advice). To be defined as a network, two relationships at least are required (Chetty and Holm, 2000). However, to meet the product specifications, the set of flows can become large and complex. Specific needs arising from normative or governmental institutions for example can impact the current network of flows and modify the boundaries of the system.

The supply chain is traversed by three minimum flows (Lapide, 2000): a physical flow, a financial flow and an information flow.

A physical flow corresponds to a set of units circulating (Tchernev, 1997). A physical flow can be defined as the purchase of material, from the transformation of raw materials into products or the delivery of products (Tan et al., 1998). In order to satisfy supply chain customers, companies seek to optimize this flow (Féniès, 2006).

A financial flow moves in the opposite direction of the physical flow in a disordered way (Féniès, 2006). It corresponds to the monetary counterpart of the physical flow, which aims to satisfy the companies, members of the supply chain (Féniès, 2006).

The information flow allows the coordination of financial and physical flows between each company (Fawcett and Magnan, 2001). These flows contain the data necessary to manage all the activities within the supply chain (Féniès, 2006). Note that the physical flow includes some information because the material exchanged often carry information: a delivery date, a quantity, a product code, and so on. (Lorino, 2003).

Processes and activities:

A process is made up of activities (Tchernev, 1997), the basis of a process (Evraert, 1997). An activity is composed of a set of homogeneous tasks that mobilize inputs to transform them into outputs (Romeyer, 2001). Specific tasks are expected in the realization of a particular activity in order to design an output, tangible or intangible. Activities are carried out by one or more individuals with specific skills and abilities. The activities represent the “daily work” of the people in the company and then appeal their know-how. Therefore, the activities make it possible to provide an accurate, tangible and intangible output (Lorino, 2003).

In a process, a combination of heterogeneous activities organized in a sequential network develops a material product of value to the customer (Féniès, 2006; Hammer and Champy, 1993; Lorino and Tarondeau, 2006; Tchernev, 1997). They are interconnected by flows of information or materials (Lorino, 2003) and can be carried out by different entities (Féniès, 2006).

Due to its more global purpose, the process differs from the activity. Indeed, the combination of activities within a process provides an appreciable value component, directly or indirectly for the customer (Lorino, 2003). The following example provided by (Lorino, 2003) illustrates this point: the “manufacturing” process is a combined set of activities to transform the purchased material into a finished product.

By referring to the preceding definitions, a process can be represented as a material flow or an information flow (Lorino, 2003) because it facilitates the circulation of a good within a space. Two types may be distinguished: manufacturing and selling processes.

By generating products, a company creates wealth, that is, it generates by its own growth an over-value (De Rosnay, 1975). In the supply chain, the processes represent the sum of the interfaces (input/output) existing in the realization of the products intended for the final customer. It is a succession of tasks carried out using personnel, equipment, material to lead to the final product (Cattan et al., 2008). The process perspective can only exist if the human and systemic perspectives exist, the process being supported by humans and flow.

The design and the production of an innovative product are based on a succession of well-defined processes and operations. During the design process, the future product passes through different stages, tracing the successive forms of the object under construction: the idea, the sketch, and the prototype, for example, each of which is referred to as Intermediate Design Objects. All these objects describe the transformation process of the innovative product (Boly et al., 2016). The production process identifies the essential steps in the manufacturing of the product, thus allowing its industrialization (manufacturing of electrical components, rotomolding for example). The supply chain organizes the processes supported by companies

d. Market focus

The strategies implemented by the companies in the ecosystem aim to align the product and the market, i.e. to offer an innovative product in line with customer needs. A company must determine the attractiveness of each market segment and offer a product consistent with these segments. Thus, different strategies are possible: market research, customer integration among others (Marche et al. 2017).

Customer integration helps to collect data from the market in innovative projects. The supply chain gets access to a set of knowledge and may benefit from interactions with other stakeholders (Gurgul et al., 2002) thanks to tools, concepts, and methods allowing the transfer of knowledge between them (Krawtchenko, 2004).

Once on the market, an innovation goes through two phases: an adaptation phase (from the first introduction on the market to large-scale dissemination) and a market stabilization phase

(from production and large-scale dissemination to partial or complete product substitution) (Ortt et al., 2007). There is a lack of valid methods that can predict the length of these periods (Ortt et al., 2007). However, anticipating the ecosystem of the future product can lead to a reduction in adaptation time.

e. Conclusion concerning the supply chain

In the supply chain, product innovations can lead to significant changes. It is important to model the nature of the change in order to anticipate their impact on the supply chain. To plan actions directed outside the company to change the supply chain, several components of the supply chain have to be considered:

- The stakeholders;
- The flows and the processes;
- The value;
- The market.

At least, two stakeholders share information or physical elements (raw material, components or final product) to operate several processes thanks to multiple flows. The combination of activities involved in the implemented processes creates value. The processes sequence leads to a final product. This product can be launched on the market. Thus, the supply chain of the product is obtained.

2.2.3 Preliminary conclusion on the supply chain/ product couple concept

The architecture of the product requires the involvement of several companies as each component, each interface requires a specific know-how. Thus, the set of components mobilizes processes and skills distributed between a set of actors, both able to master a phase but also to act collectively with others. As a result, the product architecture influences the architecture of the supply chain.

There is a product/process duality (Eynard, 1999) where product data are the results of design activities and, by reciprocity, the latter use this data for their development.

In addition to the technical aspects, the data have to contribute to the management of activities. Product data are to be associated with the description of the sequence of activities making up the manufacturing process, i.e. the supply chain.

Thus, in order to better understand our research, we take into account three logic (Figure 5):

- The logic of the product to be realized (product decomposition—*what*);
- The temporal logic of the processes (sequence of activities—*how* and *when*);
- The logic of the organizational structure (the supply chain—*who* and *where*).

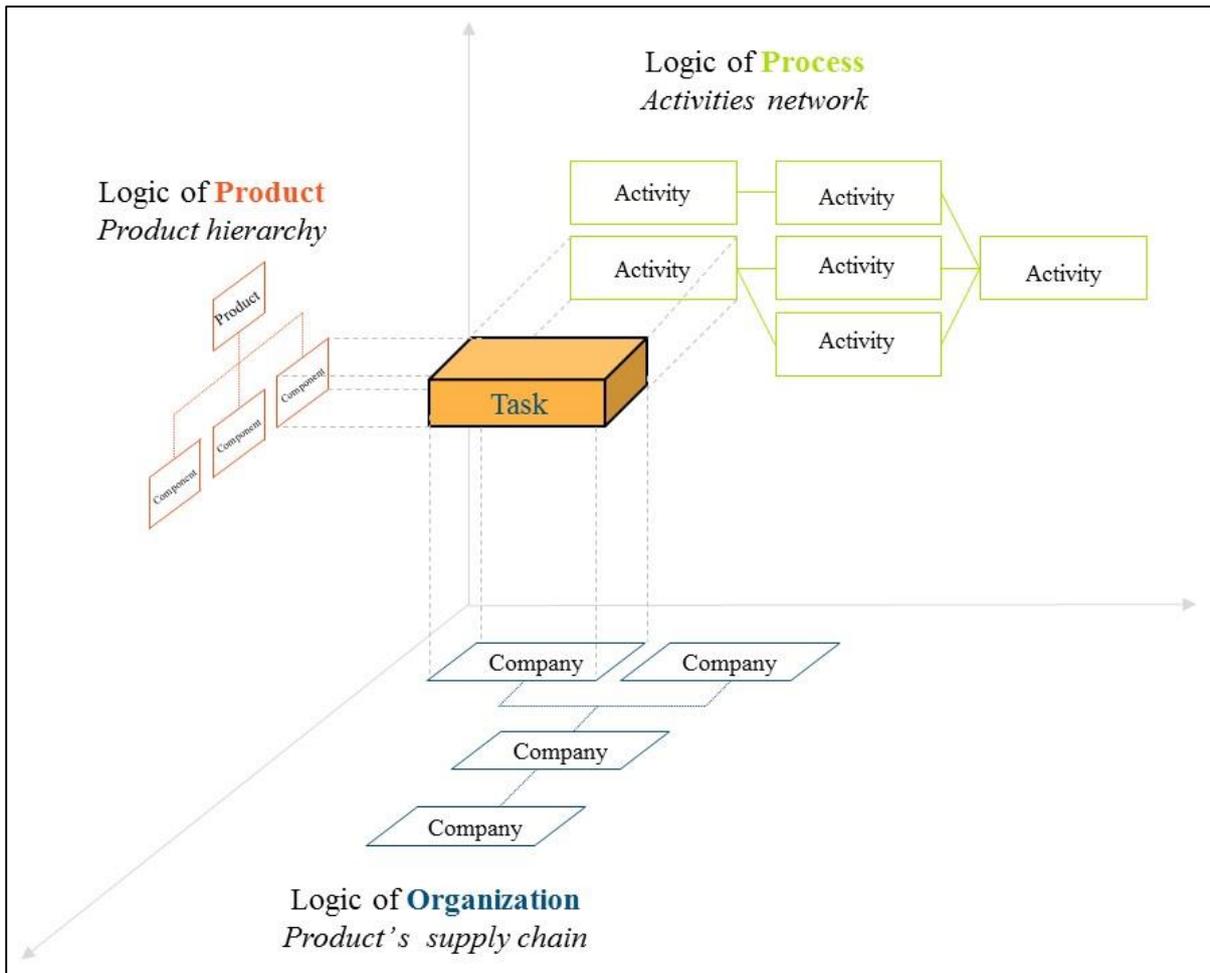


Figure 5: The task at the heart of the three logic (inspired by (Meinadier, 2002a))

The tasks are at the crossroads of these three logic: they are generated by applying an activity to a product component to be produced and assigned to a company in the supply chain. Thus, it seems relevant to focus on this observation for the remainder of our research.

Choice for this research: Faced with this observation, this research focuses on a functional representation of the supply chain.

However, this logic is evolutionary, by design decisions on the product or by adaptations to external constraints (regulation, technical evolution, customer demand...). The product/supply chain couple is therefore the object of permanent adjustment and optimization procedures.

Conclusion of the Chapter 2

The objective of this chapter is to define the different concepts used in this research: the product and the supply chain. Particular attention is paid to the supply chain concept in order to highlight its complexity: a supply chain is a space composed of various stakeholders (suppliers, manufacturers, subcontractors, distributors...) organized in a network, flows (monetary, physical, informational) and processes whose implementation leads to the manufacture and distribution of the product in a targeted market. This process sequence generates value.

The notion of “product” is a constitutive element of a supply chain: these two notions are linked. Indeed, the product is the result of a process sequence and it is this same sequence that defines the supply chain. The existence of a functional link between the product and the supply chain is revealed. Consequently, a part of our work will focus on this interrelation, because its highlighting and deepening can be positive for an innovative company. Indeed, a better understanding of the product/supply chain couple can lead a company to anticipate the implementation of a supply chain adapted to its product and thus reduce certain uncertainties when launching it.

However, the functional study of the product/supply chain couple is not sufficient to ensure the success of the innovative product when it is launched on the market. Chapter 3 provides additional theoretical knowledge on the product/supply chain relationship and highlights the role of the company in product and supply chain design. Thus, we will try to describe the product, company and supply chain relation under a theoretical angle to emphasize the dynamic character of this relationship.

IN BRIEF

- The **product innovation** is the main type of innovation considered in this document
- The research focuses on **two “levels”**: the product and the supply chain
- One product has its **own supply chain**
- A supply chain is described by **stakeholders, flows, processes and performance**
- The **process** is involved in the link between the product and the supply chain

KEY FINDINGS OF THE CHAPTER 2

The main contribution of this chapter lies in the clarification of different concepts (innovation and supply chain) in relation to our problem, with the aim of laying solid theoretical foundations. However, many definitions exist about innovation, given its inherent complexity. Similarly, the sequence of companies supporting the manufacture and distribution of a product is defined by different appellations (Supply Chain, French *filière* or Global Value Chain) depending on the context and its scope. However, the supply chain concept is a recurring concept in scientific research. The variety of appellations and definitions demonstrates the complexity of this concept. By limiting our research to innovative products, we were able to highlight that the link between the innovative product and the associated supply chain is created through the determination of manufacturing processes.

CHAPTER 3 Related theory to describe the product, company and supply chain relation

Introduction

Chapter 3 provides theoretical details on the links between the different study objects of our research: the product/supply chain link and the supply chain/company link.

Within the literature, product design and supply chain design are considered as two distinct activities, the latter often being little considered. Chapter 2 showed that the product and supply chain impact each other through common processes that link them together. Thus, the dominant paradigm could be described as causal, because it highlights a cause-effect relationship between the product and the supply chain. However, within the innovation process, this causal relationship does not appear to be sufficient and needs to be re-examined. In this chapter, the relationship between product and supply chain is viewed differently, through a paradigm integrating complex thinking. This reflection is based on the concept of dialogism and recursiveness in the sense of (Morin, 2015) in order to consider product design and supply chain design as two interdependent activities within the innovation process. Thinking of the product/supply chain link from a design point of view requires taking into account the influence of the company on this couple, the company then supporting these design activities. In this chapter the theoretical context will be detailed and the dynamic character of the supply chain will be addressed.

On a theoretical point of view, Chapter 3 reinforces the answers to the research questions in Chapter 2 and gives the base to answer questions in Chapters 4 and 5:

- How to better describe the interdependence between the characteristics of a product and those of the supply chain in the context of innovation?
- How to determine the type of supply chain required for a particular product?
- The adjustments required to transform the supply chain in the case of innovation can be better understood?
- How to anticipate (if possible) the future supply chain needed for innovation?
- How to better understand the in-situ phenomena within the supply chain caused by the emergence of an innovative product?

In the first part, the product/supply chain link is studied within the innovation process. In a first step, the systemic approach is presented and the notion of complexity is introduced. Thus, our first contribution is presented: we propose to consider the product/supply chain design as a complex activity. The consequences of this new paradigm on the functioning modes of innovative enterprises will then be discussed. In a second part, the company/supply chain link will be approached through various other theories including the SSP model.

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3.1 Pertinence of the systemic theory

This section proposes an alternative to the analytic vision, consisting to treat the product design and the supply chain design separately, by fostering a systemic vision that highlights the interactions and complementarities existing between these two elements.

The system modeling approach in the sense of (Le Moigne, 1994) has been adopted. In fact, it appears to be adapted to the complex nature of the innovations by taking into account a large number of influential variables belonging to multiple categories, by the analysis of sets and their subsets, and by the representation of a large number (in form and in kind) of interactions between variables (Serres, 1991). In addition, this modeling principle considers the evolutionary aspect of the process and the different decision-making levels (Girod-Seville and Perret, 1999).

3.1.1 Theoretical foundation: the systemic theory

The development of Western thought and science is based on a rationalistic and analytical tradition. It is considered as a universal reference. However, the rationalist tradition is now being challenged by the systemic approach.

This approach is based on the notion of the system, which can be defined by “a set of elements in a dynamic interrelation, organized according to a goal” (De Rosnay, 1975). This is a conceptual tool able to help to solve a complex problem (Yatchinovsky, 2012).

Systemic is the outcome of three precursor scientific movements (Durand, 2006):

- The Structuralism, introducing the notion of structure as a basis for reflection. This movement is used notably in the human sciences (linguistics, psychology and so on);
- The cybernetics, reflecting the action of direction, of governing. Cybernetics, or “governance science”, represents a crossroads that has seen many discoveries emerging from various scientific fields. Together with structuralism, it contributed to the emergence of the concept of organization and encouraged the exchange of ideas between specialists from various disciplines;
- The theory of information, which developed at the same time as cybernetics, and which was even considered part of it before its field of research widened considerably.

Consequently, a definition of a systemic approach can be a theory that combines practical, theoretical and methodological approaches relating to the study of what is recognized as too complex to be approached in a reductionist way. Systemic raises problems of boundaries, internal and external relations, structure or emerging properties that characterize the object of study as such, or problems of mode of observation, representation, modeling or simulation of a complex whole (Donnadieu et al., 2003).

The systemic approach considers the organization as a system open to the environment. Firstly, it proposes to focus on interactions and feedback processes, so it highlights a dynamic vision of the organization. Secondly, the systemic approach is based on the recognition that

there are many types of possible organizations to cope with the environment. Therefore, there is no single way to achieve positive results (Rouleau, 2007).

3.1.2 A Systemic/Rational opposition

The systemic is opposed to the rationalism shaped in the “Discours de la Méthode” in 1637 by (Descartes, 1637). The four fundamental precepts described by (Descartes, 1637) are as follows:

- “The first was to never receive anything for real that I obviously do not know it for such, i.e. to avoid rush and prevention carefully.”
- “The second is to divide each of the difficulties that I would examine into as many parts as I could and that would be required to solve them better.”
- “The third is to lead my thoughts in order, starting with the simplest and easiest objects to know, to ascend little by little as in degrees to the knowledge of the most complicated.”
- “And the last one to such complete counts and reviews so general that I assured that nothing was omitted.”

In his book “La théorie du système général”, (Le Moigne, 1994) opposes the four precepts of Descartes to the precepts of the systemic.

Rationalist precepts	Systemic precepts
Evidence	Relevance (in relation to the researcher’s objectives)
Reductionism (analysis)	Globalism (consideration of the system environment)
Causalism (linear reasoning)	Teleologism (research of the system behavior)
Exhaustiveness	Aggregation (for a simplified representation)

Table 3: Comparison of rationalist and systemic precepts (source: Le Moigne 1994)

The four systemic precepts are the following (Le Moigne, 1994):

- **Relevance** (as opposed to evidence) consists to consider something as true in relation to explicit purposes. The perception of an object changes according to the modeler’s intentions;
- **Globalism** (as opposed to reductionism) challenges the supremacy of analysis. Each object is considered as an included and active part of a larger whole (its environment). Globalism puts forward the notion of emergence by considering that the whole is more (or less) than the sum of the parts, according to the Aristote’s maxim;
- **Teleologism** (as opposed to causalism) consist in questioning the causalistic thinking. The causalistic thinking proposes reasoning in terms of necessary and sufficient condition and linearity. The teleological precept proposes a reflection on the behavior, and the purposes of the objects as well as on the resources it mobilizes. It is a question

of considering that the relationship between two elements is not a simple causal action of A on B, it involves a double action of A on B and B on A;

- **Aggregation** (as opposed to exhaustiveness) puts into question the principle of comprehensiveness. This precept proposes to accept differences and variability of situations, not by “omitting” elements but by aggregating them voluntarily and explicitly.

Therefore, these four precepts reconsider the rationalist and analytical approach in favor of a systemic and complex vision. It is on the basis of these four precepts that we will base our proposal for a new paradigm for the understanding and the common management of product and supply chain within the innovation process.

3.1.3 A key concept: the complexity

The systemic approach is also based on four fundamental concepts (Donnadieu et al., 2003; Durand, 2006). In addition to the system concept previously defined, it considered the concept of:

- **Interaction** that reflects the relationship of influence and exchange between the entities of the system;
- **Wholeness** that expresses both the interdependence of the entities of the system and the coherence of the whole. It prevents sequential analysis of the study object;
- **Complexity** that highlights the difficulties of understanding raised by the apprehension of a complex reality.

The complexity concept can be considered as a paradigm. It is a set of heterogeneous constituents that are inseparably linked and organized together. Each constituent is characterized by uncertainties, indetermination and random phenomena (Enjolras, 2016).

Thus, complex thinking consists in substituting the simplification paradigm, including principles of disjunction (separate what is linked) and/or reduction (unify what is diverse), a paradigm including principles of the conjunction that allow to distinguish without disjunction and associate without reducing (Morin, 2015).

To study the paradigm of complexity, (Morin, 1988) proposed to consider on three principles.

- The dialogic principle allows maintaining the duality within the unit. It associates two terms at the same time complementary and antagonists (Molina-Sanchez and Schmitt, 2016). In the Volume 3 of *The Method*, (Morin, 1986) defines the dialogic principle as the complex association of instances necessary together for the existence, functioning and development of an organized phenomenon;
- The principle of organizational recursion is the organization whose effects and products are necessary for its own causation and production. All that is produced goes back to what produces it in a cycle that is self-constitutive, self-organizing and self-producing (Morin, 2015). This principle is an idea that breaks with the cause-and-effect principle;

- The holographic principle highlights that each part of the hologram contains a substantial portion of the total image. If one cuts a hologram in half, one does not get two half-images but two complete ones. Thus, this principle suggests that the whole is in each part (Morin, 2014).

Thus, to open up to complex thinking is to seek to connect in order to construct meaning, rather than just piecemeal analysis (Le Moigne, 2007). It is necessary to “conjoin to understand” whereas the simplification exercise requires separation in order to understand, which implies a reduction and/or disjunction of reality. Thus, the complex thinking represents a fundamental notion to think the relationship “Product design/Supply Chain design” in terms of complementarities. Contrary to disjunctive thinking, complex thinking highlights unifying and common elements without merging the whole.

3.1.4 Product and supply chain view as systems

A system is the result of the arrangement of relationships between components or individuals, where the representation of this arrangement can be considered as the system architecture (Bonjour and Dulmet, 2006). The study of a system architecture deals with structural aspects (the element and their relationships) and temporal aspects (the dynamics of functioning) (Meinadier, 2002a).

Consequently, a product and its supply chain can be considered as **systems**.

The notion of complementarities can take different shapes (Morin, 1977):

- Interaction;
- Links establishing a common part;
- Association and combinations of complementary activities;
- Informational communications.

As an innovative product and its future supply chain are interdependent, links existing between the product and the supply chain may be described as the interrelation between systems. More precisely, the precedent chapter highlighted interactions between these two systems in the form of reciprocal actions including information exchanges. Indeed, a two-way relationship may be stated between product and supply chain. These are interactions in the form of reciprocal actions including exchanges of information where the information from product design activities reinforces the information from supply chain design activities and inversely.

However, in our research, we propose to go further by considering that product design and supply chain design share common design activities within the innovation process to ensure the success of the product. Therefore, we are getting closer to complementarity between product design activities and the supply chain.

Thus, based on the systemic approach, we highlight the interest to co-design the product and the supply chain within the innovation process. Thus, this means relying on the theoretical

foundations of systemic and the associated complex thinking and then applying the major precepts to the product and supply chain design management in the innovation context.

3.2 First theoretical contribution: the product/supply chain design as a complex activity

In the previous section, the fundamental theories and notions underlying the creation of a new paradigm for thinking about the relationship between product and supply chain were highlighted. Thus, it was possible to propose a new point of view on this relationship, based on complementarities and the emergence of common design activities within the innovation process. However, it is necessary to clarify the relevance of this new paradigm for innovative companies.

3.2.1 From disjointed thinking to a complex thinking

Product/supply chain couple is often disjointed in the literature. Consequently, product design and supply chain design are often considered as two separated activities, although they have a mutual impact on each other.

In contrast, in this research, we consider the product design and supply chain design as two complementary and integrated activities within the innovation process.

The disjunctive thinking isolates what is separated and occults what connects and interferes. The complex thinking, in contrast, helps to connect while distinguishing.

In his book “Introduction à la pensée complexe”, (Morin, 2015) estimates that by joining cause and effect, the effect will return to cause, by feedback. Thus, the product will also be a producer, which we could also call “leading artefacts”. Therefore, the concepts considered have to be distinguished and joined at the same time. Based on this observation, we propose to apply the dialogic principle and the principle of organizational recursion to the product/supply chain couple. Thus, the proposed paradigm considers the product and the supply chain as two interdependent objects of study of the same dialogical and recursive duality, i.e. these two poles form a virtuous circle (recursiveness) within which they are united without the duality being lost in this unity (dialogism). The chapter 2 highlights these phenomena, the product being both the cause and the effect of the supply chain. The product appears in the constituent elements of the supply chain.

Moreover, we propose to consider product design and supply chain design as two interrelated, complementary and simultaneous activities within the innovation process. These activities represent the joint activities to the supply chain design and product design. The development of these joint activities enables mobilizing resources, skills and processes common for the product and the supply chain and thus, minimizes the effort associated with the creation of a product/supply chain.

Hence, the presence of joint design activities incites and facilitates to **co-design** the product and the supply chain within the innovation process.

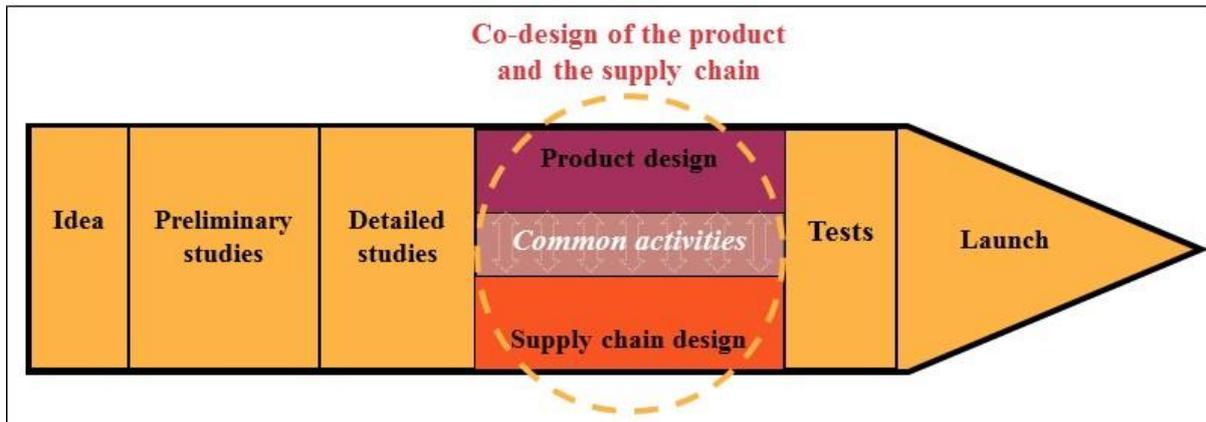


Figure 6: Product and supply chain design as two complementary activities within the innovation process

To conclude, this paradigm is based mainly on a basic notion of the systemic: complexity. It applies two principles: dialogism and recursiveness. Finally, it is based on a vision in terms of complementarities, where the product and the supply chain are co-designed through joint design activities. This paradigm, going against the traditionally widespread disjunctive vision, can be particularly interesting in a context of innovation.

3.2.2 What are the contributions of this paradigm for innovative companies?

An innovative company manages the development of its innovative product, its market launch and often do not consider the development of the corresponding supply chain before launching. The problems relating to the supply chain are then considered as practical obstacles to solve when facing them. Complex thinking, at the opposite, allows to consider the joint design of the product and supply chain in order to minimize the risk of product failure during market launch. Joint product and supply chain design activities therefore help the company to reduce time and resources when launching its product on the market.

Indeed, the emergence of an innovation has a (more or less) significant impact on supply chain processes and can lead to its disorganization. The company may try to minimize this disruption or follow different alternatives if the value creation may be higher. As a consequence, the supply chain is an important element in the strategy of the innovative company.

According to (Morin, 2015), complexity requires strategy. The lack of a formalized strategy and compartmentalized management of product design and supply chain design activities can lead to the failure of the product on the market.

Considering our research the innovation strategy of a company integrates decision on the structure of the future supply chain, on its position in this supply chain and the value distribution along it. Thus, the product/supply chain relationship within its strategy of the innovative company is dialogical and recursive. The complex vision highlights that a product does not exist without an adapted supply chain and a supply chain does not exist without a product.

Hence, by considering the product/supply chain in the paradigm of complexity, the innovative company can:

- Reinforce coherence and consistency of the company's strategy, leading to its market position and sustainability;
- Initiate a global vision by “decompartmentalizing” product design activities and supply chain design activities and taking into account the interrelations between them.

Finally, this theoretical background highlights the lack of integration new product development methodologies including: how to define simultaneously the specification of the product and the supply chain, how to consider the production processes inside and outside the company, how to link design activities with the search of a future supply chain member.

3.3 Understanding the company/supply chain relationship through others theoretical backgrounds

The previous sections highlighted the influence of the company in the product/company/supply chain tryptic. The product/company link is the subject of many research and will not be studied in this document. However, the company/supply chain links require a thorough study. Thus, the company/supply chain link is addressed in this section using different complementary scientific theories.

This section provides an articulation of the different scientific theories that support our research. Our thinking is based on the theory of the industrial economy and its SSP model (Structure, Strategy, and Performance). On this basis, several scientific theories are presented in order to complete the SSP model and adapt it to our problems. Our approach is intended to be unifying, in the sense that it seeks to take up in each school of thought the best, to be able to elaborate a framework leading to a better understanding and explanation of our research.

3.3.1 The theory of Industrial Economy: the SSP model

The central question in industrial economy is how a company or a set of companies can gain a competitive advantage and how it can strengthen it.⁶ As part of our research, the innovative company within its supply chain seeks to gain a competitive advantage through the success of its innovative product.

The first industrial economy works around the Structuralist School, also known as Harvard School revolves around the Structure-Strategy-Performance (SSP) paradigm. According to this paradigm, the market structure determines the strategies of companies, which determine performance. The structure of the market refers to environmental factors: supply, demand, and competitive intensity, the existence of barriers to entry, standards and regulations, among others. Thus, the supply chain is an integral part of the market structure. Companies' strategy describes what companies do and how they do it (positioning, pricing, R&D, distribution

⁶ « Concurrence et économie industrielle » — Thierry Penard

strategies, etc.). Finally, performance refers to the results of industrial sectors and companies (profitability, growth, efficiency, technical progress, etc.)⁷.

From the 1970s, the SSP model was questioned, and in particular the causal and linear relationship between the three elements: Structure, Strategy and Performance (Tirole, 1988). A new school of thought appears: the New Industrial Economy, also called the Theory of Industrial Organization. Its main contribution consists in considering that the company can modify its environment through strategic decisions (Uzunidis, 2016). Thus, the market structure (here, the supply chain) will depend on the strategies of companies.

Various feedback effects are then added to the Harvard School model, making the SSP paradigm more dynamic.

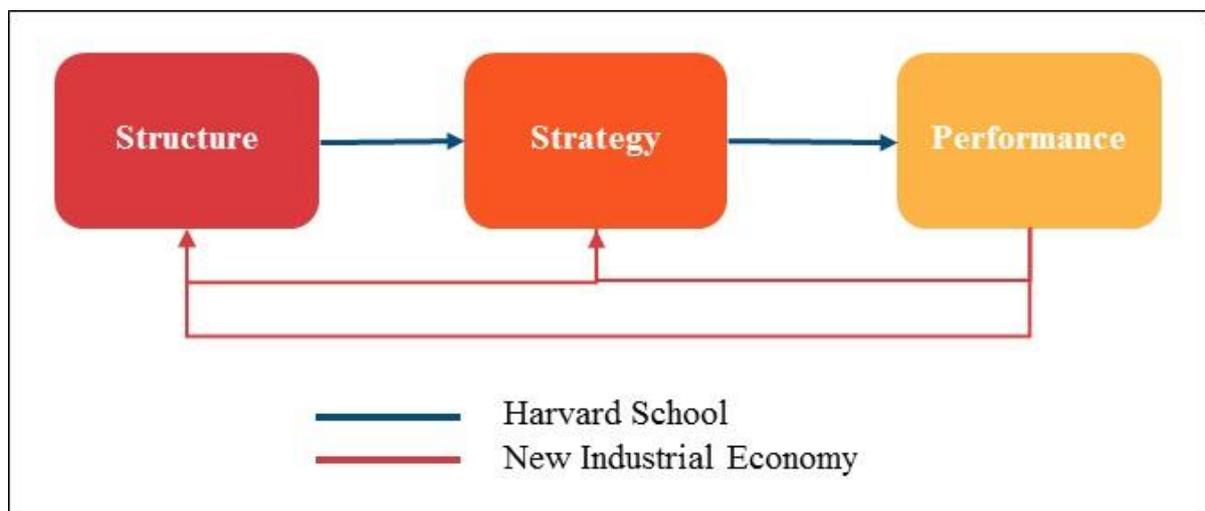


Figure 7: Theory of Industrial Economy: the SSP Model (source: [Tirole, 1988])

In our research, the SSP model is relevant to study the influence of the innovative company's strategies on the supply chain but also how the supply chain will influence the innovative company.

Indeed, by modifying its product strategy (by developing an innovation for example), a company can modify the supply chain and improve its performance and the supply chain performance. Thus, the interdependency between the product and the supply chain (in the sense of influence) is illustrated. Changes in the strategy of companies within the supply chain stems from strategic decisions to influence its organization.

⁷ « Concurrence et économie industrielle » — Thierry Penard

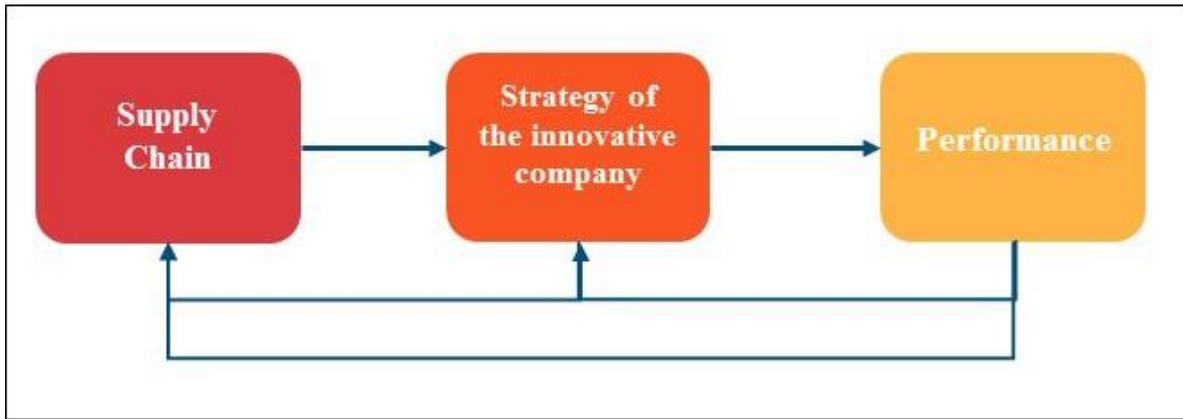


Figure 8: The SSP model applied to our research

However, the SSP model needs to be further refined to adapt it to the specific context of our research. Therefore, we propose to examine, on the basis of different scientific theories from different schools of thought, each dimension (S, S and P) in order to propose a comprehensive and relevant theoretical framework for the company/supply chain link. Thus, we seek to combine economic analysis (Theory of Industrial Economy), strategic analysis (Theory of contingency and the Resource-Based View Theory) and supply chain management analysis.

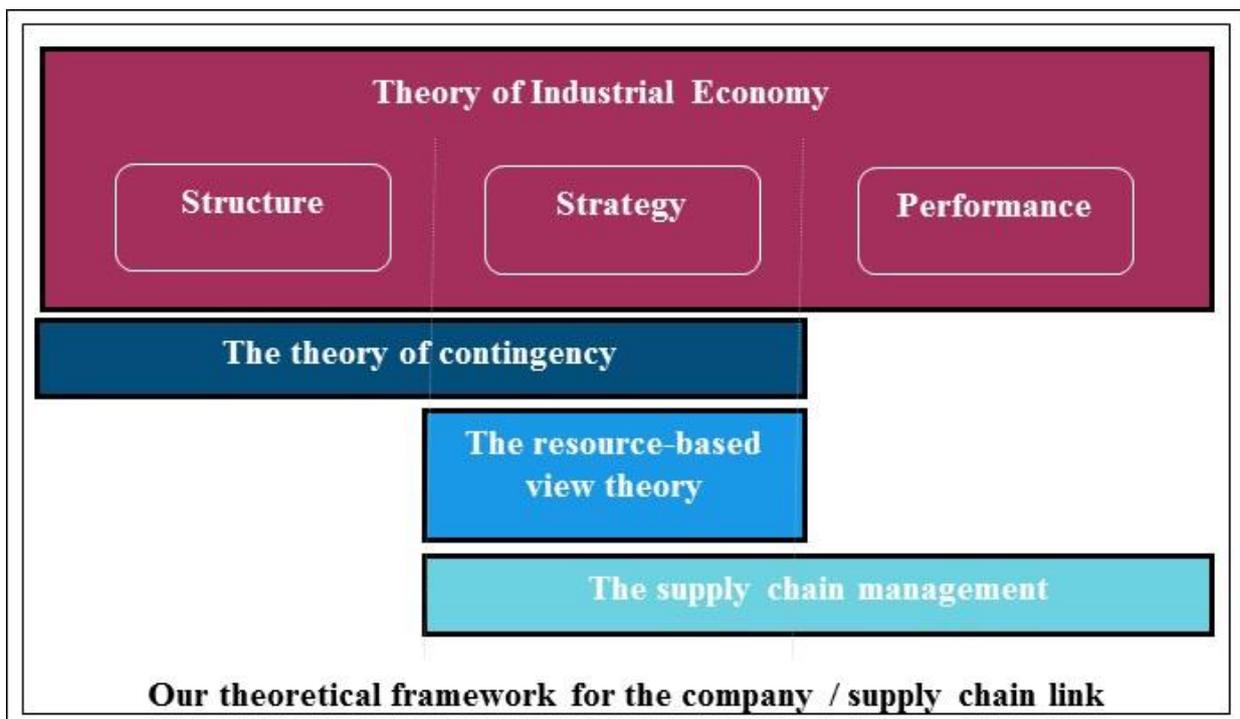


Figure 9: Construction of the theoretical framework for the company / supply chain link

3.3.2 The relationship between Structure and Strategy: the theory of contingency

In our research, the theory of contingency appears as complementary to the theory of industrial economy, particularly by looking at the relationship between the structure and company's strategy. The contingency theory belonged to the environmental school, which is based on the opposition with the confident assertions of classical management that there is "one best way" to run an organization (Mintzberg et al., 2005). While other schools consider the environment as a factor to be integrated into the company's strategy, the environmental school considers it to be a real actor. This school of thought seems relevant to our research because the supply chain is an essential component of the organization.

The theory of contingency describes the relationship between the specificities of the environment and certain dimensions of the organization. In other words, contrary to classical management theories, there is no good organization "in itself". In other words, there is no single way to manage and conceive the organization (Cole and Scott, 2000), but several according to its age, its size, its technology, its power relations and its environment (Mintzberg, 1978).

The environment of the organization can be defined by

- Its stability (from stable to dynamic);
- Its complexity (from simple to complex);
- The diversity of its market (from integration to diversification);
- Its hostility (from munificent to hostile).

Thus, the structure of an organization depends not only on its proposed characteristics but also on the nature of its environment which implies that the design of an organization depends on the strategy: the structure follows the strategy (Chandler, 1962).

The theory of contingency suggests that some external variables influence the supply chain. This includes: standards, laws, technological evolution, political instability, unexpected new general trends in customer demand. These factors generate dynamic links between the supply chain, the company and their environment. Hence, technological evolution as well as market trends changes influence the knowledge of products and customers owned by companies which characterized the supply chain (*cf Chapter 5*). Hostility is influenced by competition between supply chains, by the relationships with government as well as by the availability of resources.

Therefore, there is no universal structure adapted to all situations. A supply chain has to be adapted to its environment, and the environment shapes the supply chain. Consequently, the innovative company has to consider the different contingency factors (age, size, technology, power relation and environment) (Mintzberg, 1979) in the adjustments it makes to adapt the supply chain to its innovative product. Note that this concept of adjustment introduces the notion of "supply chain agility" developed in Chapter 4.

3.3.3 Acting on the strategy of the supply chain: a vision in terms of resources

The theory of contingency highlights the importance of strategy in the design of the supply chain. Then, in this section, we focus on the strategy of the innovative company within the supply chain. Strategic management is based on a theoretical framework that creates a competitive advantage where the managers of a given company implement a strategy that exploits its own strengths while responding to the opportunities of its environment.

Resources and capabilities are “sources” of competitive advantage, but do not necessarily contribute to competitive advantage (Bitar and Hafsi, 2007). To contribute to competitive advantage, resources and capabilities have to be valorized through products and service provided to customers willing to pay a cost effective price (Ambrosini and Bowman, 2009). (Christopher, 2000) considers that the notion of competitive advantage has shifted and extended to the supply chain that supports the manufacture of the product. Consequently, strategies within the supply chain lead to a competitive advantage if they exploit the collective strength based on main capacities and distinctive skills of the members of the supply chain. Therefore, the performance resulting from the implemented strategy can be analyzed by:

- What each company does (individual drivers);
- All individual and collective actions (all individual and participative drivers).

The Resource-Based View theory belongs to the cultural school of thought. Culture is what is unique about the way things are done. It is about what differentiates one organization from another (Mintzberg et al., 2005). This school seeks to understand the influence of the culture on the organization economic development. One way of questioning culture is to examine the resources associated with the organization. Then, strategic development becomes the management of collective knowledge. Two periods in the life of the company may be distinguished: consolidation in which a rich strategic perspective is vigorously pursued, reframing or cultural revolution accompanied by a strategic turnaround (Mintzberg et al., 2005). Thus, this school seems to be relevant in the case of innovation where the innovative company needs to evolve its organization and intrinsically, that of the supply chain of its product.

The resource-based view theory focuses on how competitive advantage is generated through a combination of resources within an organization (Dhanaraj and Beamish, 2003). The resource-based view theory considers the heterogeneity and disparity of resources and strategies within all firms and firms within a supply chain. Thus, it suggests that firms ought to identify resources that will most likely make them more competitive on the market, and then use these resources to exploit their value (Gligor, 2016; Sirmon et al., 2007). To achieve superior firm performance, firms have to possess resources (Sirmon et al., 2007) but resources also have to be effectively managed and exploited (Fawcett et al., 2012; Lippman and Rumelt, 2003; Zott, 2003). In addition, combinations of resources are more likely to explain higher performance in firms than resources employed in isolation (Gligor, 2016).

According to Resource-Based View theory, supply chain can be considered as a set of resources, and these resources are distributed heterogeneously within firms (Teece et al., 1997). For example, these resources include formal and informal systems of planning, control and coordination, as well as informal relationships within the company, between supply chain companies and between a company and its environment (Barney, 2001).

The identification and exploitation of resources involve the implementation of specific and strategic activities to achieve the desired result. These strategic activities represent evidence of a company's ability to use the resources it has available.

By considering that a supply chain is composed of a set of heterogeneous resources, the strength of the supply chain resides in the capacity of the members of the supply chain to combine and exploit these collective resources. Thus some questions arise: is the way a company mobilizes its resources to innovate independent of the way other members of the supply chain mobilize their own resources? Is the collective reflection about mobilizing resources among members of the supply chain important to increase the innovation success rate of one particular member and of all the members?

In our research, the resource-based view theory represents a complementary theoretical basis to the SSP model because it highlights the way in which a supply chain mobilizes heterogeneous resources to manufacture a product and thus create a competitive advantage.

3.3.4 The relationship between Strategy and Performance: the Supply Chain Management

Two meanings of the term "performance" are generally admitted (Folan et al., 2007; Lakri, 2016):

- Performance is defined as a numerical result at the end of a test;
- Performance is an exploit, a remarkable success.

Performance has long been limited to a simple interpretation of financial indicators. Nowadays, performance is multi-criteria. Indeed, performance indicators have to be aligned with companies' objectives and strategies in order to be relevant and representative (St-Pierre and Cadieux, 2011). Hence, at our study scale, we can consider that a supply chain management can lead to a better performance.

There is no accurate definition of the Supply Chain Management (SCM) (Table 4). Thus, the term "supply chain management" presents a source of confusion for those attempting to establish a supply chain approach to management (Mentzer et al., 2001).

Authors	Definitions
(Monczka et al., 2015)	SCM requires traditionally separate material functions to report to an executive responsible for coordinating the entire materials process, and also requires joint relationships with suppliers across multiple tiers. SCM is a concept, “whose primary objective is to integrate and manage the sourcing, flow, and control of materials using a total system perspective across multiple functions and multiple tiers of suppliers.”
(La Londe and Masters, 1994)	Supply chain strategy includes: “... two or more firms in a supply chain entering into a long-term agreement; ... the development of trust and commitment to the relationship; ... the integration of logistics activities involving the sharing of demand and sales data; ... the potential for a shift in the locus of control of the logistics process.”
(Stevens, 1989)	“The objective of managing the supply chain is to synchronize the requirements of the customer with the flow of materials from suppliers in order to effect a balance between what is often seen as conflicting goals of high customer service, low inventory management, and low unit cost.”
(Houlihan, 1988)	Differences between supply chain management and classical materials and manufacturing control: “1). The supply chain is viewed as a single process. Responsibility for the various segments in the chain is not fragmented and relegated to functional areas such as manufacturing, purchasing, distribution, and sales. 2) Supply chain management calls for, and in the end depends on, strategic decision-making. ‘Supply’ is a shared objective of practically every function in the chain and is of particular strategic significance because of its impact on overall costs and market share. 3) Supply chain management calls for a different perspective on inventories which are used as a balancing mechanism of last, not first, resort. 4) A new approach to systems is required—integration rather than interfacing.”
(Jones and Riley, 1985)	“Supply chain management deals with the total flow of materials from suppliers through end users...”
(Cooper et al., 1997)	Supply chain management is “... an integrative philosophy to manage the total flow of a distribution channel from suppliers to the ultimate user.”

Table 4: Main definitions of the supply chain management (Mentzer et al., 2001)

Although definitions of Supply Chain Management (SCM) differ across authors, they can be classified into three categories: a management philosophy, implementation of a management philosophy and a set of management processes (Table 5).

Category of SCM	Characteristics
Supply Chain Management as Management Philosophy	<ul style="list-style-type: none"> • A systems approach to viewing the supply chain as a whole, and to managing the total flow of goods inventory from the supplier to the ultimate customer (Ellram, 1990; Jones and Riley, 1985); • A strategic orientation towards cooperative efforts to synchronize and converge intra-firm and inter-firm operational and strategic capabilities into a unified whole (Ross, 1998); • A customer focus to create unique and individualized sources of customer value, leading to customer satisfaction (Langley Jr and Holcomb, 1992).
Supply Chain Management as a Set of Activities to Implement a Management Philosophy	<p>This consists of focusing on the various activities necessary to successfully implement a Supply Chain Management (Mentzer et al., 2001):</p> <ul style="list-style-type: none"> • Integrated Behavior; • Mutually Sharing Information; • Mutually Sharing Risks and Rewards; • Cooperation; • The Same Goal and the Same Focus on Serving Customers; • Integration of Processes; • Partners to Build and Maintain Long-Term Relationships.
Supply Chain Management as a Set of Management Processes	<p>Supply Chain Management is the process of managing relationships, information and materials flows across enterprise borders to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption (La Londe and Masters, 1994).</p>

Table 5: Different categories of SCM (Mentzer et al., 2001)

Thus, the scope of SCM is functional and organizational. The functional scope of SCM refers to which traditional business functions are included or excluded in the implementation and the process of SCM. The organizational scope of SCM concerns what kinds of inter-firm relationships are relevant to the participating firms in the implementation and the process of SCM (Mentzer et al., 2001).

Based on these observations and the work proposed by (Mentzer et al., 2001), we will consider his definition of Supply Chain Management as part of our research. Thus, supply chain management is “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).

(Mentzer et al., 2001) proposes a synthetic model of the SCM (Figure 10). This model highlights supply chain flows: products, services, information, financial resources, demand and forecasts. Traditional functions such as marketing, sales, R&D, forecasting, production, purchasing, logistics, IT, finance and customer service manage and implement these flows from suppliers’ suppliers to customers’ customers, with the aim of creating value and satisfying the customer. This model emphasizes the importance of customer satisfaction to

maintain or achieve competitive advantage and ensure profitability for companies individually and the supply chain collectively.

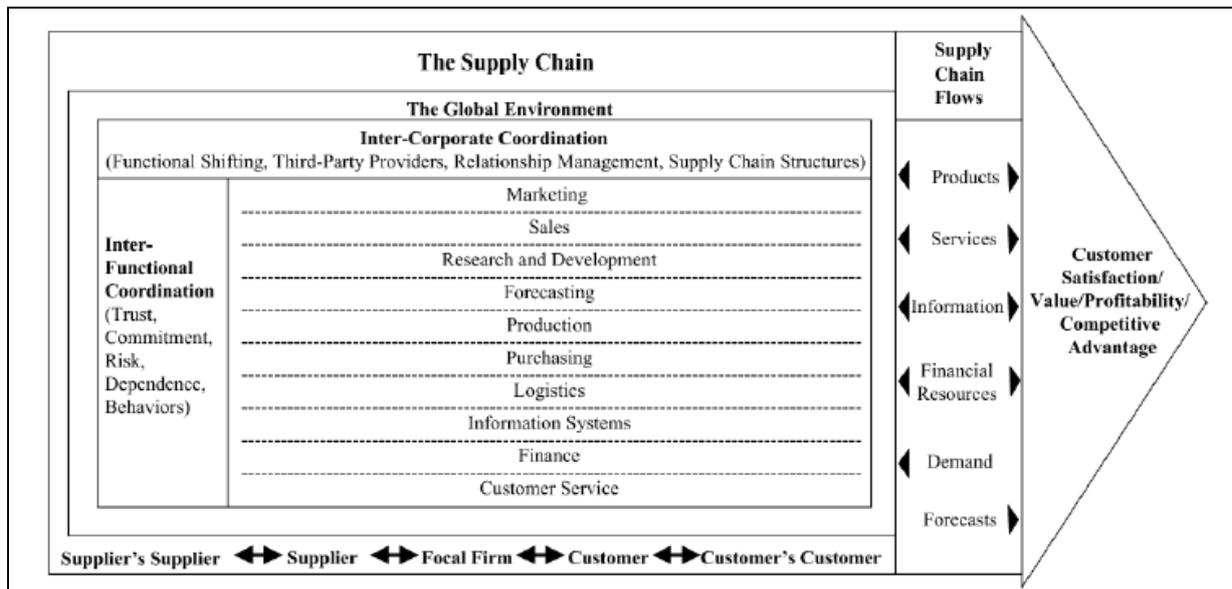


Figure 10: A Model of Supply Chain Management (Mentzer et al., 2001)

In this model, all supply chain flows (products, information, financial...) are implemented by all the individual companies' traditional functions (marketing, production, logistics...). These functions enable the transfer of different flows from suppliers' suppliers to end customers in order to create value and to satisfy customers.

According to (Lakri, 2016), performance is not definable in the absolute. Performance is:

- Context-specific, i.e. two supply chains will not have the same vision of performance;
- Specific to decision-makers;
- Multi-stakeholders.

Hence, **the performance is relative**. In our research it will be difficult to use this concept as the performance of a future supply chain supporting a new product will be differently assessing regarding each of the members of this future. And for a researcher it is difficult to assess the individual performance, because of the high number of stakeholders. Consequently, we will rather focus on the concept of "misfits" (see chapter 4). The misfit describes the problems (technical, information, lack of resources among others) meet by people in charge of innovation to develop their new product within the supply chain. Thus, based on the SSP paradigm, the misfit emphasizes that the uncertainties linked to innovations impact the supply chain performance. As a result, a supply chain adjusts its strategies to be sufficiently efficient and competitive.

3.3.5 Articulation of different theories: the SSP model revisited

The combination of different schools of thought has led to the development of a theoretical framework that strengthens our research. This theoretical framework combines the Structuralism School, the New Industrial Economy, the Environmental School, the Cultural School and the Supply Chain Management. The theory of Industrial Economy helps to highlight the links between the supply chain, the company's strategy and the performance generated. In the rest of this document, we will consider performance as the success of the innovative product on the market when it is launched. Then, according to contingency theory, to ensure the success of its product on the market, an innovative company has to respond to the constraints of its environment by making internal or external adjustments, i.e. within its supply chain. These adjustments require the identification and acquisition of resources; whose exploitation leads to a competitive advantage. The articulation of these three theories is summarized in the following model, adapted from the SSP approach.

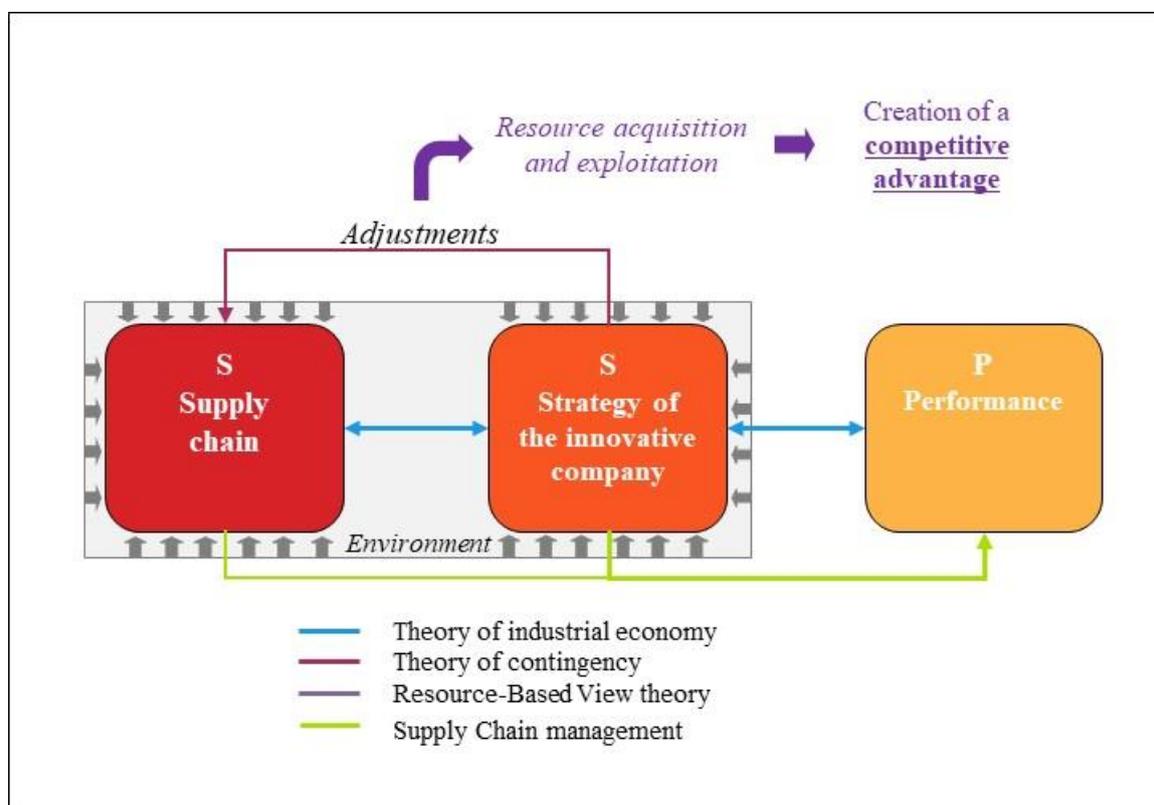


Figure 11: The SSP model adapted to our research

Conclusion of the Chapter 3

The chapter 3 clarifies from a theoretical point of view the product/supply chain link and the company/supply chain link. It has a dual objective. On the one hand, it offers an original positioning integrating the complexity of the product/supply chain link. On the other hand, it establishes a theoretical framework around the supply chain/company couple.

Our literature review highlighted the predominance of an analytical vision of the product/supply chain pair. This relationship is mostly considered in terms of the impact on each other, under the influence of a paradigm that can be described as causalist. However, from our conclusions, it seems necessary to consider this link not by limiting ourselves to a cause-and-effect relationship, but by integrating the notion of complementarity. It was chosen to study this complementarity through the theoretical foundations of the systemic and complexity, which led to the proposal of a new vision of the product/supply chain relationship that the design of these two systems has to be joint within the innovation process. This co-design highlights the emergence of joint design activities to limit the efforts associated with product and supply chain design.

An innovation often leads a company, and the associated supply chain, to modify its behavior and practices in order to adjust to the constraints of its environment (new market, new technologies, new competitors, new regulations among others). This adjustment involves identifying, acquiring and exploiting new resources within the supply chain and modifying and/or formalizing their strategies. An efficient use of these resources requires the implementation of specific activities that they must introduce into the supply chain in order to create a competitive advantage. Thus, to help companies structure their supply chain, we propose to give priority to decisions leading to adjustments in the supply chain, so as to give them the means to exploit the resources they must mobilize. This theoretical framework highlights a vision in terms of adjustment that will be developed in Chapter 4.

In complement to the theoretical results highlighted in this chapter, chapter 4 proposes to study the product, the company and the supply chain from a managerial point of view and focuses in more detail on the concept of adjustment.

IN BRIEF

- The product and the supply chain are **two interrelated systems**.
- The product and the supply chain can be studied with a **systemic approach**.
- The **product/supply chain co-design** can be seen through the complexity paradigm.
- The innovative company has to **adjust the supply chain** to ensure the success of a product.
- A suitable acquisition and exploitation of resources can lead to a **competitive advantage**.

KEY FINDINGS OF THE CHAPTER 3

This chapter has two objectives: the presentation of our scientific positioning and an articulation of different scientific theories related to our problem in order to propose a solid theoretical framework adapted to our research.

Based on a review of the literature concerning the link between innovation and supply chain, we have highlighted the limits of this field of research. The link between innovation design and supply chain design is often considered under the influence of a causalist paradigm. However, it is not limited to a cause-and-effect relationship. Hence, we propose to apply the complexity paradigm to product/supply chain design due to the fact that the supply chain/product consistence is a dynamic and multi-level phenomena and there are many complex interactions between a lot of variables. Indeed, the complex thinking highlights unifying and common elements without merging the whole, it connects while distinguishing. More precisely, it is a question of considering the design of an innovation and the design of the supply chain as two complementary activities within the innovation process. Thus, the innovative company co-designs its innovation and the associated supply chain. Therefore, the first contribution of Chapter 3 lies in proposing a new vision of product/supply chain design, through the complexity paradigm.

Moreover, by combining the contributions of the SSP (Structure-Strategy-Performance) model of the Theory of Industrial Economy with those of Contingency Theory, Resource-Based View Theory and Supply Chain Management, this chapter has enabled us to present a revisited SSP model so that it can be adapted to our research work. Thus, we bring together several research fields specific to both management science and industrial engineering, in order to propose a global vision of the problem of innovation and the supply chain.

Introduction

The link between the product and the supply chain can be materialized from a functional point of view through the notion of architecture (chapter 2). However, the relationship between the product and the supply chain is complex and considering only the technical aspect would be restrictive. Moreover, a supply chain and its link with the product can be influenced by the innovative company or the environment (chapter 3).

The environment is impacting because of the evolution of knowledge, the technologies, the competition between companies, standardization and other regulations, economic and political events among others. A supply chain evolves with its environment, depending on its companies that compose it and the markets it serves and thus over time. Thus, the emergence of an innovative product impacts the company that develops it but also transforms its supply chain.

In addition, through the actions it implements (technical choices, partnerships, distribution methods, etc.), a company is involved in structuring the supply chain during the design and the launch of its product. Thus, the link between the product and the supply chain can also be considered from a managerial point of view, especially when an innovation emerges. Indeed, the innovative company can implement strategies to fit the product and the supply chain or to adjust the current supply chain to obtain a more suitable supply chain. These strategies lead to adjustments between the present and the future supply chain: either the companies act to change the supply chain along with the product (driving force) or they implement actions to adapt to supply chain changes after product design (adaptation force). Thus, the product and the supply chain perpetually adjusts.

By considering the influence of companies on the supply chain, this chapter aims to study the product/supply chain link from a managerial point of view. This part completes the answers to the following research question:

- How to better describe the interdependence between the characteristics of a product and those of the supply chain in the context of innovation?
- How can the adjustments required to transform/type the supply chain in the case of innovation be better understood?
- How to match the typology of the supply chain required for a typology of products?
- How to anticipate (if possible) the future supply chain needed for innovation?

In a first part, the link between the product and the supply chain will be approached from at a macro level (paragraphs 4.1 and 4.2). The influence of the company will then be raised and studied. In a second part, we will focus on a micro view (paragraphs 4.3 and 4.4), mainly oriented on the dynamism of the supply chain following the product development. This second part supports our second contribution.

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4.1 Determinants of the dynamic link between the product and the supply chain

To have a better understanding of the two directional influences between the product and the supply chain, categories of supply chains are proposed according to the type of product considered.

Several researchers have focused on the product/supply chain couple pointing out some major variables (Fisher, 1997; Lee, 2002; Vonderembse et al., 2006).

4.1.1 Demand and offer

(Fisher, 1997) was the forerunner in showing that innovative products and functional products (accessible products satisfying basic needs for which demand is predictable) do not have the same supply chain requirements. This author based its analysis on the concept of demand: a predictable demand (functional product) requires physically efficient processes while an unpredictable demand (innovative product) requires market-responsive process (Figure 12). Fisher conceptualized the concept of “match” by exploring how the nature of the company’s products fits into the design of the company’s supply chain (Gligor, 2016).

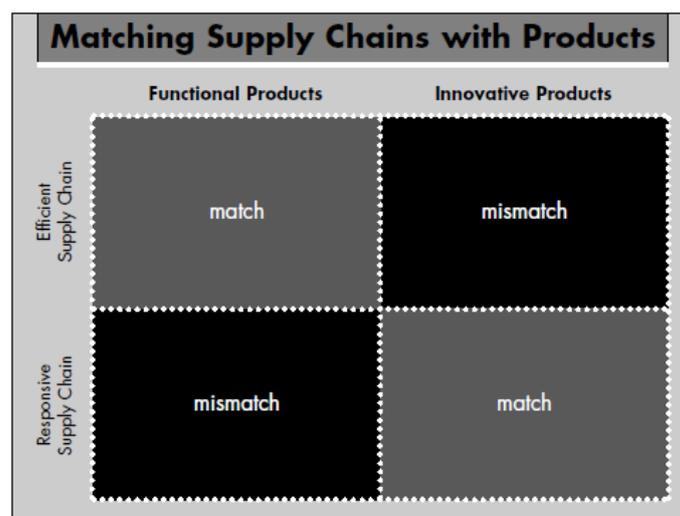


Figure 12: Supply chain classification based on the product type (Fisher, 1997)

4.1.2 Uncertainties

(Lee, 2002) completes Fisher’s work by considering that companies need to understand the uncertainties faced by the demand and supply of its products in order to try to match these uncertainties with the right supply chain strategies. This author directed its attention towards the concept of uncertainties of supply and demand faced by the firm: an innovative product can stem from a stable supply process (purchasing and manufacturing process and underlying technologies are mature) or an evolving supply process (purchasing and manufacturing processes and underlying technology are still under development and are rapidly changing). Thus, the strategy implemented by the innovative company depends on the maturity of the supply chain processes.

4.1.3 Customer expectations

(Vonderembse et al., 2006) considers that the product life cycle is a significant factor in supply chain design. Thus, the design of the supply chain depends on the characteristics of the product and the expectations of the end customers (Calantone et al., 2002; Fisher, 1997; Reiner and Trcka, 2004; Singhal and Singhal, 2002). (Vonderembse et al., 2006) examines three types of products:

- Standard products: they have stable demand, their design characteristics and production requirements change slowly over time. Design and production processes are well defined and predictable;
- Innovative products: they are new or derivative products that are intended for new customers and markets and are designed to be adaptable to changing customer needs. These products require close and continuous contact with end customers, demand is uncertain and their design may be less defined and predictable (Fisher, 1997; Mason-Jones et al., 2000);
- Hybrid products: they are complex products that can be a combination of standard and innovative products.

4.1.4 Time dimension

The launch period (introduction and growth of the product) can be called the “pre-diffusion” phase. It begins after the market introduction of the innovative product and end when the diffusion of this product takes off, i.e. when the regular S-shaped diffusion curve begins (Ortt, 2010; Ortt and Schoormans, 2004).

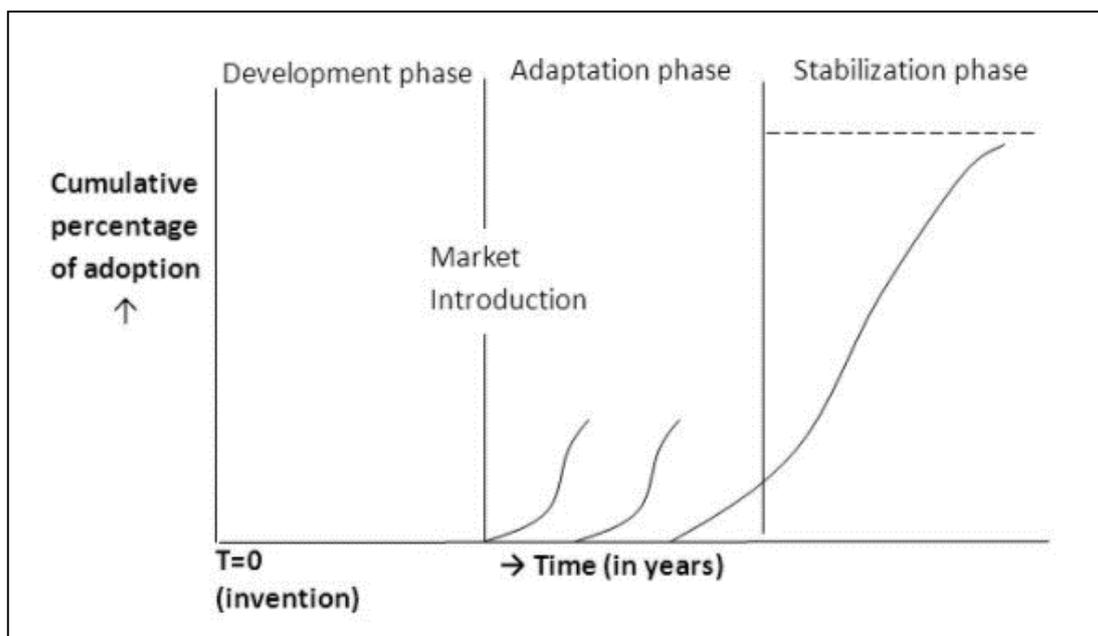


Figure 13: Pre-diffusion phases: development and adaptation (Ortt, 2010)

As a result, the pre-diffusion phase is important to guarantee the success of an innovative product launch because it enables to strengthen the new processes or the new sequence of stakeholders.

There pre-diffusion phase has been described from different scientific perspectives:

- An economic perspective based on (Marx, 1867)'s vision: it focuses on the supply side of the market and considers that the pre-diffusion phase is seen as a kind of trial-and-error process. It is required to improve the production methods. From this perspective, the management of the innovation process is important to minimize costs;
- A sociologist perspective based on (Rogers, 2003)'s vision: it focuses on the demand side of a market and considers the pre-diffusion phase as a communication process with a segment of customers. It considers the influence of demand-side factors on the pre-diffusion side. From this perspective, the market introduction strategies of new products are crucial;
- A management perspective based on (Moore, 2002)'s vision: it focuses on the interaction of the demand and supply side of the market. It considers that the diffusion does not proceed smoothly due to the variety of the customers' behavior. From this perspective, the pre-diffusion phase is risky and need companies' managerial implications.

The pre-diffusion phase requires considerable investment and precise strategies. Thus, to manage this pre-diffusion phase, an innovative company has to implement strategy leading to an adapted supply chain and the product/supply chain adjustment. Indeed, at this step, the market is unstable and this phase is different for each product (Ortt, 2010; Ortt and Schoormans, 2004). Consequently, there is no standard supply chain, but context-based supply chain.

4.2 Agile supply chain, reflection about the behavior of a supply chain at a given moment

4.2.1 Typology of supply chain

Three types of supply chain are examined in the literature:

- A lean supply chain is made up of stakeholders who individually focus on eliminating non-value added steps. Companies master lean manufacturing technic and collaborate with other members of the supply chain to improve performance (Lee, 2002). A lean supply chain has difficulty in adapting to changes in the environment (standards or customer demand for example). Alliances between companies are formed in the shape of partnerships with changes in stakeholders within a lean supply chain being infrequent;
- An agile supply chain is made up of stakeholders who individually understand customer requirements (Christopher, 2000; Lee, 2002) through an interface with the market. Companies also have a collective knowledge that is expressed through joint activities (colloquia, meeting within professional structures such as trade unions, a research program within a shared entity) or bilateral (customers—supplier relationship during which customer information is discussed). An agile supply chain has the ability to adapt quickly to future changes (investment capacity, development of standards,

etc.), alliances between companies are dynamic to produce new products. Partners can often vary according to offers and customer demand;

- It should be noted that a supply chain can adapt its behavior and take characteristics of each one in order to form a hybrid supply chain. A hybrid supply chain can be called leagile (Christopher and Towill, 2001). A leagile supply chain separates its lean and agile focus in reference to a decoupling point (Mason-Jones et al., 2000; Naylor et al., 1999). This decoupling point determines where the lean emphasis stops and the agile emphasis begins. For some supply chains, this decoupling point is naturally the point where the assembly or finale production takes place (Stavrulaki and Davis, 2010).

(Vonderembse et al., 2006) offers a very precise description to differentiate these three types of supply chain (Table 6).

Category	Lean Supply Chain (LSC)	Hybrid Supply Chain (HSC)	Agile Supply chain (ASC)
Definition	A LSC employs continuous improvement to focus on the elimination of waste, or non-value added steps in the supply chain. It is supported by the reduction of setup times to allow for the economic production of small quantities; thereby achieving cost reduction, flexibility and internal responsiveness. It does not have the ability to mass customize and be adaptable easily to future market requirements.	A HSC generally involves “assemble to order” products where demand can be accurately forecasted. The supply chain helps to achieve some degree of customization by postponing product differentiation until final assembly. Lean or ASCs are utilized for component production. The agile part of the chain establishes an interface to understand and satisfy customer requirements by being responsive and innovative.	Agility relates to the interface between a company and the market. ASCs profit by responding to rapidly changing, continually fragmenting global markets by being dynamic and context-specific, aggressively changing, and growth oriented. They are driven by customers designed products and services.
Purpose	Focus on cost reduction and flexibility for already available products. Employs a continuous improvement process to focus on the elimination of waste or non-value-added activities across the chain. Primarily aims at a cost cutting, flexibility and incremental improvements in products.	Employ lean production methods manufacturing. Interfaces with the market to understand customer requirements. Achieve a degree of customization by postponing product differentiation until final assembly and adding innovative components to the existing products.	Understands customer requirements by interfacing with customers and market and being adaptable to future changes. Aims to produce in any volume and deliver to a wide variety of market niches simultaneously. Provides customized products at short lead times (responsiveness) by reducing the cost of variation.
Integration	Integrates manufacturing, purchasing, quality and suppliers.	Similar to the LSC at component level and follows an ASC at product level.	Integrates marketing, engineering, distribution and information systems.

Table 6: Differentiation between lean, agile and hybrid supply chains (Vonderembse et al., 2006)

Category	Lean Supply Chain (LSC)	Hybrid Supply Chain (HSC)	Agile Supply chain (ASC)
Production planning	Works on confirmed orders and reliable forecasts.	Works on confirmed orders and reliable forecasts with some ability to achieve some produce variety	Has the ability to respond quickly to varying customer needs (mass customization).
Length of product life cycle	Standard products have relatively long life cycle times (> 2 years).	Involved the production of “assemble to order” products, which stay in the maturity phase of the life cycle for a long time.	Innovative products have short life cycle times (3 months–1 year).
Alliances	May participate in traditional alliances such as partnerships and joint ventures at the operating level.	Along with traditional operating alliances, HSCs may utilize strategic alliances to respond to changing consumer requirements.	Exploits a dynamic type of alliance known as a “virtual organization” that works on product design.
Markets	Serves only the current market segments.	Responds to customer requirements with innovative features in existing products. This enables the organization to capture a larger segment of that product market.	Acquires new competencies, develop new product lines, and open up new markets.
Organizational structure	Uses a static organizational structure with few levels in the hierarchy.	Maintain an organization similar to an LSC. May create temporal relationships with partners to implement innovative features.	Create virtual organizations by creating alliances with partners that vary with different product offerings that change frequently.
Approach to choosing suppliers	Supplier attributes involve low costs and high quality.	Supplier attributes involve low costs and high quality, along with the capability for speed and flexibility, as and when required.	Supplier attributes involve speed, flexibility, and quality.
Demand patterns	Demand can be accurately Forecasted.	Similar to the LSC.	Demand is unpredictable.
Inventory strategy	Generates high turns and minimizes inventory throughout the chain.	Postpones product differentiation and minimize functional component inventory.	Makes in response to customer demand.
Manufacturing focus	Maintains high average utilization rates.	Combination of lean and ASC depending on components.	Deploys excess buffer capacity to ensure that raw material/components are available to manufacture the innovative products according to market requirements.
Product design strategy	Maximizes performance and minimize costs.	Uses modular design in order to postpone product differentiation for as long as possible.	Designs products to meet individual customer needs.
Human resources	Empowered individuals working in teams in their functional departments.	Empowered individuals working in teams in their functional departments.	Involves decentralized decision-making. Empowered individuals working in cross-functional teams, which may be across company borders too.

Table 6: (Continued)

The dynamic nature of modern supply chain suggests that, in order to fit the products' characteristics with their supply chain design, companies need to be able to quickly adjust their supply chain as products move through their life cycle (Gligor, 2016). Thus, the supply chain fit is considered as “a perfect strategic consistency between the supply and demand characteristics of a product (such as demand predictability, life cycle duration, variety of products, services, delays and specific market needs) and supply chain's design characteristics (such as inventory strategy, product design strategy and supplier selection aspects)” (Wagner, Grosse-Ruyken, and Erhun 2012, p. 341).

From the characteristics of the product and those of the supply chain, (Vonderembse et al., 2006) proposes a supply chain classification on product types and product life cycle (Figure 14).

Product Type \ Product Life Cycle	Standard	Innovative	Hybrid
Introduction	Lean Supply Chain	Agile Supply Chain	Hybrid Supply Chain
Growth		Hybrid / Lean Supply Chain	
Maturity			
Decline			

Figure 14: Supply chain classification based on product types and product life cycle (Vonderembse et al., 2006)

Consequently, in the case of our research, an innovative product requires an agile supply chain during the introduction and growth phases. Thus, during the first period (launching) innovative product and agile supply chain are always combined.

4.2.2 Characteristics of an agile supply chain

(Christopher, 2000) has identified a number of characteristics of an agile supply chain (Figure 15):

- Market sensitive: it is closely connected to end-user trends;
- Virtual: it relies on shared information across all supply chain partners;
- Network-based: it gains flexibility by using the strengths of specialist stakeholders;
- Process integration: it has a high degree of process interconnectivity between the network members.

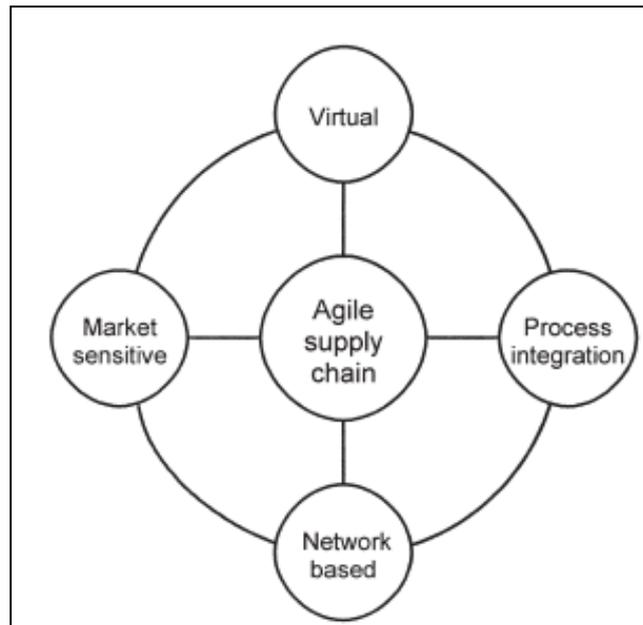


Figure 15: Characteristics of agile supply chain (Christopher, 2000)

4.2.2.1 The agile supply chain is market-sensitive

A supply chain is market-sensitive if it is closely linked to market trends, that is to say that the supply chain is able to capture and respond to real demand (Christopher, 2000). To be market-sensitive, the supply chain based its functioning on tools and technology of information to capture the demand (Christopher, 2000): regular use of point-of-sale data, market survey, digital platforms accessible to the customer to obtain feedback, after-sales service among others. The market sensitivity is affected by the level of collaboration between the supply chain partners and their abilities to use IT tools (Agarwal et al., 2007). Thus, collaboration improves trust between the supply chain partners, motivating them to share information and work on the same data (Agarwal and Shankar, 2002): concurrent engineering, collaborative project, co-design, for example.

Therefore, market sensitivity increases the level of agility because it leads to quick adjustments based on customer requirements and feedback. Thus, the customer is an important element in the product development and production.

4.2.2.2 The agile supply chain is digital

A supply chain is virtual if it based on information shared across all supply chain partners. Given the recrudescence of digital tools used by the stakeholders of the supply chain, we propose to use the term “digital” to define this characteristic of an agile supply chain. The supply chain is connected and integrated through shared information on real demand (Christopher, 2000). To be digital, the supply chain uses information technology to share data between buyers and suppliers (Christopher, 2000), information technology providing the mechanism for organizations to effectively collect, store, access, share and analyze data (Swafford et al., 2008): RSS feed implementation, common Enterprise Resource Planning (ERP), collaborative platform, Electronic Data Interchange (EDI) among others. Thus, a digital supply chain is more based on information rather than inventory (Agarwal et al., 2007)

and leads to an active collaborative organization composed of business processes of several companies that provide the essential complementary capabilities and resources (Narasimhan et al., 2006). Without IT support, the flow of information and resources becomes much slower than necessary to enable a rapid response to market changes (Ngai et al., 2011).

Therefore, digitalization increases the level of agility because it leads to quick adjustments based on strong collaboration and information technology mastering. Thus, the supply chain can be considered as one and the same company.

4.2.2.3 The agile supply chain is network-based

A supply chain is network-based that is to say that it gains flexibility by using the strengths of specialized stakeholders (Christopher, 2000): each company in the supply chain provides its human resources, its expertise and its equipment to manufacture a component or the product and meet the customer demand. Thus, it is recognized that individual businesses no longer compete as stand-alone entities, but rather as supply chain members (Christopher, 2000). The network is based on stakeholders' cooperation through joint strategy (development, design, procurement, production and so on) (Hoek, 2001).

Therefore, network increases the level of agility because it leads to quick adjustments based on privileged relationships between supply chain members. Thus, the supply chain considers the strengths of each company to provide the innovative product to the customer.

4.2.2.4 The agile supply chain integrates processes

The term "integration" is defined as "the unified control of a number of successive economic or, more particularly, industrial processes carried out independently" (Grove, 2002). Thus, a supply chain integrates processes through processes interconnectivity between network members. The processes interconnectivity, a close relationship between a company and its subcontractor for example, leads to a new business process, it consists in establishing a synergy between the various processes involved in the manufacture of a product. This interconnected process is complex and involves several companies (Chaari, 2008). Thus, there is collaborative working between buyers and suppliers, joint product development, common systems and shared information (Christopher, 2000). As a result, the supply chain has the ability to develop process, product and management innovations (Hoek, 2001). The process integration leads to an extensive form of cooperation where companies focus on managing their core competencies and outsource all other activities (Agarwal et al., 2007).

Therefore, process integration increases the level of agility because it leads to quick adjustments based on a global management of the processes within the supply chain. Thus, it involves the identification of joint strategy, buyer-supplier teams, and transparency of information.

4.2.2.5 Conclusion

These characteristics describe the behavior of an agile supply chain. Moreover, we can see that the fulfillment of one characteristic can be involved in the fulfillment of the other. For example, the development of a robust network facilitates process integration and conversely. These characteristics guide the actions to be implemented to obtain a more agile supply chain.

This is especially the case for SMEs which by their small size relies on the strengths of their partners and on their relationships.

Each of these characteristics provides information on the results to be achieved to have a more agile supply chain, but it does not provide a pragmatic action plan.

4.3 Supply chain agility: reflection about the dynamic nature of the supply chain

In this part, a micro view is privileged. By micro view, we mean a more in-depth analysis of the supply chain adjustments that occur when an innovative product emerges. This part focuses on the strategy needed to obtain a supply chain more agile.

4.3.1 The company: actor responsible for the product / supply chain adjustment

To adjust the product/supply chain couple, an innovative company has to determine its orientation.

The orientation of the supply chain is considered as “the recognition by an organization of the systemic and strategic implications of tactical activities involved in managing different flows in a supply chain” (Mentzer et al., 2001). Thus, in the case of an innovative product, companies wishing to a more agile supply chain have to be inclined to define the orientation of the supply chain and then to manage it (Gligor, 2014). The choice of the orientation of the supply chain leads to the development of consistent strategies (Gligor, 2014). Indeed, an agile supply chain does not stem from the same strategies as a lean supply chain.

The term “strategy” is used to describe all kinds of decisions, actions, processes or resources. Strategy translates finalized intention into actions (Lorino and Tarondeau, 2015). It exploits resources and skills that are likely to generate sustainable competitive advantages. Different strategies require different capacities to carry out the required actions and lead to objectives (Sharma et al., 2017) targeted by supply chain companies.

(Lorino and Tarondeau, 2015) establishes the boundaries of strategy management with five proposals:

- Strategy as set of actions or intentions finalized, defined by a set of objectives;
- Strategy as a set of decisions or intentions aimed at influencing the company’s conditions of insertion in the environment;
- Strategy as a theory of action in a hostile, complex, dynamic and uncertain environment whose results cannot be calculated or predicted with certainty;
- Strategy as the use and exploitation of available resources or capacities including time;

- Strategy as a framework for analyzing the resources and capacities to be developed in order to modify competitive conditions and improve the firm's performance.

In our case, the product-supply chain fit strategy is a set of decisions and actions leading to the implementation of an agile supply chain. Thus, the strategy implemented has to allow the stakeholders to organize themselves in the supply chain to produce and sell the product. However, it is also interested in orchestrating these stakeholders in order to mobilize the necessary resources and skills, but also to collectively adapt to the environment. Consequently, the implementation of a strategy to fit the product and the supply chain requires technical, financial and managerial decisions, operating at different levels.

The work of the Strategic Planning School provides a solid basis for organizing and formalizing an appropriate strategy. Indeed, the strategic orientation favored by the innovative company can be quantified by short-term, medium-term and long-term strategic plan. (Ansoff, 1965), the influential author of this school, proposes a division of strategic management by distinguishing three types of decisions:

- Strategic decisions determine the orientations to be followed by the company which involve it over the long term. They are non-repetitive. According to (Ansoff, 1965), these decisions concern the company's relationship with its environment. They are uncertain as environmental data are sometimes difficult to understand (Lorino and Tarondeau, 2015);
- Tactical decisions extend strategic decisions and command operational decisions. These decisions involve the company in the medium term and the risk attached to decision-making, although not negligible, is not vital for the company. They relate to resource management. They concern the acquisition, development and organization of the company's resources in such a way that its objective can be achieved (Lorino and Tarondeau, 2015);
- Operational decisions ensure the proper functioning of the company, they are not vital for the company. They relate to the operation of the company. They aim at "maximizing the efficiency of the resource utilization process" (Ansoff, 1965) and specifically addresses the problems of allocating resources to different product lines or business units and monitoring the use of these resources (Lorino and Tarondeau, 2015).

The design of a supply chain requires making a set of decisions, at different hierarchical levels. In our case, the three levels of supply chain decisions are:

- Supply chain strategic decisions concerns the orientation of the supply chain, i.e. an agile supply chain. They represent the characteristics that define an agile supply chain. These decisions include market-sensitive decisions, digital supply chain decisions, network-based decisions and process integration decisions;
- Supply chain tactical decisions concerns the acquisition, development and organization of the resources (human, monetary, material...) within the supply chain: use of market data to create new products, subcontracting, co-design, for example.

They manage the relationship and partnerships between the supply chain stakeholders and they structure the flows: implementation of cross-functional teams, collaboration with experts;

- Supply chain operational decisions concern the process management and the use of the resources in order to run the supply chain. They use skills and equipment present in supply chain companies. These decisions are in the order of training plans, cluster integration, information systems sharing or achievement of market survey.

A lower performance is often linked to a lack of adjustment (Gresov, 1989). To ensure that the future supply chain is adapted to the innovative product, the company aims to predict its performance. These performance predictions are called “adjustments” (Drazin and Van de Ven, 1985). The aim of these performance predictions is to specify both the state of the ideal supply chain or the configuration that produces the optimal performance and to show that the gap in this ideal state leads to a lower performance (Gresov, 1989).

Supply chain decisions lead to adjustment of the supply chain. In our study, we refer to the term “adjustment” as the deployment of specific actions resulting from the decisions taken by the innovative company to make its supply chain more agile. These adjustment lead to a transformation of the supply chain that has to support the company’s strategy (consistent with the SSP paradigm).

Therefore, on a semantic point of view, a supply chain may be “agile”, it is one of its characteristics. The capacity of a particular supply chain to become “agile” may be called its “agility”. But to avoid any misunderstanding, we will use the term “adjustment” to describe the decisions to get an “agile” supply chain. However, talking about the “adjustment capacity” of the supply chain can be confusing because it suggests a shift from lean to agile, but also from lean to improved lean. Therefore, we prefer to talk about the “agility adjustment capacity” of a supply chain.

4.3.2 What are the adjustments that occur in the supply chain?

To achieve the optimal supply chain for an innovative product, three supply chain abilities are considered. At first sight, agility seems the most accurate answer to obtain a more agile supply chain. However, there are two other concepts, flexibility and responsiveness, that should be studied to see if they can be a better response. In addition, there is a confusion between the notions of agility and flexibility which needs to be clarified.

4.3.2.1 Supply chain flexibility

Flexibility, according to the Oxford Dictionary, means either the “ability to bend” or “the ability to adapt” (Holweg, 2005). Flexibility in management research is generally considered as an adaptive response to environmental uncertainty (Gerwin, 1993; Gupta and Goyal, 1989; Holweg, 2005).

Supply chain flexibility encapsulates components of flexibility inherent at the inter-firm level together with those at the intra-firm level (Stevenson and Spring, 2007). The intra-firm flexibility concerns the manufacturing flexibility that focuses on the machine, material handling, operations, automation, labor, process among others (Vokurka and O’Leary-Kelly, 2000). The inter-firm level concerns the relationships. (Das and Abdel-Malek, 2003) define supply chain flexibility as the “elasticity” of the buyer-supplier relationship under changing supply conditions. At the inter-firm level, supply chain flexibility consists of operational systems, logistics processes, supply network, organizational design and information systems flexibility (Lummus et al., 2003b). For example, logistics processes flexibility relates to receiving and delivering products as sources of supply and customers change, while supply network flexibility refers to the ability to re-configure the supply chain, altering the supply of products in line with demand (Stevenson and Spring, 2007).

Thus, the literature on flexibility is divided into operational and organizational functions. Operational aspects focus on resources and plant. The organizational aspects of flexibility are conceptualized such as supply, production, distribution and information systems (Fayezi et al., 2017).

Although flexibility goes beyond the company’s borders, it is often seen as an operational response. For our research, we consider the supply chain flexibility as an operational ability that helps organizations to change effectively internally and/or through their key partners in response to internal and external uncertainties through integration of supply chain relationships (Fayezi et al., 2017).

4.3.2.2 Supply chain responsiveness

Responsiveness, according to the Oxford Dictionary, means “the quality of reacting quickly and positively”. Responsiveness, in the management literature, refers to the ability to modify organizational strategies to match environmental threats or opportunities (Tushman et al., 1986; Weick, 1979).

(Gindy et al., 1999) refer to responsiveness as the ability of a manufacturing system to make rapid and balanced adjustments to the predictable and unpredictable changes characterizing manufacturing environment. Thus, responsiveness is the ability of the manufacturing system or organization to respond to customer requests in the marketplace (Holweg, 2005). Thus, responsiveness leads to react quickly and cost effectively to changing market requirement in order to create value for the supply chain stakeholders (Gunasekaran et al., 2008). Supply chain responsiveness is an important indicator of how well the supply chain strategy fulfills its objectives since it denotes the ability of the supply chain to adapt to changing customer needs and ultimately lead to elevated performance (Blome et al., 2013).

Consequently, responsiveness focuses mainly on the customer change, it is market-oriented. For our research, the supply chain responsiveness is considered as a behavioral ability that helps organization to quickly react to changes by deploying resources to seize potential opportunities (Bernardes and Hanna, 2009; Wei and Wang, 2011).

4.3.2.3 Supply chain agility

Agility, according to the Oxford Dictionary, means “the ability to move quickly and easily”.

Agility is considered as a holistic concept (Kidd, 1995). Indeed, agility depends on the ability of easy adjustments that are achieved through the ability to reorganize the processes, structures, organizations and people. By summarizing the research of several researchers, (Rimienè, 2011) defines agility as the ability, in a changing market environment, to profitably exploit market opportunities, to quickly and flexibly respond to the customers’ needs, and qualitatively, to suffer minimum cost, by using innovative solutions and partnership cooperation. (Sharifi et al., 2006) define supply chain agility as the ability of the supply chain as a whole and its members to rapidly align the network and its operations to the dynamic and turbulent requirements of the demand network. Thus, supply chain agility extends beyond a single company and involves alignment with major customers and suppliers (Braunscheidel and Suresh, 2009).

Agility is a multidimensional concept (Fayezi et al., 2017). It influences the strategic and operational orientation of companies and their interactions within the supply chain (Jin Hai et al., 2003; Sanchez and Nagi, 2001; Sherehiy et al., 2007). That’s why, agility is characterized by flexibility and responsiveness (Blome et al., 2013).

For our research, the supply chain agility is considered as a strategic ability that helps organizations to quickly perceive and respond to internal and external uncertainties through effective integration of supply chain relationships (Fayezi et al., 2017).

4.3.2.4 Conclusion

Even if authors often use the same adjectives to define different term, some trends may be observed. Flexibility, responsiveness and agility are all organizational perspectives but at different scales. Flexibility seems to be an inherent supply chain property with a more operational orientation (Bernardes and Hanna, 2009). Responsiveness can be seen as the behavior of the supply chain, whereas agility is considered as an approach to organizing the supply chain. The table 7 summarizes the definition of each organizational perspective.

Organizational perspective	Flexibility	Responsiveness	Agility
Definition	An <u>operational ability</u> that helps organizations to change effectively internally and/or through their key partners in response to internal and external uncertainties through integration of supply chain relationships (Fayezi et al., 2017).	A <u>behavioral ability</u> that helps organization to quickly react to changes by deploying resources to seize potential opportunities (Bernardes and Hanna, 2009; Wei and Wang, 2011).	A <u>strategic ability</u> that helps organizations to quickly perceive and respond to internal and external uncertainties through effective integration of supply chain relationships (Fayezi et al., 2017).

Table 7: Our definition of each organization perspective

Definitions of agility highlight that agility is characterized by flexibility and responsiveness (Fayezi et al., 2017; Gunasekaran et al., 2008; Shaw et al., 2005) and spans organizational structures, processes, information systems and mindsets (Christopher and Towill, 2001; Shaw et al., 2005).

Consequently, agility is an organizational perspective including flexibility and responsiveness among others. In our research, supply chain agility seems relevant to characterize the adjustments needed following the emergence of an innovative product. Indeed, it enables to have a comprehensive view by considering both the supply chain, the companies and the market. The interest of agility for our research is detailed in the next session.

4.3.3 Agility supply chain: an organizational response

The emergence of an innovation can disrupt the organization of a supply chain, so the supply chain has to be able to provide effective and efficient organizational responses (Fayezi et al., 2017; Purvis et al., 2014) to satisfy the characteristics of his new product.

The concept of agility is an organizational orientation that is based on manufacturing and commercial flexibility to allow for greater responsiveness to change. So, agility is considered as one of the fundamental characteristics necessary for the supply chain to survive and thrive in turbulent and volatile markets (Agarwal et al., 2007; Braunscheidel and Suresh, 2009), as it is the case for an innovation, for example.

Agility is a paradigm. More precisely it is a paradigm of change in the management of the supply chain (Tseng and Lin, 2011; Vinodh, 2010) which constantly promotes proactivity, responsiveness, information systems/technology, speed, adaptability, flexibility and cooperation within and among supply chain participants (Fayezi et al., 2017).

The supply chain agility underscores the ability of companies to make quick adjustments to their supply chain to respond or adapt to changes (Gligor et al., 2013), i.e. the companies quickly and collectively find solutions (in terms of resources, organization among others) to overcome a shortcoming in the supply chain. It relies on effective integration of relationships within the supply chain (Fayezi et al., 2017) and reconfiguration of their resources in a collaborative way (Sharifi et al., 2006) to function more efficiently according to the characteristics of the product they handle (Gligor, 2016). The agility of the supply chain is a source of competitive advantage for companies (Gligor et al., 2013) which seek to coordinate their activities in order to achieve together a higher level of agility than their competitors (Lin et al., 2006). Then, the agility of the supply chain helps companies to deal with uncertainty better by reacting quickly to new situations and facilitates the realization of the product-supply chain without, however, making it possible to design the supply chain adapted to the product (Gligor et al., 2013).

Consequently, to gain a competitive advantage in the current business environment, an innovative company needs to be closely linked and aligned with companies located upstream and downstream of its supply chain in order to ensure the success of its innovative product. This is a principle for creating agility: the companies have to be able to quickly align their

collective capabilities to responds to changes in market and customer demand (Gligor et al., 2015). Consequently, increased agility requires less effort to implement changes to get closer to the ideal situation (Rimienė, 2011). We propose to illustrate this concept with the case of the Swatch⁸.

Illustration of the concept of agility: the case of the Swatch

Originally, the Swiss watch industry was organized in the form of a cartel where each company of the supply chain was involved in the realization of a very specific activity (manufacture of a brass movement only for example). The emergence of Japanese watches has threatened Swiss industry. Hence the need for innovation: Swatch has appeared. Its development has led to a radical change in the organization of the supply chain, impacting in particular assembly and distribution activities.

To face the uncertainties, the innovative company transformed the supply chain through the integration of relationships: the members of the supply chain are collectively involved in the realization of the new product. Indeed, component suppliers adapt their production to product needs, equipment suppliers share their know-how (plastic forming) and lend injection machines to test and stabilize the new manufacturing process. This operation breaks the rules of the cartel. Thus, technical skills and resources are made available within the supply chain in a collective approach. Even customer returns help organize the supply chain to improve the manufacturing process. In addition, the choice of the manufacturing process promotes product customization, allowing the supply chain to react quickly to market trends. This reconfiguration led to the success of the Swatch which competed effectively with Japanese watches.

This example illustrates the concept of agility by highlighting how companies have collaborated to face an external threat, going so far as to deeply reorganize their supply chain.

Choice for our research: Agility is considered as a dynamic ability to adjust the supply chain to the product data and vice versa.

4.3.4 Conclusion

Beyond the concept of agile supply chain, we can consider another associated principle: agility. Therefore, the agility of a supply chain corresponds to its ability to change its configuration according to the strategic, technological, organizational or human plans of the innovative company that make up it. A supply chain, and its companies, face or generate innovations, adapt (or not) to fluctuating markets and anticipate (or not) different environmental hazards (Christopher and Peck 2004). This requires collective agility at the industry level (Paché, 2004), which can lead to a reconfiguration of the supply chain. Therefore, agility operates at several levels. At company and supply chain levels, the latter is

⁸ This case will be studied in depth in the next chapter.

expressed by the agility of its stakeholders, upstream and downstream of the focal company (Christopher and Peck, 2004).

4.4 Implementation of an agility strategy

4.4.1 Agility: an ability to do some pragmatic activities of adjustment

Following the previous definitions, it is necessary to go into deeper details about the agility adjustment that members of a supply chain must have. Indeed, we can consider three types of supply chain changes that do not require the same level of adjustment (Figure 16):

- **Increase the agility degree of an initial agile supply chain.** Many innovations appear in highly competitive markets, such as high-tech products. Thus, the regular evolution of products requires agile supply chains so that the companies of these supply chains can survive. However, when launching innovative products, the agility of the agile supply chain has to be increased to ensure product success on the market. Although remaining agile, the degree of agility of the supply chain decreases throughout the product life cycle.
- **Transformation of the initial supply chain.** To reach the innovative product-supply chain fit, an initial lean supply chain has to be transformed. To achieve an agile supply chain, the supply chain has to reorganize itself to adjust its processes to those of the product. This requires investments in terms of skills, equipment, business models and/or digital tools among others. The case of the Swatch is an interesting example: the initial supply chain is organized in a cartel (lean type) to support luxury products while the new supply chain is agile at the launch of the new watch to react quickly and adjust to new trends, the Swatch being a fashion accessory.
- **Creation of a new agile supply chain.** The development of a really new product can lead to the creation of a totally new supply chain, i.e. it leads to the involvement of new stakeholders (suppliers, manufacturers, distributors...), new processes, and new skills. This is the case for certain breakthrough innovations such as Nespresso or the Iphone. The development of espresso capsules has led to the creation of totally new agile supply chain requiring the integration of new suppliers and manufacturers in charge of capsule production, new distributors and the emergence of specialized resellers. This also applies to the iPhone where the integration of new technologies has created a totally new supply chain.

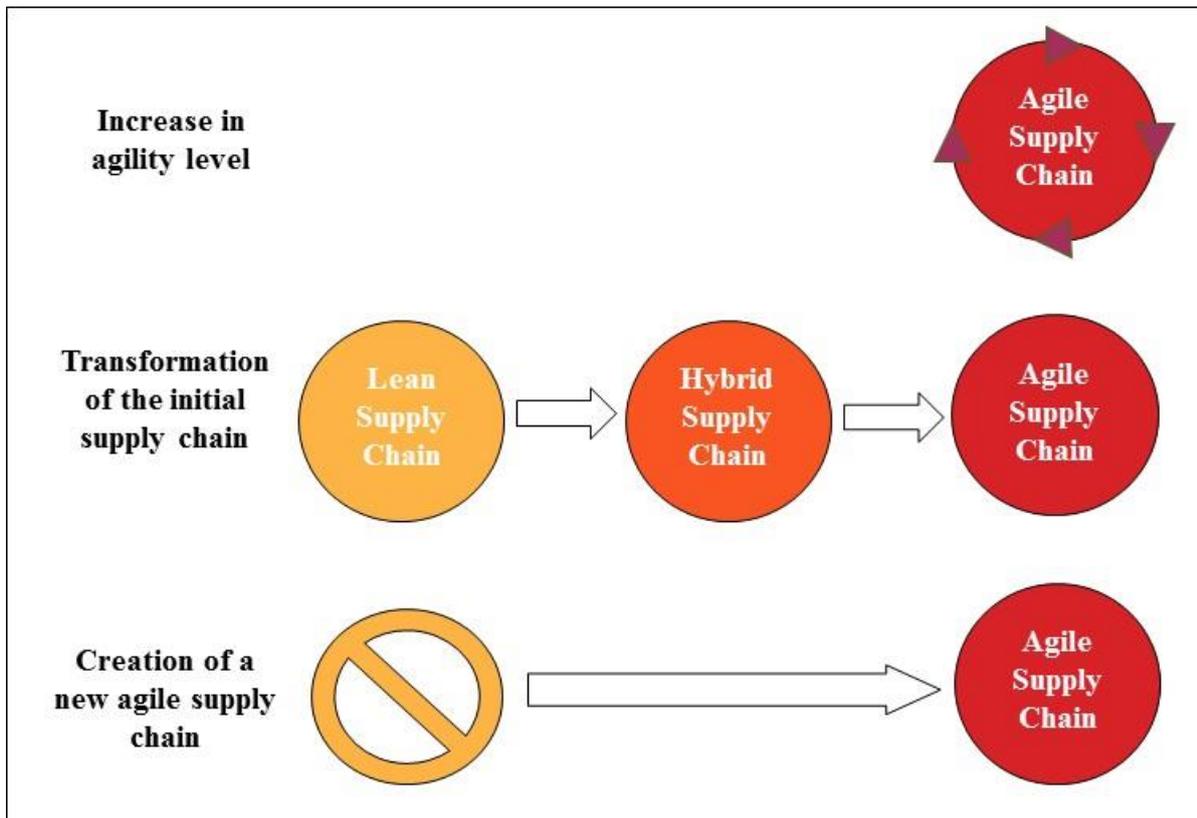


Figure 16: Different types of agility adjustments

Each case requires an appropriate strategy what is consistent with the SSP paradigm. Indeed, in the case of innovation, the structure of the supply chain has to be aligned with the innovative companies' strategies to obtain an agile supply chain, which increases the product's chance of success on the market, i.e. the supply chain performance. In addition, strategy literature suggests that, in order to maximize performance, companies should adopt a strategic approach to developing the level of agility in their desired supply chain (Goldsby et al., 2006).

4.4.2 A fuzzy literature about pragmatic action plans

Currently, in the literature, there is no overall framework of approaches that contribute to designing an agile supply chain. There are only a few documents that attempt to establish a set of approaches influencing the agility of a supply chain (Sangari et al., 2015).

(Sharma et al., 2017) present an in-depth review of the literature on agility approaches and highlights the existence of seven approaches families based on several criteria: integration, flexibility, collaboration, strategic sourcing, information sharing, IT-enabled, competence, market sensitivity, supply chain risk management. These approaches seek to summarize all research on this subject. By considering this literature review and other similar researches, a non-exhaustive list of approaches reveals the different themes addressed.

The research on agility approaches is multiple and diffuse. To gain a more objective overview, we categorized these approaches into four categories: integration, expectation of change, response to change and product design adaptation (Table 8).

Themes	Dimensions from the literature	Authors
Integration	Supply chain integration	(Ngai et al., 2011 ; Sharma et al., 2017 ; Tse et al., 2016)
	Value chain integration	(Vázquez-Bustelo and Avella, 2006)
	Virtual integration	(Kumar Sharma and Bhat, 2014; Sharma et al., 2017)
	Demand and supply process integration	(Gligor, 2014; Sharma et al., 2017)
	Network integration	(Sharma et al., 2017)
	Internal and external integration	(Braunscheidel and Suresh, 2009, 2018; Sharma et al., 2017)
	IT integration	(Sangari et al., 2015; Swafford et al., 2006, 2008)
Expectation of change	Information system/technology	(Fayezi, Zutshi, and O'Loughlin 2017; Sharma et al. 2017; Sangari, Razmi, and Zolfaghari 2015; White, Daniel, and Mohdzain 2005; Liu et al. 2013)
	Proactiveness	(Fayezi et al., 2017)
	Responsiveness	(Fayezi et al., 2017; Li et al., 2008)
	Market sensibility	(Braunscheidel and Suresh, 2009; Gligor, 2014; Kumar Sharma and Bhat, 2014; Sangari et al., 2015; Sharma et al., 2017)
	Knowledge management	(Vázquez-Bustelo and Avella 2006; Christopher 2000; Gligor 2014; Sangari, Razmi, and Zolfaghari 2015)
	Learning orientation	(Braunscheidel and Suresh, 2009; Ngai et al., 2011)
Response to change	Flexibility	(Ngai, Chau, and Chan 2011; Gligor, Holcomb, and Stank 2013; Fayezi, Zutshi, and O'Loughlin 2017; Kumar Sharma and Bhat 2014; Sharma et al. 2017; Braunscheidel and Suresh 2018; Li et al. 2008; Sangari, Razmi, and Zolfaghari 2015)
	Cooperation, collaborative relationships	(Fayezi, Zutshi, and O'Loughlin 2017; Kumar Sharma and Bhat 2014; Sharma et al. 2017)
	Adaptability	(Fayezi, Zutshi, and O'Loughlin 2017; Kumar Sharma and Bhat 2014)
	Accessibility	(Gligor et al., 2013)
	Information sharing	(Sangari et al., 2015; Sharma et al., 2017)
	Strategic sourcing	(Chiang et al., 2012 ; Sangari et al., 2015 ; Sharma et al., 2017)
	Competence	(Li et al., 2008 ; Ngai et al., 2011 ; Sangari et al., 2015 ; Sharma et al., 2017)
	Knowledge management	(Vázquez-Bustelo and Avella 2006; Christopher 2000; Gligor 2014; Sangari, Razmi, and Zolfaghari 2015)
Product design adaptation	Built to order	(Kumar Sharma and Bhat, 2014; Stavrulaki and Davis, 2010)
	Simultaneous engineering	(Vázquez-Bustelo and Avella 2006)

Table 8: Dimensions studied in the literature in the case of agility implementation

Some authors talk about agility enablers (Gligor and Holcomb, 2012; Gligor et al., 2013; Kumar Sharma and Bhat, 2014; Ngai et al., 2011; Sharma et al., 2017), others use the term of antecedents (Braunscheidel and Suresh, 2009, 2018; Fayezi et al., 2017; Gligor, 2014; Ngai et al., 2011; Tse et al., 2016) but these terms remain imprecise, due to the consideration of:

- Different scales: company or supply chain;
- Different implementation results: decisions (built to order for example) or tools (information technology for example);
- Different strategic options: tactical (virtual integration for example) or operational (IT integration).

However, these works are a good basis to be exploited. Thus, we propose a “practical approach” based on a non-exhaustive list of observable phenomena leading to a more agile supply chain, i.e. a supply chain with the characteristics defined by (Christopher, 2000). Indeed, this “practical approach” considers the actions undertaken by companies individually or in more or less formal partnership. This practice-based vision is consistent with the SSP paradigm, the S (Strategy) being these company practices.

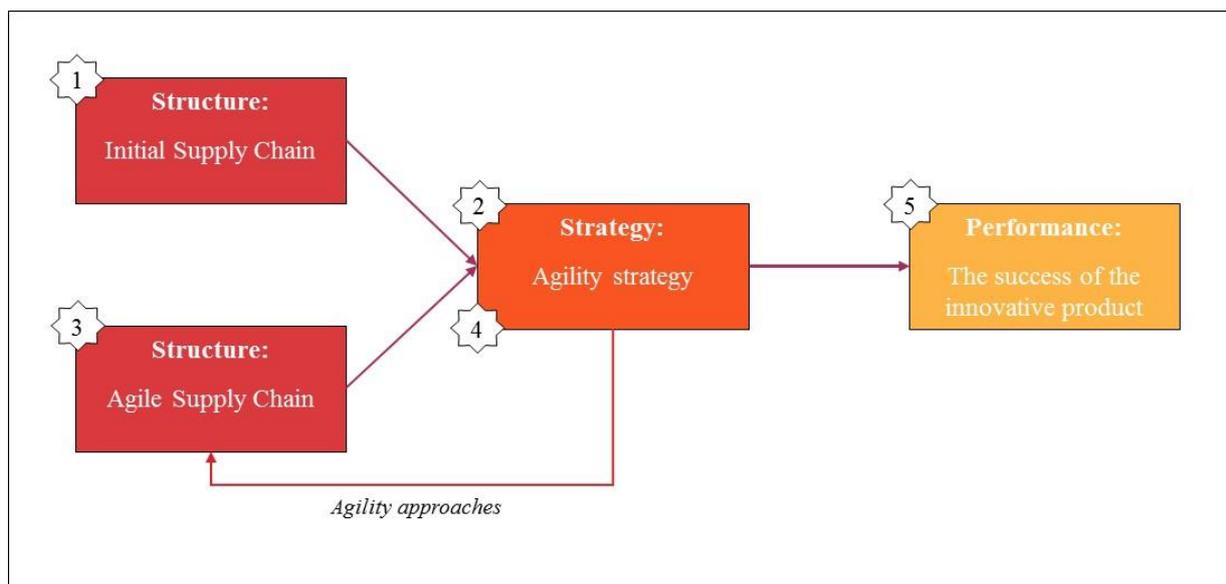


Figure 17: Importance of implementing agility in our research framework

4.5 2nd theoretical contribution: Ability to implement an agility strategy

Some authors focus on dimensions leading to improve the agility of the supply chain (4.4.2) but there is no framework informing the company on the way to influence the agility of its supply chain. We propose to explain, based on the literature, what are the best decisions to reach an agile supply chain. These dimensions are classified based on their contributions to an agile characteristic and they are illustrated at different scales (tactical and operational) thanks to observable phenomena (4.5.2).

Our contribution consists in helping innovative companies to formulate a supply chain agile strategy by proposing a list of actions to guide an innovative company in the achievement of its objectives, i.e. to design a market-sensitive, virtual, network-based supply chain whose processes are integrated. This list of actions is inspired by research on agility approaches (paragraph 4.4.2), and in particular the synthesis work of (Sharma et al., 2017). These agility approaches were merged in dimensions to meet the agile supply chain characteristics.

To consider the different scales of action, the proposed classification is based on the definitions of the decisions proposed by (Ansoff, 1965) where observable phenomena from the literature are identified and organized according to their tactical or operational responses, key strategic decisions leading to the four characteristics of (Christopher, 2000).

4.5.1 A methodology based on theoretical data

From the literature review on supply chain agility, several thematic are addressed to implement an agility strategy. The first phase of this study is to determine which are the main agility dimensions that can be used to obtain each of the characteristics of an agile supply chain. A cross-study of (Christopher 2000) and (Sharma et al., 2017) helps to determine and define the main dimensions for each characteristic. The second phase of this study consists of the collection of activities aiming to complete each dimensions of each characteristic. By considering definitions, several agility factors founded in the literature are merged within each dimension to have a comprehensive view of each dimension. The references provided by (Sharma et al., 2017) mainly contributed to seeking agility activities. These activities appear in the form of observable phenomena, surveyed in the literature.

An observable phenomenon can be defined as the tangible and verifiable proof(s) of an activity carried out routinely within the company. Therefore, the observable phenomena act as indicators to assess the activity in question (Enjolras 2016). If these observable phenomena are present within the supply chain, the decision they characterize can be implemented. One hundred observable phenomena are collected.

By using (Ansoff, 1965)'s decision classification, each observable phenomenon is classified in one dimension of one agile supply chain characteristics according to their finality (tactical or operational), the four agile supply chain characteristics being considered like strategic decisions. Our contribution is a classification of observable phenomena into decisions leading to the achievement of the four main strategic decisions.

The figure 18 summarizes and describes our second contribution.

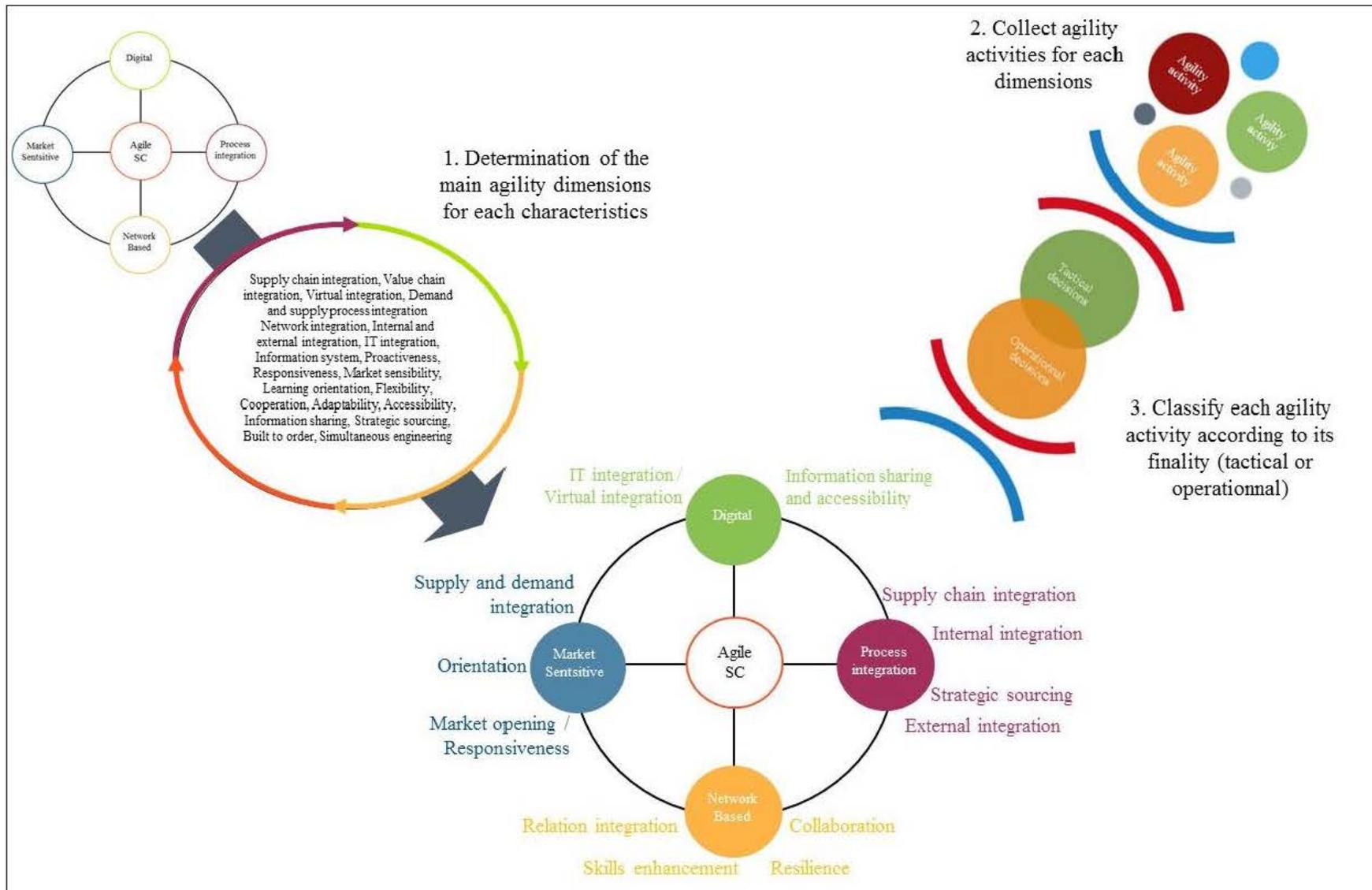


Figure 18: Description of our second contribution

4.5.2 Identification of agility actions leading to adjustments

This part presents our contribution. For each agile supply chain characteristics, dimensions are shortly defined and the tactical and operational contents are quickly presented. The full classification is in the Appendix 1.

4.5.2.1 The supply chain has to be market-sensitive **a. Orientation**

The orientation concerns a set of practices to quickly build standards or customized products on the basis of spontaneous orders received without forecasts, inventory or purchase lead time (Kumar Sharma and Bhat, 2014).

To do this:

The supply chain seeks to delay differentiation to allow customization (Braunscheidel and Suresh, 2018) by including processes dedicated to customizing the product (assembly, colorization...) (Lee, 2004) or positioning customization processes at the end of the product manufacturing process (Lee, 2004; Mesnard and Pfohl, 2000; Stavrulaki and Davis, 2010).

The supply chain favors modular, specialized or custom manufacturing of the product (Hoek, 2001; Stavrulaki and Davis, 2010), the processes in the supply chain depending on the choice of customers in terms of components, functionality or product (Mesnard and Pfohl, 2000) or providing alternative processes to adapt as well as possible to the customer's request (Braunscheidel and Suresh, 2018).

The supply chain has few/no intermediaries between the innovator and the end customer (Stavrulaki and Davis, 2010), leading to selling directly to end customers or selecting a limited number of resellers (Stavrulaki and Davis, 2010).

The supply chain is composed of few companies (Stavrulaki and Davis, 2010): the commercial services seek to have few retailers or resellers and/or the manufacture of the product is managed by a limited number of companies (Stavrulaki and Davis, 2010).

Production is linked to commercial activity (the purchase order is equivalent to a production order) and/or is discontinued according to customer demand (Stavrulaki and Davis, 2010). In addition, the customer can request the innovative company to design a product that meets their needs (Meredith and Francis, 2000; Mesnard and Pfohl, 2000). Therefore, the supply chain manufactures the product in response to customer demand (Stavrulaki and Davis, 2010).

b. Market opening / Responsiveness

The market opening is a set of practices that enable the supply chain to read and respond to actual demand (Sharma et al., 2017).

To do this

Members of the supply chain conduct marketing intelligence and market research (follow-up of market developments) (Ayadi, 2009; Meredith and Francis, 2000) leading to a use of a

market data to create a new product. In addition, the end customer participates in consultations or investigations (Meredith and Francis, 2000; Mesnard and Pfohl, 2000), consciously and actively.

The supply chain disseminates market data to all its members (Braunscheidel and Suresh, 2018). The supply chain members have information on the level of demand and the innovative company or distribution centers adjust delivery of products according to demand (Lee, 2004) through CRM-type tools. Resellers/retailers inform the supply chain of product requirements (Lee, 2004) via ERP, for example.

The supply chain takes into account the customer feedback: the supply chain pays particular attention to after-sales service (Braunscheidel and Suresh, 2018) and sets up feedback processes to retrieve customer comments (Fundin and Bergman, 2003).

c. Supply and demand integration

Supply and demand integration correspond to a set of processes by which the supply chain creates value for its customers by moving goods and information through marketing channels: demand-driven and supply-side processes (Esper et al., 2010).

To do this:

The customer is actively involved in the product development process (co-design) (Braunscheidel and Suresh, 2018): the client participates in working groups, product testing (Meredith and Francis, 2000; Mesnard and Pfohl, 2000) and/or he shares his ideas and needs with the commercial and/or R&D departments of the innovative company (Fundin and Bergman, 2003; Mesnard and Pfohl, 2000).

The level of demand and its fluctuations are visible throughout the supply chain (Braunscheidel and Suresh, 2018) thanks to shared order management tools such as ERPs. In addition, the supply chain recovers customer feedback on quality and delivery performance (Braunscheidel and Suresh, 2018) and/or it organizes and improves its processes based on customer feedback (Fundin and Bergman, 2003; Garel and Mock, 2012) obtained through after-sales service or product warranties. Therefore, the supply chain operations are impacted by market information.

The supply chain has contingency plans in place to deal with supply-side uncertainties and disruptions, by informing customers of stock levels and production plans (Braunscheidel and Suresh, 2018) and/or informing customers of the shipping and delivery status of orders (Lee, 2004). Another option concerns the way that the commercial department is in constant contact with the market to resolve litigation (Fundin and Bergman, 2003).

4.5.2.2 The supply chain has to be digital

a. Information sharing and accessibility

Information sharing and accessibility consist of a set of practices for accessing relevant data (Gligor et al., 2013).

To do this:

The supply chain capitalizes the data thanks to a monitoring process that is implemented at the supply chain level (study of target markets, standards, legislation, trends, patents, geopolitics...) (Ayadi, 2009; Meredith and Francis, 2000) and/or an active information exchange between the members of the supply chain (Braunscheidel and Suresh, 2018) through collaborative platforms, digital workspaces, information systems like Product Life Cycle Management in order to facilitate data sharing.

Members of the supply chain actively and regularly exchange information (Braunscheidel and Suresh, 2018). Information is disseminated and shared through communication systems between members of the supply chain (Jahre and Fabbe-Costes, 2005), through computer and Internet tools (Agarwal et al., 2007; Braunscheidel and Suresh, 2018; Soni and Kodali, 2012) such as digital collaborative platforms, digital workspaces or information systems among others. In addition, information on products, inventory levels, shipment status and production requirements are provided in real time (Radstaak and Ketelaar, 1998). Thus, the supply chain disseminates and shares information (Christopher and Lee, 2004).

b. IT integration/ Virtual integration

IT integration (also called virtual integration) is a set of practices in which information technology is used to coordinate and integrate information in the functions of the innovative enterprise and with the corresponding supply chain companies (Swafford et al., 2008).

To do this:

The members of the supply chain frequently exchange (Lee, 2004; Sanders and Premus, 2005): collaborative interdependencies exist between supply chain members (Lee, 2004; Sanders and Premus, 2005) and/or information technologies facilitate collaboration between members of the supply chain (Giunipero et al., 2006).

The members of the supply chain have a common thinking on the information technologies to be used by setting up computerized data exchange systems (purchase orders, invoices, delivery notes, etc.). (Min and Galle, 1999) and/or using connected, compatible and modular information technologies (Ngai et al., 2011).

4.5.2.3 The supply chain has to integrate processes

a. Strategic sourcing

A strategic sourcing consists on all procurement network design and management processes that are consistent with operational and organizational performance objectives (Narasimhan and Das, 1999a, 1999b).

To do this:

Companies know the inventory level in the supply chain (Braunscheidel and Suresh, 2018). Alliances are set up between suppliers and buyers to meet a varied demand (Qrunfleh and Tarafdar, 2013) by:

- Creating buffer stocks to cope with supply disruptions and increased demand (Braunscheidel and Suresh, 2018; Lee, 2004)
- Using rapid response initiatives such as continuous replenishment, vendor-managed inventory, collaborative planning, forecasting and replenishment (Braunscheidel and Suresh, 2018)
- Knowing how to manage manufacturing resources: raw materials, components... (Ngai et al., 2011)

b. External integration

External integration corresponds to a set of practices to coordinate the flow of information and goods with upstream and downstream members of the supply chain (Braunscheidel and Suresh, 2009).

To do this

The innovative company has joint planning with its suppliers to facilitate purchasing and production, shares information on inventory levels with its suppliers and/or develops a long-term relationship with its suppliers (Braunscheidel and Suresh, 2018). Therefore, the activities of the innovating company are coordinated with those of its suppliers and customers (Stock et al., 2000).

c. Internal integration

Internal integration consists on the set of practices that enable functions within an organization to coordinate and cooperate with each other (Braunscheidel and Suresh, 2009)

To do this

The company's activities are reliable and optimized or outsourced by using methods to optimize activities (process mapping...) (Brandenburg and Wojtyna, 2006), collaborating with subcontractors to carry out activities/processes that it does not control (Wiendahl and Lutz, 2002) and/or using customer feedback to optimize and improve the reliability of its activities/processes (Garel and Mock, 2012).

The company sets up cross-functional teams by organizing internal meetings (Braunscheidel and Suresh, 2009), setting up teams based on the expertise of its employees (Gotteland and Haon, 2011) and/or sharing information among team members, between different departments of the company (Gotteland and Haon, 2011).

d. Supply chain integration

Supply chain integration corresponds to a set of practices used by a company to collaborate with its supply chain partners and jointly manage intra- and inter-organizational processes (Flynn et al., 2010).

To do this

Companies work in collaboration with their suppliers and share a common information system (Christopher, 2000). In addition, the innovative company develops its new products jointly with its suppliers and customers (Braunscheidel and Suresh, 2018) leading to a joint product development (Christopher, 2000) or a concurrent engineering.

The supply chain plans contingency plans to address operational uncertainties and disruptions by creating buffer capacities to cope with potential disturbances (Braunscheidel and Suresh, 2018), by continuously learning to prepare for a disruption in the environment (Ngai et al., 2011) and/or making quick decisions in response to change (Ngai et al., 2011).

4.5.2.4 The supply chain has to be networked-based

a. Resilience

The resilience includes the notions of flexibility and adaptability (Samuel and Ruel, 2017) and consists of a set of practices that organizations implement to adapt to any type of event and to reorganize quickly and in a coordinated manner after a major disruption (Sheffi, 2005).

To do this

The members of the supply chain have the opportunity to move quickly from one component/product production to another according to the customer's demand (Braunscheidel and Suresh, 2018; Lee, 2004) and/or ensures the flexibility of its supply networks, operations and distribution networks being able to propose new alternatives of routing of the products (Braunscheidel and Suresh, 2018) in order to anticipate possible problems from a supply chain member. In addition, they are able to produce different combinations of products (Zhang et al., 2003). Thus, the supply chain members are able to design flexible production systems that can accommodate multiple products (Rice and Caniato, 2003) in order to easily offer different products to customers without disrupting the functioning of the supply chain.

Supply chain members are able to adapt to demand by producing at different levels of production and changing production quantities quickly and cost-effectively (Zhang et al., 2003) due to a flexible production planning (Christopher and Lee, 2004), the adoption of internal flexible practices: flexibility of machines, flexibility in material handling, and flexibility of work... (Zhang et al., 2003) and/or the adoption of flexible external practices: volume flexibility, range flexibility (Zhang et al., 2003)

b. Collaboration

Collaboration is a set of practices promoting bilateral relations between supply chain partners (Narayanan et al., 2015)

To do this

Supply chain members maintain close and coordinated relationships with their main trading partners (suppliers, manufacturers and distributors) (Kisperska-Moron and Swierczek, 2009; Ngai et al., 2011), exchange market information and/or share information about production, supply or customer demand (Braunscheidel and Suresh, 2018) and/or share so-called agile methodologies (SCRUM...) (Trudel and Boisvert, 2011). Therefore, supply chain members exchange information and knowledge (Narayanan et al., 2015).

The supply chain members make joint efforts to integrate economic but also environmental, social, technological or political considerations into their decisions (Seuring and Gold, 2013) to ensure the development and the sustainability of their supply chain through analysis tools such as PESTEL. In addition, supply chain members have set common objectives leading to cooperation and participation in the management of the supply chain (Narayanan et al., 2015).

c. Skills enhancement

Skills enhancement is a set of practices for applying knowledge and performing a task that depends on context (Le Deist and Winterton, 2005).

To do this

The members of the supply chain have access to training (in and outside the fields of competence) (Dries et al., 2012), recruit people by taking into account the skills needed to manufacture the product (Dries et al., 2012) and/or know the current and future availability of skills and resources (Jahre and Fabbe-Costes, 2005). Therefore, they have a common thinking on the skills to be acquired.

The members of the supply chain know how to surround themselves with experts: the members of the supply chain are integrated into clusters, into institutional networks (competitiveness clusters) and/or collaborate with research laboratories (Camarinha-Matos and Afsarmanesh, 2006). In addition, they are in regular contact with funding bodies.

d. Relation integration

Relation integration includes a set of practices shared between customers and suppliers regarding business-to-business dependency and collaboration principles (Stank et al., 2001).

To do this:

Innovative company forges partnerships based on a network of reliable suppliers and distributors (Jahre and Fabbe-Costes, 2005) where the relations are contractualized (Mesnard and Pfohl, 2000).

4.5.3 Conclusion

The main contribution consists of an observable phenomena classification enabling to make tactical and operational decisions. These decisions are involved in the implementation of

strategic decisions. The actions implemented following operational decisions have short-term consequence while those following tactical decisions have medium-term consequence.

This classification is based on about one hundred observable phenomena that consists to describe the actions implemented by the members of the companies. Not being at the heart of this research, this list is non-exhaustive and can be completed and deepened by a complementary literature review or a field study.

Conclusion of the Chapter 4

The objective of the chapter 4 is to clarify the relationship between the product and the supply chain from a managerial point of view, i.e. through the strategy implemented by the innovative companies. From a macro point of view, the typology of the supply chain evolves with the type of product: an agile supply chain for an innovative product for our research. From a micro point of view, obtaining an agile supply chain requires a combination of actions stemming from an agility strategy implemented by an innovative company.

Chapter 4 contributes to better describe and understand the interdependence between the characteristics of a product and its supply chain in the context of innovation by adding managerial clarifications. Thus, it highlights that there is a fit between the typology of the supply chain and the typology of products. Then, it becomes essential to know the fit to be targeted to ensure the success of the product on the market. Thus, the notion of fit requires the notion of adjustment and the chapter 4 lead to a better understanding of the adjustments required within a supply chain in the context of innovation. It is the basis of our second contribution that consists to collect several agility actions from the literature to implement an agile strategy. As a result, the future supply chain required for an innovation can be anticipated from a managerial point of view, knowing that the context and the environment have a significant influence on its design.

Chapter 4 brings a more “behavioral” view of the innovative product/supply chain couple and highlights the influence of the innovative company in our research. It complements the contributions of chapters 2 and 3 and leads to study the innovative product/innovative company/supply chain tryptic empirically and methodologically in order to consolidate these theoretical results.

IN BRIEF

- An innovative product requires an **agile supply chain**.
- The product's characteristic can **fit** with those of the supply chain.
- The pre-diffusion phase requires **strategies** to ensure the success of the product.
- The strategy is based on three **decisions** (strategic, tactical and operational) that lead to adjustments.
- An **agility strategy** seems to be relevant to obtain an agile supply chain.
- Agility strategy is an **organizational answer** and an **ability to make adjustments activities**.

KEY FINDINGS OF THE CHAPTER 4

Based on the theoretical contributions of Chapter 3, we have shown that an innovative company has to implement strategies to fit the product and the supply chain or to adjust the current supply chain to obtain a more suitable supply chain. Indeed, an agile supply chain seems to be more adapted to an innovative product. This chapter provides a managerial vision of the supply chain by focusing on adjustments within the supply chain: either companies act to change the supply chain along with the product or they implement actions to adapt changes in the supply chain after product design. The product and the supply chain are constantly adjusted. Thus, the supply chain strategy favored in the case of the launch of an innovative product is an agility strategy. The agility implementation is a recent subject in the literature and a theoretical framework is lacking. Therefore, the contribution of the chapter 4 is to illustrate the link between the supply chain structure and the dedicated strategy. So, a framework based on observable phenomena from the literature is developed. These phenomena highlight the individual or collective decisions taken by the innovative company concerning the supply chain. It constitutes a basis to estimate the agility implementation within the supply chain. Indeed, with this framework, it is possible to analyze the company's actions and to evaluate if the supply chain can be more agile. Consequently, the transformation of the supply chain becomes concretely conceivable.

Introduction

The scientific process consists of multiple interactions between theories and facts. It consists of a series of observations, explanations of the observed phenomenon, predictions and their testing on other real situations (Chatelin, 2005).

Two approaches are commonly used by researchers: deductive and inductive approaches. These two approaches refer to two types of reasoning, each leading to the use of specific methodology. The deductive approach corresponds to the theoretical part of our research (Chapters 2–3-4). Based on our state of the art, our reasoning consists in confronting theory with reality, i.e. validating our theoretical conclusions with information from the practice, hence the importance of our empirical research (Figure 19). Thus, chapter 5 has two ambitions:

- Validate our theoretical conclusions;
- Initiate an inductive approach to generalize our observations.

The inductive approach is based on this empirical analysis that focuses on how the consequences of the emergence of an innovative product within the supply chain, i.e. innovation is not directly studied.

The objective of this empirical research is multiple:

- Get a detailed description of phenomena that occurs within the supply chain during the emergence of an innovation;
- Visualize the transformation between the initial supply chain and the final supply chain;
- Understand how the concept of supply chain is perceived by an innovative company, i.e. understand its posture in terms of the supply chain during the emergence of its innovative product;
- Clarify the way innovative companies perceive the adjustments to be implemented in the supply chain;
- Compare the real adjustments implemented by innovative companies with the theoretical results of our second contribution (Chapter 4).

Three case studies of firms within different sectors support this empirical part and lead to our third contribution.

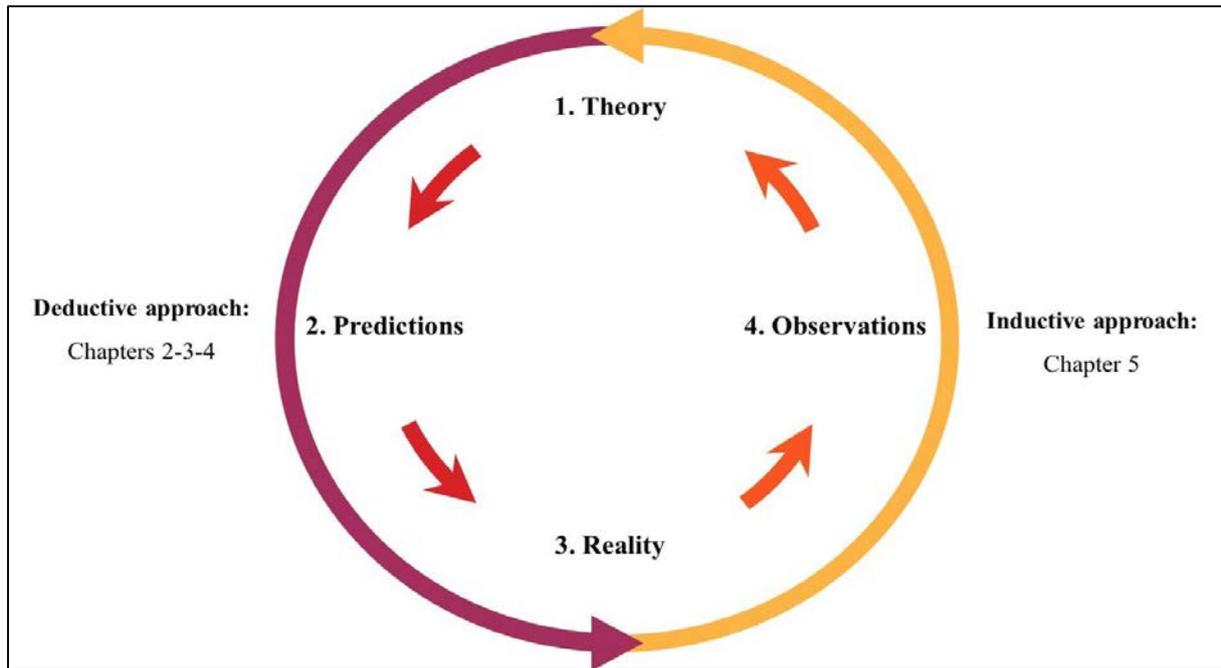


Figure 19: Research process

In this research, the first ambition consists in better understand the in-situ phenomena within the supply chain caused by the emergence of an innovative product. The second ambition consists in investigating the difference between SMEs and large companies. Thus, our three companies' panel integrates two SMEs and an international company.

First, the epistemological background and the research approach (part 5.1) are presented. Three case studies will then be presented (part 5.2). Secondly, phenomena observed in the supply chain following the emergence of an innovative product or process, are detailed (part 5.3) and analyzed (part 5.4), leading to our third contribution.

This contribution is the subject of a publication ⁹ from which part of this chapter is derived.

⁹ Marche, B., Boly, V., Morel, L., Camargo, M., & Ortt, J. R. (2017, July). Overview of phenomena occurring in supply chains during the emergence of innovation. In *Supply Chain Forum: An International Journal* (Vol. 18, No. 3, pp. 150–165). Taylor & Francis.

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5.1 Why adopt an epistemological positioning for the empirical side of the research?

This section helps to justify the privileged mode of research.

5.1.1 An empirical and constructivist research

According to (Le Moigne, 2012), epistemological questioning focuses on three questions:

- The gnoseological question, which concerns the nature of knowledge;
- The methodological question, which concerns the constitution of knowledge;
- The ethical question, which concerns the value or validity of knowledge.

One main aspect is to question on the nature of the reality that can be grasped through the acquired knowledge, that is to say, the nature of the knowledgeable reality (Perret and Séville, 2003).

As a result, according to (Bulinge, 2014), epistemology seeks to know whether:

- Knowledge is objective;
- It reflects the researcher's independent reality;
- It is an interpretation of reality;
- It is the fruit of an explanation, an understanding or a construction.

Science is based on two basic approaches: rationalism and empiricism. Rationalism is concerning mainly "hard" science (mathematics, physics, chemistry, biology) and supports the idea that the observable world is based on laws to be discovered through logical-mathematical reasoning. Empiricism is the foundation of the social sciences and lay on the idea that knowledge is constructed from the observation of phenomena, the understanding of which enables to infer laws. Therefore, empiricism is a discovery of the world through experience (Bulinge, 2014). Hence, this research uses an empirical approach.

Empiricism is at the origin of two paradigms, interpretativism and constructivism, which consider reality as a set of observable phenomena.

Interpretativism seeks to explain the "why" of a situation, distinguishing the understanding of explanation from a phenomenological perspective (Bulinge, 2014). The process of knowledge creation involves an understanding of the meaning that actors give to reality. It is no longer a question of explaining reality, but of understanding it through the interpretations made by the actors. Thus, it develops an approach that has to consider the intentions, motivations, expectations reasons and beliefs of the actors, which is less factual than practical (Perret and Séville, 2003).

Constructivism considers that reality is constructed, in other words, it is an emerging cognitive representation of a project that is built around it and transforms it. In fact, it is a complex universe that organizes itself around a finality. As a result, knowledge produced implies a knowing subject and has no meaning or value outside of it (Bulinge, 2014).

By considering the complexity of the environment, the constructivist paradigm strengthens the empirical approach privileged in our research.

Thus, in this paradigm, the environment is made up of interpretations constructed through the interaction of actors. Thus, individuals are supposed to create their environment through their thoughts and actions, guided by their goals (Le Moigne 1990). Thus, due to the interpretation, the reality is multiple and depends on the knowledge.

In conclusion, as the research aims both a better understanding of in situ phenomena and the elaboration of methodologies to manage the couple supply chain/product in an objective of value creation, an empirical and constructivist approach seems to be useful.

5.1.2 Importance of the case study

One option for researchers to achieve an empirical approach consists in studying case studies (Yin, 2017).

The case study is a research strategy that explores complex and little-known phenomena in order to identify patterns, with a view to generating theory (Eisenhardt, 1989; Yin, 2003). It consists in seeing an event in its proper context and observe how it manifests and develops. First, it seeks to understand a contemporary phenomenon and the influence of the context (Hamel, 1997). Second, it mobilizes many sources of information and can focus on one situation at a given moment, but also on a situation in its development (Leplat, 2002). Hence, the case study is adapted to questions about more or less implicit interactions linked to a phenomenon and in our case between the product and the supply chain.

The potential of the case study lies in its ability to highlight the observation of the singularity of the problem participating in the understanding of a problem likely to be repeated (Chatelin, 2005).

Thus, the case study aims to build theory by:

- Distinguishing relevant variables;
- Distinguishing relevant relationships (and mechanisms);
- Combining that in a model/theory inductively, that can be tested by others deductively.

Therefore, in our research, the case study is useful to:

- Observe and describe the phenomena that occur in the supply chain;
- Understand the influence of its phenomena on the supply chain;
- Determine the variables impacted and to be taken into account in the design of a supply chain;
- Understand how companies react.

In conclusion, in our study, the case study has a double role. Firstly, it is useful to validate the problem. Secondly, it is a support to validate proposals.

5.1.3 Our research approach

The chosen approach consists of an in-depth study of a small number of different cases (heterogeneous) to reveal as many variables and relationships as possible.

5.1.3.1 Sample of firms

Our choice to work on three companies from different sectors was to broaden the scope of analysis. In this way, the most relevant phenomena are highlighted and this allows us to better understand the limitations of previously proposed concepts.

Case studies selection criteria included:

- The degree of novelty of the product or process in the corresponding market;
- The observability of the impacts of the product or process on the supply chain.

5.1.3.2 Data collection procedure

Different data collection methods are used. The case of the company A is a bibliographical case. The scientific data come from the literature (Aguillaume, 2004; Crevoisier, 1995; Garel and Mock, 2012; Glasmeier, 1991; Pasquier, 2008; Rognié and Vivien, 2012). Information concerning companies B and C are collected by interviews, participation to company project teams and document analysis. For the company B, one of the researchers collaborates with the company for six months. The case of the company C corresponds to a twenty years observation campaign where the research team has worked with the company to develop several projects.

As the research consists in observing projects in the specific context of each company, some variations may emerge in the depth of data. Several causes may be determined:

- The difficulty to access to data and information for confidentiality reasons: some companies provide only general information related to skills or processes;
- The level of integration of researchers within the company: the researchers were either observer or actor in the innovation design;
- The size of the company: it is often easier to get access to data in small size companies because of the reduced number of interlocutors;
- The simplification of technical terms: for reasons of understanding, some terms specific to the company or sector have been replaced by more universal terms, more commonly used to describe processes, activities or skills;
- No interview was possible in case A, limiting access to local data;
- While observing projects, researchers have access to documents attesting of internal practices. As the formalization tasks are highly variable between companies, the depth of the analysis is also heterogeneous within the panel.

Note that the problems of terminology or confidentiality do not alter in any way the results proposed in this research.

5.1.3.3 Data treatment procedures

For each case study, the data analysis method remains the same. This method is divided into five steps. The first one consists in modeling the initial supply chain: stakeholders are listed (suppliers, subcontractors, partners, distributors, and customers), their interrelation flows are described (material, financial and informational) and their activities and resources (skills, equipment...) are described. Moreover, this analysis enables to characterize accurately the typology of the supply chain (Vonderembse et al. 2006; Christopher 2000). The second step is represented by the description of inner variables that allows a further representation of the company through the Porter value chain model. These key elements are:

- The company's activities (related to the five categories of Porter: inbound logistics, operations, and outbound logistics, marketing and sales, service);
- The production process (technical data including the technology, types of equipment and performance level);
- The skills (technological and support among others: lean know-how, quality management, maintenance capacities, and marketing skills);
- The rules and standards related to the company market (related to the rules);
- The distribution channel.

Then, the same models are used to describe the situation after the emergence of the innovation. Hence, the third step is the modeling of the new supply chain after the innovation emergence. The fourth one is the representation of the required value chain to support the future activity and product. During the fifth stage, the adjustments made to move from a supply chain to another are registered and analyzed. The comparison of each activity or tasks at specific periods highlights the supply chain evolution during time. Then, the strategies implemented by innovative companies to reduce the misfits are identified and investigated to understand how companies have voluntarily reacted to the development of new supply chain able to support their innovative product.

Case studies' results will be compared to understand phenomena involved in supply chain changes. This study highlights the impact of the items previously mentioned as well as the invariable patterns. By doing this, the present research aims to contribute both to the identification of strategic perspectives and to the predictability of the supply chain changes.

5.2 Presentation of the case study

In order to validate our theoretical conclusions and initiate empirical generalizations, a series of case studies is analyzed. The theoretical findings to be confirmed are as follows:

- One product has its own supply chain (Chapter 2);
- A supply chain is described by stakeholders, flows, processes and performance (Chapter 2);

- Processes are involved in the link between the product and the supply chain (Chapter 2);
- The product and the supply chain are interrelated (Chapters 2–3);
- The co-design the product and the supply chain generates more Value than separate and linear design tasks (Chapter 3);
- The innovative company has to adjust the supply chain (Chapter 3);
- An agile supply chain is more suitable to an innovative product (Chapter 4);
- The product/supply chain fit lead to a competitive advantage (Chapter 4);
- The pre-diffusion phase plays a primordial role to the success of the product (Chapter 4);
- Agility strategy enables to obtain an agile supply chain (Chapter 4).

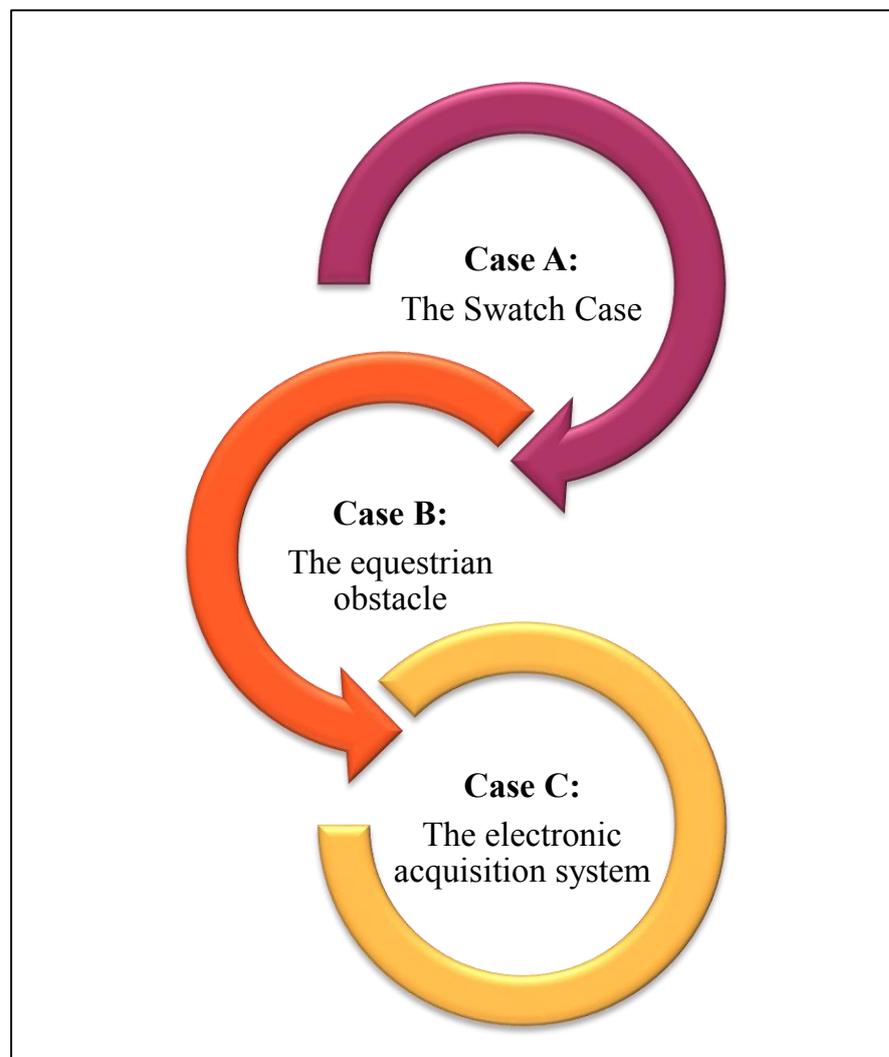


Figure 20: The preferred approach to dealing with case studies

Case A allowed a better understanding of the supply chain concept and confirmed and clarified the theoretical results in real time. Based on a bibliographic study, case A has therefore validated our results derived from our deductive approach but also to lay the

foundations for our empirical generalization. Cases B and C reinforced the theoretical conclusions, corroborated the observations from the case A and highlighted new empirical findings. The findings from each case are validated by the other cases, so we set up a retroactive approach to lead to our empirical generalization.

5.2.1 Case A: the Swatch Supply Chain

5.2.1.1 Overview of the product

At the end of the 1970s, the Swiss watch industry faced a major crisis that threatened its survival. Swiss industrialists are convinced of their technical superiority. According to them, true watchmaking can only be mechanical (Garel and Mock, 2012). However, Asian countries have invaded the world market with digital and analogue quartz watches. It is an upheaval in the sector: quartz sweeps the mechanics (Garel and Mock, 2012).

Although not programmed as it is not the result of a deliberate innovation strategy, Swatch is proving to be the solution to compete with this competition (Garel and Mock, 2012). It becomes an alternative to traditional quartz watches and differs, among other things, by its architecture, its aesthetics, its manufacture.

History of the Swatch

(Garel and Mock, 2012)

Its history began at the end of 1979 at ETA, a key cartel company owned by Ebauches SA.

In 1976, Elmar Mock is hired at ETA and a plastic injection machine is given to him (bought illegally because at that time, ETA has the right to use only brass to manufacture its plates). Mock starts working with plastic with little knowledge before starting a continuous training in this field. The small injection machine becomes insufficient for its experiments, a more powerful and more expensive machine becomes necessary. To justify his request, he draws, with the help of Jacques Müller, the watch that such a machine could realize. The technical concept of the watch is there: monocoque case, welded glass and motor fixed separately. This concept is proposed to Ernst Thomke who sees it as a potential product and process innovation. He understands that it is possible to compete with Japanese watches without competing with the existing Swiss offer. The project is launched from a simple drawing.

The only constraints stated by Thomke are: a manufacturing price lower than 10 Swiss francs CH; an industrial mass production in Switzerland and operation similar to that of a hand watch.

In March 1983, the first Swatch watch appeared on the Swiss market. Nearly 400 million models have been sold since the launch.

The traditional quartz watch is made in three parts:

- A movement consisting of a plate on which the watch components are fixed: spring, gear, escape wheel, balance, spiral...
- A display system (dial and hands) which is fixed on the movement;
- A case in which the movement and the display element fit together. The glass and the bracelet are mechanically fixed.

The manufacture of this watch is very complex: the parts are mounted from above, from below or on the sides. Therefore, the watch can only be made manually (Garel and Mock, 2012).

The Swatch is a quartz watch with needles (or analogue), in welded plastic, simple in appearance, robust, very inexpensive to manufacture with the quality and durability of traditional Swiss watches. It is an artistic and emotional object, but also functional. It has a completely different architecture in order to automate its manufacture, it is also made in three parts:

- A movement whose number of components has decreased;
- A display system;
- An injected plastic case whose bottom serves as a support for the movement (replacing the plate). The components of the movement are grafted onto the case. The case and bracelet become one thanks to a plastic injection process and the glass is ultrasonically welded to the case by ultrasound.

These technical choices imply a unidirectional manufacture of the watch, the components are mounted only by vertical stacking (Figure 21).



Figure 21: Assembly of the Swatch¹⁰

Figure 22 compares the assembly of a traditional quartz watch and a Swatch (Müller and Mock, 1983).

¹⁰ <https://invention-europe.com/2017/05/13/apres-avoir-cree-la-swatch-je-suis-devenu-un-serial-inventeur/>

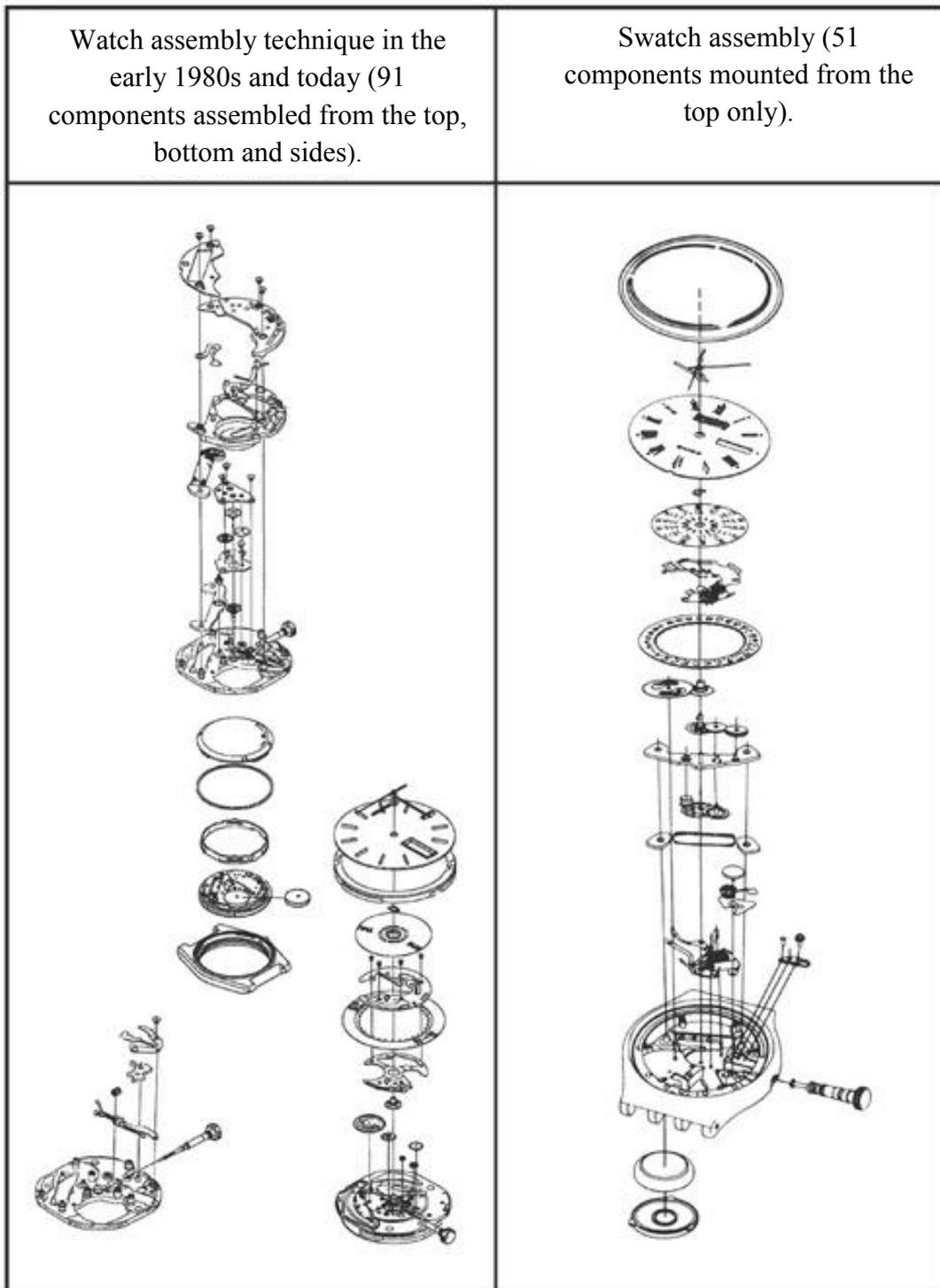


Figure 22: Comparison of the assembly of a traditional quartz watch and the Swatch

(Müller and Mock, 1983)

5.2.1.2 Overview of the supply chain

Originally, the watch industry is organized in the form of a cartel where each company carries out specific tasks according to its expertise. This strict division in activity impacts the length of the supply chain; which includes many actors. Indeed, there were up to one hundred and fifty companies involved in the design of traditional watches (Aguillaume, 2004). To counter

the emergence of low-end watches, one company of the cartel decided to offer a customizable plastic watch. The new product radically changes the organization of the supply chain. The first experiments were on plastic and used specialized equipment loaned by equipment manufacturers. At the earliest stages of the new product development, data about future manufacturing are underlined. The choice of ultrasonic welding (Garel and Mock, 2012) as manufacturing process for the new product, impacts the field of skills, equipment and also manufacturing decisions. In fact, from manual to industrial manufacturing, production changes: production rates and planning are adapted to the machines. Company A adopts knowledge of plastic manufacturing and selects its suppliers to match the new watch. Process automation reduces the number of components, thus reducing the number of companies within the supply chain (Garel and Mock, 2012). The watch becomes a fashion accessory and it catches the attention of new customers and gradually imposes itself on the market.

All these changes lead to a reorganized supply chain: some companies have disappeared while others have emerged (those in the field of plastics processing). Company A has developed its expertise and operates in several stages of the new product manufacturing (its production, its marketing).

5.2.2 Case B: the equestrian obstacle supply chain

5.2.2.1 Overview of the product

Company B is a SME, leader in the field of the equestrian barrier with an international clientele (present throughout Europe, the Middle East, Japan or the USA). The company's customers are racecourses, training centers and a few equestrian establishments. The company's values are based on the safety of the products offered to customers, they are simple to install and use and require minimal maintenance. These barriers have smooth, rounded surfaces and total flexibility in the event of an impact, thus minimizing the risk of accidents. The systems are designed to withstand the strain of a horse and rider and immediately recover their original shape.

It is in the same mind that the innovative product was born. In order to replace existing wooden, metal or concrete obstacle structures that cause significant injury to horses and jockeys during a high impact, Company B has developed an obstacle:

- For horse racing to increase its presence on the market;
- For equestrian sports (the eventing specifically) to develop its activity and acquire new markets.

Difference between horse racing and eventing

The cross-country in the eventing discipline has many similarities with the obstacle races.

Obstacle races (hurdle, steeplechase) consist of jumping, within a racecourse, so-called “natural” obstacles having the shape of a wall, a hedge trimmed to a certain shape or slopes using materials such as wood, concrete or soil.



*Photo of a race obstacle*¹¹

The cross-country of the eventing competition, for its part, consists of jumping natural obstacles, mostly made of wood, to artistic forms reminiscent of elements that can be found in nature.



*Photo of a cross-country obstacle (eventing)*¹²

Therefore, the company hopes to develop a safe product that meets the requirements of racecourses and the eventing. The desire to integrate the equestrian sports market is a real challenge for the company due to the conservative nature of the market: the natural and artistic aspects of obstacles are paramount. Cross-country obstacles are designed by a small number of specialized companies or mainly directly by equestrian establishments (for financial reasons).

Hence, the innovative product is a completely safe polyethylene obstacle capable of absorbing shocks by deforming during an impact.

The success of the product on the market is mitigated. Although it has been well received in the racecourse market, the equestrian sports market has not been interested for three reasons:

- A price unsuited to the financial means of the equestrian establishments: the craft products remain more accessible and the “Do-It-Yourself” is privileged. Note that

¹¹ <http://www.coursedulion.com/grand-public/plans-et-caracteristiques-des-pistes/>

¹² <http://www.obstacle-cross.com/obstacles/classique>

unlike racecourses, equestrian establishments have many items of expenditure (horse feed and care, infrastructure maintenance, instructors' salaries among others) which limit investment;

- A product that is too far away from the values of the discipline: the artistic and the natural has disappeared in favor of safety, yet at the present time they remain essential purchasing criteria;
- The limited customization of obstacles tends to standardize a discipline based on the aesthetics, natural aspect and originality of obstacles.

5.2.2.2 Overview of the supply chain

Originally, company B manufactures and sells high-performance PVC barriers for the racing world. The company manages manufacturing by extrusions, storage, distribution, marketing, sales and installation of barriers. As the company manages most of the activities required to manufacture and upgrade the product, the supply chain is simple, without too many intermediaries.

To complement its product range, the company has developed highly secure fences to reduce the risk of injury to horses and riders. The existing obstacles were made of wood or stone, locally and by hand. These obstacles can be designed to order. They are sold at trade fairs, by word of mouth or following catalogue orders. With its new product, company B proposes an industrial product and takes advantage of the expertise of specialized companies to improve the safety aspect during horse races. Rotomolding is the main manufacturing process to meet the company's needs. The company mobilized external specialists and invested in cast iron molds used in this process. New skills, new for the company, appear in the industry and lead to the integration of new companies, specialized in polyethylene to design products. The company uses its core related know-how to develop its products and enter new markets.

Company B has built a new supply chain around its product, coordinating the different stakeholders to meet the requirements of its product. It is the leader of the supply chain.

For the case B, we collaborate with the company for six months. This choice is justified by the simplicity of the supply chain, thus changes occurred by an innovation can be easily highlighted.

5.2.3 Case C: the electronic acquisition system supply chain

5.2.3.1 Overview of the product

Company C is a company specialized in development, supply and implementation of physiological sensors for data measurement and analysis, related by physical activity, movement, eye-tracking as well as software of data treatment from the sensors. It operates on the market of ergonomic workstation (Marche et al., 2016).

Company C has its own set of sensors and different data treatment software, including CAPTIV elaborated by the National Institute of Research and Safety (INRS), the main French research center about work safety. CAPTIV is the result of a technology transfer. The company focuses exclusively on niche markets, selling sensors and software of data treatment to the workplace ergonomics, neuromarketing, research domain, man-machine interface. Company C works in a

sector where technologies quickly change: the market stimulates the company's activity and its capacity to innovate (Marche et al., 2016).

Data acquisition (DAQ) consists in measuring an electrical or physical phenomenon such as a voltage, a temperature, a pressure with a computer. A data acquisition system is made up of¹³:

- Sensors, which convert a physical phenomenon into a measurable electrical signal;
- A data acquisition measuring devices, which digitizes the incoming analog signals so that it can be interpreted by a computer;
- A computer with programmable software to process, view and store the measurement data.

The data acquisition system can be illustrated as follows (Figure 23).

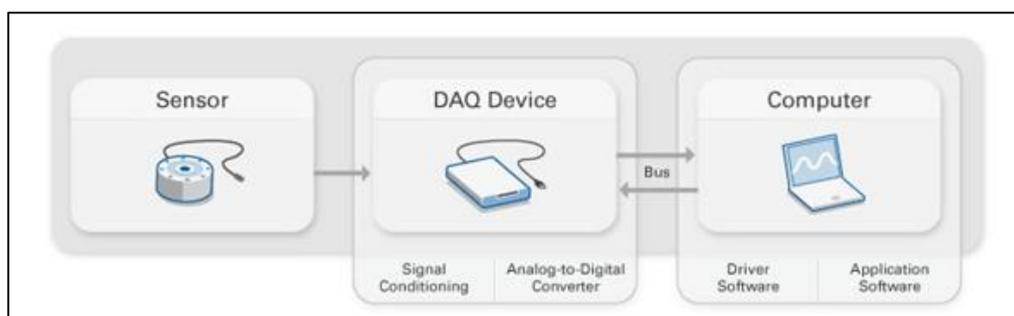


Figure 23: Data acquisition scheme¹⁴

Thus, company C offers solutions to each component of its data acquisition system:

- Sensors to measure temperature, respiration, acceleration, ECG for example;
- Wireless data loggers to transform data;
- CAPTIV software to synchronize, analyze, process and report data.

History of the innovative product and company

(Marche et al., 2016)

In 1985, the company was a service company, which proposed a methodology of state variable research to characterize the operation of an industrial production system. Thus, it positioned itself ahead of companies that were developing automation systems for industrial sites. The company's activities were: carry out measurement campaigns, process the results of these campaigns, search for a model to automate and optimize the system in the field of chemistry.

In 1998, a collaboration with the INRS¹⁵, the French Institute competent in the area of occupational risk prevention, allowed developing the acquisition central, CAPTIV that combines computing, measurement and video. This product is the result of the CEO's willingness to

¹³ <https://www.ni.com/data-acquisition/what-is/f/>

¹⁴ <https://www.ni.com/data-acquisition/what-is/f/>

¹⁵ National Research and Security Institute

propose a product on the market. This relationship with the research will be predominant in the development of the company. Indeed, technological survey will be constantly provided by the university world and research laboratories. To propose a diversified offer, the company C was using sensor suppliers while it has developed its own sensors gradually. It used existing competitor products to integrate new markets and to position its own products. In this way, it was able to impose CAPTIV slowly and stop offering other components. During this period, the turnover was distributed in the following manner: 50% for automation, 40% for sensors resale and 10% for CAPTIV. The automation activity ceased after 10 years.

Around the year 2005, the company C moved to embedded systems. It really distinguished itself thanks to its own range of sensors and wireless systems. With the development of its own sensors, the company C is released from its suppliers. Paradoxically, thanks to its innovations, the previous sensors suppliers became the distributors of the company's products. Today, CAPTIV represents 60% of sales while the sensors resale is 40%. The company C maintains an active technology survey thanks to its collaboration with universities and laboratories. This collaboration is useful to develop smaller, more autonomous and more robust components.

5.2.3.2 Overview of the supply chain

The skills related to the data measurement and processing remain the same while other competences, specific to the valorization of the new product, appear: computing, electronic, marketing, sales among others. The data processing process is evolving and takes account of this new acquisition unit. With this new product, company C opens up to other markets, in the medical field and is committed to an R & D approach. To support its offer, the company is surrounded by suppliers specialized in sensors before embarking on the development of its own sensors. More recently, the company has improved its range of sensors by focusing on embedded systems. It acquired the equipment and skills in electronics and embedded electronics to develop its expertise. This new orientation has broadened the company's market and allowed it to develop its business, in particular its commercial activities. Now, the company manufactures a set of sensors (movement, temperatures, ECG, breathing for example) and also data processing software for medicine, neuromarketing, research domain and human-machine interfaces. It offers a data acquisition system and software to synchronize measurements of human activity.

The supply chain of the company C's product was gradually designed, considering its ecosystem and taking benefits from it. Finally, the company is now leading to a pole position place.

The case C corresponds to a twenty years observation campaign done by the research team working with the company to develop several projects. The choice of this case is justified by frequent changes in the supply chain due to the dynamics of the market. Thus, changes can be quickly observable and the recurrence of certain facts can easily be emphasized.

5.2.4 Global conclusion about the three cases

The table 9 summarizes the three cases that will lead us to an empirical generalization.

Firm	Activity	Size of the company	Position in the initial supply chain	Description of innovative product/process
Firm A	Watch industry. It's a movement-black manufacturer, it carries out the "chassis" of the watch.	Large company	Company upstream of the manufacturing	A customizable plastic watch for a low-end market
Firm B	SME in the equine industry. The company is a world-leading manufacturer of high-performance PVC fencing in the horse-racing world.	SME (Less than five employees)	New entrant in the supply chain	A horse-riding fence in polyethylene to attenuate injury risks
Firm C	SME in the electronics sector. The company has set of sensors and different data treatment software to analyze the workplace ergonomics, neuromarketing, research domain and man-machine interface.	SME (From ten to twenty employees)	Company initiating the initial supply chain	A wireless data acquisition system and software to synchronize human activity measures

Table 9: Summary of case studies

5.3 A thorough industrial case analysis

5.3.1 A comparative approach

To better understand and categorize changes in the supply chain following the launch of a new product, the different case studies are compared to understand the phenomena during the emergence of innovation. Different perspectives are taken into account: type of supply chain, evolution of the value chain, evolution of processes, evolution of the core competencies and evolution of the customers of the product.

5.3.1.1 Type of supply chain

Table 10 shows the evolution of the type of supply chain and final status of the project.

	Supply chain before innovation	Supply chain just after innovation	Success of innovation
Firm A	Hybrid	Agile	Success
Firm B	Lean	Hybrid	Mitigated success
Firm C	Agile	Agile	Success

Table 10: Overview of the evolution of the supply chain and the final status of the project

Companies A and B supply chains move from a type to another while the company C does not register any change in its supply chain type.

Company A's new watch is now highly adaptable to the customer demand through slight evolution of the color and the form of parts. The company, engaged in a new inner activity, is launching new varieties of watches following the fashion trends. Top management highlights

the role of designers in the performance of this new activity, as meeting users' needs and reducing the life cycle of each version of the product is key success factors. Note that the secondary literature that we used, does not point out major misfits between the product and the supply chain; this could be an argument to explain the successful launching of the watch (Garel and Mock, 2012).

The supply chain of the company B was a lean-type with an artisanal-like production of rather standardized horse riding fences. Then company B offers an innovative product, manufactured industrially thanks to a rotational molding technology. The focal company is also responsible for the final assembly of all modules among hedges, obstacle box etc., facilitating product customization and an assembly to order strategy. The modular design of the product can delay differentiation. The final customer only intervenes when selecting the product, the choice to be limited to two options. The company B has established a strategic alliance with its subcontractors in rotational molding and plastic injection leading to the co-development of the fabrication process of the final product. The product industrialization contributes to the transition of the supply chain typology, from a lean-type of hybrid type. The interviews point out that the industrial process chosen limits the misfit between the product and the upstream supply chain. However, the final product does not fully meet the customers' requirements that want a more natural and more aesthetic product. This could be an argument to explain the mitigated success of the product.

The company C evolves in a sector where technologies quickly change: the market stimulates the supply chain and its capacity to meet the customers' requirements. The company C assumes R&D activities operated by its internal service and in partnership with public research laboratories. Researchers develop continuous improvement of sensors ranges, reducing the life cycle of products. To understand customer requirements and offer customized products, the specifications of the product are detailed and co-established with the customers through focus groups. This facilitates the addition of innovative components on existing products, such as integrating a new acquisition system to the existing software (sensors with its eye-tracking software to interpret eyes movement for example). Successive interviews show that the company C, by enriching the range of components designed internally or acquired from suppliers, is able to propose on the market combinations of these components (sensors associated to video sub-systems and data treatment software) and consequently is able to offer a large range of complete systems. This capacity is in line with the agile type of a supply chain.

5.3.1.2 Evolution of the value chain

The evolution of each innovative company value chain during the emergence of the new innovative product is presented. These evolutions are detailed in the table 11.

	Activities of value chain	Value chain before innovation	Value chain after innovation
Firm A	Inbound logistics		Components
	Production	Movement-blanks design	Plastic watch design
	Outbound logistics		Delivery to the retailers
	Marketing—Sales		Product promotion
	Service		
Firm B	Inbound logistics		Components
	Production	Wood horse-riding fence	Plastic component assembly in horse-riding fences
	Outbound logistics		Distribution
	Marketing—Sales	Wood horse-riding fence	Plastic horse-riding fence
	Service		Installation, After-sales service
Firm C	Inbound logistics		
	Production	Data processing	Data processing— Programming Sensors and software design
	Outbound logistics	Distribution	Distribution
	Marketing—Sales		Product promotion—Sales
	Service	Custom solution	Custom solution

*Table 11: Overview of the evolution of the focal company value chain due to the emergence of the innovation*¹⁶

Companies A, B and C have integrated new activities internally to control the development and the commercialization of their products.

Originally, the company A only produced movement-blanks (Aguillaume, 2004; Crevoisier, 1995; Glasmeier, 1991). By developing its new product, the company A changed its organization by integrating new activities within its structure. It designs its components (movement-blanks essentially), plastic watches and manages the distribution (in sports shops, hard discount, specialized retailers...) and product promotion. The automation of the production impacts activities such as logistics or marketing/sales, being integrated by the company to add value to the product (Garel and Mock, 2012). The integration of new activities within the company A is part of the success of the innovation (Donzé, 2011, 2014; Rognié and Vivien, 2012).

The product industrialization changed the focal company B structure. Originally, it produced wood horse riding fences by craftsmen employees. Following the development of the innovative product and the related new production process, components are still produced internally and their production is managed thanks to optimization approaches. Company B assembles the final products and manages their distribution. The activity of marketing and sales is still present but enriched. Indeed, the company uses specialized retailers to sell its products. It also proposes a new service: the product installation and after-sales service.

¹⁶ Grey cell means “Activity not conducted by the company”

Despite the integration and enrichment of new activities, the success of innovation remains mitigated.

Following the emergence of new products, the company C has expanded its production activity: data processing (measurement campaigns, measurement processes), sensor design and programming. Outbound logistics and service activities are always carried out internally. The reliability of the different products allows forward to develop a marketing and sales activity, then the company makes itself the promotion of its products and goes directly to meet potential customers. So company C value chain has changed and the added value has increased taking financial and sales criteria into account.

5.3.1.3 Evolution of processes

The evolution of the technical processes within the supply chain following the emergence of the new innovative product is presented. These evolutions are detailed in the table 12.

	Process before innovation	Process after innovation
Firm A	Movement components design Machining, polishing Manual assembly of movement components	Movement components design Other components design (needles or plate) Plastic powder storage Industrial manufacturing of injected plastic products—Welding technique Quality control
Firm B	Wood receipt and storage Craftmanship manufacturing of wood products Components assembly (sawing, screwing, gluing...)	Rotational molding—Plastic injection Plastic components receipt and storage Plastic components assembly (screwing)
Firm C	Chemical measurement campaign Data studies	Biological measurement campaign—Data studies Data video processing (capture and analysis of movement, signal processing) IT development (software design) Electronic development (sensor design)

Table 12: Overview of the evolution of the process due to the emergence of the innovation

The processes of the company A and B have changed drastically, impacting the supply chain organization. Company C has enriched its processes following the emergence of innovative products.

The processes of the company A have radically changed from manual manufacturing to industrialized manufacturing. The process of watch’s components like movements, needles or plate remain the same. The innovative product requires industrial manufacturing achieved through a plastic injection plastic. This new process leads to a watch design in a single element (Garel and Mock, 2012). As the production process is more integrated, it all occurs in the same building and is no more distributed in several suppliers units. Then, the process of production is centralized in one location. Moreover, the final choice regarding the manufacturing process influenced the shape and appearance of the new product.

The processes used by the company B have also radically changed from a craft manufacturing approach to industrial manufacturing. Indeed, the initial process focused on the woodworking and assembly. The innovative product requires industrialized processes: rotational molding and plastic injection, resulting to products in plastic materials. Moreover, new equipment is required to store the raw materials in a safe way. These processes are most suited to produce a larger volume of products. A process of assembling plastic components is still needed to customize products according to customer choices (type of the hedge, shape of protection bars...). Note that the choice of the manufacturing process influenced the architecture and features of the product, mainly the welding or collage of the compounds.

Company C has enriched its processes to support innovation. Indeed, in addition to measurement campaigns and data studies, the company integrates data video processing, IT and electronic development. The integration of these new processes within the company allows it to expand its product range. Note that the highly specialized level of these processes allows the company to easily innovate within its supply chain.

5.3.1.4 Evolution of core competencies

The evolution of the skills within the supply chain during the emergence of the new innovative product is presented. These evolutions are detailed in the table 13.

	Skills before innovation	Skills after innovation
Firm A	Movement-blank manufacturing Movement-blank distribution Components assembly Products delivering Product sales After-sales service Maintenance	Movement-blank manufacturing Welding of plastic Micromechanics Movement kinematics Micromechanical parts assembly Watch production Products promotion, delivering, sales
Firm B	Wood horse-riding fence design Product distribution to equestrian centers Products promotion and sales	Plastics characteristics Digital command machine programming Plastic components assembly Products promotion, sales and installation
Firm C	Functional equipment design and distribution Data processing (capture and analysis of movement or signal processing)	Electronic components design Real-time data processing software development Embedded electronics, microelectronics Computer programming language Image and signal processing Products promotion to research centers and ergonomics service providers, distribution and sales After-sales service all over Europe—Training on products use

Table 13: Overview of the evolution of the skills due to the emergence of the innovation

In all cases, technical skills have evolved to adapt to the new processes. In contrast to company B, companies A and C have also developed significantly marketing and sales skills to gain autonomy.

Company A has acquired skills linked with the manufacturing process privileging the design of its watches: welding of plastic, micromechanics. It adapted these new skills to its core-competencies in watchmaking for the needs of its products: micromechanical parts assembly, movement kinematics. The skills are acquired by training or partnerships with experts (Garel and Mock 2012). The industrialization process led to the development of an irreparable watch (zero defect manufacturing) and then to an improvement of quality management and production scheduling skills. In the environment, maintenance and after-sales service disappear in the new supply chain (Garel and Mock 2012). Finally, company A has expanded its skills related to the promotion, distribution and sale of its products. Note that the skills acquired are related to new activities supported by the company described previously.

Company B has acquired many technical skills, including characteristics of polymers, components assembly, through close relations with subcontractors in rotational molding and plastic injection equipment. However, it still gained specific technical knowledge from the processes it uses to be able to develop its product range. The company B is recognized for its business skills such as sales abilities, network management but also for its expertise and advice capacity (installation tips, horse morphology). Thus, it acquired skills by hiring an engineer to manage the project and co-developing the product with its subcontractors.

Company C has acquired many skills to develop innovative products. New products require new and very specific technical skills, as embedded electronics and microelectronics. To gain autonomy, it also acquired skills previously belonging to other stakeholders, members of the supply chain, including components design, image and signal processing. Its numerous new product projects required agile project management skills. The expansion of its product range and the technical nature of its products have led the company to acquire teaching skills in order to help users to adopt the product elaborated to meet their specific requirements. To do this, the company has set collaborations with research laboratories, universities and hired qualified staff. The acquisition of skills helps the company to develop activities internally.

5.3.1.5 Influence of the regulatory environment

The table 14 shows the companies that have developed an innovation in an environment which influences design decisions. The presence of strict regulations is particularly studied.

	Influence of standards on product design
Firm A	Moderate
Firm B	Strong
Firm C	Low

Table 14: Overview of the influence of standards on product design

The regulatory environment of companies A and C has a low influence on the product design and on the associated supply chain. On the contrary, the company B operates in an environment governed by strict standards that influences the development of new products.

Originally, the supply chain of the company A was organized in a cartel, which forced companies: the companies' cooperation is horizontal; the division of activities between enterprises is strict (Pasquier 2008). The standards imposed by the cartel block initially the development of innovative products, but entrepreneurs' initiatives succeed in encouraging innovation (Garel and Mock 2012). The emergence of the product has changed the shape of the supply chain, breaking the cartel organization. The standards have a moderate influence on the product design.

The company B operates in an environment where user safety is essential. Many standards influence the design of the products to ensure optimum safety and reduce the number of accidents. It is imperative to offer a product that meets criteria such as: shape of the fence, size and impact resistance.

The company C operates in a rapidly changing environment. There are no specific standards for the sector that influence product design.

5.3.1.6 Evolution of marketing for the product

The emergence of a new process and product may change the type of targeted customers at the end of the supply chain. The table 15 shows the evolution of the market during the emergence of the new innovative product.

	Market before innovation	Market after innovation
Firm A	B to C	B to C
Firm B	B to B	B to B
Firm C	B to B	B to B

Table 15: Overview of the evolution of the market due to the emergence of the innovation

The markets type of companies A, B and C do not change after the innovation product. Company C decided to change parts of its market following its various innovations.

The company A maintains a B-to-C market. It expanded its targets by offering low-end products and extending its distributors to reach more customers (Carrera, 1992; Garel and Mock, 2012; Lury, 2004).

The company B maintains a B-to-B market. In addition to hippodromes, the company offered its innovative product to equestrian centers. Note that the innovative fence market remains weak due to the conservative behavior of the customers.

The company C strengthens its B-to-B market by offering customized products. Now, the company develops a commercial activity to valorize its innovative products to a B-to-C market (research centers for example). Note that the company has not yet exploitable results on this point.

5.3.2 List of misfits and implemented adjustments

These three case studies have highlighted various misfits that prevent the initial supply chain from being effective with the emergence of the new product. Table 16 lists seven misfits encountered by the three companies and that led to the implementation of strategic actions. The companies studied do not react the same way facing a misfit. The table 16 shows the adjustments implemented to reduce the misfit between the initial supply chain and the future supply chain.

List of misfits		Implemented adjustments	Firm A	Firm B	Firm C
Initial supply chain	Future supply chain				
The supply chain supports a <i>service</i>	The supply chain supports a <i>product</i>	Creating a new company			X
The supply chain has <i>well-defined</i> skills	The supply chain has <i>new specific</i> skills	Research partnership	X		X
		Skills acquisition	X	X	X
		Knowledge transfer	X	X	
The production is small-volume type	The production is mass oriented	Customer integration	X		
		Co-development		X	
The added value is essentially captured by <i>one or more stakeholders</i>	The added value is essentially captured by <i>the focal enterprise</i>	Upstream vertical integration			X
		Co-development		X	
The stakeholders are <i>well-known</i>	The stakeholders are <i>new</i>	Choice of stakeholders according to their skills	X	X	
Strict regulations govern the operation of the supply chain	Some standards remain the same but some former ones are no more useful	Development following the standard guidelines		X	
The target market for the innovative company is <i>well-known</i>	The target market for the innovative company is <i>new</i>	Similar products resale			X
		Support by the cluster		X	
		Customers integration	X	X	
		New commercial activity			X

Table 16: Inventory of misfits and overview of the implemented adjustments to minimize the misfits ¹⁷

The emergence of the new product led to gaps between the initial supply chain and the ideal supply chain. Each project requires adjustments to reduce the risks associated with these gaps

5.3.2.1 Case 1: Company A

For company A, skills move from well-defined sectorial skills to owned specific abilities. Then, top manager's attention is directed towards experimentation thanks to partners providing cutting-edge polymer injection laboratory equipment and also establish exclusivity

¹⁷ Note that in this table, sign X means "Implemented by".

contracts with various companies, design studios among others in the early stages of new product design (Garel and Mock, 2012).

The company also moves from a small volume to a mass oriented supply chain. It increased production process investment to ensure the transition from one to the other. The most important impact is at the consumer level in terms of the image of the new product. Consequently, the company has chosen to integrate customers during the implementation of the process to strengthen reliability (customers' feedback) (Garel and Mock, 2012).

The company faces a new network of stakeholders. If component suppliers and distributors are the same after innovation, the organization within the supply chain is modified. Indeed, the flow of information and products change. More precisely, the collaboration between the focal company and upstream and downstream stakeholders become vertical: all decisions are coming from the company A. Moreover, new retailers are associated and also external designers specialized in trends and machine suppliers to equip factories (Garel and Mock, 2012; Rognié and Vivien, 2012).

In addition, the company targets a new downstream market. The strategy consists of attracting new customers with a new low-end product accessible to a large number of customers. To foster this strategy, it involves new customers during the product development (Carrera, 1992; Garel and Mock, 2012; Lury, 2004).

5.3.2.2 Case 2: Company B

Company skills move from well-defined sectorial skills to company-specific abilities. Indeed, technology transfer is emphasized by partnering with specialized companies: it chooses to co-develop products with subcontractors.

Company also moves from a small volume to mass oriented supply chain. Company B has invested in the production process and partnership with subcontractors to benefit from expertise in production (co-conception).

Company has shifted the added value within the supply chain. The firm gained from the suppliers. It minimizes the position of its subcontractors by coordinating production.

Company faces a completely new network of stakeholders: new suppliers and distributors.

Company has to take into account specific standards of the supply chain. The product of the company B respects shape, size and physical characteristics required by these standards.

Finally, the company targets a new downstream market. It integrates users in its design and production approach to meet their requirements thanks to a marketing study and the assistance of the cluster.

5.3.2.3 Case 3: Company C

The company moves from a supply chain providing a service to a supply chain providing a product. The company top management chooses to create a new company not to confuse customers.

Company skills also move from well-defined sectorial skills to owned specific abilities. So, partnerships were developed with research laboratories that are effective in the early stages of new product design. Moreover, it operates in a supply chain supporting new technologies, but the company is often faced with a lack of skills among its stakeholders. It solves this problem by integrating its internal these, such as skills, embedded electronics or microelectronics.

Company has shifted the added value within the supply chain, gain from the suppliers to the focal enterprise. It takes the leadership in the supply chain by integrating suppliers: designing and producing their own sensors lead to propose a best variety of product on the supply chain, making them essential, and forcing distributors to work with it.

At last, the company targets a new downstream market. It integrates new markets by selling existing similar products (bio-mechanical sensors) to gain notoriety and develop a commercial activity.

5.4 Empirical contribution: Overview of phenomena occurring in supply chains during the emergence of innovation

Following the observation tasks, some phenomena emerge. First, the impacts of various key items on the evolution of the supply chain are analyzed. Secondly, the case studies highlight the invariant aspects in supply chains and required changes in supply chains after the emergence of an innovative product.

5.4.1 Impact of items on the evolution of supply chain type

Several scenarios were observed for the evolution of supply chain types. Preliminary findings are consistent with research previously conducted by (Fisher, 1997; Lee, 2002; Vonderembse et al., 2006). The studied cases show that innovative products, integrated into an agile supply chain, have been successfully accepted by final customers. Increasing the agility of the supply chain seems to help promote successful innovation. In our study, the transition from a lean-type supply chain to a hybrid-type supply chain facilitates the integration of innovative products but does not guarantee their success in the market. Then, the insertion of an innovative process in a lean supply chain without changing it doesn't lead to a successful integration of the product innovation into the supply chain.

To preserve or guarantee the agility of the supply chain, firms A and C have developed internal operations: they design and launch new industrial production activities like plastic watch design via plastic injection or sensors design via electronic development.

They bring value to several product development stages and have enough financial resources to master all the process. Their strategies induce changes within the supply chains. Firms B has less grip on the process of innovation, they depend on other stakeholders who have a greater experience and visibility on the market. The Business to Business market of the company B, by proposing a mitigated response to the product, has impacted the innovation process. Companies had difficulties to sustain their place in the supply chain due to volatile

demand. To increase the resilience of the supply chain, companies must also demonstrate internal resilience.

The choice of the manufacturing process is the trigger that causes changes in the supply chain. In a supply chain with a good resilience, a change of process is relatively easier. For example, the company C integrates easily a process like data video processing or electronic development because the rest of the supply chain is well established.

Acquisition of skills is needed to change the supply chain for all case studies. Identifying the misfit, companies react by acquiring new competencies. The way to acquire skills (through employment, knowledge transfer, partnerships...) depends on the strategy chosen by the company and on the personal behavior of the entrepreneur. Generally, once they mastered the skill acquisition pathway, the company reproduced this operation to ensure the success of its strategy. This is often one of the first implemented actions.

Companies that develop their own activities, integrate related skills, such as marketing. To promote the success of their innovations, they incorporate more specialized skills adapted to the requirements of the product. Therefore, the development of internal operations involves the acquisition of external knowledge beyond the scope of their own R&D.

The case studies show that the presence of standards influences the type of supply chain. Indeed, rules and standards seem to limit the resilience of the supply chain. The firm A could become agile by removing the requirements imposed by the cartel. The flexibility of the environment plays an important role in the changes in the supply chain.

Market characteristics (Business to Business or Business to Consumer) have little influence on the evolution of supply chain types. One characteristic seems important, however: the degree of conservatism of the customers (case of firm B). Even the traditionalist eventing market did not prevent the implementation of the new supply chain.

5.4.2 Impact of misfits on innovation success

The innovative products proposed by companies A, and C have been accepted by customers. Some misfits are present in both situations. Firstly, companies' skills move from well-defined skills mastered by the entire sector to company-specific abilities. Secondly, both companies target a new downstream market. To reduce the first misfit, companies A and C develop partnerships that are effective in the early stages of new product design: loan equipment, partnership with research laboratories. Skills acquisition seems to be an important item to support a new innovative product.

To reduce the second misfit, companies A and C set up a solid interface between them and their market: either by integrating customer feedback in the product development (Garel and Mock, 2012), or by selling existing similar products. Note that it is an essential characteristic of an agile supply chain. One element seems relevant to highlight: both companies strengthen

their position in the supply chain: Company A fosters a vertical collaboration by selecting relevant qualified stakeholders and giving orders, Company C gains added value by integrating suppliers.

The innovative product or process of company B has mitigated success with customers. We can assume third explanations. Firstly, companies' skills change from well-defined sectorial skills into company-specific abilities. Secondly, companies face a new network of stakeholders. Thirdly, companies have to take into account standards specific to the supply chain.

To reduce the first misfit, companies B looks for external skills by collaborating with experts and specialized companies. To reduce the second misfit, companies B selects stakeholders with specific core-competencies: it chooses companies with rotational molding and plastic injection expertise. To reduce the third misfit, companies C develops all its innovations by following the standards. The new product has to meet the normative requirements. The companies also consider a change of rules in favor of their product/process. In this case, the proposed solution does not allow this evolution of standards: the misfit is not reduced between the initial supply chain and the ideal supply chain.

One element seems relevant to highlight concerning these two cases: no customer integration is observed. Only a marketing study realized during the product development has been developed. Skills acquisition is a strategy shared by all studied companies to elaborate an innovation product or process. It seems to be a necessary but not sufficient condition to foster the success of the product. A solid interface with the market, characteristic of an agile supply chain, fosters direct links with customers. It seems to be a necessary condition to enhance the success of the product. Product development success is affected by a normative context leading by rules and standards. Complying with standards is mandatory but changing standards in favor of the product would increase product success.

5.4.3 Strategic perspectives

Our case studies highlight different strategic perspectives for dealing with various misfits caused by the emergence of an innovative product. These are voluntary strategic decisions taken to stimulate the evolution of the supply chain or to respond to limited market access.

The "skills" perspective highlights the skills transition throughout the supply chain within the company but also outside of it. As a project allows knowledge exchange between stakeholders, we can consider that new knowledge is the result of interactions between stakeholders (Gurgul et al., 2002). There is a relationship between the product life cycle and the demand for skills. The introduction of a new product causes the appearance of less well-defined tasks. The integration of new skills helps develop and master new tasks imposed by the product. Once the innovative properties of the product, service or process are understood, the new supply chain is shaped. The supply chain is seen as an evolving set of skills.

The “market” perspective is considered as a key element of the environment. The implemented strategies aim to align the product and the downstream supply chain market. Products with different characteristics are not necessarily positioned on the same segment. The company must determine the attractive aspect of each market segment and offer a product consistent with these segments. Different strategies are possible to enable this: marketing research, integration of customers...

The “stakeholders” perspective focuses on the nature of the supply chain members. Several variables are taken into account to describe these stakeholders: their nature (Evers and Knight, 2008; Zain and Ng, 2006), their relationships (social, business, personal, formal or informal partnership) (Evers and O’Gorman, 2011; Harris and Wheeler, 2005; Kontinen and Ojala, 2011) and the network structure (Chetty and Holm, 2000; Coviello and Munro, 1997). Collaboration between different companies is essential to use resources optimally (Wernerfelt, 1984). In addition, it facilitates access to new markets and impact the innovation process, including reducing the time to market (Arora and Gambardella, 1994; Hagedoorn and Schakenraad, 1993; Rycroft and Kash, 2004). This stakeholder perspective attests of some problems because it is necessary to frame the supply chain system: how many suppliers are taken into account, and, if it is necessary to study the suppliers of each supplier (chain grade). The network of interconnected stakeholders is often vast and complex.

The “activity” perspective points out primarily the activities adding value to the product (Porter, 1986). The supply chain can be modeled as a list of activities carried out by different companies. Note that one company can perform several activities. This demonstrates the link between the two basic concepts: the supply chain and the value chain. The “process” perspective underlines the importance of choosing processes within the supply chain. The process meets the product requirements and mobilizes specific skills. Any shift or process change causes a modification in the system, either within the company or across the entire supply chain. Integrating a new process involves changing production equipment and skills to ensure proper operation.

Finally, the “environment” perspective highlights the external phenomena that could impact the supply chain. The various case studies show that the normative requirements have a key role in the structure of the supply chain, but these requirements can be of various types: cultural, technological, environmental... In the case of the firm B, the mitigated success of the product is due to a rejection of the market for cost issues but also for reasons of customers values to be respected. In this context, cultural requirements have affected the success of the product.

To conclude, the three dimensions of the system (the company, the supply chain and the environment) are impacted by the emergence of an innovative product. Despite highlighting several strategic perspectives, it is possible that several of them are closely related. For example, the “process” impacts the “skills” perspective and/or the “stakeholders” perspective. It is unusual that only one perspective is affected during the appearance of a new innovative product.

5.4.4 Willfulness and Predictability

By comparing our theoretical research about agility strategy with the adjustments implemented by companies, several questions may be raised: Does the future supply chain result from an initial vision of the CEO or from an evolving vision that is built during the innovation process? Is the supply chain designed intentionally or underlying the product design? Is the supply chain predictable?

The design of the supply chain for the companies A and B is built during the innovation process, underlying the product design, i.e. these companies modify the supply chain to respond to the technical decisions taken for their innovative products according to its needs in terms of skills, equipment or processes. The new manufacturing process leads to investment decisions for company A and subcontracting decisions for company B. In fact, company A has invested in specialized machines (plastic injection machines, ultrasonic welding machines, etc.). Partnerships have been formed with equipment manufacturers to create the necessary installations. Company B has entered into subcontracting contracts to design the various modules (boxes, synthetic ornaments, plastic hedges) of its final product, subcontractors have been put in competition to integrate the supply chain. It should be noted that the major component of the company B's product (the boxes) was co-developed with a rotational molding company, which led to entrust it with the production of this component. In both cases, the choice of process also requires new raw material supply requirements, in particular from plastic powder suppliers (valid for cases A and B). Suppliers were approached and put in competition in order to integrate the future supply chain. Finally, in terms of personalization, these two cases propose differentiation processes (colorization process for case A, assembly among a limited choice of components for case B). These process choices enable companies to offer a range of products based on the same supply chain, with customers choosing from the existing supply chain.

Reading the various documents, it does not seem that the project team of company A has integrated a "supply chain" problematic into its innovation strategy. However, it appears that the managers of the firm A had no vision of the future supply chain. The supply chain is unpredictable, its modeling is impossible at first. As the numerous required processes were not defined, it was not possible to detail the chain of participants. Even if it seems that the CEO was ready to change its environment and face external conservatist behaviors. In fact, Swatch's history shows that its supply chain continued to evolve once the product was on the market: customer feedback helped to stabilize and make more robust the box production processes.

Unlike Company A, the innovative product supply chain of company B was easily predictable: the CEO of the company B knew the future supply chain as soon as he chooses the production process: the rotational molding process. He decided to subcontract this process and to let his subcontractor manage its supply. Consequently, the CEO observes the supply chain changes. It is not involved in its design and implementation. Thus, the implementation

of the supply chain resulted from the technical choices made for the product. Hence, the CEO has not integrated a “supply chain” problematic into its innovation strategy.

The design of the supply chain for company C is built during the innovation process. By offering on-demand design, company C has to ensure that the supply chain can respond positively to customer needs. The CEO of company C develops a supply chain vision within his innovation process, without deploying a specific strategy for the supply chain. Changes in the supply chain are facilitated by progressive integration decisions. Indeed, he develops related activities (development of its own range of sensors, creation of a sales company) to its main activity, which allows it to extend its position in the supply chain and better control any transformations. Strong partnerships with suppliers of components (eye-tracking or motion sensors for example) and with universities have been set up to allow a rapid and adapted response. These decisions seem to be primarily made to design the product but it includes the “supply chain” problematic.

Therefore, the supply chain design is intentional. During the emergence of its first innovation, the CEO of the company C could predict the shape of the future supply chain: during the interviews, he explains that he knew exactly what types of skills had to be detained by stakeholders (suppliers, subcontractors and distributors) and what types of interrelation would be relevant. The competences expected by the company being rare, the transformation of the supply chain occurred when the first desired skills appeared on the market. Hence, the supply chain of company B was quickly predictable by the CEO. Future impacts on the supply chain following the emergence of its innovative product are known and he was able to quickly represent the shape of the future supply chain.

The study of these three cases highlights two points that can be considered as factors to facilitate product and supply chain co-design:

- The design of the supply chain depends on the willfulness of the manager or the project team;
- The supply chain can be predictable or unpredictable.

Firstly, the study of these three cases leads us to wonder whether the design of the supply chain is supported by an initial specific strategy within the innovative company. It remains difficult to estimate whether the decisions impacting the supply chain are intentional or whether they are merely an organizational response to a series of product design problems to be solved. Then, there seems to be a gap between the theory that advocates an agility strategy to support an innovative product and the reality where supply chain design stems from innovation strategy. However, these three cases underline that product and supply chain design activities are interrelated and complementary, which reinforces our proposal to co-design the product and supply chain (Chapter 3). However, our study points out that, in reality, supply chain design very often results from product design. The non-implementation of a supply chain-specific strategy, i.e. an agility strategy in the case of innovation, may explain this. Thus, we can ask ourselves whether the agile supply chains obtained in our study are the result of chance or intention.

Secondly, some of the case studies have shown that it is not always possible for top managers to predict the future structure of the supply chain. Two scenarios are possible: a predictive scenario or a non-predictive scenario. In all cases, a trigger is needed to initiate the transformation of the supply chain. Unlike the predictive scenario, the non-predictability of a supply chain requires considering several intermediate supply chains before obtaining a stabilized and adapted supply chain. These supply chains are called intermediate as the choices in terms of stakeholders, equipment, processes among others are not finalized. However, the final supply chain is not fixed and may still evolve for technical, managerial or environmental reasons. The figure 24 illustrates these two scenarios.

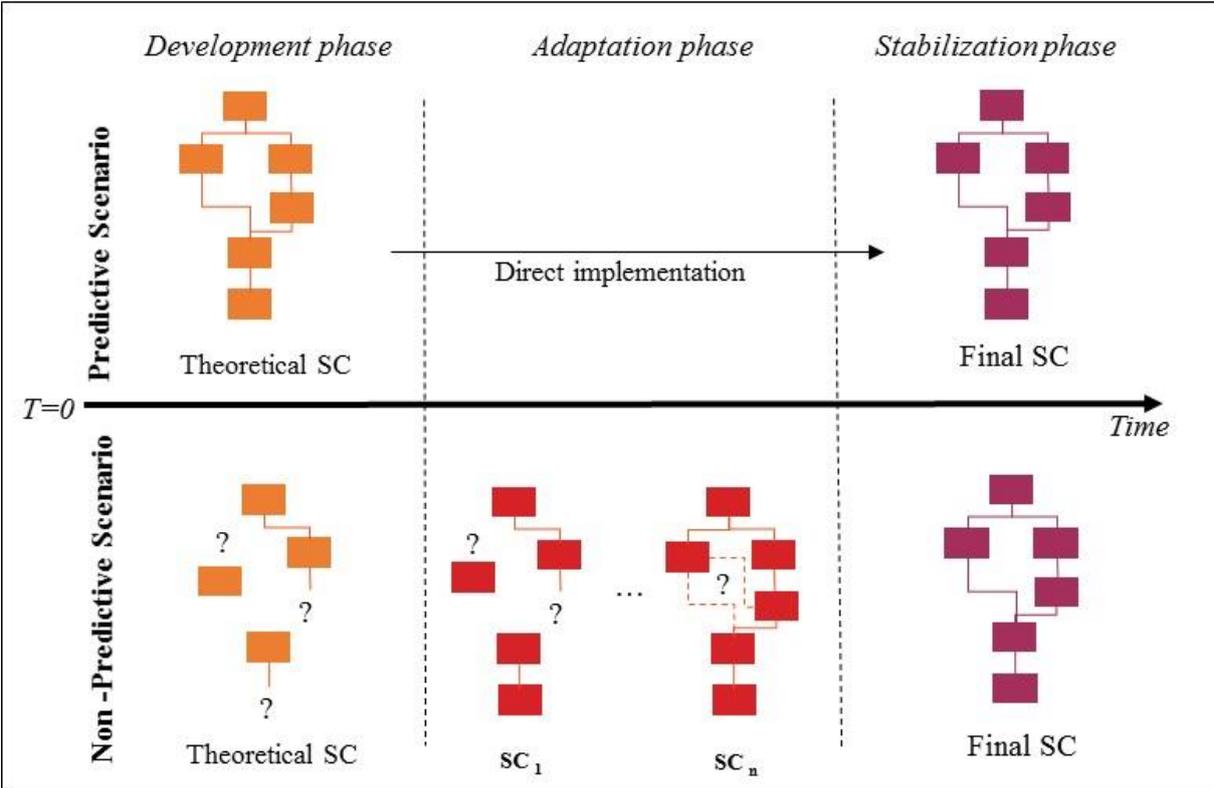


Figure 24: Predictable or unpredictable new supply chain

5.4.5 Conclusion

The final result of a process of innovation remains uncertain, because the successful implementation of a new supply chain depends on strategic directions chosen by companies, environmental constraints, stakeholder behavior or the relationship with the market. Consequently, the creation of an adjustment process to match the needs of innovative products with their supply chain is required to optimize performance. By examining the different variables affecting the supply chain (including the value chain, skills, processes, stakeholders, the environment and the market), several phenomena have emerged that highlight the limitations of the research. Although the study is exploratory, identifying various misfits and associated adjustments allow to note that some events are predictable and can be easily anticipated. Other events are specific to the company, the environment or market.

Conclusion of the Chapter 5

Through its empirical approach, this chapter provides details on the phenomena that occur in a supply chain during the emergence of an innovation. Moreover, it provides encouraging results, supporting the theoretical findings of Chapters 2, 3 and part of Chapter 4. However, there is a managerial gap between reality and theoretical results: the importance of the supply chain when launching the innovative product highlighted by the literature seems underestimated by companies. This leads us to question the management of the supply chain design.

Therefore, we have checked whether there are currently any supply chain design tools available to companies. The SCOR (Supply Chain Operations Reference) model, designed by the Supply Chain Council, is a tool at the service of the stakeholders in global logistics processes. It is divided into two parts, one to model the process and the second part to evaluate the performance of this process. (Lepori, 2012). Its implementation is based on 4 steps¹⁸:

- A first strategic step is based on an analysis of the competitive positioning (performance required by the market, measurement of current performance, gap analysis and optimization plan);
- A second operational step is based on physical flows (geographical, quantitative analysis, optimal distribution);
- A third systemic step is to represent existing information flows and processes
- A fourth implementation step consists of developing, testing and putting into production the optimized chain.

The contributions of this model are multiple (Lepori, 2012) :

- It is based on a common language between customers and logistics providers ;
- It provides performance indicators ;
- It allows to develop different scenarios and to evaluate their performance (locally and globally).

The limits of this model are as follows (Lepori, 2012) :

- Difficulty of customization: the names of the processes do not characterize the content of the process, the order of the processes corresponds to that recommended by the model;
- The readability of the results for too extensive supply chains (problems of size, ease of navigation);
- The absence of correlations between indicator categories (it is impossible to show that time has an impact on cost);
- Indicators not always adapted to the problem under consideration.

¹⁸ <http://www.bpms.info/lexique/scor/>

This model is rather focused on supply chains already in place with a view to optimization. In addition, it focuses more on the logistics aspect of the supply chain and makes it possible to build a standardized reference system that facilitates exchanges with customers. Therefore, this model is not adapted to our problem:

- In terms of time, it is mainly used once the product has been launched, while we seek to develop a tool to use during the innovation process.
- In terms of structure, it seeks to move towards lean supply chains while we seek to develop agile supply chains.
- In terms of decisions, it focuses first on the strategic positioning of the company and then on the flow while we propose the opposite path.
- In terms of focus, it seems more company and supply chain focus while we focus on the product.

This model seems complementary to our approach by providing a post-product launch response to the company.

In addition, this chapter gives a list of phenomena occurring between the design of a new product and the associated supply chain. It encourages deepening empirically the study of the supply chain.

According to (Glaser et al., 1968; Yin, 1994), the validity of data derived from qualitative methods is based on the notion of theoretical saturation, which is directly related to the number of cases. (Eisenhardt, 1991) points out that the number of interviews to be carried out depends on the existing knowledge of the subject under study. He adds that the ideal number is between 4 and 10 for reasons of data volume control. As part of our research, the theoretical data from the literature is to be enriched. The existing knowledge on the topic studied is therefore relatively important, which makes it possible to limit the number of cases to be studied. Consequently, we have decided to study a fourth case (Chapter 8) to validate our data on the subject.

Based on an innovation that is still in development, the role of this fourth case is twofold: it allows us to reach empirical saturation while allowing to validate our methodological contributions. Consequently, it will be studied in depth in Chapter 8. Chapters 6 and 7 present our methodological contributions: an instantiated supply chain model of the supply chain and a Model-Based Supply Chain Engineering. These two contributions intend to formalize the results for our research in order to make them accessible to companies. They serve as an interface between reality and theory, leading to a more real and operational vision of the product/supply chain links and supply chain/innovative company.

IN BRIEF

- The validation of theoretical conclusions is done by an **empirical** and **constructivist** approach.
- Increasing the supply chain **agility** seems to help **promote a successful innovation**.
- To increase the **agility** of the supply chain, companies must also demonstrate internal **agility**.
- The **choice of the manufacturing process** is the trigger that causes changes in the supply chain.
- **Skills acquisition** is often the first implemented actions.
- The **flexibility of the supply chain environment** plays an important role in the change of the supply chain.
- For dealing with various misfits caused by the emergence of an innovative product, there are **different strategic perspectives**: skills, market, stakeholders, activity and environment.
- This chapter raises the issue of the **willfulness of the CEO** in designing the supply chain.
- The future supply chain can be **predictable** or **unpredictable**.

KEY FINDINGS OF THE CHAPTER 5

Based on empirical analysis, Chapter 5 favors an inductive approach. Thus, this research uses three case studies to observe the consequences of the emergence of an innovation on the supply chain. The final result of a process of innovation remains uncertain, because the successful implementation of a new supply chain depends on strategic directions chosen by companies, environmental constraints, stakeholder behavior or the relationship with the market. Consequently, the creation of an adjustment process to match the needs of innovative products with their supply chain is required to optimize performance. By examining the different variables affecting the supply chain (including the value chain, skills, processes, stakeholders, the environment and the market), several phenomena have emerged that highlight the limitations of the research. Although the study is exploratory, identifying various misfits and associated adjustments allow noting that some events are predictable and can be easily anticipated. Other events are specific to the company, the environment or the market. The contribution of this chapter lies in a better understanding of in-situ phenomena within the supply chain and an initial observation of the differences between SMEs and large enterprises. This empirical study highlights a significant gap between theory and reality: the importance of the supply chain in the product launch highlighted by the literature seems to be underestimated by companies.

PART 3: METHODOLOGICAL CONTRIBUTION

INTRODUCTION OF PART 3:

This part focuses on the development of the supply chain design engineering in order to propose to companies a methodology allowing them to co-design their product and the associated supply chain.

The Chapter 6 proposes a model to facilitate data collection and analysis in order to understand the supply chain as a system based on a systematic review of the literature and case studies. Then, it presents a representation model for any supply chain. This chapter supports our first methodological contribution: an instantiated supply chain model.

The Chapter 7 seeks to model the different supply chain scenarios based on the data collected during product design. It supports our second methodological contribution: the Model-Based Supply Chain Engineering.

CHAPTER 6 3rd Contribution: Proposition of an instantiated supply chain model

Introduction

A well-designed and coordinated supply chain that fits a particular product leads to competitive advantages. Therefore, international competition is also existing at supply chain level (Christopher, 2016). As emergence of a new product impacts the organization of a company, it is clear that every new product impacts also the supply chain: changes in the stakeholders' interrelations, emergence or disappearance of stakeholders (O'Connor and Rice, 2013), evolution or new skills in the supply chain... Indeed, in innovation, matching the characteristics of a new product and its associated supply chain appears as a key success factor (Fisher, 1997; Vonderembse et al., 2006). So the configuration of the supply chain plays an important role in the development of the final product. The supply chain has to be adapted to the specification of the new product in terms of processes, skills...

Therefore, particular attention is drawn towards forecasting of a product innovation's impacts on the whole supply chain. For that, a description and modeling of the supply chain are required to better understand the way a supply chain evolves with the emergence of a new product. This includes the collection of data about the relations between the product characteristics and the potential transformation within the supply chain.

From the systematic review presented in chapter 2 and case studies, this chapter aims to describe and model a supply chain and supports our third contribution: a proposition of an instantiated supply chain model. This contribution leads to a representation model for any supply chain by considering the emerging data of the product.

This chapter is structured as follows. Firstly, the relationship between literature-based theory and empirical-based theory is presented. Secondly, our first methodological contribution is detailed through the description of our model.

This contribution is the subject of a publication¹⁹ from which part of this chapter is derived.

¹⁹ Marche, B., Boly, V., Morel, L., & Ortt, J. R. (2017, June). Innovative product's supply chain: How to model it. In *Engineering, Technology and Innovation (ICE/ITMC), 2017 International Conference on* (pp. 177–188). IEEE.

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6.1 Relationship between literature-based theory and empirical-based theory

6.1.1 Research approach

Many models and behaviors resulting from innovation and design management come from the positivist paradigm. The positivist approach stems from a rationalist approach based on the control of variables (see Figure 25). However, the product design is a complex phenomenon that depends on the interaction of many stakeholders. Research in the field of design aims to understand what leads to improvement in practice to increase the chances of producing a successful product (Blessing et al., 1995; Eckert et al., 2003). The impact of design decisions can be unknown for months or even years because of the delay between the implementation of a product design and its ultimate market results. The design deals with human interactions with artefacts and situations that contain many uncertainties (Swann, 2002).

In contrast to rationalism approach, the empiricism one is based on the idea that knowledge is constructed from the observation of phenomena, the understanding of which enables to infer laws. Therefore, empiricism is a discovery of the world through experience (Bulinge, 2014). It contributes to the constructivist paradigm which considers that reality is constructed and that it is self-organized around a finality (Bulinge, 2014).

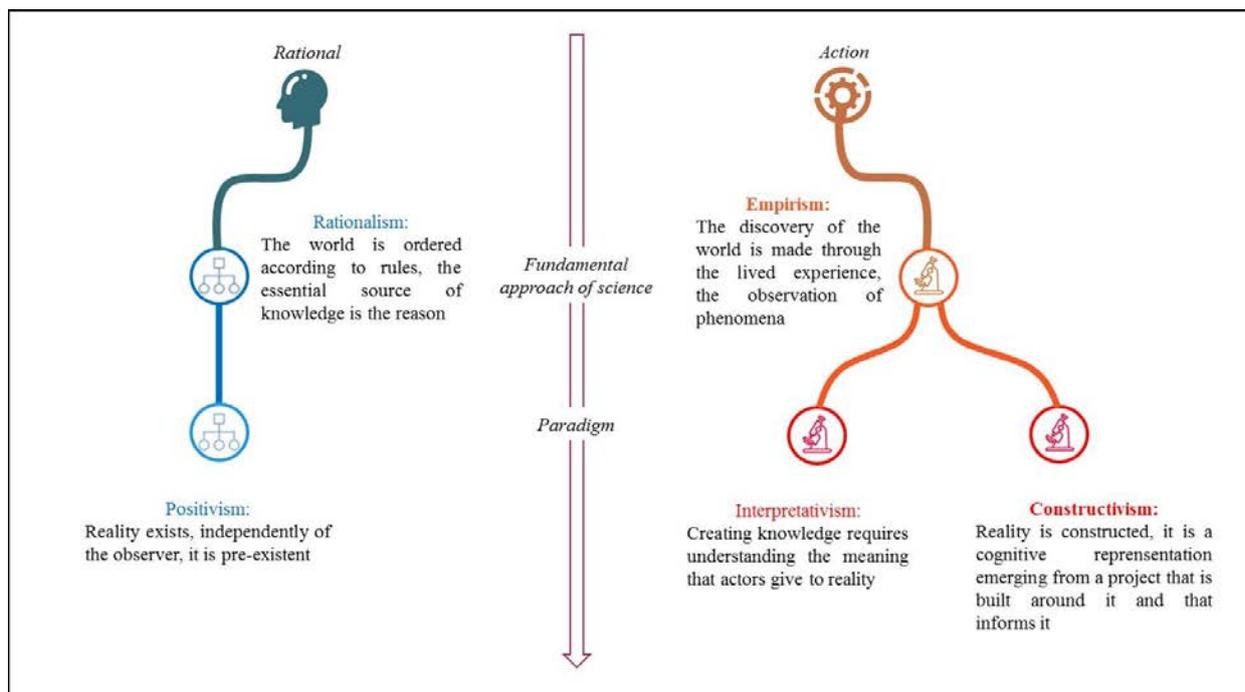


Figure 25: Representation of different approaches of science and associated paradigm

(definitions from [Bulinge, 2014])

Within the constructivist paradigm, the study of phenomena (i.e. the phenomenology) focuses on the understanding of events and the search for a more desirable future for the actors (Susman and Evered, 1978). Thus, phenomenology belongs to constructivist paradigm. This approach contributes to knowledge while providing direct benefits for companies. This

methodological approach is consistent with the ambitions of this research leading to a relevant supply chain model to support innovative companies (Moultrie et al., 2007).

In an empirical reasoning, one of the strategies of analysis concerns the use of a theoretical model. A theory is built on the study of examples and allows the detection and identification of invariant, to model and to anticipate future developments of a problem.

Used extensively in empirical research, the case study is adapted to questions about the more or less implicit interactions linked to a phenomenon. The potential of the case study lies in its ability to highlight the observation of the singularity of the problem participating in the understanding of a problem likely to be repeated (Chatelin, 2005).

6.1.2 Research design

Inspired by the methodology proposed by (Moultrie et al., 2007), our research was carried out in four phases: a literature review, an observation campaign, the development of the model and finally its validation. Each step is described in detail (Figure 26).

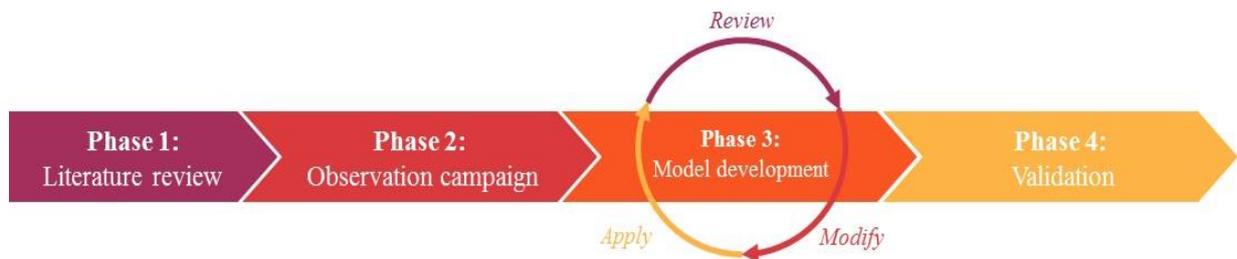


Figure 26: Implemented methodology inspired by (Moultrie et al., 2007)

6.1.2.1 Phase 1: Literature review

The literature review helps to identify constitutive elements of a supply chain by synthesizing all relevant studies on this subject. The structure of the supply chain is described and justified thanks to a state of the art from 1960 to 2016 (see chapter 2).

6.1.2.2 Phase 2: Observation campaign

The exploratory study focuses on three innovative companies that launched their new product on the market (see chapter 5). This leads to a better understanding of the design of a new product supply chain, in parallel with the design of the related product. The heterogeneity of the case studies highlights the recurrence of phenomena during the structuring of the supply chain, from the initial stages of the product design to its launch on the market. Data from each case study are collected in three different ways:

- Empirically based on an in-depth study of the literature;
- Through meetings and interviews with the CEO;
- Immersion and observation within the companies from the initial stages of the product design to launching.

Phenomena issued from the case studies can be used to illustrate and check evidence from the literature review (*see chapter 5*)

6.1.2.3 Phase 3: model development

These different exploratory cases and the evidence provided by the literature lead to the development of a representation model of the supply chain. Modeling reduces reality for a certain purpose: communicate, pilot, capitalize, simulate, reproduce, duplicate... By focusing on the essential, the model offers a simplified and intelligible representation of reality (Thiault, 2007).

Therefore, models are used to visualize a part of the real world to simplify its understanding. The supply chain model we create is meant to be used as a prospective tool for companies designing an innovative product. It is applied to a company whose product is still in the design stage, the structuring of its future supply chain being indispensable to guarantee its industrialization.

Modeling involves knowing how to represent information in order to better communicate it. A system is a model of an original made by an observer, but it is not the original itself (Gomez, 1981). Then, the determination of the system depends on the frame of reference of the observer.

There are different types of modelling software packages (Schekkerman, 2011) that can help us in supply chain modeling (McKinsey Architecture, EAS Architecture, Mega International Software among others). MEGA International Software²⁰ has been chosen for several reasons:

- It describes the functioning of the system, here of the supply chain, at its different levels. It considers the multi-scale nature (activities, processes, companies) of the supply chain;
- It allows a complete overview of the supply chain, thus facilitating its design and implementation and the management of its inherent complexity;
- It is a tool dedicated to process modeling and optimization. It links the different components of a system. It allows to visualize the impacts of the constituent elements of the supply chain on each other;
- It favors the use of a modelling language and standardized formalism to transmit information. UML are discursive languages where information is communicated as text (Durand, 2006). The UML language is a standardized visual specification language for modeling objects that includes a graphical notation used to create an abstract model of a system.

The MEGA software is based on messages linking objects (stakeholders, processes, activities...) (Castro Espiritu, 2010). A message represents a flow circulating within a company or exchanged between companies in the supply chain. In our research, the MEGA software is used as a didactic approach.

²⁰ www.mega.com/fr

6.1.2.4 Phase 4: Validation

A fourth company initiating the design of a new product is finally studied to validate the model and evaluate its applicability. This phase will be detailed in part 4, Chapter 8.

6.2 First methodological contribution: an instantiated supply chain model

6.2.1 Elements of conceptual modeling data

As a methodological approach, System Engineering (SE) plays an important role in representing the theory of a system and its complexity, the result of the type and number of elements and the relationships between them (Bonjour and Dulmet, 2006). As part of the development of a product and its supply chain, this approach allows the complex system to be decomposed in different layers, the identification and organization of activities and the control of the information needed to elaborate the product and the supply chain (Bonjour and Dulmet, 2006).

To represent a model, the System Engineering use entities linked by relationship. Cardinalities and constrains give information to get as close as possible to reality.

An entity is a set of objects that belongs to its system composed of information characterizing it as an attribute. Within a model, a relationship is a link between entities. There are different types of relationships (Table 17).

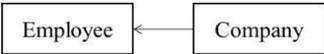
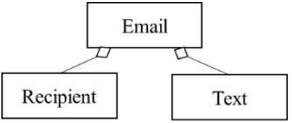
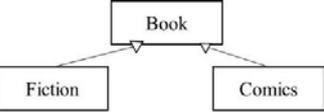
A \longrightarrow B	Association: equality relation between two elements <i>A uses B</i>	
A $\cdots\longrightarrow$ B	Dependency: two elements but one depends on the other <i>A depends on B</i>	
A $\text{---}\diamond$ B	Aggregation: an element is an optional component of the other <i>A participates in the composition of B without being essential to its functioning</i>	
A $\text{---}\blacklozenge$ B	Composition: one element is a compulsory component of the other <i>A participates in the composition of B and is essential to it</i>	
A $\text{---}\triangleright$ B	Generalization: dependency of filiation type between two elements <i>A is a kind of B</i>	

Table 17: Types of relationship in the UML Language (inspired by [Fagnon and Gaston, 2012])

The cardinality associated with an association, aggregation or composition termination declares the number of objects that can occupy the position defined by the association termination. Several cardinalities are conceivable (Table 18):

1	1 object exactly
*	Several objects
1... *	1 object at least
1... N	From 1 to N objects

Table 18: Types of cardinalities in the UML Language

Within a model, certain entities can be constrained to get as close as possible to reality. Several constrains is conceivable (Table 19):

Exclusion E	If an entity participates in the relationship R1, it cannot participate in the relationship R2. <i>(R1 not R2)</i>	
Simultaneity S	Any entity participating in R1 participates simultaneously in R2. <i>(R1 and R2 together)</i>	
Totality T	Each entity participates at least in one of the two relations R1 or R2. <i>(R1 or R2 or both)</i>	
Exclusion and Totality E and T	Each entity participates at least in either the relations R1 or the relation R2, but not both at the same time. <i>(R1 or R2, not both)</i>	
Inclusion I	If an entity participates in the relation R1, it also participates in the relation R2. <i>(R1 and R2)</i>	

Table 19: Types of constrains in the UML Language

Note that here are presented all the types of relationships, cardinality and constraints that can be found in a UML diagram, but that our model does not use them all.

6.2.2 Summary of cross-observations

This research phase aims at identifying the recurrent or common elements that could influence the development of representation model of a supply chain. The key points are summarized as follows.

A supply chain has to include at least two different companies.

The company A's supply chain is made up of suppliers of plastic materials, suppliers of watch components (mechanisms, movements...), company A transforming the material into a plastic watch, and retailers (sports shops, jeweler...).

The company B's supply chain is made up of suppliers of plastics, rotomolding company, foundry company, company B assembling all components, and finally logistics distributors and retailers.

The company C's supply chain is made up of suppliers of sensors, suppliers of electronic components, companies specializing in video processing, company C and distributors.

These observations are in line with phenomena described in the literature.

A supply chain is characterized by three flow types

- The supply chains of the three companies are crossed by *physical flows*.

Company A's supply chain is traversed by watch components, plastics, plastic watches among others. Company B's supply chain is traversed by plastics, cast iron molds and polyethylene fences among others. Company C's supply chain is traversed by electronic components, sensors and video among others.

- The supply chains of the three companies are crossed by *information flows*.

Each company orders resources to its suppliers: components and plastic for company A, sensors for company C and cast iron molds for company B. Moreover, there are exchanges with their distributors (A and B), customers and partners (B and C during the installation of the product).

- The supply chains of the three companies studied are crossed by *financial flows*.

All companies pay their suppliers (components and plastic suppliers for company A, plastics, cast iron molds and rotomolding services for company B, sensors, electronic components, video processing for company C). Financial flows include resellers (companies A and B), distributors (company C).

These observations are in line with phenomena described in the literature.

A supply chain is composed of processes detailed in activities:

Each process set up within the supply chain is made up of activities facilitating the process. These activities are divided into tasks, carried out by individuals within the companies in the supply chain. The choice of the process is the trigger element in the layout of the future supply chain, as it determines the relevant skills and equipment and informs about the type of the stakeholders.

Within the company A's supply chain, there are:

- Technical processes: assembly, ultrasonic welding...
- Business processes: sales, marketing, purchasing

Within the company B's supply chain, there are:

- Technical processes: plastic injection, rotomolding, foundry, product installation
- Business processes: sales, marketing, purchasing, consulting...

Within the company C's supply chain, there are:

- Technical processes: embedded systems, programming, assembly of sensors, interfacing of the embedded system, sensors implementation...
- Business processes: sales marketing, purchasing...

These observations are in line with phenomena described in the literature.

A supply chain generates value.

The company A's supply chain generates financial (increase of turnover), commercial value (increase of its market share), it captures the attention of the customer (increase of customers number) and it generates novelty. The company B's supply chain generates financial (increase of turnover), strategic (differentiation within the market), functional value (increase of the number of product functions) and generates novelty. The company C's supply chain generates financial (increase of turnover), strategic (differentiation within the market), commercial value (increase of its market share) and offers the associated development opportunity.

These observations are in line with phenomena described in the literature.

The confrontation of the results from the literature with the observations highlights the important characteristics of a supply chain. This first analysis is the basis of the future model.

6.2.3 Model description

The proposed model is decomposed into four interrelated boxes. Note that the environment around the supply chain is not taken into account in the current representation which focuses on the functional aspect of the supply chain. The boxes are: actors, flows between actors, processes represented through tasks and finally value.

Within the model, each actor belongs to a family of actors having the same role (supplier, subcontractor...). Roles may be characterized with attributes like: having to do, knowing how to do, being able to do and wanting to do (Figure 27).

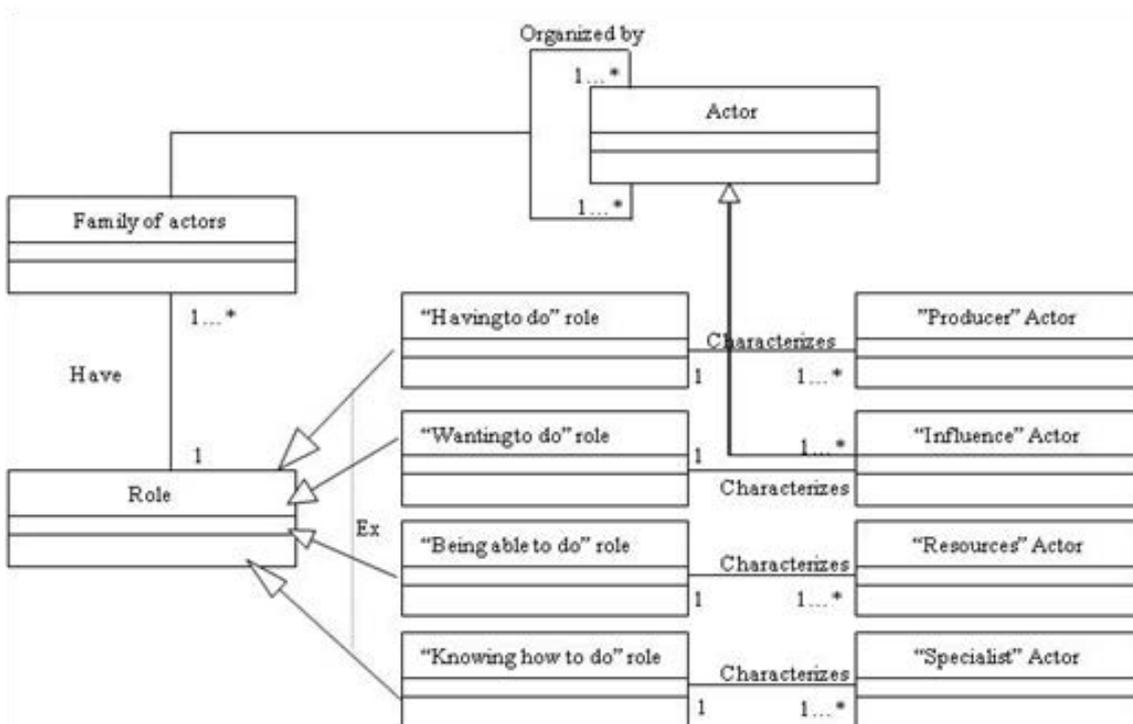


Figure 27: Representation of actors and their role in a UML class diagram

To produce a “Having to do” object, here a component or a final product, the process uses skills (“Knowing how to do” objects), resources (“Being able to do” objects) and decisions (“Wanting to do” objects) (Mayer, 2008). All these elements are necessary to realize the product (Figure 28).

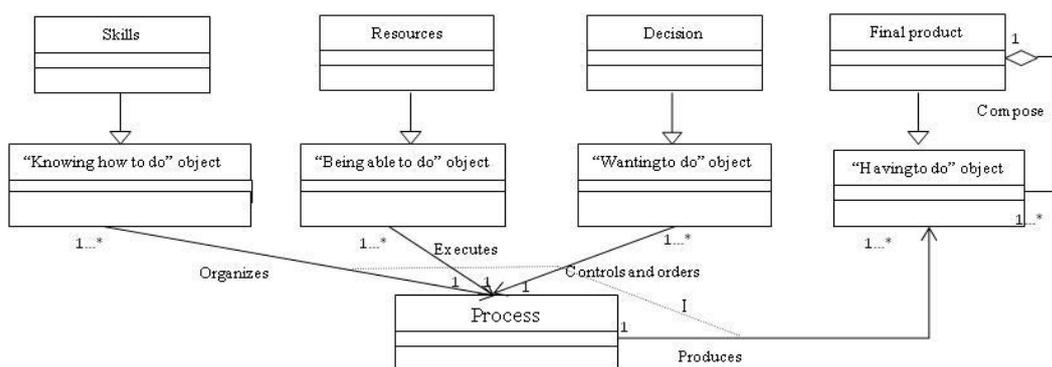


Figure 28: Representation of the process in a UML class diagram

At least, one skill, one resource and one decision is needed to operate a process and make at least one tangible or intangible product. Each actor is connected to the other ones through flows (Figure 29).

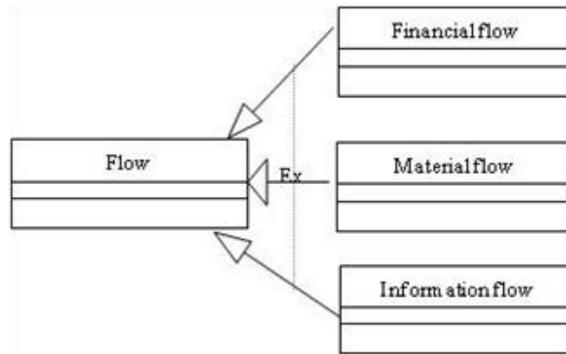


Figure 29: Representation of flows and their type in a UML class diagram

A process can be decomposed into at least one activity. Each of these activities creates at least one type of value. The figure 30 represents part of the model, dedicated to process decomposition and value generation. This part is directly linked to the resources needed to manufacture the product and the actors.

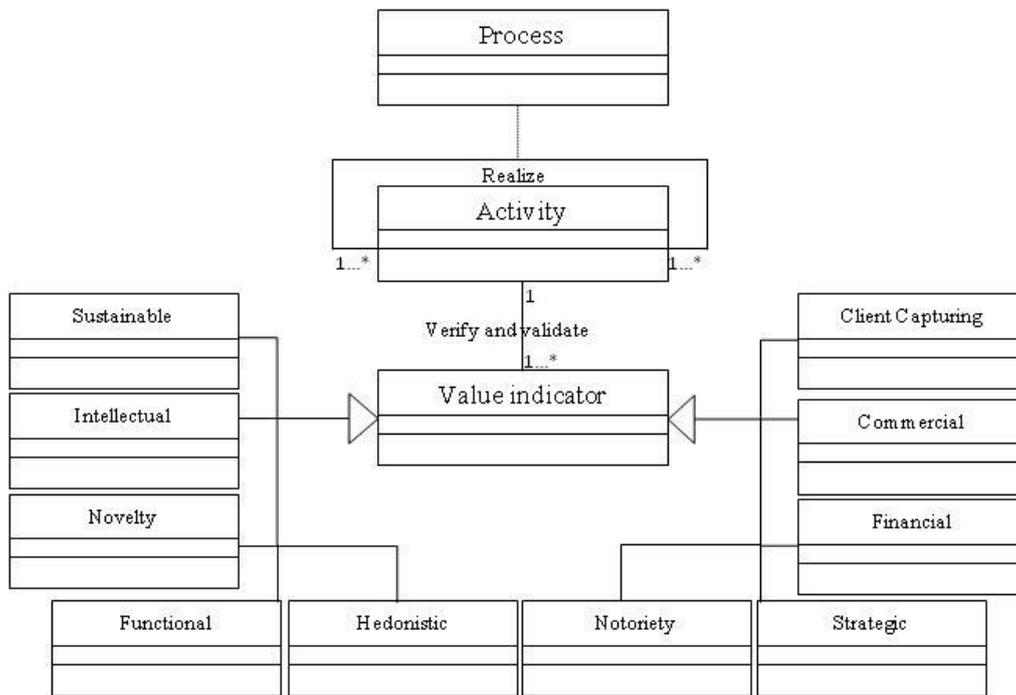


Figure 30: Representation of activities in a UML class diagram

The global model is presented in figure 31²¹.

²¹ As a reminder, not all the relationships, cardinalities and constraints presented previously are necessarily present on this model.

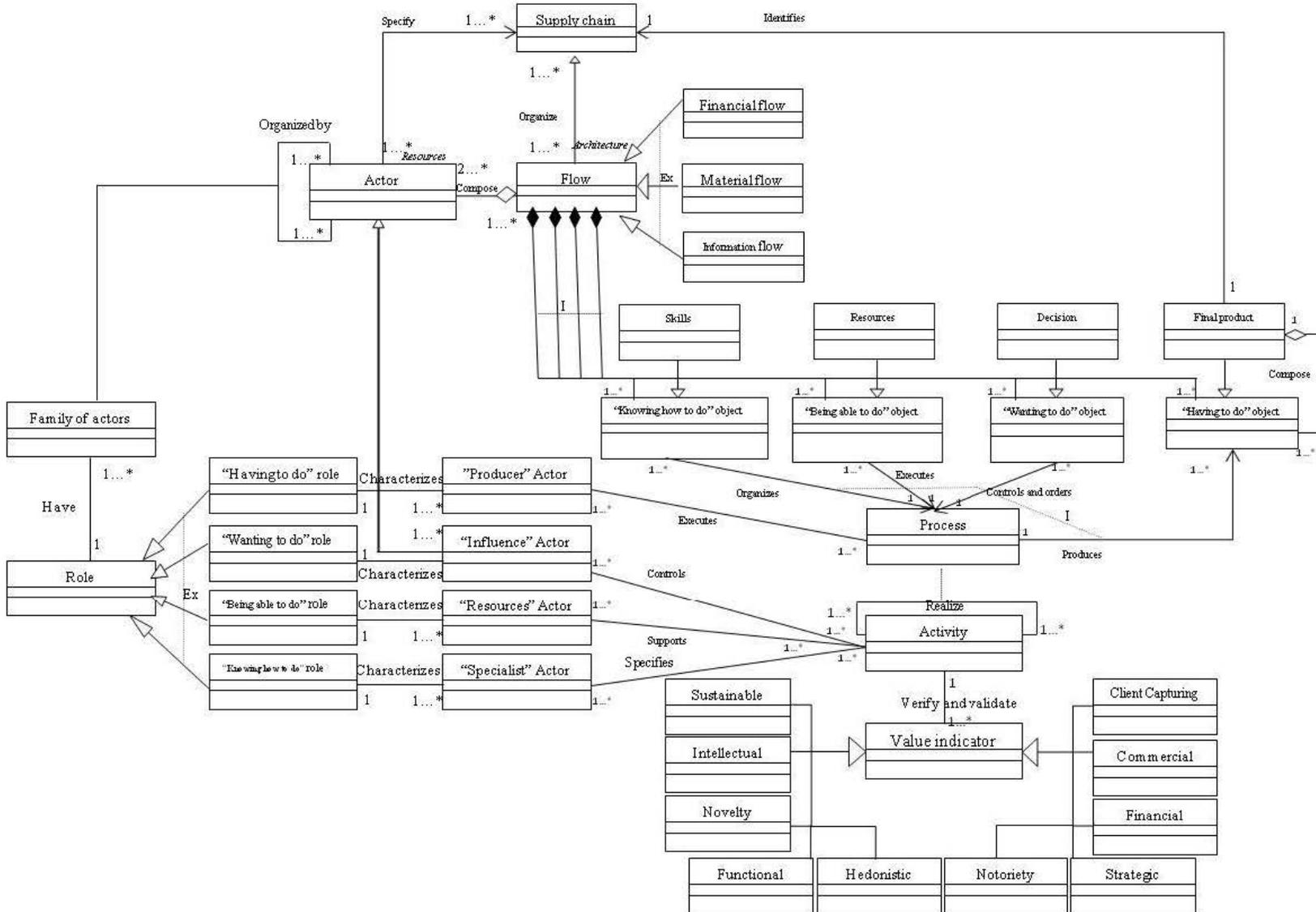


Figure 31: An instantiated supply chain model represented in a UML class diagram

Conclusion of the Chapter 6

Chapter 6 validates the characteristics of a supply chain from the literature thanks to four exploratory cases in order to better understand it. The research outcome is represented by a system modeled according to a System Engineering Based on the Models in order to underline the interdependencies between the constituent elements of a supply chain (Marche et al., 2017b). The main contributions of this work are:

- A systemic model based on evidence and literature;
- A reality-based representation that synthesizes the constitutive elements of any supply chain from a wide variety of source that integrates the literature of multiple domains;
- A valid basis for the design of a future supply chain prospective analysis tool;
- An overview of the importance of the supply chain in the design of an innovative product.

This research focuses on the correlation between the product and its supply chain, hence the need to link the product system to the supply chain system. The product architecture has to be aligned with the supply chain. Knowing the architecture of the system brings several advantages (Marques Pereira and Sousa, 2004). By organizing and structuring the system, the architecture provides a global perspective of information resources, eliminating redundancy in processes. The decomposition of the product appears to be a good alternative to identify information specific to the design and manufacture of the product. Apart from the perfect type of supply chain for a new product other considerations might also determine the optimal supply chain (Marche et al., 2017b):

- The availability of an existing supply chain with partners for the other products produced by the company;
- The supply chain of competitors and the possibility to protect the new supply chain against competitors.

The choice of the modeling based on the System Engineering allows the capitalization of the information in the databases. In perspective a complementary prospective analysis tool for supply chain design is required, as it will highlight the design invariant as well as the motor and dependent variables and will thus consolidate the knowledge bases for future research.

IN BRIEF

- Literature review helps to **identify constitutive elements** of a supply chain
- Case studies **validate evidences** from literature review
- The model is developed to **simplify the understanding** of a supply chain
- System Engineering helps to **represent the supply chain and its complexity**
- This chapter present our **first methodological contribution**: an instantiated supply chain model

KEY FINDINGS OF THE CHAPTER 6

Based on an in-depth analysis of the literature and case studies, this chapter seeks to propose an instantiated model of the supply chain, a reality-based representation in order to highlight:

- The constitutive elements of any supply chain (stakeholders, flows, processes, values among others) and the relationships and influence between them;
- The multi-scale character of a supply chain (companies, processes, activities);
- The operation of the supply chain has to consider all scale to be efficient.

The choice of the modeling based on the System Engineering allows a capitalization of the information. This model is meant to be used as a data collect tool for companies designing an innovative product, it is a description of the supply chain at a given time.

CHAPTER 7 4th Contribution: Proposition of supply chain design engineering

Introduction

The importance of the supply chain in the product launch highlighted by the literature seems to be underestimated by companies (see Chapter 5). In order to fill the gap between theory and reality, a supply chain engineering has been developed as part of this research.

The objective of this chapter is to describe each stage of the engineering to obtain different supply chain scenarios. This engineering is intended to help innovative companies position themselves in the future supply chain and develop a strategy to facilitate its implementation. Indeed, this engineering insists on the need to co-design the product and the supply chain while highlighting the influence of the innovative company in this co-design.

Such a methodology has a triple interest for companies. Firstly, it leads to **co-design** the product and the supply chain. Secondly, it **positions** the company within the supply chain. Finally, it helps the innovative company to **evaluate** the different supply chain scenarios adapted to the innovative product in order to ensure its launch and promote its success on the market.

Each engineering stage includes tools that facilitate data collection, processing and modeling, including two our previous contributions: the instantiated supply chain model and the framework to implement an agility strategy. In addition, interactions with the innovative company or project team are frequent in order to ensure that the scenarios obtained are relevant, i.e. they make possible to manufacture the innovative product while considering the company's strategy.

As a first step, a general presentation of engineering is proposed in order to present the major stages that constitute it. In a second step, a detailed description of each step, based on different tools, is presented.

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7.1 General presentation of our engineering

To design a supply chain, we propose to develop a Model-Based Supply Chain Engineering (MBSCE). Inspired by the model-based system engineering (MBSE) (Estefan, 2007), our MBSCE is a *methodology for designing, specifying, validating and implementing the supply chain of a new product*.

The Model-Based Supply Chain Engineering provides the ability to develop and analyze different supply chain scenarios through a design process, based in particular on the complexity paradigm (see Chapter 3—section 3.2). By considering the product, the company and the supply chain, this engineering facilitates the thinking work on the development of a supply chain. Thus, its originality relates to the transformation of “product” specifications into “supply chain” specifications via different tools. This engineering thus facilitates the transition from the expression of product specifications to the definition of the corresponding supply chain scenarios (modeling) by giving the innovative company the opportunity to evaluate them (position and decision to take). Therefore, this engineering includes three major phases. It is illustrated in figure 32.

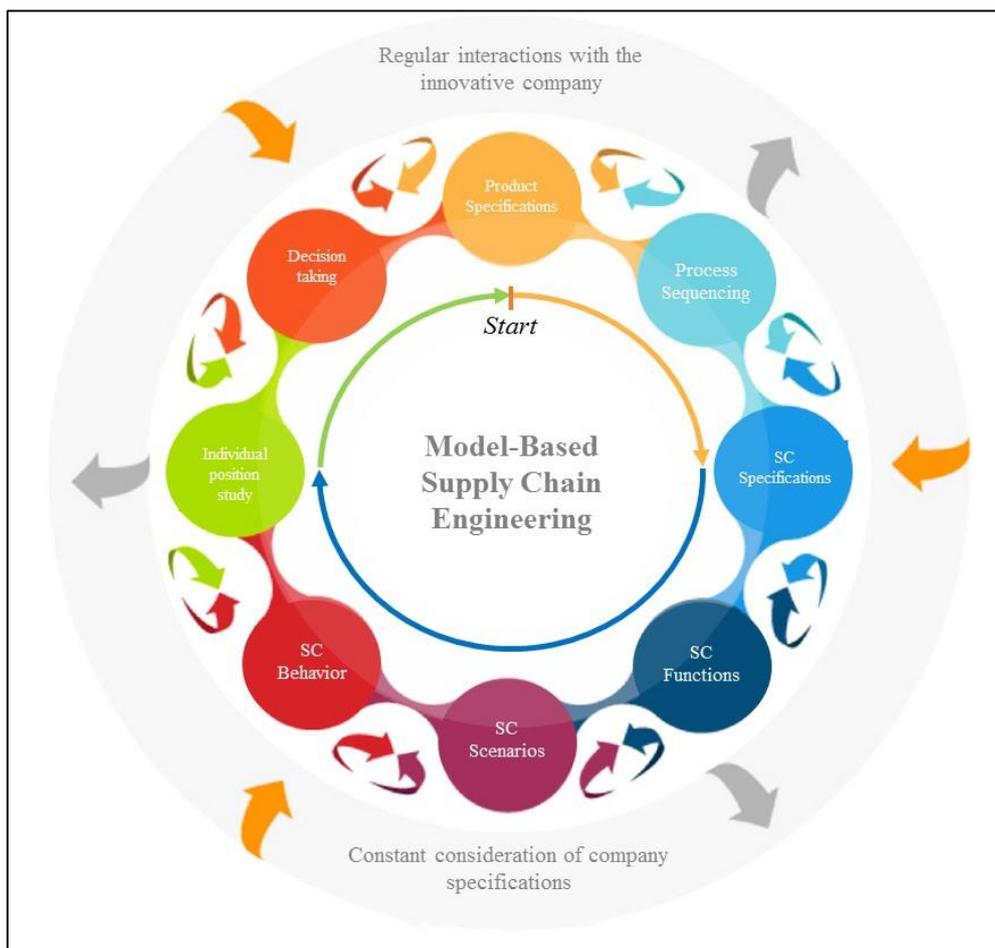


Figure 32: The Model-Based Supply Chain Engineering ²²

²² Visual support inspired by (Dupont et al., 2015) with the kind permission of the authors

The three main stages of engineering are represented by the cycle at the heart of the circle: the yellow part represents the co-design stage, the blue part the position stage and the green part the evaluation stage. These three main steps are defined by specific tasks, represented by bubbles in this diagram. Each engineering task requires the use of a tool, these tools will be detailed in the next section. Between each bubble, the circular arrows underline the back and forth between each task in order to validate that the result obtained remains consistent with the work done previously. Finally, the “in/out” arrows represent frequent interactions with the innovative company or project team.

The **co-design phase** aims to link common data to the product and the supply chain. It can be decomposed into two stages:



The product specification consists in producing a technical description of the product and identifying the design decisions that will be at the origin of the future supply chain of this product (*section 7.2.1.1*).



The sequencing of the processes aims to order the processes that will form the future supply chain. These processes contain the supply, manufacturing and distribution processes proposed and validated at the design stage (i.e. the company’s specifications). This stage leads to an initial visualization in the form of a supply chain of the product’s manufacture (*section 7.2.1.2*).

The **position phase** aims to transform the company’s specification in the supply chain’s specification in order to elaborate supply chain scenarios. It can be decomposed into four stages:



The supply chain specification consists in writing and modeling the company’s requirements with regard to its future product and the corresponding supply chain (*Requirement Pillar—section 7.2.2.3.1*).



The supply chain function defines what the supply chain will do and positions the company and other stakeholders according to their involvement in these functions (*Descriptive Structure Pillar—section 7.2.2.3.2*).



The supply chain scenarios specify how the supply chain works and what the stakeholders will have to do. This stage leads to a functional vision of the supply chain in the form of alternative supply chain scenarios, i.e. an overview of the different supply chains described in the shape of a sequence of processes (*Prescriptive Structure Pillar—section 7.2.2.3.3*).



The supply chain behavior consists in positioning the supply chain over time. Therefore, this stage highlights the way in which the innovative company will work within the supply chain (*Behavior Pillar—section 7.2.2.3.4*).

The **evaluation phase** aims to analyze the supply chain scenarios in order to position the innovative company, determine its role and then make technological and strategic decisions. It can be decomposed into two stages:



The individual position study consists in analyzing the different supply chain scenario to determine which would be most suitable in order to ensure the success of the product on the market and to enhance and sustain the company (*section 7.2.3*).



The technological and strategic decision to take seeks to implement the scenario chosen by the innovative company (*section 7.2.3*).

The figure 33 summarizes the objectives of each task in the engineering.

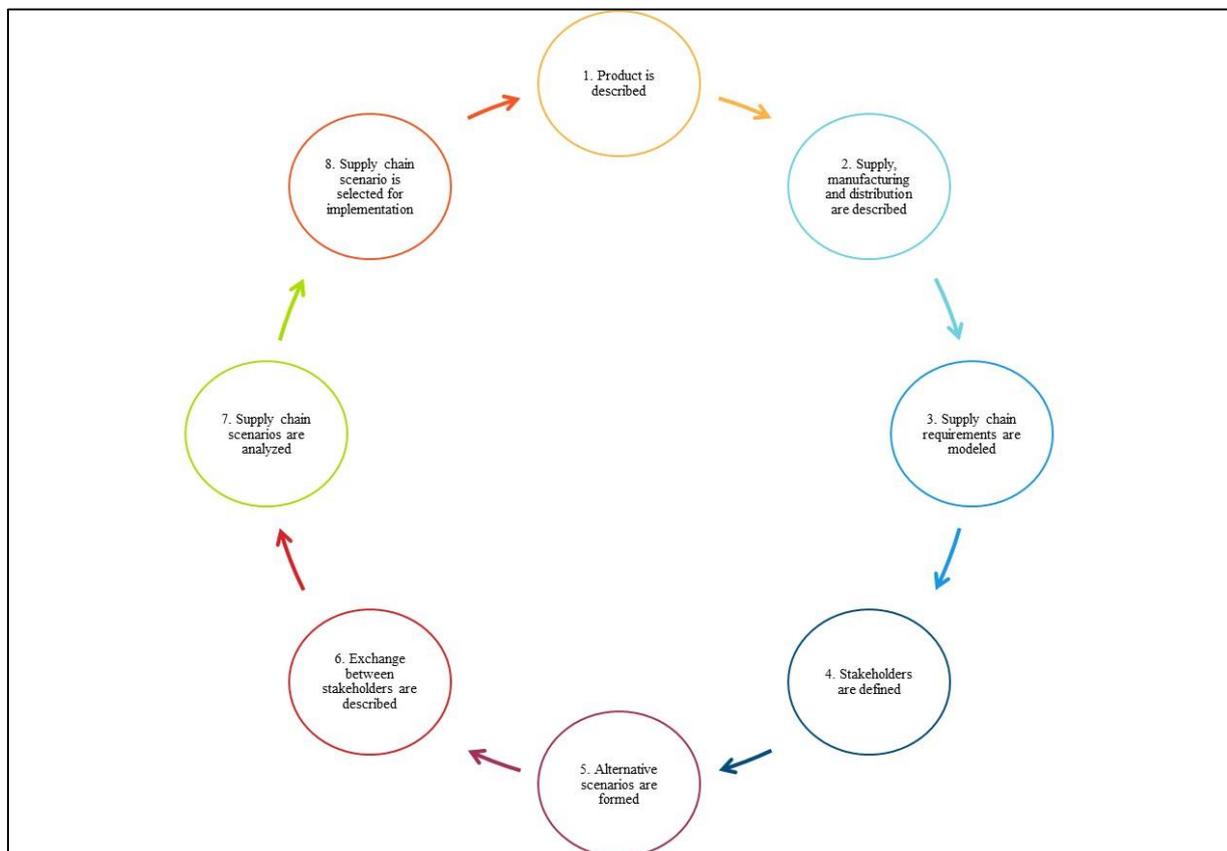


Figure 33: Schematic representation of the objectives of each engineering task

Note: This engineering aims to model mainly the physical flows characterizing the supply chain, i.e. the sequence of processes transforming raw material/component into the final product. Consequently, information and financial flows appear little or not at all in our different scenarios.

7.2 Detailed description of the engineering

This section presents in detail each engineering stage as well as the tools mobilized. For each of them, a step-by-step explanation of our protocol will be proposed.

7.2.1 Product and Supply Chain co-design

The **co-design phase** aims to link common data to the product and the supply chain. It can be decomposed into two stages: the product specification (*section 7.2.1.1*) and the sequencing of the processes (*section 7.2.1.2*).

7.2.1.1 Technical description of the product and identification of design decisions

This step seeks to collect data from the product design process.

a. Objectives of this step

The objectives of this step are as follows:

- Understand the product (design, architecture, assembly...);
- Collect the data that will be used to model the different supply chain scenarios;
- Understand the vision of the innovative company (project team or company manager);
- Capture a first vision of the supply chain, that of the innovative company.

b. Tool to realize this step

The instantiated supply chain (see Chapter 6) model is used to guide interviews and collect information. Given the amount of information needed to design a supply chain, its use seems relevant to guide the search of information. Moreover, its structure facilitates exchanges between the researcher and the innovative company to validate the accuracy of the data.

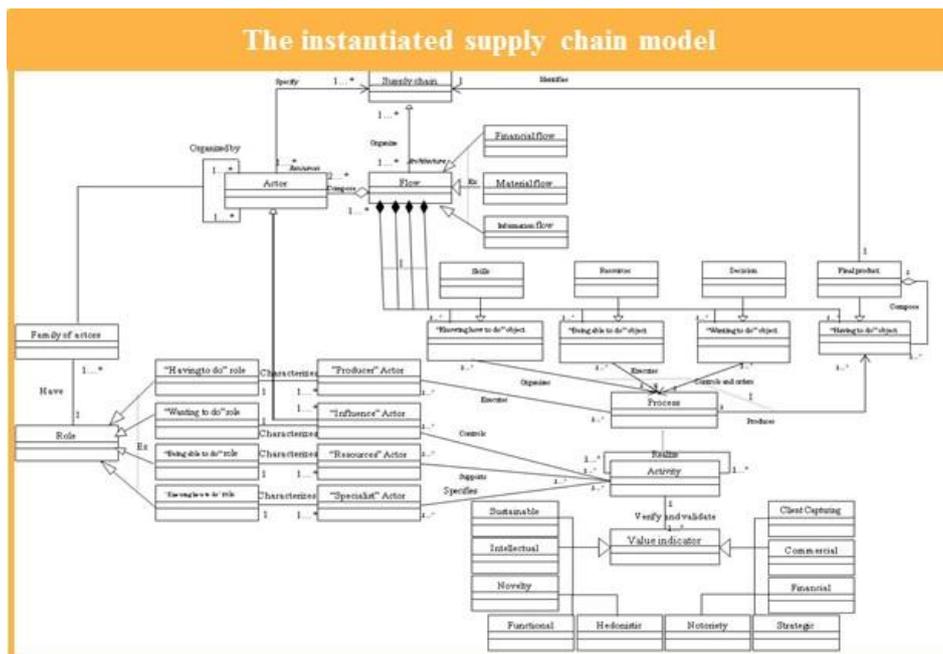


Figure 34: The instantiated supply chain model to obtain a technical description of the product

c. Methodology

The source of data can be multiple: interview, design documents, expertise, and surveys among others. Product analysis collects data that will be used to model supply chain scenarios.

IN PRACTICE: How to describe the product and identify the design decisions

Step 1: Decompose the product

- Collect all constitutive elements of the product (raw material, components, modules, product)
- Fill the instantiated supply chain model (one sheet for each element)

Step 2: Collect information related to each element of the product

- Collect the characteristics of each element from design decisions (raw material, antecedents of the component, manufacturing process, activities, equipment, intended stakeholders)
- Fill the instantiated supply chain model

Step 3: Focus on technical information

- Deepen the technical data (through internal technical studies, benchmark of candidates solutions, research articles, technical survey, contacts of suppliers for example)
- Fill the instantiated supply chain model

Step 4: Validate the correctness of the data with the innovative company

Source: Our research

d. Conclusion

This first step allows us to collect data necessary to carry out the next steps of our engineering. The validation by the innovative company of the collection work is important: the processing and modeling of this data will be based on reliable data, corresponding to the company's vision. Moreover, this step allows the researcher and/or the user of this engineering to better understand the subject, to acquire the necessary knowledge to model the different supply chain scenarios.

The methodology of this step is summarized in the figure 35.

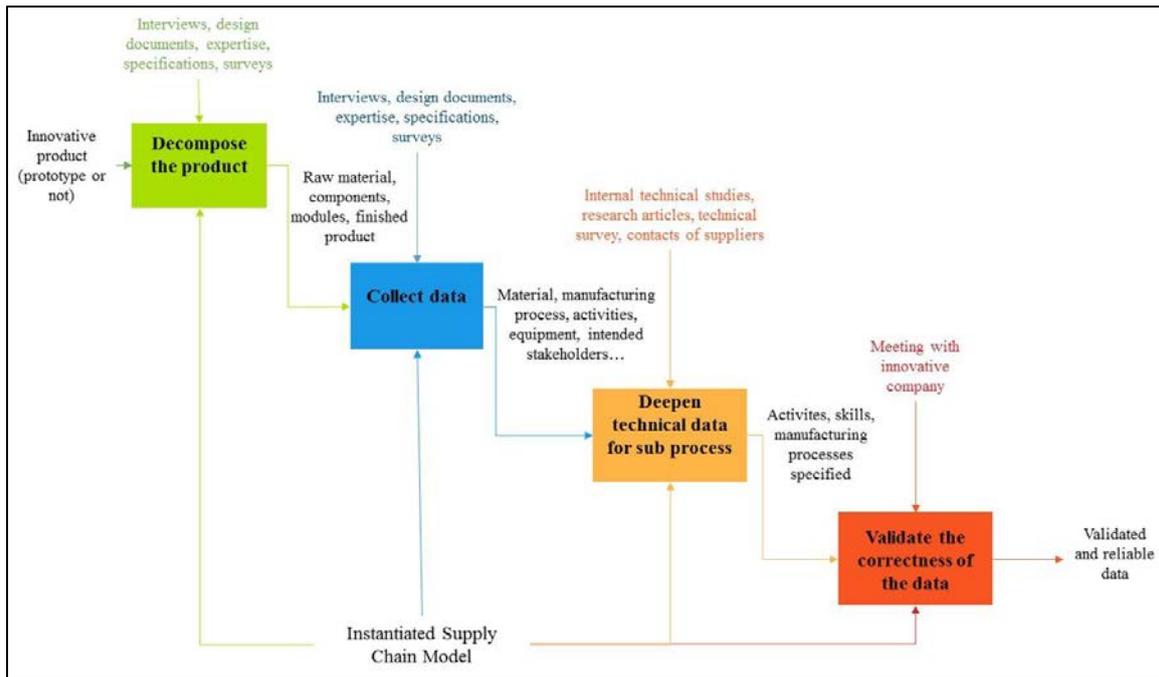


Figure 35: Procedure for describing the product and identifying the design decisions

7.2.1.2 Sequencing of processes and physical flows

This step seeks to order and sequence the data from the previous step. This stage aims to accompany the transition from “product-centered design” to “supply chain-centered design”.

a. Objectives of this step

The objectives of this step are as follows:

- Identify the relationships between the product, manufacturing processes and processes;
- Analyze the relationships between the product, manufacturing processes and processes to understand the way in which they are organized to form a supply chain, i.e. to describe the functional behavior of the supply chain;
- Create a representation of the sequence of processes;
- Improve and validate this representation with the innovative company.

b. Tool to realize this step

The DSM (Design Structure Matrix) is a modeling tool used for analyzing system elements and their interactions. It emphasizes the architecture of the system (or its design structure). DSM is particularly well suited for the design of complex engineered systems and should be used in the field of engineering management (Eppinger and Browning, 2012).

The DSM and DMM (Domain Mapping Matrix) matrices give a visualization, an analysis and a management of the dependencies among the constituent elements of any complex system, such as products, process and organization.

Compared to other networks modeling methods, the main advantage of DSM is the graphical nature of the matrix display format. The matrix provides a highly compact, easily scalable and intuitively readable representation of the system architecture (Eppinger and Browning, 2012).

The use of a DSM/DMM matrix seems relevant for two reasons:

- It helps us to represent the internal couplings of the system (Bonjour, 2008), i.e. it highlights the component/process coupling of the product inside the supply chain;
- The sequence of processes obtained is a premise of the future supply chain.

c. Methodology

To link product components, manufacturing processes and processes, these matrices are combined in the form of a DSM-DMM matrix chain (Eichinger et al., 2006). According to (Lindemann, 2007), these assembled matrices form a multi-domain matrix (MDM). Then, there are used to couple product design and supply chain design from a functional point of view (represented by the sequence of its processes).

The MDM matrix obtained in our research is represented in the figure 36:

- Framed in blue: the matrices focus on the products and its components and their manufacturing processes;
- Framed in red: the matrices focus on the processes associated with these manufacturing processes. These processes will be used to model the supply chain (see section 7.2.3).

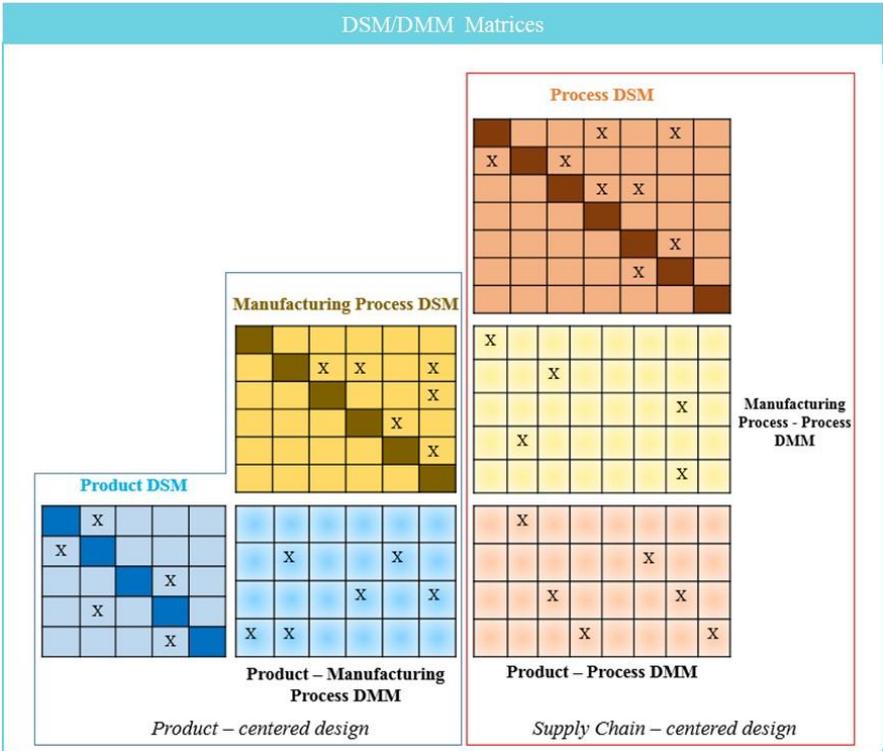


Figure 36: Representation by MDM to link product and processes

The development of an MDM matrix is based on three types of matrices: two DSM matrix classes (Bonjour, 2008) and a DMM matrix class. The table 20 describes each type of matrices.

Matrix class	Focus	Representation	Application	Algorithm
Static DSM		Interactions between components	Identification of the product architecture	Clustering
Temporal DSM		Input/output relationships between processes	Structuring of processes	Sequencing
DMM		External couplings between product, manufacturing processes and processes	Link between product, manufacturing processes and processes	/

Table 20: Different types of matrices and their applications (inspired by (Bonjour, 2008))

According to (Danilovic and Browning, 2007), the algorithms of these two approaches are generally called “clustering” or “sequencing”:

- A clustering algorithm is used to reorder the matrix elements in order to group together related elements;
- A sequencing algorithm seeks to maximize flows between activities based on their dependencies.

IN PRACTICE: How to achieve the sequencing of processes and physical flows

Step 1: Understand and formalize the links between the different components of the product

- List all the components of the product collected during the previous step: from the raw material to the final product (in the rows and columns of the matrix)
- For each cell, put an “X” if the element of the row is integrated in the component, module, product of the column

Representation: Product DSM (Static DSM)

Step 2: Identify the candidate manufacturing process required for each component, modules or product

- List all the manufacturing processes collected during the previous step (in the column of the matrix) and the raw material, component, modules and products (in the row of the matrix)
- For each cell, put an “X” if the component is obtained from this manufacturing process (“1” if a module or finished product is obtained and “?” if the choice of the manufacturing process is not definitive)

Representation: Product—Manufacturing Process DMM

Step 3: Formalize the sequence of manufacturing processes to minimize reverse loops

- List all manufacturing processes collected during the previous step (in the rows and columns of the matrix)
- For each cell, put an “X” if the manufacturing process of the row contributes to the manufacturing process of the column

Representation: Manufacturing Process DSM (Temporal DSM)

Step 4: Identify the candidate process required for each manufacturing process

- Define and standardize the process integrating the manufacturing process, which is a specific activity of the process.
- List all the processes (in the column of the matrix) and the manufacturing process (in the row of the matrix)
- For each cell, put an “X” if the manufacturing process is integrated within the process

Note: In order to use a thesaurus of precise technical terms to describe the activities and by opting for a usual terminology to facilitate the comparison between several supply chain, we opted for the «*Répertoire Opérationnel des Métiers et des Emplois*» proposed by the French institution, *Pôle Emploi*. This frame of reference lists all the activities and skills to carry out a process by profession.

Representation: Manufacturing Process-Process DMM

Step 5: Validate that each component, modules or product is achieved through a process

- List all the processes collected during the previous step (in the column of the matrix) and the raw material, component, modules and products (in the row of the matrix)
- For each cell, put an “X” if the component is obtained from this process (“1” if a module or finished product is obtained and “?” if the choice of process is not definitive)

Representation: Product—Process DMM

Step 6: Formalize the sequence of processes to minimize reverse loops

- List all processes collected during the previous step (in the rows and columns of the matrix)
- For each cell, put an “X” if the process of the row contributes to the process of the column

Representation: Process DSM (Temporal DSM)

Source: Our research

d. Conclusion

This second step seeks to use the data from the first step to model them. It is important due to its possibility to transform raw data from the product into data that can be used to design supply chain scenarios. The results provided by these matrices help to formalize the design requirements, the starting point of the modeling. This is an intermediate outcome in supply chain design. The methodology of this step is summarized in figure 37.

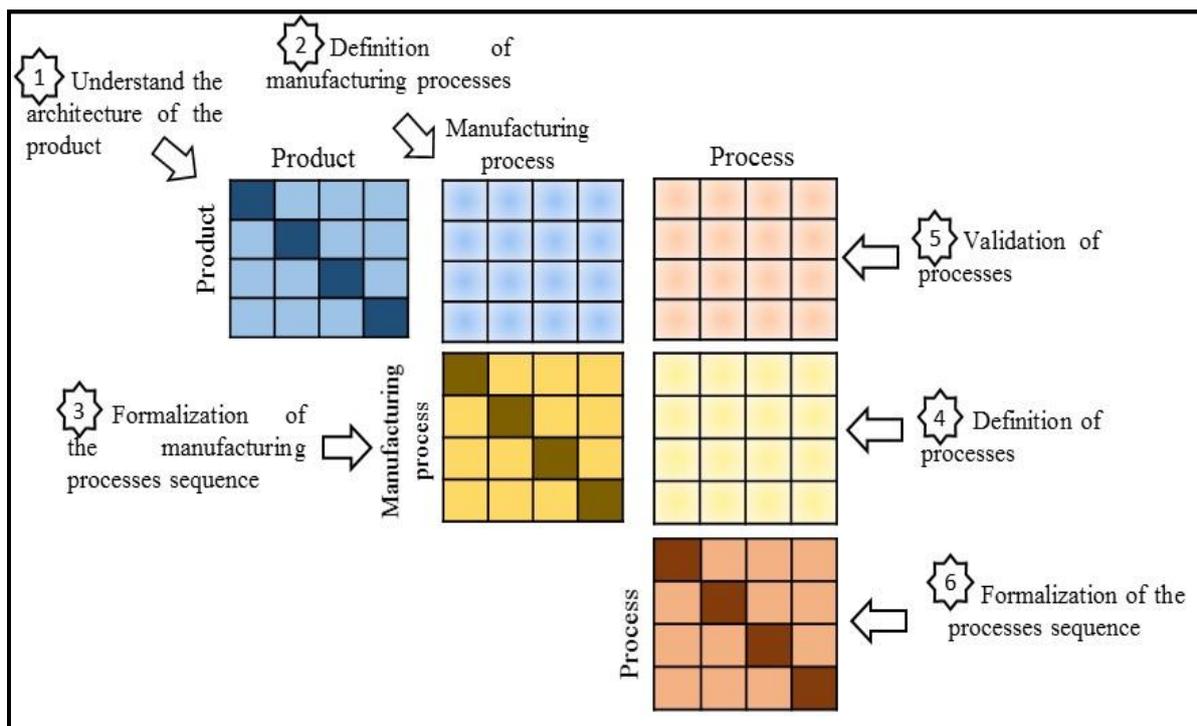


Figure 37: Procedure for sequencing of processes and physical flows

7.2.1.3 Conclusion of the co-design stage

The first stage of our engineering is based on two tasks to describe the product using our instantiated supply chain model (see chapter 6) and to describe the sequence of processes leading to its manufacture and thus constituting the future supply chain through the use of DSM-DMM matrices. The figure 38 summarizes this first engineering step with the associated tools.

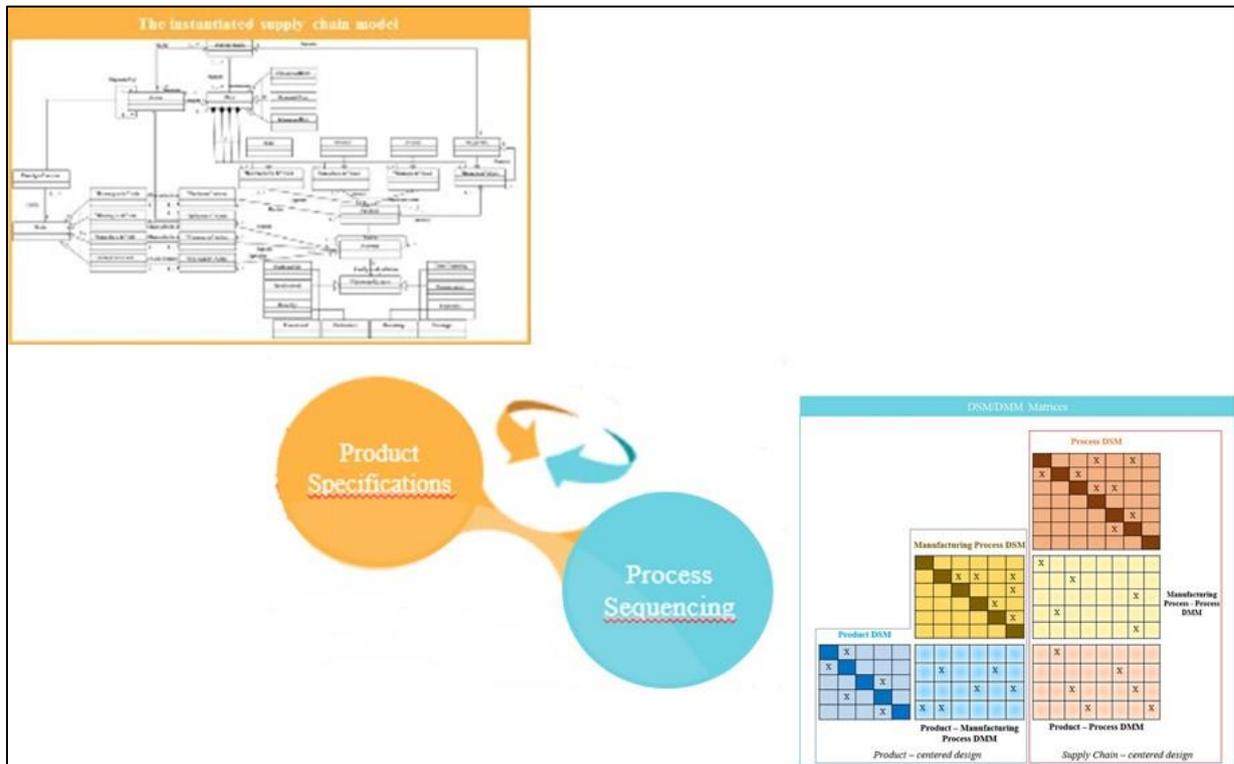


Figure 38: Summarize of the first stage of our engineering

This first step helps to move from a product-centered vision to a supply chain centered vision. However, in order to understand the complexity of the future supply chain, a simple description of the sequence of processes characterizing it seems limited. Consequently, the second stage of this engineering encourages us to question ourselves on all the dimensions of the supply chain. In a way, it is a process of constructive critical analysis based on systematic questioning.

7.2.2 Position the company within the supply chain modeling of supply chain scenarios

Modeling data from the product/supply chain co-design step helps to position the company within the supply chain. Consequently, our modeling methodology is built from a Model-Based System Engineering approach (Estefan, 2007): it is organized according to four pillars (i.e. point of view) of modeling and uses the SysML language adapted and recommended by practitioners (Fundamentals in Appendix 2).

7.2.2.1 Objectives of this step

The objectives of this step are as follows:

- Formalize the results of the previous step to model the different supply chain scenarios;
- Detail supply chain functions and associated stakeholders;
- Propose supply chain scenarios;
- Visualize the behavior of these scenarios.

Consequently, our supply chain modeling methodology scans:

- A “Requirement” pillar: based on a requirement diagram, it is used to model the requirements written from the data reported by the DSM/DMM matrices (*specified in paragraph 7.2.3.3.1 and illustrated in paragraph 8.3.1*);
- A “Descriptive structure” pillar: based on use case diagram, it describes the use cases of the supply chain to meet the requirements (*specified in paragraph 7.2.3.3.2 and illustrated in paragraph 8.3.2*);
- A “Prescriptive structure” pillar: based on activity diagram, it prescribes the supply chain structure supporting supply chain use cases (*specified in paragraph 7.2.3.3.3 and illustrated in paragraph 8.3.3*);
- A “Behavior” pillar: based on sequence diagram, it models and executes activity diagrams to check the dynamics of the supply chain structure (*specified in paragraph 7.2.3.3.4 and illustrated in paragraph 8.3.4*).

This description by pillars facilitates the supply chain modeling process and makes the use of our method more educational by allowing users to focus on each point of view.

The table 21 shows the type of response provided by each pillar.

	Why	What	Who	How	When
Requirement Pillar	Requirement Pillar				
Descriptive Structure Pillar		Use case diagram			
Prescriptive Structure Pillar			Activity diagram		
Behavior Pillar					Sequence diagram

Table 21: Response of each pillar in the design of the supply chain

One of the benefits modeling delivers to systems engineering is the capability to define and visually see the interactions from one aspect or view of the system to another. Thus, we should be able to answer “Does the supply chain design meet the product needs?” Answering this question requires an understanding of how each pillar connects with one another.

7.2.2.2 Tool to realize this step

In this perspective, we based on the *Harmony for System Engineering* process and the associated Rational Rhapsody® tool to develop step-by-step supply chain scenarios (justification of this choice in Appendix 2). The relationships between each pillar (through their diagram) are managed by the Rational Rhapsody® tool thanks to the SysML language which allows the results obtained to be validated at any time. There are illustrated by figure 39 that highlights that:

- Any requirement has to be satisfied by a supply chain function (represented by a use case);
- Any function in the supply chain can be represented as an activity sequence, i.e. a part of the supply chain and underlines its behavior.

Therefore, this tool allows to transform the previous intermediate design object into supply chain scenarios.

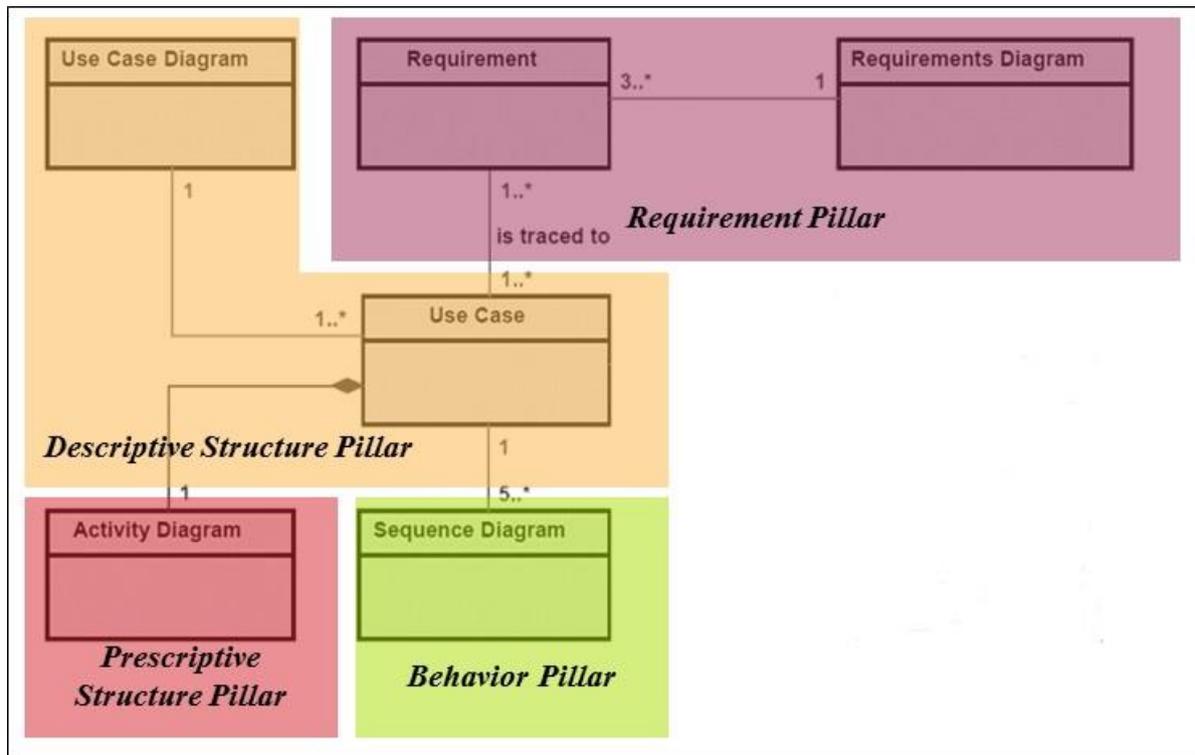


Figure 39: Relationship between the different components generated by SysML (adapted from Harmony for systems Engineering methodology)²³

Note that the use of this tool requires some constraints:

- A requirements diagram visualizes the dependencies of at least 3 requirements;
- A Use Case Diagram contains at least one Use Case;
- A use case should always have one Activity Diagram that captures the functional flow;
- A use case should be described by at least 5 Sequence Diagrams.

7.2.2.3 Methodology

a. The requirement pillar

The Requirement Pillar helps to determine the specification (which we will later refer to as requirements) of the innovative company with regard to its future product and the corresponding supply chain.

A requirement is “a statement that identifies a system, product or process characteristic or constraint, which is unambiguous, clear, unique, consistent, stand-alone (not grouped), and verifiable, and is deemed necessary for **stakeholder** acceptability” (INCOSE, 2010).

In our research, the system considered is the supply chain and two types of requirements are considered:

²³ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

- **The Stakeholders Requirements:** they are based on an analysis and transformation of the needs of stakeholders (here, the innovative company through its project team or CEO) into a set of requirements that express the expected interaction of the system (here, the innovative product) with its operational environment (here, the supply chain) (ISO/IEC/IEEE, 2015). They serve as a reference to validate each step of the modeling.
- **The System Requirements:** they transform the vision of the stakeholders (here, the innovative company through its project team or its company manager) by creating a set of measurable requirements that specify what characteristics, attributes and functional requirements the system (here, the supply chain) is to possess in order to satisfy the stakeholder requirements (ISO/IEC/IEEE, 2015), thus of the innovative company.

In brief, the stakeholders requirements focus on the product specification and the system requirements focus on supply chain specification.

The principal view used to display and communicate the requirements of a system is the **Requirements Diagram** (Figure 40).

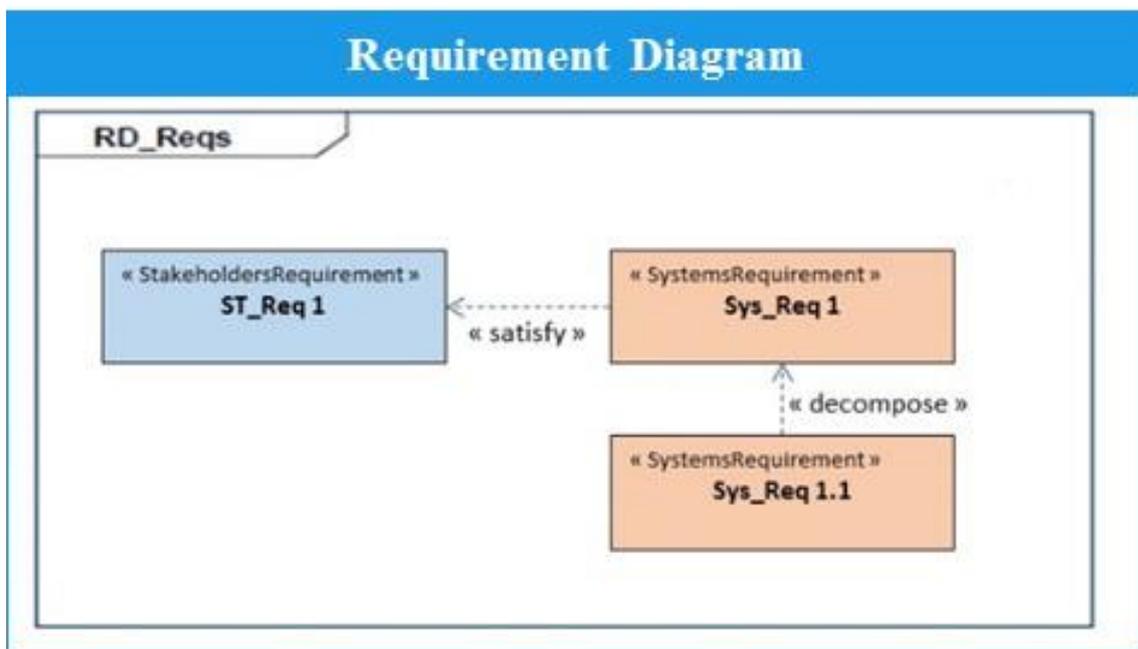


Figure 40: Example of a requirement diagram

This diagram is used to visually represent the requirements of the system (Stakeholders Requirements and System Requirements) and also show the various relationship types explicitly between requirements (Hampson, 2015). The requirement diagram can be used to build traceability between requirements in the model where traceability assures the innovative company that the developed supply chain supports the specification from the innovative product. For traceability, the identified System Requirements are linked to the associated Stakeholder.

To conclude, the Requirement Pillar consists in defining and developing the requirements that the supply chain have to meet in order to satisfy the product specifications but also the constraints of the stakeholders involved in the design and future manufacture of the product. Modeling requirements allows to express the impact of the implementation of a requirement on the other requirements that have to constitute the supply chain.

b. The descriptive structure pillar

The Descriptive Structure Pillar helps us to define what the supply chain will do.

Through objects called Use Case, this pillar specifies the behavior of the supply chain as perceived by the stakeholders without revealing the structure of the supply chain. Thus, a use case describes the specific operational aspect of the supply chain.

The principal view used to represent the behavior of the supply chain is the **Use Case Diagram** (Figure 41).

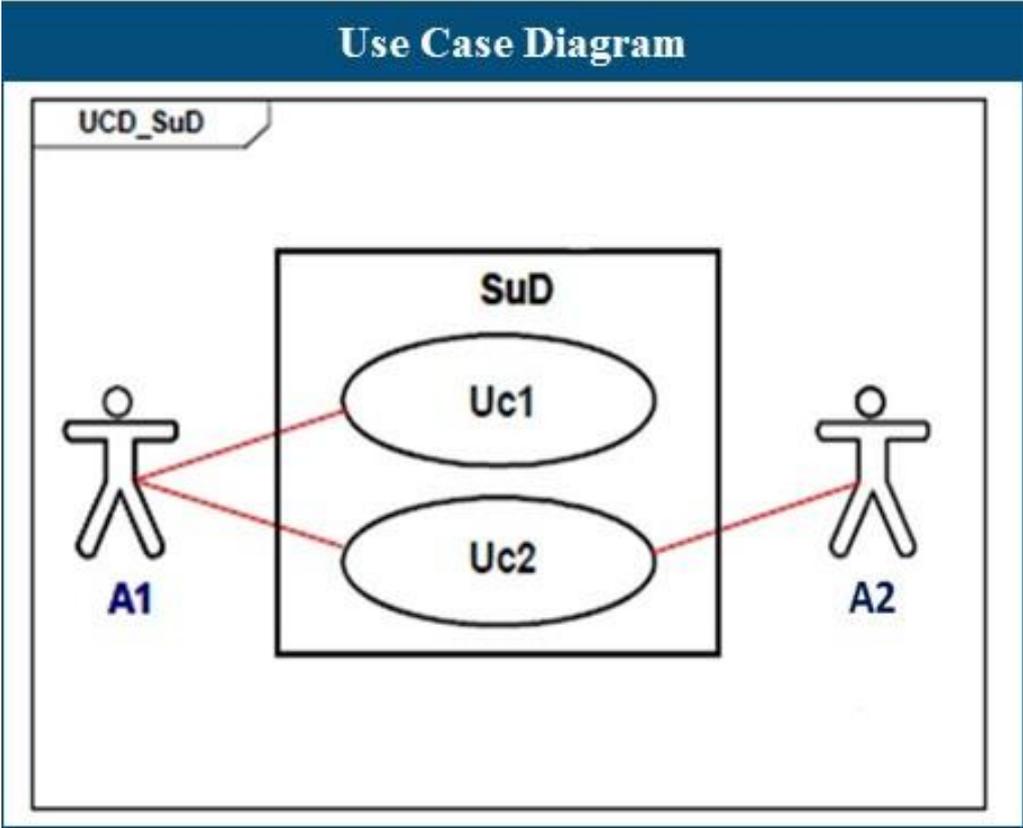


Figure 41: Example of a Use Case Diagram ²⁴

This diagram delineates the supply chain precisely without specifying how it works and what stakeholders will do. Hence, all the use cases contained in a use case diagram describe one mission that the supply chain will address (Hampson, 2015). It provides a means for

²⁴ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

describing basic functionality of the system in terms of goals by stakeholders (Friedenthal, 2009). These stakeholders can be known (innovative company’s partners or involved in the design) or unknown (only the typology of the stakeholders can be provided). However, it is important to determine which stakeholders will soon be involved and the instantiated supply chain model plays an important role to collect information about expected stakeholders.

To conclude, the Descriptive Structure Pillar leads to a reflection on the stakeholders who can satisfy the system requirements.

c. The prescriptive structure pillar

The Prescriptive Structure Pillar seeks to specify how the supply chain works and, therefore what the stakeholders will have to do. Focusing on the functioning of the supply chain means focusing on its processes and activities.

The principal view used to describe the processes and activities that compose the supply chain is the **Activity Diagram** (Figure 42).

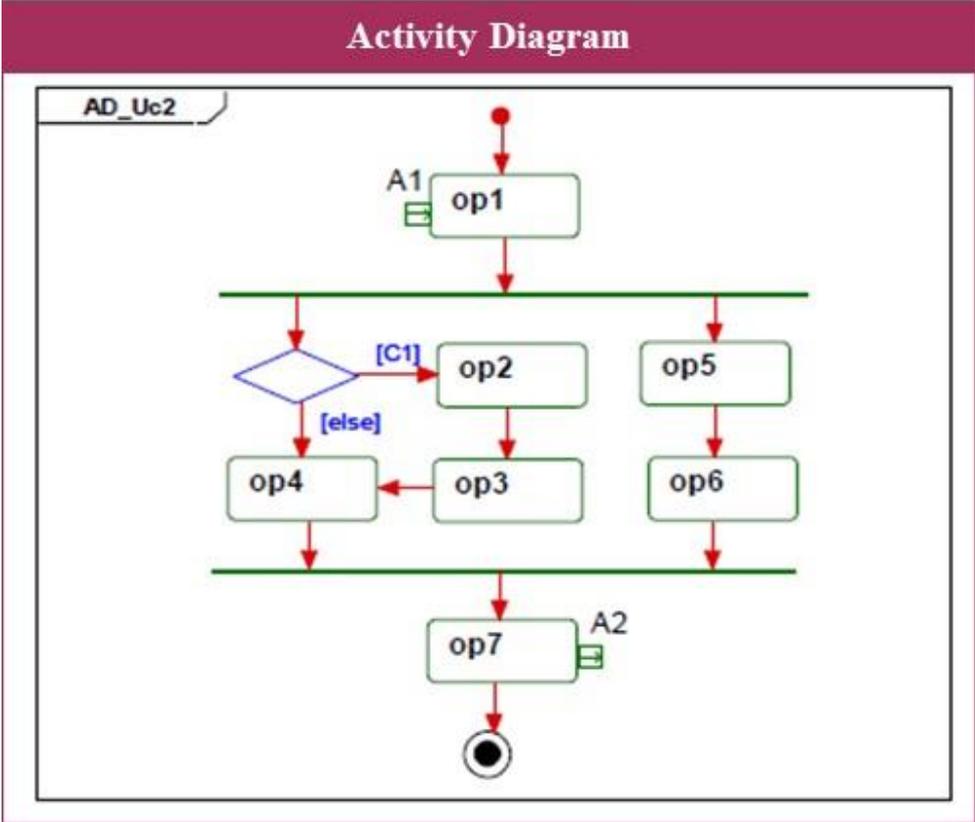


Figure 42: Example of an Activity Diagram ²⁵

It consists of developing the storyboard of the supply chain. Thus, based on the system requirements, the activity diagram represents the sequence of activities and highlights the interaction between the stakeholders through the activities of the supply chain. Indeed, each

²⁵ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

activity is carried out by one or more stakeholders. In addition, the decisions to implement the supply chain impacting the activities can be materialized within this diagram.

The activity diagram is the main important diagram of our engineering for several reasons:

- It describes the supply chain from a functional view;
- It brings precision about stakeholders involved in each activity and thus the degree of involvement of each stakeholder within the supply chain;
- It gives an interesting visual support to analyze the typology of the supply chain.

Hence, the Prescriptive Structure Pillar provides a first vision of the global supply chain for a particular product, combining the functional and managerial views. It leads to a timeless representation of the supply chain.

d. The behavior pillar

The behavior pillar seeks to position the supply chain over time, which is to revitalize its behavior.

The principal view used to describe the dynamic behavior of the supply chain is the **Sequence Diagram** (Figure 43).

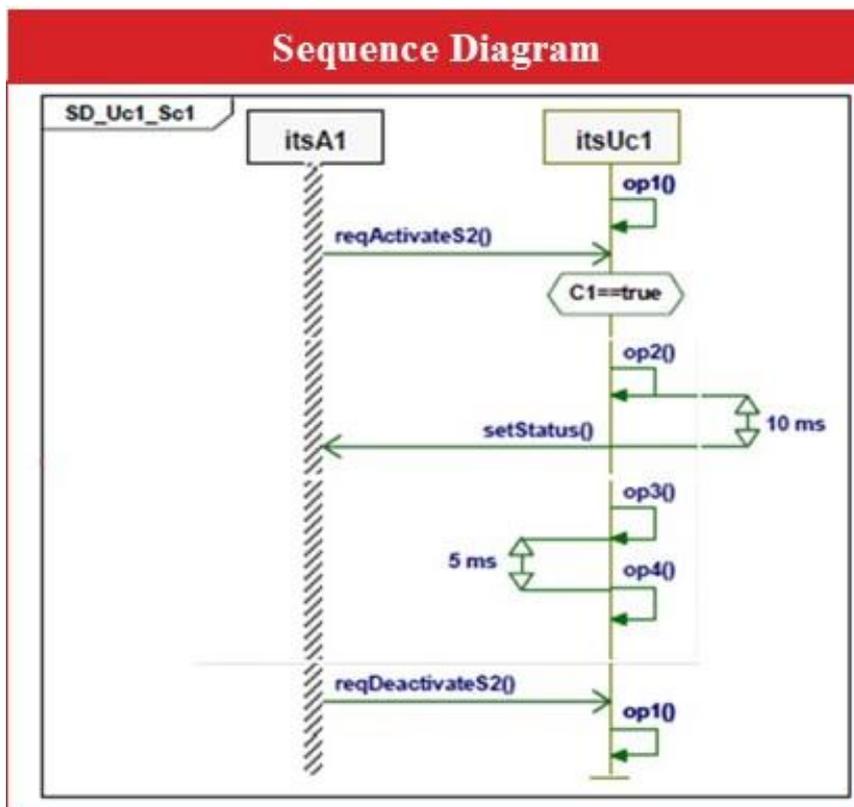


Figure 43: Example of a Sequence Diagram ²⁶

²⁶ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

It provides a temporal representation of the supply chain. Thus, the sequence diagram specifies and synchronizes the informational exchanges between the stakeholders throughout the supply chain during a chronological sequence of activities. The temporality facilitates the design of scenarios in order to get as close as possible to reality. Hence, the sequence diagram is used to check the consistency of the functional supply chain by considering the involvement of the various stakeholders over time.

To conclude, the Behavior Pillar seeks to validate in the most realistic way the functioning of the supply chain.

e. The methodology in practice

IN PRACTICE: How to model the supply chain scenarios	
Requirement Pillar	<p>Step 1: Formalize and draft the requirements</p> <ul style="list-style-type: none"> • From the <u>Manufacturing Process DSM</u>, write the <u>stakeholder requirements</u> in the form “<i>The supply chain has to be able to...</i>” • From the <u>Process DSM</u>, write the <u>system requirements</u> in the form as a process (e.g.: adjustment and manufacturing assembly) <p>Step 2: Model the requirements</p> <ul style="list-style-type: none"> • Upload requirements (Stakeholders and Systems) to <i>Rational Rhapsody®</i> • Import all requirements (Stakeholders and Systems) into a requirement diagram • Link System requirements to Stakeholders requirements through a “satisfy” dependency • Validate that each Stakeholder requirement finds an answer in the form of a System requirement <p style="text-align: center;"><u>Representation:</u> Requirement diagram</p>
Descriptive Structure Pillar	<p>Step 3: Determine and characterize the functions of the supply chain</p> <ul style="list-style-type: none"> • Create three Use Cases: supply, manufacturing and sales • Integrate the stakeholders identified during the data collection step • Link each stakeholder to the Use Case in which it participates through an “association” link • Validate that each identified System Requirement is linked to a use case. <p style="text-align: center;"><u>Representation:</u> Use Case diagram</p>

Prescriptive Structure Pillar

Step 4: Create supply chain scenarios

- Detail each identified and formalized process (Step 1 of the Requirement Pillar) into activities
- Design the sequence of activities representing each use case (with reference to the sequence provided by the Process DSM matrix)
- Assembly each sequence to form a supply chain scenario
- Add each stakeholder involved in the realization of each activity (In, Out or In/Out) thanks to an Actor Pin
- Validate that each process (Step 1 of the Requirement Pillar) appears in the activity diagram

Representation: Activity diagram

Behavior Pillar

Step 5: Model the dynamic exchange of the supply chain

- Select one supply chain scenario or a part of the supply chain
- Generate a sequence diagram for each scenario selected

Representation: Sequence diagram

Source: Our research

The methodology of this step is summarized in the figure 44.

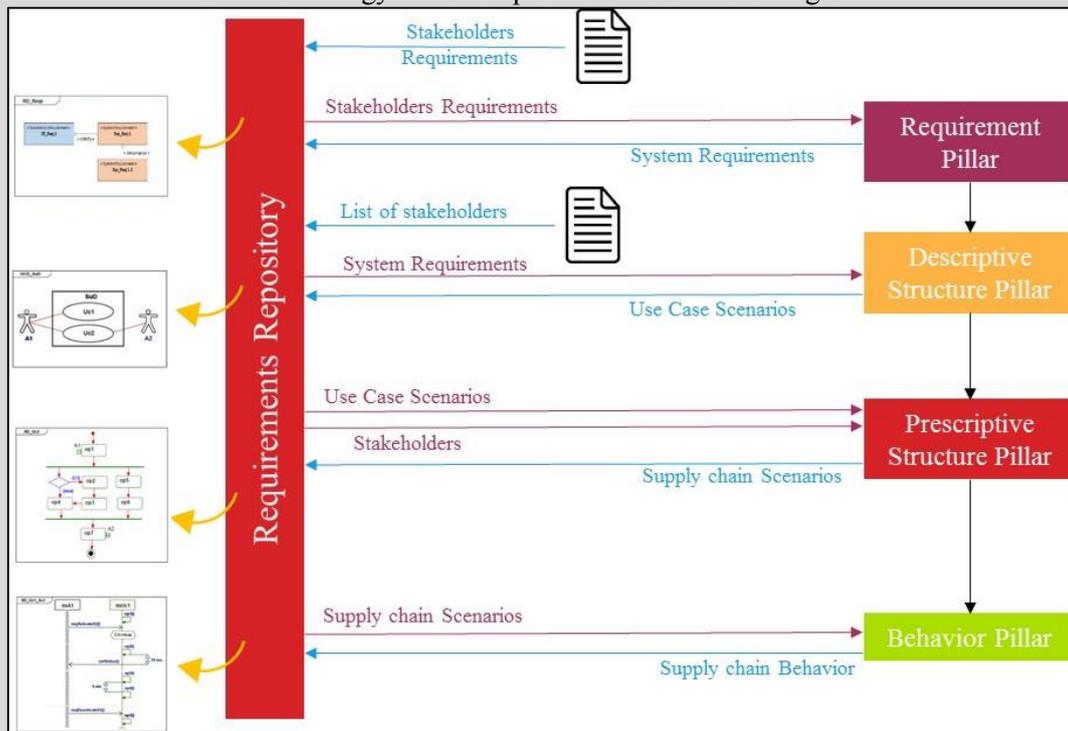


Figure 44: Procedure for modeling supply chain scenarios

Source: Inspired by “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

7.2.2.4 Conclusion of the position stage

This major step in our engineering leads to model one or several supply chain scenarios based on the data collected during the interviews. At each stage, the results are confronted with a set of requirements (characterized by stakeholders requirements) in order to ensure that the answers provided are in adequacy with the specifications expressed by the innovative company.

Multiple scenarios for the same product can mean that:

- There are uncertainties in the manufacture;
- The final customer has the choice between several components to compose his product.

Each of the possibility envisaged is then modeled in the form of a scenario.

Note that this modeling focuses essentially on the succession of activities that characterize the supply chain, providing a more accurate visualization of the product path, i.e. product transformation is studied between supply chain companies but also within companies. Other models could have been envisaged, such as modeling by stakeholder sequence, which underlines the complex nature of the supply chain.

The second stage of our engineering is based on four tasks to describe the supply chain by using different types of diagram. The figure 45 summarizes this first engineering step with the associated tools.

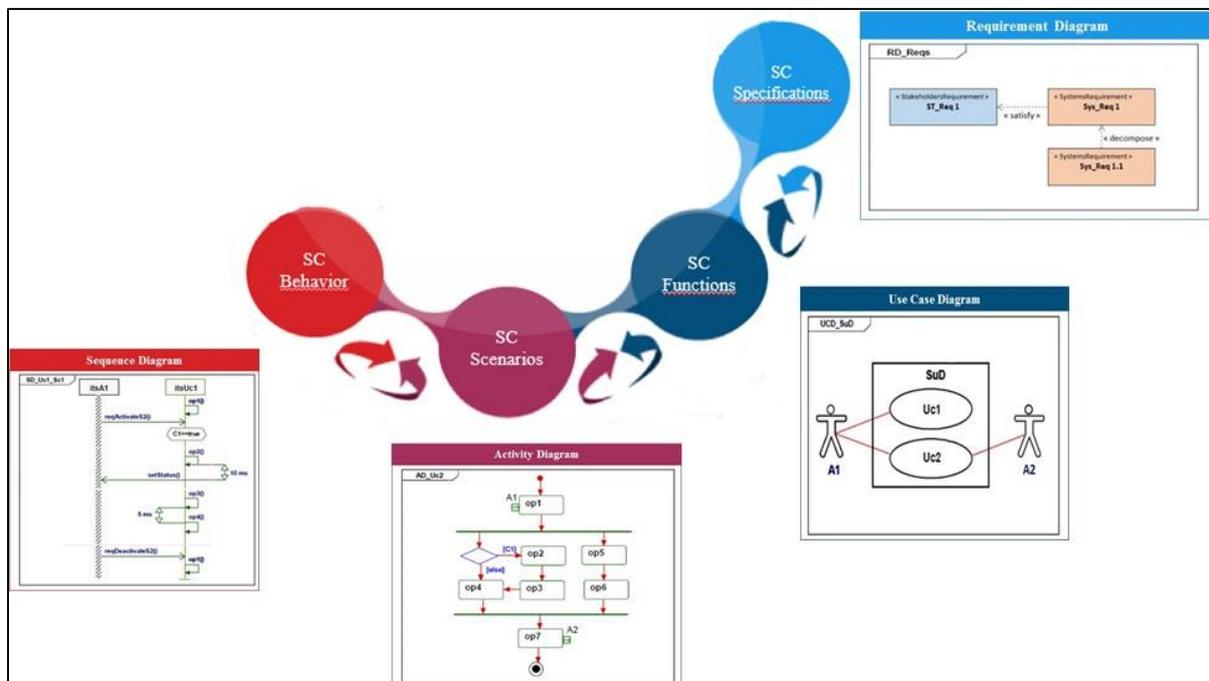


Figure 45: Summarize of the second stage of our engineering

7.2.3 Evaluate the supply chain scenarios

Once the supply chain scenarios have been modeled, an analysis and evaluation work is necessary to define one or more action plans in order to implement it. Several evaluations are possible: agility, value generated among others. As part of our research, we will limit ourselves to agility in order to assess whether the current structure of the supply chain is adapted to an innovative product.

7.2.3.1 Objectives of this step

The objectives of this step are as follows:

- Analyze the different scenarios;
- Position and define the company's role in the supply chain;
- Define the typology of the supply chain;
- Define the actions to put in place to implement a supply chain adapted to the product.

7.2.3.2 Methodology

This step is the result of interaction between the company/project team and the researcher. Two frames are used to evaluate the supply chain scenarios: the table detailing the characteristics of each type of supply chain proposed by (Vonderembse et al., 2006)²⁷ and our framework to implement agility strategy (section 4.5 and appendix 1).

IN PRACTICE: How to evaluate the supply chain scenarios and make decisions to implement the supply chain

Step 1: Visualize the changes to be expected and the role of the innovative company in the supply chain

- Stakeholders to be determined, new technologies and/or new processes to be integrated for example

Note: The variables influencing the choice of a scenario can be structural or technical.

Structural variables:

- Stakeholders (experience of existing stakeholders, expertise, number of new stakeholders...);
- Processes/activities (mastery, presence and availability on the market, manufacturing capability...);
- Key skills and equipment (degree of mastery, flexibility, differentiation...);
- Generated value;
- Context in which the company evolves (standards, market).

Technical variables:

- Ease of implementation;
- Number of changes required.

²⁷ Section 4.2.1

Step 2: Determine the typology of the supply chain

- Analyze the different points of view, characteristics of a supply chain (see Table detailing the characteristics of each type of supply chain)
- Determine if the supply chain is market-sensitive, network-based, digital and if processes are integrated
- Conclude about the presumed typology of the supply chain

Support: Table detailing the characteristics of each type of supply chain

Step 3: Make strategic and technological decisions

- Depending on the company’s choice and strategy, define the decisions leading to the implementation of the supply chain thanks to the framework
- Determine the changes in the supply chain that may result
- Validate if the results of these decisions are consistent with the supply chain scenarios targeted

Support: Framework to implement agility strategy (Appendix 1)

Source: Our research

7.2.3.3 Conclusion of the evaluation stage

The supply chain scenario evaluation stage is organized around interactions and exchanges between the researcher and the project team on the models obtained in the previous phase. This is an iterative process: the steps can be repeated several times until the company finds the most suitable solution. In our case, our analysis focuses on the notion of agility to ensure that the supply chain is capable of supporting an innovative product. The assessment of the degree of agility of the supply chain remains subjective until now. The methodology of this step is summarized in the figure 46.

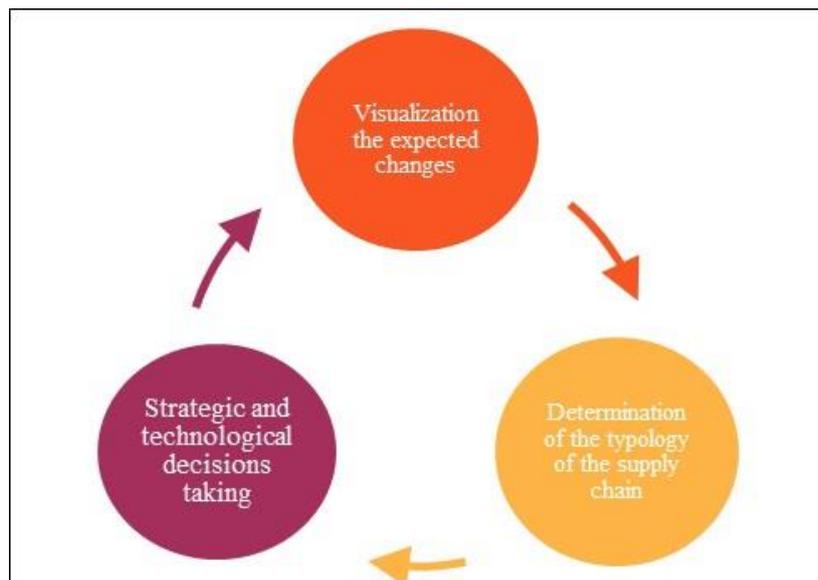


Figure 46: Procedure for evaluating the supply chain scenarios

The third stage of our engineering is based on two tasks to determine and implement the supply chain scenario privileged by the innovative company. To do this, we based our analysis on our framework to implement an agility strategy in order to determine if the supply chain implemented has agile characteristics. The figure 47 summarizes this first engineering step with the associated tools.

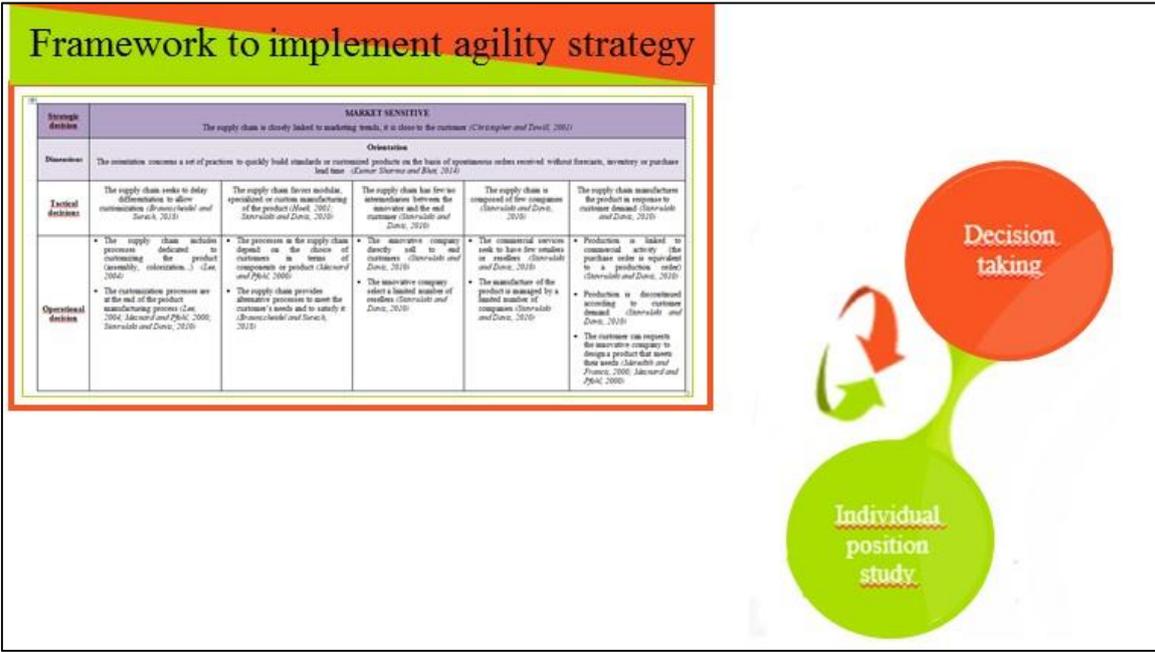


Figure 47: Summarize of the third stage of our engineering

7.2.4 **Conclusion**

In conclusion, the proposed engineering is based on different tools to understand the complexity of the supply chain. The figure 48 integrates the tools used at each stage of this methodology.

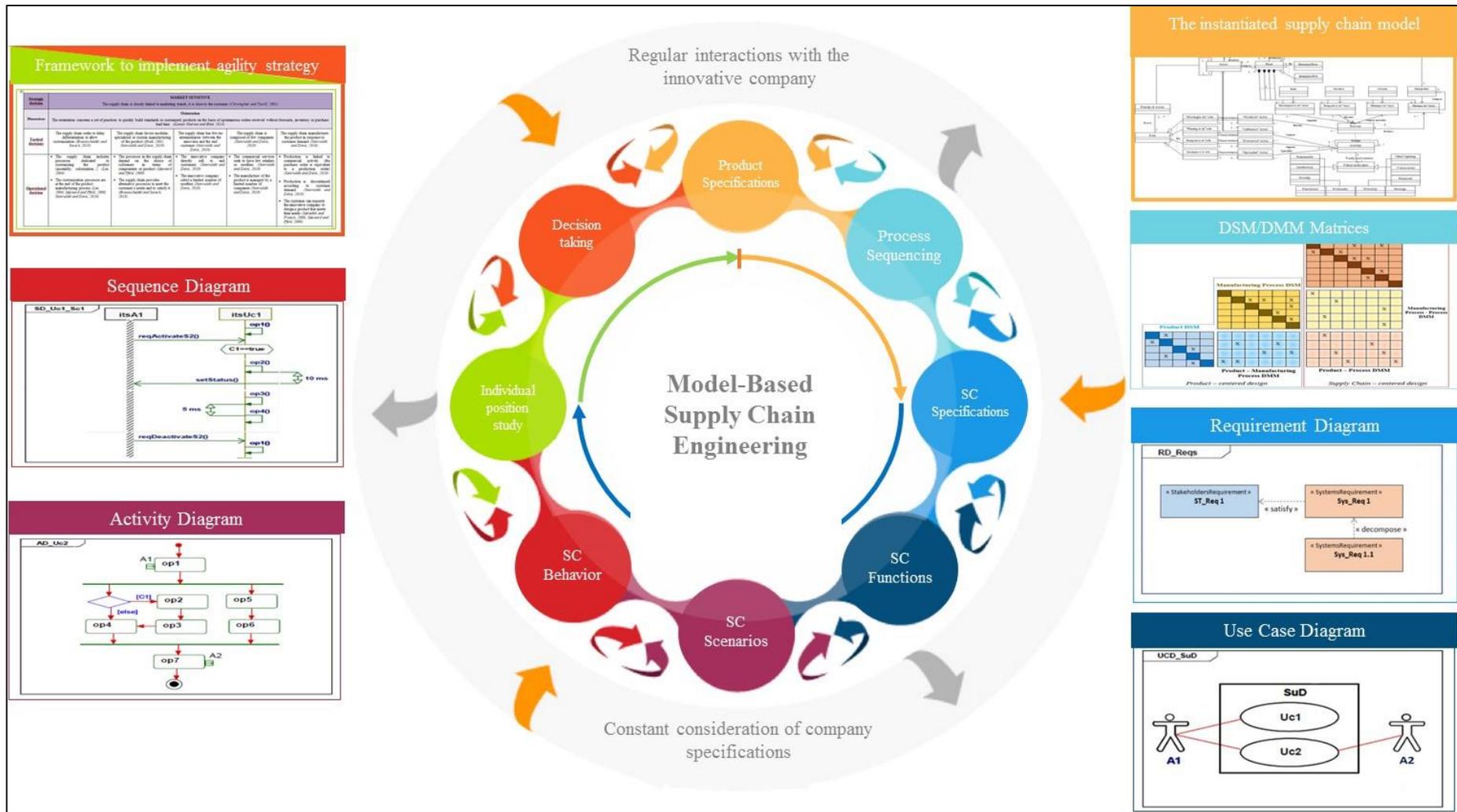


Figure 48: Representation of the engineering and tools used at each stage (Source: Our research ²⁸)

²⁸ Visual support inspired by (Dupont et al., 2015) with the kind permission of the authors

Conclusion of the Chapter 7

The purpose of this chapter is to bridge the gap between theory and practice through the development of model-based supply chain engineering. Based on a product under development, it seeks to simultaneously design different supply chain scenarios in order to increase the product's chances of success on the market. Thus, within our research, scenarios have to lead to agile supply chains by considering the context in which the innovative company evolves as well as its strategy.

This engineering is original in the sense that it presents the supply chain not in the form of a sequence of stakeholders, but in the form of processes to which stakeholders are linked. Thus, we consider that the representations obtained assume the complexity of the supply chain concept. Consider a supply chain only from stakeholders point of view seems to be restrictive. Indeed, to obtain the different supply chain scenarios, our engineering proposes to “split” the companies to be interested in their expertise and more precisely their key manufacturing processes. This leads to a multi-scale representation and optimization of the supply chain.

Since the beginning of our research, we have insisted on the fact that the product/supply chain couple is evolutionary. This specificity is considered: for each evolution of the couple, the engineering is repeated until the product/supply chain couple is stabilized.

Chapter 8 proposes an application of this engineering to an on-going case at the time of our study. Each step will be detailed and the results obtained will be presented and analyzed. This chapter is also an opportunity to highlight the importance of our two theoretical contributions.

IN BRIEF

- Data collection uses the **instantiated supply chain model**.
- Data processing is supported by **DSM and DMM matrices**.
- Data modeling is performed on the **Rational Rhapsody® tool** using the *Harmony for System Engineering methodology*.
- The engineering is based on **four pillars**: requirement pillar, descriptive structure pillar, prescriptive structure pillar and behavioral pillar.
- The **SysML language** ensures the link between each pillar.

KEY FINDINGS OF THE CHAPTER 7

Through its empirical approach, Chapter 7 underlines the existence of a gap between theory and research within our problem. In addition, the chapter 2 highlights that the product/supply chain couple is not limited to a cause and effect relationship. With the paradigm of the complexity, the product design and the supply chain design are considered as two interdependent activities within the innovation process. Thus, adopting a vision of the product/supply chain couple through the paradigm of the complexity leads to favor a product/supply chain co-design. That's why, the contribution of the chapter 7 lies in the development of a Model-Based Supply Chain Engineering leading to the design of a product's supply chain. This engineering includes a data collection stage (carried out using our instantiated supply chain model), a data processing stage (using matrices) and a modelling stage. The modelling stage uses the *Harmony for Systems Engineering* methodology coupled with the *Rational Rhapsody*® tool. The modelling stage helps to determine the requirements of the innovative company with regard to its future product and the corresponding supply chain, define what the supply chain will do and who the stakeholders are, determine how the supply chain works (sequence of processes and highlighting strategic, tactical and operational decisions implemented) and what the stakeholders will have to do in order to finally position the supply chain over time. The final representation of the supply chain helps to analyze the supply chain from a managerial point of view by visualizing if the taken decisions lead to an agile supply chain (thanks our framework to implement an agility strategy). Different scenario can be considered with a description of the agility actions implemented and help to take technical decisions about the product.

**PART 4: IMPLEMENTATION AND
VALIDATION OF OUR PROPOSITION**

INTRODUCTION OF PART 4:

This part consists of the implementation, and the validation of our propositions through an on-going case in order to discuss the whole of our research.

The Chapter 8 is a direct application of Model-Based Supply Chain Engineering and illustrates each step of the engineering process, from the product study to the modeling of a corresponding supply chain scenario.

The Chapter 9 provides a discussion of our overall findings from a scientific, methodological and pragmatic point of view. It focuses in particular on the contextual elements to be considered in the analysis of a supply chain.

REMINDER: Summary of research choices and theoretical findings

Choice of the product: (Chapter 2)

- Modular
- Complex (the use of the whole engineering is not necessarily relevant for a simple product where the supply chain can be quickly predicted)

Representation of the supply chain: (Chapter 2)

- Functional

Type of scenarios: (Chapter 4)

- Functional transformation of the supply chain and increase in the agility degree
- Functional transformation of the supply chain and change of the initial typology
- Creation of a new agile supply chain

Variables that may influence the choice of a scenario: (Chapters 2–5-6)

Structural variables:

- Stakeholders (experience of existing stakeholders, expertise, and number of new stakeholders...)
- Processes/activities (mastery, presence and availability on the market, manufacturing capability...)
- Key skills and equipment (degree of mastery, flexibility, differentiation)
- Generated value
- Context in which the company evolves (standards, market)

Technical variables:

- Ease of implementation
- Number of changes required

Applying agility to scenarios: (Chapter 4)

Three types of decisions:

- Strategic (market-sensitive, digital, network-based, process integration)
- Tactical
- Operational

INTRODUCTION

In order to reach a theoretical saturation and validate the empirical results, a fourth case was selected and studied. This case concerns an ongoing innovation, i.e. the product is at the last steps of its development and not on the market when the supply chain analysis was completed. Note that at the time this thesis is written, the innovation has just been launched. Thus the interest of this study is multiple.

Adding a new case in the experimental approach is motivated by:

- The uncertainties about the researcher independence and the hindsight bias: In the previous cases we were able to describe the final supply chain structure which means that the risk exists to try voluntarily or not to miss certain problematic or limitations because our models are pertinent regarding the initial and final perfectly known contexts;
- The application to a time-limited project: Even if all data were not at disposal, there were no time limitations in the data collection tasks for the previous cases. We had the opportunity to enrich our material at any moment: more literature, contact with the companies among others. So it was interesting to experiment in a more constraining temporal context;
- The incompleteness of information: The absence of information is specific to innovation, so it is important to be able to develop models that take this characteristic into account (Boly, Camargo, and Morel 2016);
- The need to know the data relevant to the design of the supply chain: Working on an on-going project helps understanding the genuine data needed to elaborate the models;
- The opportunity to compare our results with the reality: The confrontation of the models with the designers is one supplementary objective of this fourth case. Does our approach broaden the vision of the designers about the context of the innovation and if so, how?

Chapter 8 is a direct application of the Model-Based Supply Chain Engineering presented in the previous chapter. This chapter illustrates each step of the engineering process, from the product study to the modeling of a corresponding supply chain scenario.

This case allows to evaluate the applicability of our engineering by a constructivist approach, i.e. we seek to answer the following questions:

- Can we upgrade the data available to designers?
- Can we obtain specific supply chain scenarios?
- Can any decisions be made with the results of the methodology?

Consequently, during our experiments, this case was selected for several reasons:

- The question of the industrialization of the product was in progress, the design phase had come to end;
- The decomposition of the product is possible layer by layer;
- The coordination between stakeholders is being questioned;
- The product requires processes and highly technical skills.

In a first section, the case will be described. The innovative company and stakeholders involved in product design will be presented. The innovative product will then be detailed. In a second part, data from the product will be collected using our instantiated supply chain model and processed using DSM and DMM matrices. Subsequently, one of the supply chain scenarios will be illustrated by SysML diagrams generated on Rational Rhapsody®. Finally, a study of the supply chain strategy envisaged during the design phase will be detailed based on our framework.

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8.1 Description of the case study

For reasons of confidentiality, the name of the product and the innovative company will not be disclosed. This study is based on data from the public domain (press kit, technical file, patents and so on) and working meetings with some of the designers.

8.1.1 Description of the innovative company

Company D is a company specializing in ball bearing for industry, automotive and aeronautical sectors. It designs, develops, manufactures and markets different ranges of bearings, encoders, seals and spare parts for vehicles. It is positioned as a tier one supplier of large companies in the automotive sector. In addition, it also provides distributions and spare parts. It is a large company (approximately 2800 employees for a turnover of more than €905,600,000 in 2017²⁹) belonging to an international group.

8.1.2 Description of the innovative product

The innovative product is an electromagnetic sensor integrated into ABS technology as an alternative to the Hall Effect sensor.

The ABS technology is an assistance system integrated in a car to help the driver during braking so that the wheels are no longer locked. To continue to steer the control unit needs precise data on the speed of the individual wheels, which are obtained by means of sensors. These sensors are located directly on the wheel hub near the brakes. They are subject to harsh environmental conditions, due to their position on the vehicle, which do not have to impact the accuracy of the measurements made. The sensor is accompanied by a special signal processing unit called Application-Specific Integrated Circuit (ASIC) provided by an automotive supplier. This ASIC processes sensor signals directly and transmits the data to the vehicle control unit.

This innovative product consists of a magnet and a sensor, sensitive to the external magnetic field to vary the electrical resistance of the assembly. This sensor provides high-precision detection and low power consumption. Contrary to current technologies, the characteristics of the sensor and its integration possibilities offer industrial partners several applications:

- Speed and position measurement for the automotive sector;
- Current measurement for the management of electric vehicles, for example;
- Field measurement for medical sector (magneto-cardiogram or magneto encephalogram).

²⁹ Source: societe.com

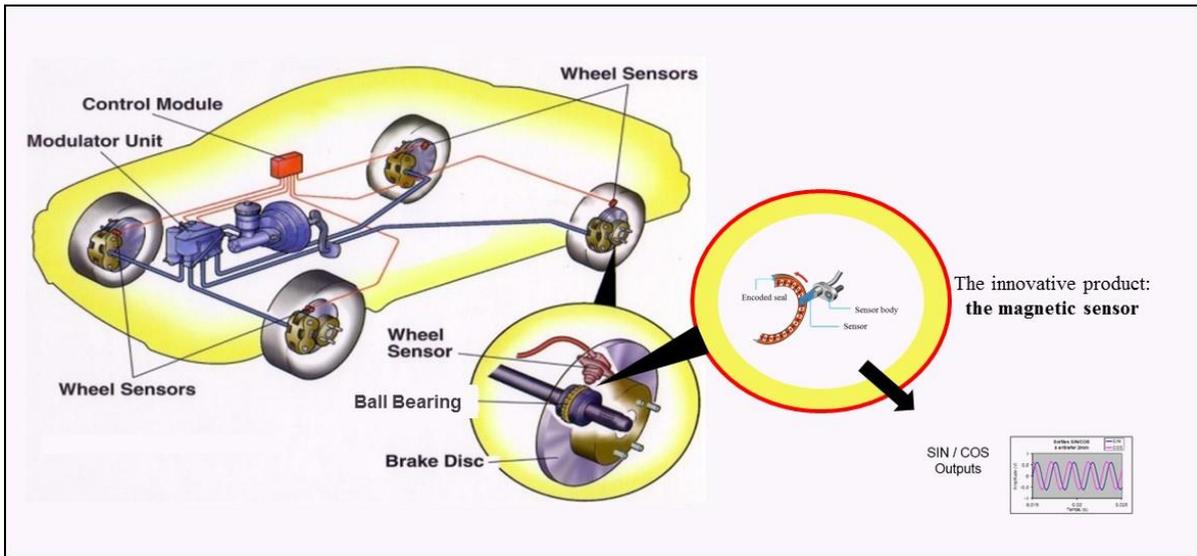


Figure 49: Scheme of the technology studied

The innovative product is a so-called active technology, consisting of various separate components: a ball bearing, an encoded seal, a magnetic sensor and a sensor body. The innovation is at the level of the magnetic sensor, a particular attention is paid to it in order to propose a relevant supply chain analysis.

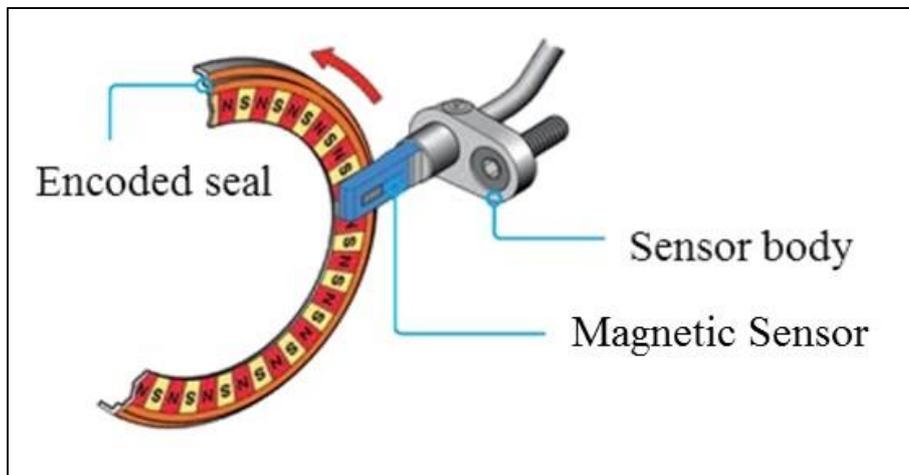


Figure 50: Schematic diagram of the active technology

Active technology provides a constant amplitude signal (even at low or zero speed), which allows more accurate use of the rotational speed signal (see figure 49). This technology is based on the change in the resistance of a ferromagnetic material according to the magnetic field, therefore, it is often used in front of a magnetic encoder (which is located on the wheel bearing). This technology consists of a magneto-resistive element, and an integrated electronic part.

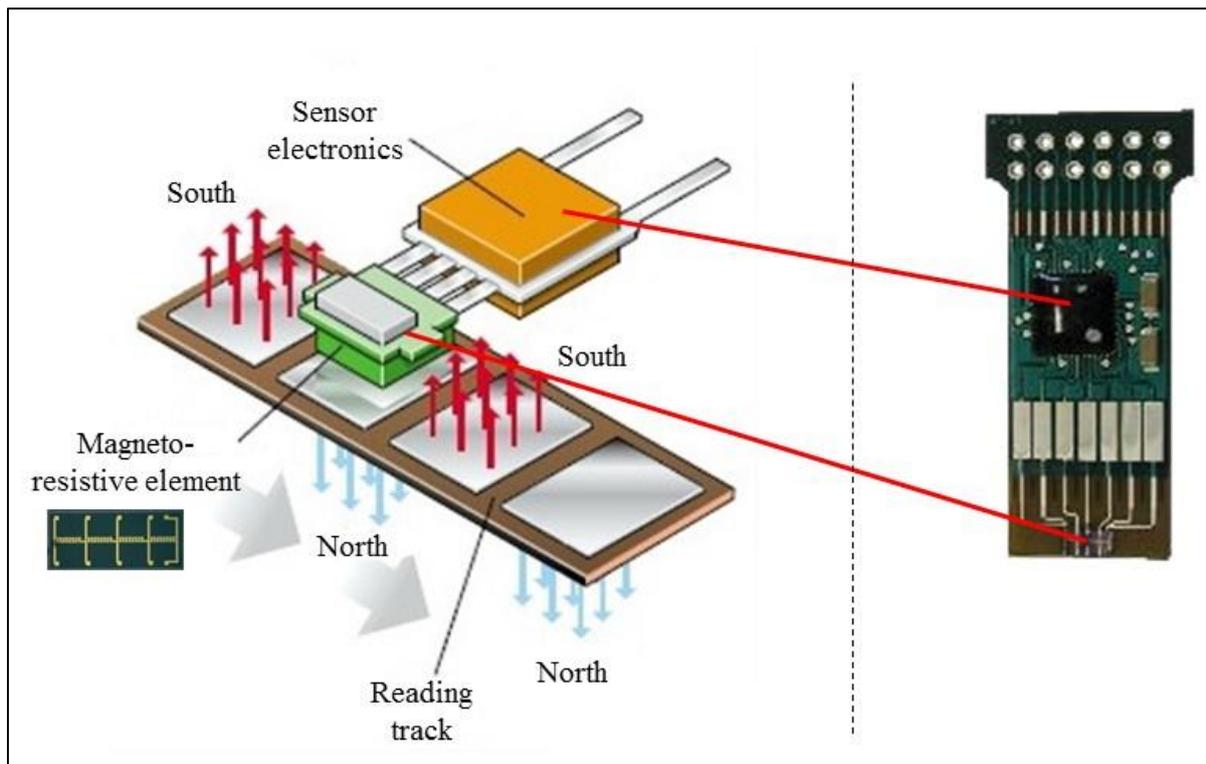


Figure 51: Schematic diagram of the magneto-resistive element and the integrated electronic part

SCIENTIFIC DETAILS

A sensor is considered active when an external power supply is required for its operation. The active speed sensor has a magneto-resistive element. Its resistance varies according to the magnetic field lines cut by the ball bearing with reading track. The ball bearing on the wheel hub consists of a reading track with magnetized fields to the north and south poles, it rotates along the fixed sensor element.

In the magnetized areas, the field lines are located vertically on the reading track. Depending on the polarity, they move away from or towards the track. Since the distance between reading track and sensor is very small, the field lines cross the sensor element and change its resistance. An electronic amplification/trigger circuit integrated in the sensor converts resistance variations into two different intensity levels:

- If the resistance of the sensor element increases due to the direction of the magnetic field lines passing through it, the current drops.
- If the resistance decreases, as the direction of the field lines reverses, the current increases.

Since the north and south poles alternate on the rotating reading track, a sequence of sinusoidal signals is obtained whose frequency constitutes the speed measurement.

To facilitate understanding, this product will be divided into three parts (see Figure 50):

- Target magnet, i.e. the ball bearing and the **encoder seal**;
- Detection device, i.e. the **magnetic sensor**;
- Protection, i.e. the **sensor body**.

8.1.2.1 The Target Magnet

The target magnet is a multipole ring magnet integrated with a bearing seal. It generates an alternating magnetic field with frequencies proportional to the rotational speed of the wheel (Duret and Ueno 2012).

This magnetic ring is called an encoder and is intended to be integral with the wheel bearing so as to move together with it. This encoder being arranged to deliver a periodic magnetic field which is representative of the encoder displacement. This comprises an alternating succession of North and South magnetic poles formed on an annular magnet which can be made from a plastic or elastomer matrix, in which magnetic particles are dispersed, in particular ferrite or rare earth particles such as NdFeB (Duret and Peterschmitt 2017; Duret and Blanchin 2005).

8.1.2.2 The Detection Device

Based on the magnetoresistance effect, the detection device measures the alternating magnetic field that the target magnet generates with no contact and calculates the wheel rotation (Duret and Ueno 2012), as illustrated in figure 49.

The detection device (Figure 52) is composed of³⁰:

- A measuring assembly;
- An electronic circuit and a permanent magnet;
- A plug connector.

The detection device is protected by a plastic sensor body and mounted on the vehicle with a metallic insert.

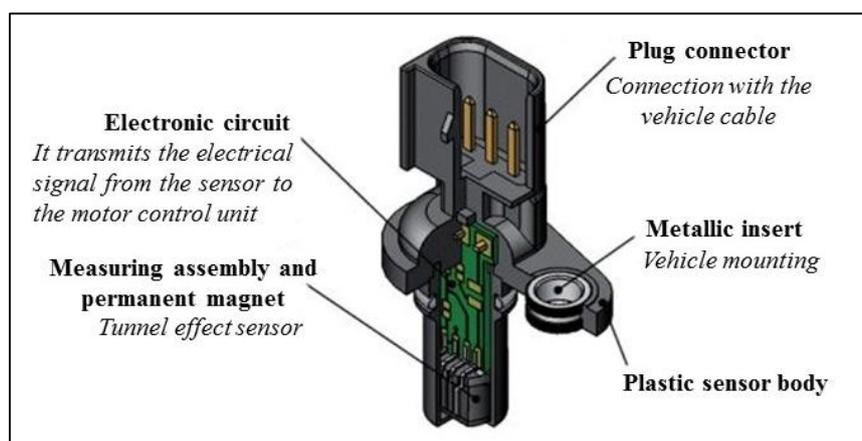


Figure 52: Representation of the detection device and its protection

³⁰ Our analysis will focus on the measuring assembly and the electronic circuit.

The active sensor consists of several sensitive elements that are integrated in a measuring assembly. Each sensitive element may include at least one pattern based on a magneto resistive material³¹, in particular a **Tunnel Magneto Resistance** (TMR) effect material whose resistance varies according to the magnetic field. Each pattern comprises two conductive layers between which an insulating layer is arranged to form a **tunnel junction** sequence (Hehn et al. 2003; Duret and Peterschmitt 2017). The conductive layers form respectively:

- A magnetic layer sensitive to the field to be measured;
- A magnetic reference layer.

The magnetic resistance between the conductive layers depends on the orientation relative to the magnetization of each of layers (Hehn et al. 2003; Duret and Peterschmitt 2017).

The electronic circuit is arranged to exploit variations in the electrical resistance and determine the movement of the moving part, i.e. the wheel bearing.

The permanent polarization magnet measures the magnetic field of the encoder by means of a magneto resistive element. It is based on ferrite to present a magnetization sufficiently strong to induce the orientation of the sensitive layer in a stable way with respect to temperature (Duret and Peterschmitt 2017).

The measuring assembly is formed on one side of the electronic board, the other side being fixed on the surface of the permanent magnet. This electronic board integrates the electronic circuit which includes a device for conditioning signals representative of the resistance (Duret and Peterschmitt 2017).

SCIENTIFIC DETAILS

(based on the work on Duret and Ueno, 2012)

The **Magnetic Tunnel Junction** (MTJ) has generally the structure of an insulation layer (nanometric thickness) of aluminum oxide (Al_2O_3) or magnesium oxide (MgO) in the middle of two stacked ferromagnetic layers (Duret and Ueno 2012). A ferromagnetic layer is a layer composed of a material(s) (ferrite, cobalt, nickel...) that forms a magnet or is attracted by a magnet.

With the MTJ element, the current flows vertically through these layers while the electrons in a ferromagnetic layer pass through the insulator by quantum-mechanical effect and are injected to the other ferromagnetic layer by the tunneling effect³². In this case, the electric resistance to the current changes significantly depends on the relative angular difference of the magnetized direction of two ferromagnetic layers. When the magnetized direction of two

³¹ Magneto resistive materials are materials that have a resistance that changes when subjected to a magnetic field.

³² The tunnel effect designates the property of a quantum object (electrons, protons...) to cross a potential barrier, here the insulation layer, even if its energy is lower than the minimum energy required to cross this barrier.

layers is antiparallel, it indicates high resistance, and when it is parallel, it indicates low resistance. That is, the resistance changes depending on the relative angle of magnetization direction of two layers. This phenomenon is called the **Tunnel Magneto Resistance (TMR)** effect. In order to detect an external magnetic field using this effect, the device is configured keeping the magnetized direction of one ferromagnetic material layer (fixer layer) fixed and allowing the magnetized direction of the other ferromagnetic material layer (free layer) to change depending on the external magnetic field.

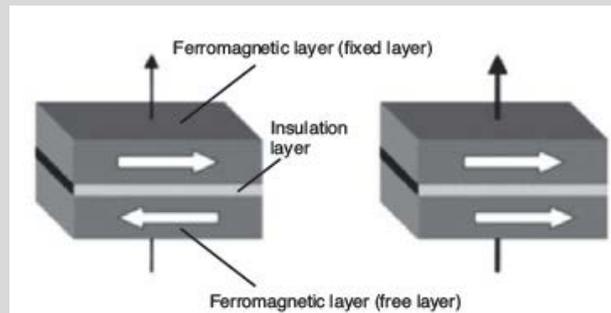


Figure 53: Representation of a MTJ in an antiparallel magnetization configuration (left) and in a parallel magnetization configuration (right).

In this picture, the black arrow represents the current going through the junction.

8.1.2.3 The Protection

The protection part focuses mainly on the sensor, it protects the active technology (i.e. the sensor and the permanent magnet) and the electrical cable connected to the car control center. This component is made of plastic that can withstand harsh environmental conditions. Its shape is adapted to this technology.

8.1.1 The start-up of the project

Company D is at the origin of this project. A market study highlighted that the demand for magnetic field sensors, reading heads and so-called “active” applications are growing rapidly. Indeed, it is used in many fields of applications such as automotive, household appliances or micro computing. Thus, limited to the case of the automobile and use within the ABS technology, more than 100 million sensors are used (25 million vehicles being equipped on each wheel). Based on its current production and by considering that it out competing alternative systems and the company is not challenged by another company, this enables company D to make production forecasts: a daily mass production is envisaged.

Consequently, the research and development focus on a Tunnel Magneto Resistance sensor and involved two stakeholders in addition to company D, selected according to their expertise:

- **Jean Lamour Institute** (University of Lorraine) is an academic research laboratory specialized in material sciences. It is in charge of the scientific supervision;
- One company, called **Company X**, focuses on the specifications of the sensitive elements and provides qualified personnel and infrastructure. They have been selected in particular for their design and manufacturing capacities. The company X will be involved in the industrialization of the future sensor.

The product design was based on a strong collaboration between these three stakeholders reinforced by the use of a common platform to share all data. Both the Jean Lamour Institute and Company X give their expertise to the project. Note that unlike Company D, Company X was not involved in an automotive supply chain prior to this project. There was even a technological academic/industry transfer between the Jean Lamour Institute and Company X.

A supply chain analysis was requested from the **ERPI Laboratory** by the Jean Lamour Institute for two reasons:

- Study and model the future supply chain of ABS technology;
- Propose a basis for reflection to find new fields of applications for Tunnel Effect sensors, i.e. to visualize if it is possible to integrate this sensor and its supply chain into another product and the corresponding supply chain.

The figure 54 represents the functioning between the main stakeholders of the innovative project.

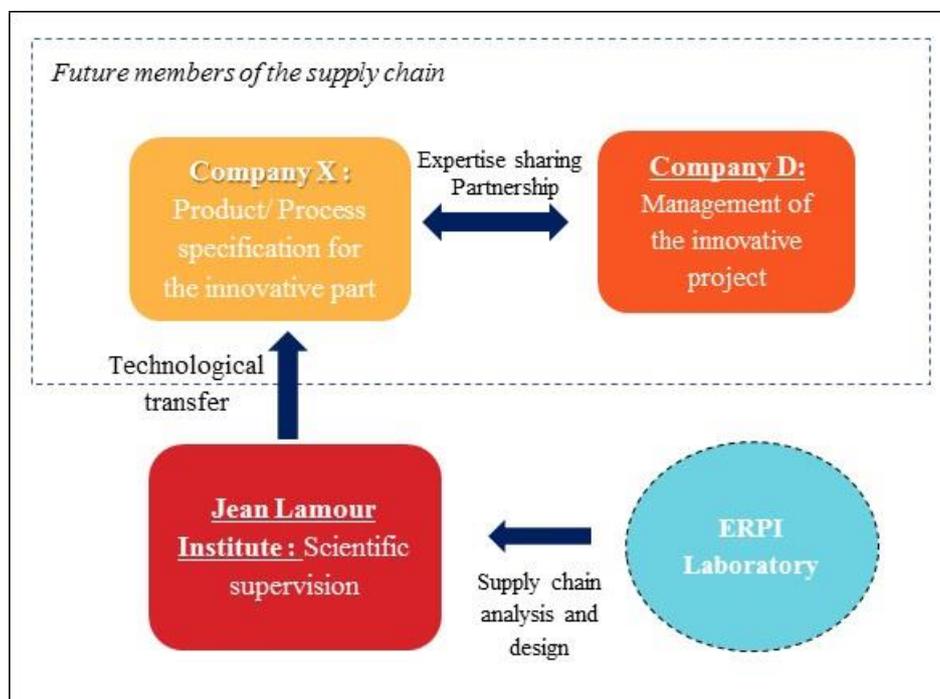


Figure 54: Overview of the functioning between the main stakeholders of the project

8.2 Product and Supply Chain co-design

8.2.1 Product specifications

In order to describe scenarios of a supply chains for the product, a detailed description of each process involved in the production of the future product was proposed thanks to our instantiated supply chain model (Chapter 1). However, for reasons of clarity, only one process will be detailed. Other technical choices will be presented to ensure consistency.

Note that for confidentiality reasons only technical data published in the patent protecting the invention is given here.

8.2.1.1 Brief description of the technical choices

Through technical documents and discussion with designers a list of technical decision taken all along the project is elaborated. The main choices are described in this paragraph.

The magnetic encoder is obtained from a seal to which magnetic particles are integrated. The joint is obtained by compression molding and machining steps. Then the magnetic encoder is inserted into a ball bearing.

The sensitive elements are sputtered and oxidized with oxygen plasma on silicon substrates to form a TMR read head. The latter is then engraved by optical lithography.

The individual electronic components are then assembled on a flex circuit. The TMR read head is thermocompressed on Cu wires of the circuit in order to control its positioning.

Finally, the assembled sensor is mounted in a suitable sensor body. Technical indecision persists concerning this component, its manufacture will depend on its shape (classic machining if simple form, 3D printing if complex form).

The result of this technical data collection phase is summarized in the table 22.

Part of the innovative product	Components	Manufacturing processes
Target Magnet	Magnetic encoder	Compression molding and machining Magnetic particles integration
	Ball bearing	Undercutting and rectification Thermal processing
	Magnetic encoder and ball bearing	Assembly
Detection device	Sensitive elements	Cathode sputter deposition Oxidation under oxygen plasma
	TMR read head	Optical lithography
	Active sensor	Electronic components assembly Assembly by thermocompression
Protection	Sensor Body	Classic machining if simple form 3D printing if complex form

Table 22: Manufacturing processes from the product study

Based on the instantiated supply chain model, a first vision of the supply chain is obtained (Figure 55), it is a succession of hierarchically organized blocks (each block being a particular

process). The hierarchy is based on one principle: one upstream process produces parts for the downstream process.

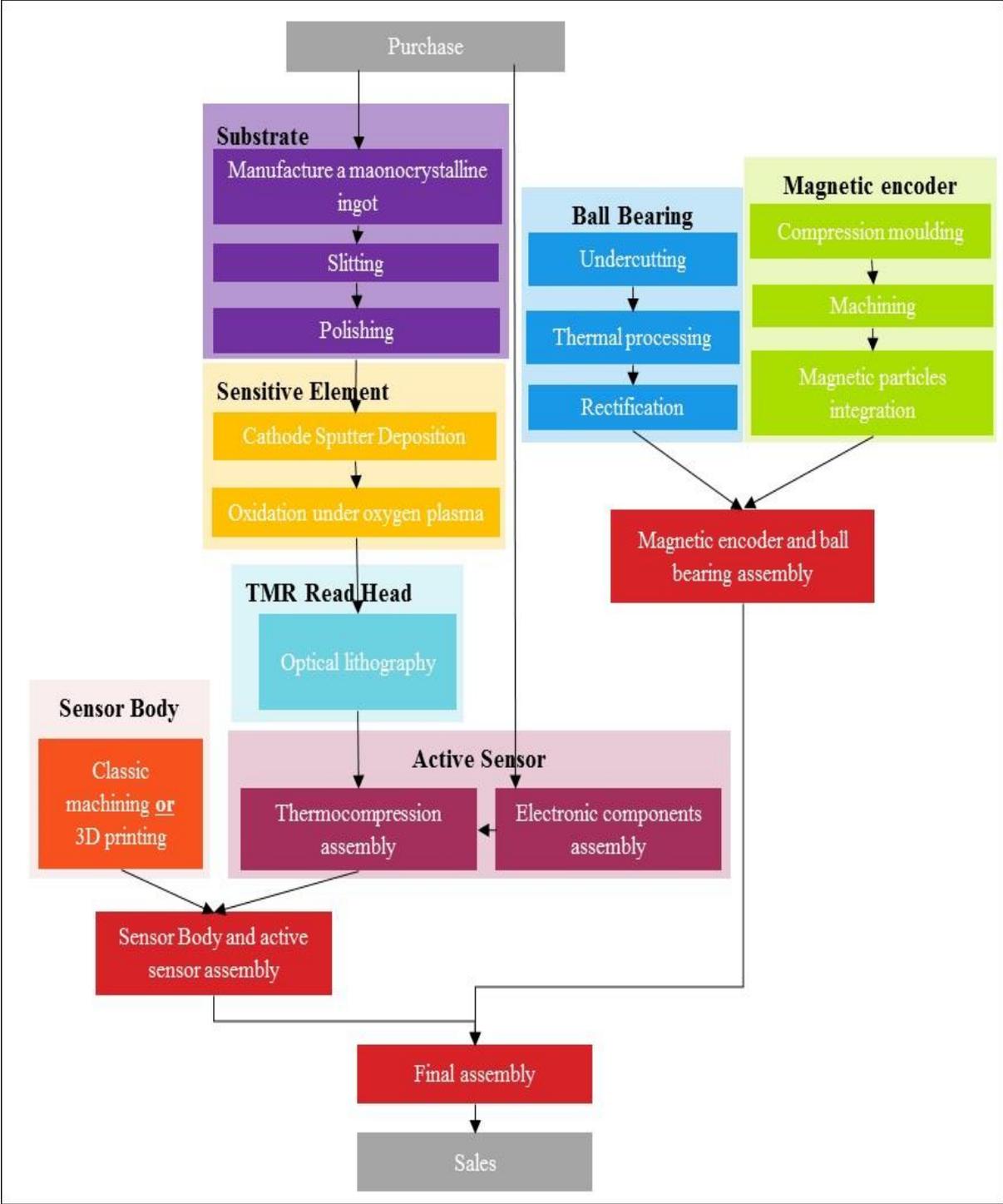


Figure 55: Simplified form of the supply chain based on the literature and obtained thanks to the instantiated supply chain model

To better understand the role of the instantiated supply chain model, a special focus is done on the “thermocompression assembly” process.

8.2.1.2 Brief description of the decisions

Manufacture managed by Company D:

Company D manages the manufacture of the ball bearing integrating magnetic encoders, as is already the case with current ABS technology.

Subcontracting:

From the outset of the project, company D excluded in-house production of the sensor in order to avoid investments in facilities, machines and skills that were too high. As a result, it preferred to subcontract this part of the technology by collaborating with a company with the capacity to implement a manufacturing process linked to the structure of the read-head layers. Thus, the preferred manufacturing process influenced the choice of the subcontractor, i.e. company X. The co-design of the sensor leads to the filing of a patent and common management of associated licenses which link Company D and Company X for at least five years.

The stakeholder in charge of the manufacturing of the sensor body is unknown. Indeed, there is uncertainty concerning the sensor body manufacturing process: either classic machining or 3D printing. In the case of classic machining, the subcontractor involves in the sensor body manufacturing of the Hall Effect sensor can be requested.

Supply:

Company D manages its suppliers: electronic components, steel, elastomer suppliers. Company X manages the supply of the sensor raw materials, i.e. substrate and layer suppliers. The future sensor body subcontractor will manage its or their plastic suppliers. In terms of suppliers, the characteristics of each supplier are known (their expertise and the raw material or components delivered) but we don't have any information on the names of the preferred companies

Sales

Company D manages the sale of the ABS technology to the end customer, the car manufacturers.

Targeted market:

At the stage of the project, Company D aims the automotive market where it is already recognized. In the future, the possibility of integrating new fields of applications (such as household appliances) is not excluded.

The partnership with the company D allows the Company X to integrate the automotive sector.

The figure 56 summarizes the supply chain decisions from the project team during the product development. This figure shows the known and unknown supply chain elements.

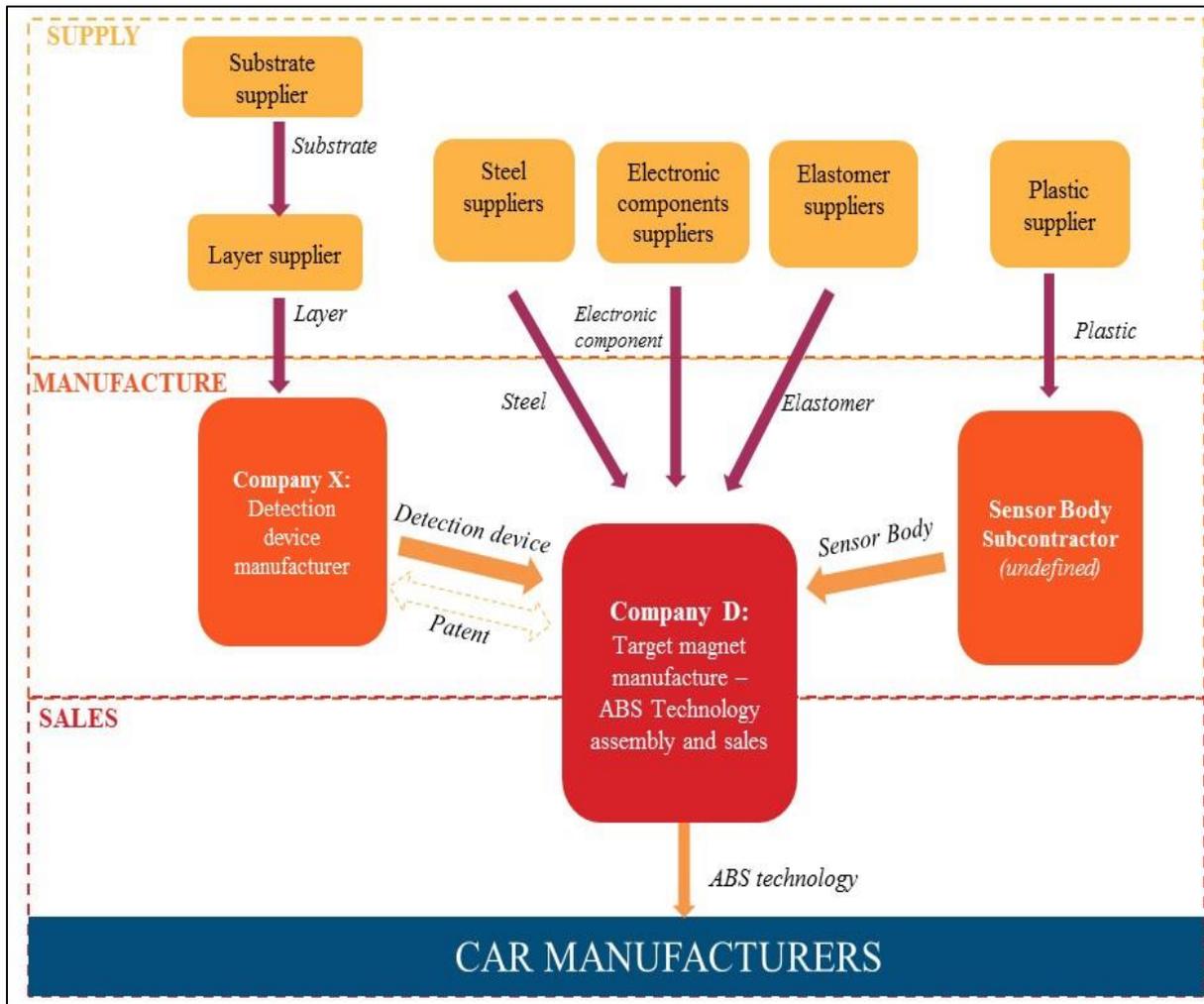


Figure 56: Summary of supply chain decisions during the product development

8.2.1.3 In-depth description of the thermocompression assembly operation

The model is completed as follows:

- The product has been decomposed into modules and components;
- Each module or component has been decomposed into processes;
- Activities have been assigned to each process;
- Skills, resources and decisions were assigned to each activity;
- Actors have been defined according to the skills and resources used to carry out the tasks;
- The generated value of the thermocompression assembly operation has been determined.

The active sensor is the result of the assembly of TMR Read Head and a Flex circuit by thermocompression. In this case, the thermocompression assembly process consists in (Table 23):

Activity	Skills	Resources
<ul style="list-style-type: none"> • Supply of materials • Position the electrical components, electronic components in the order of assembly • Assemble the elements • Check product compliance 	Electricity, Electronic Electromechanical Gluing technique Reading technical documents Tools using and maintenance Welding, Brazing	Reader head Flex circuit equipped with differential amplifiers, electronic components and copper threads

Table 23: Data collection about the thermocompression assembly data

The thermocompression assembly process is a necessary step to obtain the active sensor. The active sensor is composed of several components whose manufacture has to be prior to assembly. To achieve this, three stakeholders have to work in a coordinated manner: the read-head manufacturer (company X), the electronic components supplier and company D. Company D implements this process by means of the following activities:

- Reception of the necessary components (TMR Read-Head, Flex circuit equipped with differential amplifiers, electronic components and copper threads);
- Positioning the read-head on the flex circuit;
- Assembly of the read-head and flex circuit by thermocompression on copper threads;
- Check component operations.

Thus, the implementation of this process relies on the company’s skills in inventory and production management, assembly, thermocompression equipment mastery, equipment calibration or metrology. The production of the active sensor follows a production order for a certain product volume.

The figure 57 shows the application of the model to the example “thermocompression assembly process”. Note that for this example, the added value is functional and therefore only the latter is represented.

In this particular example, the model is completed as the corresponding design study was finished when doing this supply chain analysis (Figure 57).

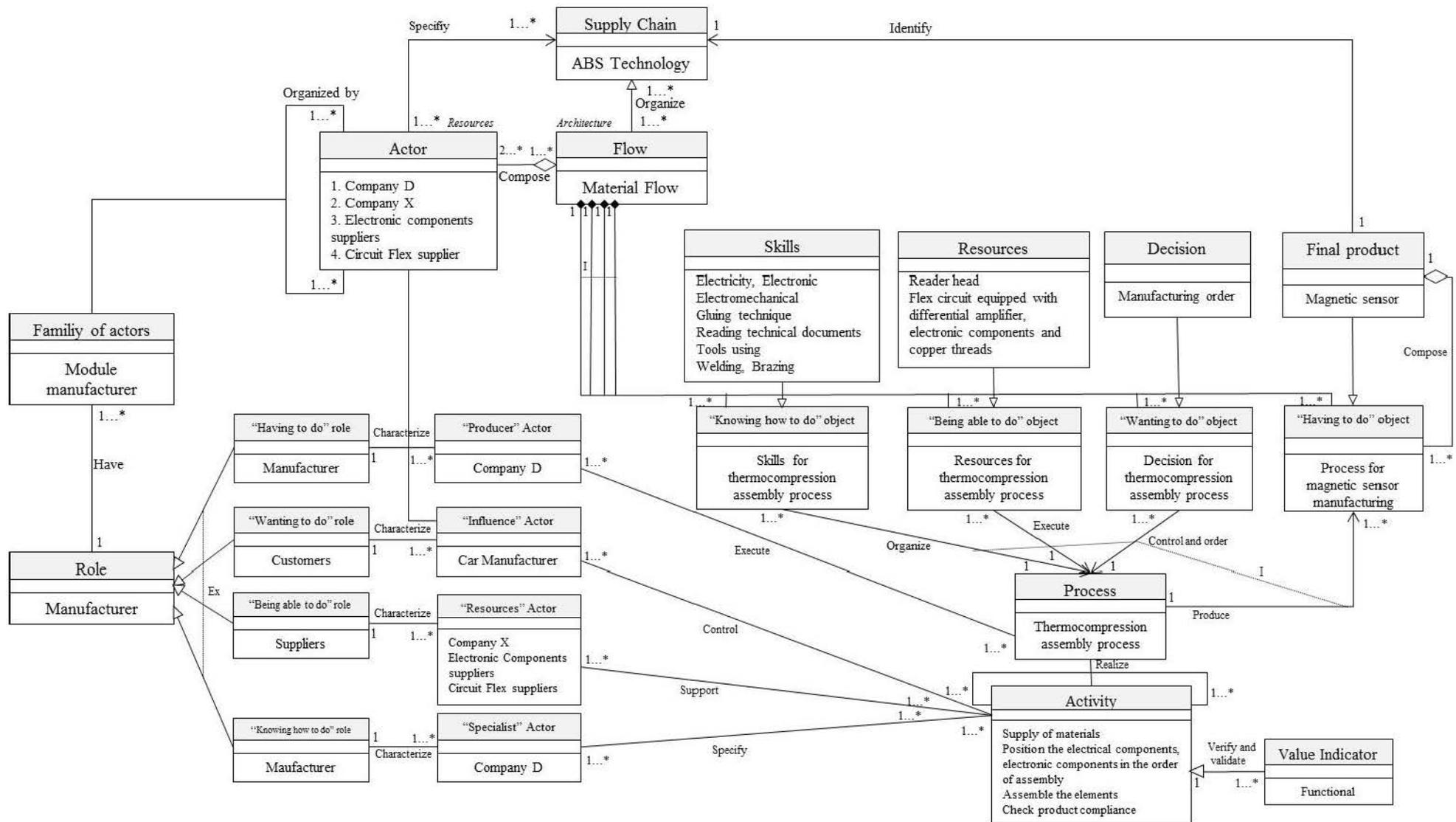


Figure 57: Study of the "thermocompression assembly process" via the instantiated supply chain model

Note that contrary to the thermocompression assembly operation, in some cases, some technical information may be missing:

- Undefined technical choices;
- Unknown stakeholder;
- Undefined skill;
- Data missing.

Thus, it becomes impossible to completely fill the model at a particular moment of the project.

This raises two issues:

- The empty boxes show the design team what information to seek;
- There are doubts between several choices which require creating as many supply chain scenarios as hesitation.

8.2.2 Processes sequencing

By deepening our first vision of the supply chain, we have finally identified 19 main manufacturing processes leading to the identification of 16 processes required to manufacture and sell the innovative product (this is explained by the fact that certain manufacturing processes are grouped within the same process as is the case for the sensitive element and read head processes). The 16 processes are then detailed into activities. They form the product's supply chain.

This step essentially seeks to detail how the product is manufactured. Therefore, we focus our analysis on product manufacturing and less on transportation, distribution, marketing, customer contact or management. However, if these activities would lead to a real transformation of the supply chain, it would be considered. However, these activities can be addressed at the time of scenario selection and implementation.

In order to have a clear view of the data from our study, the information is processed in the matrices as follows: in each cell we write:

- “X” if there is a direct link between the row variable and the column variable;
- “1” if there is a particular situation of an X. It means that the variable in line and the one in column corresponds to one of the three sub-modules of the global product (*only in a DMM matrix*);
- “?” if the information provided is uncertain (*only in a DMM matrix*)³³.

³³ As a reminder, see section 7.2.1.2.3

The case of the active sensor will be used to illustrate our data processing approach. In the figure 58, each matrix is numbered in chronological order (*in white*) and then detailed in order to explain the transition from a product-centered vision to a process-centered vision:

1. **Product DSM—yellow boxes (links between components):** To get the active sensor, the necessary components are a TMR Read-Head, a Flex Circuit and Electronic Components.
2. **Product-Manufacturing Process DMM—orange boxes (links between components and manufacturing processes):** The active sensor is obtained by thermocompression assembly of the TMR and flex circuit and assembly of electronic components.
3. **Manufacturing Process DSM—blue boxes (sequence of manufacturing processes):** For thermocompression assembly, layer etching and optical lithography have to be carried out, which is only possible after oxygen plasma oxidation and sputter deposition. These two processes occur after polishing and slitting. The electronic components can be assembled after purchase.
4. **Manufacturing Process-Process DMM—red boxes (links between manufacturing processes and processes):** The “electronic assembly” manufacturing process takes place within the “electronic component assembly” process. The “thermocompression assembly” manufacturing process takes place within the “Adjustment and manufacturing assembly” process.
5. **Product-Process DMM—green boxes (links between components and processes):** Thus the active sensor is obtained following the processes “Assembly of electronic products” and “Adjustment and manufacturing assembly” including components and their associated processes.
6. **Process DSM—purple boxes (sequence of processes):** Finally, the “Adjustment and manufacturing assembly” process requires the realization of the processes “Assembly of electronic products”, “Microelectronic production operations” and “Flex circuit Purchase”. The “Assembly of electronic products” process requires “Electronic components purchase” and “Microelectronic production operations” processes.

The resulting MDM matrix has two roles. Firstly, it validates the consistency of the product data and our understanding of the product and these processes can be validated with the project team. Secondly, it leads to the drafting of the “Stakeholders” and “System” requirements necessary for modeling.

8.3 Position the company within the supply chain

Processes sequencing has transformed product specifications into a sequence of processes. Hence, supply chain modeling in the form of sequence of activities is then feasible following the *Harmony for System Engineering* methodology. To remain consistency with the previous demonstration, the modeling will be illustrated on the production processes of the active sensor, focusing more particularly on the final assembly.

8.3.1 The requirement pillar

The drafting of the requirements is based on the MDM matrix obtained previously. The Manufacturing Process DSM (blue boxes) is used for the “Stakeholder” requirements and the Process DSM (purple boxes) for the “System” requirements.

Stakeholder Requirement:

The “Stakeholder” requirement reflects the project team’s product expectations in terms of the supply chain. It has to emphasize what the expected supply chain has to be able to do. Each “Stakeholder” requirement can be drafted as follows:

ST_RQX_Y: Name of the Manufacturing process studied

Its description in terms of the supply chain

Where:

- “X” refers to the module/product considered;
- “Y” refers to the rank of the manufacturing process considered within the manufacturing process sequence.

In our example, the stakeholder requirement for the thermocompression assembly manufacturing process (*in order to manufacture the sensor*) is defined as follows:

ST_RQ2_12: Assemble components by thermocompression

The supply chain has to be able to assemble the TMR read head on the flex circuit by thermocompression.

System Requirement:

Unlike Stakeholders requirements, system requirements are solution-oriented, i.e. it reflects what needs to be done in the supply chain to get the product. It describes all the activities that transform the state of the product. Each “System” requirement can be drafted as follows:

ST_RQX: Name of the process studied

Description of the activity achieved

SYS_RQX_Y1: description of one activity of this process

SYS_RQX_Y2: description of one activity of this process

Where:

- “X” refers to the rank of the process considered within the process. Note that this is a trick to facilitate data modeling, some processes can be performed simultaneously;
- “Y” refers to the rank of the activities describing this process within the activities sequence. Note that the manufacturing processes described above within the stakeholder requirements have to be included in the sequence of activities.

In our example, the system requirement for the thermocompression assembly manufacturing process and derived from the previous stakeholder requirement is defined as follows:

SYS_RQ9: Adjustment and manufacturing assembly

The TMR red-head and the Flex circuit are mechanically assembled.

SYS_RQ9_1: Monitor the supply of TMR Read Head and Flex Circuit

SYS_RQ9_2: Identify assembly operations

SYS_RQ9_3: Position the TMR Read Head and Flex Circuit

SYS_RQ9_4: Perform a thermocompression assembly operation

SYS_RQ9_5: Check the conformity of the active sensor

Requirements modeling:

Within Rational Rhapsody® tool, all requirements are modeled in SysML Language:

- System requirements are linked to the associated Stakeholder requirements through a <<satisfy>> dependency in order to verify that all product specifications will be met during the modeling;
- Each activity is linked to the associated System requirement through a <<decompose>> dependency;
- The <<refine>> dependency is used to represent the sequence of activities.

An extract of the resulting requirement diagram is presented in figure 59. It represents the requirement diagram of our example.

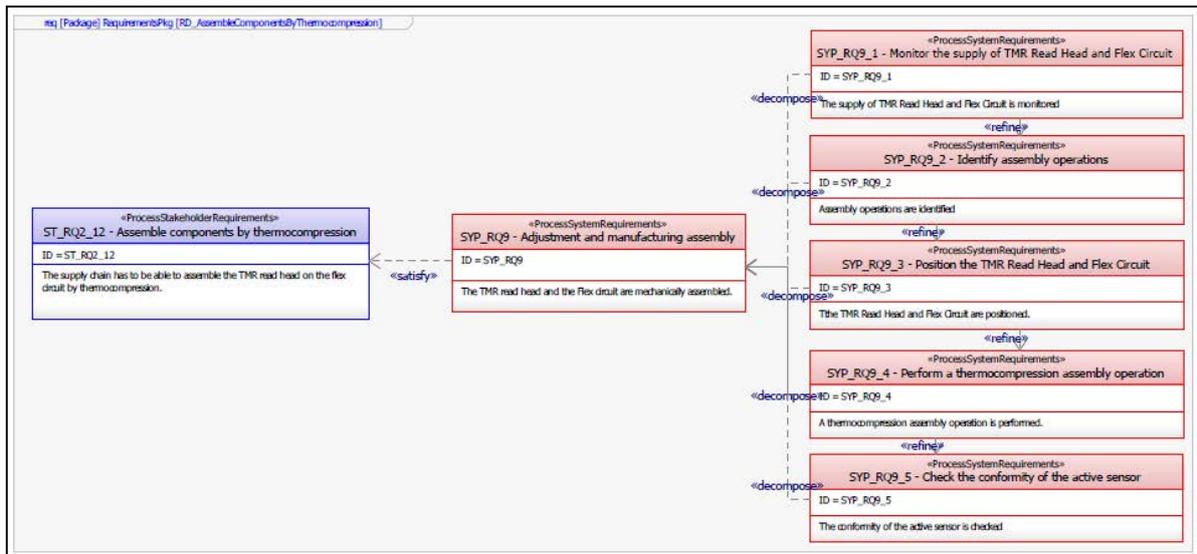


Figure 59: Requirements diagram for the thermocompression assembly manufacturing process

8.3.2 The descriptive structure pillar

To describe the functions of the supply chain, the system requirements are grouped into three use cases:

- UC1_Supply;
- UC2_Manufacturing;
- UC3_Sales.

Based on the data collect, the identified stakeholders are identified and distributed (*through an “association” link*) depending on their involvement in one or more of these functions:

- Layers suppliers;
- Electronic components suppliers;
- Steel suppliers;
- Circuit Flex suppliers ;
- Substrate suppliers;
- Elastomer suppliers;
- Company D;
- Company X;
- Sensor Body manufacturer;
- Seal manufacturer;
- Car manufacturer;
- Garage.

The Use Case diagram represents these three use cases and the associated stakeholders (Figure 60).

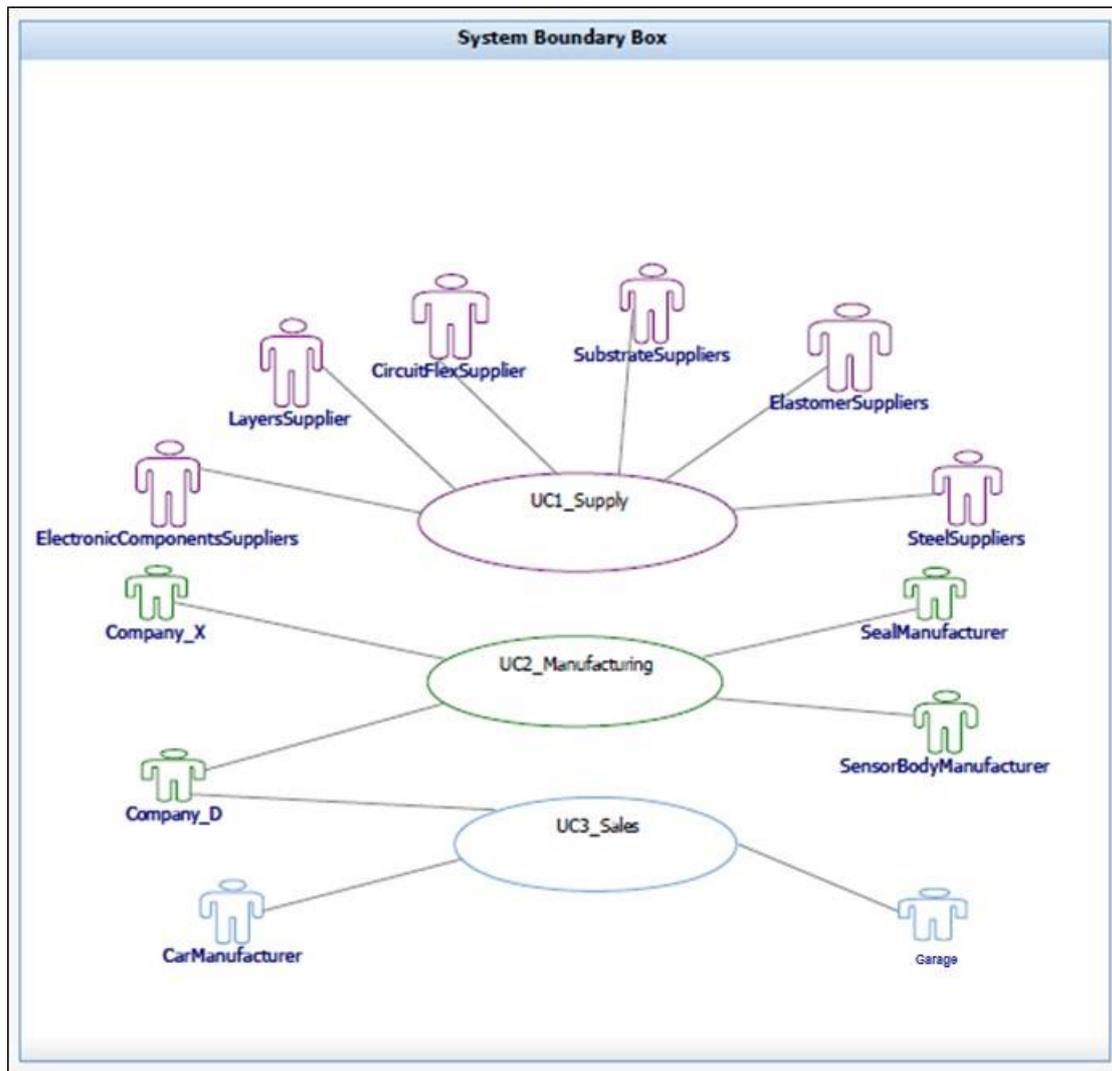


Figure 60: Use case diagram of the supply chain

In our modeling, the definition of the Use Case is a primordial step as it makes the link between all the pillars (see section 7.2.2.2—Figure 39). At this stage, two actions are indispensable:

Checking the consistency of our modeling:

We ensure that these uses cases can satisfy each of the system requirements defined above. This is an essential check to validate that future scenarios can match the project team’s expectations. To do this, in the browser of Rational Rhapsody®, System requirements are linked to the use case with a <<trace>> dependency³⁴. In our example, the SYS_RQ9 is linked with the Use Case “UC2_Manufacturing.”

Make our modeling more robust and complete:

Until now, our analysis focused mainly on processes and activities. This step completes our analysis by integrating the stakeholders needed to manufacture future products. These

³⁴ The “trace” relationship means that a requirement is somehow related to any other model element.

stakeholders may be known (i.e. the innovative company may name the company to perform certain tasks) or unknown (i.e. the innovative company may characterize the type of companies needed to perform certain tasks without having chosen a particular company). For example, in our case, in accordance with the information obtained from the data collection, company D is preferred to realize the requirement SYS_RQ9.

8.3.3 The prescriptive structure pillar

Each use case allows to model activity diagrams that characterize it, i.e.:

- “UC1_Supply” describes in the form of a sequence of activities, **everything relating to the supply** of raw materials and components involved in the manufacture of the product;
- “UC2_Manufacture” describes in the form of a sequence of activities, **everything relating to the manufacture** of components, modules and final product;
- “UC3_Sales” describes in the form of a sequence of activities, **everything relating to the sales** of a module or the final product.

Determination of activity sequences and stakeholders involved

- In the activity diagram dedicated to the sensor assembly, we create activities of the process studied. To define these activities, we use the “SYS_RQX_Y” determined in the requirement pillar (see section 8.3.1);
- For each activity, we allocate one or several stakeholders involved in its realization using an *ActorPin*. It informs the position of the stakeholder in this action (In, Out or In/Out)³⁵. Thus, it helps to visualize the interactions between stakeholders and product flows (internal to the company or between two or more stakeholders).

In our example, the activity diagram of the “Adjustment and manufacturing assembly” process is presented in figure 61. It is completely realized by company D.

³⁵ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

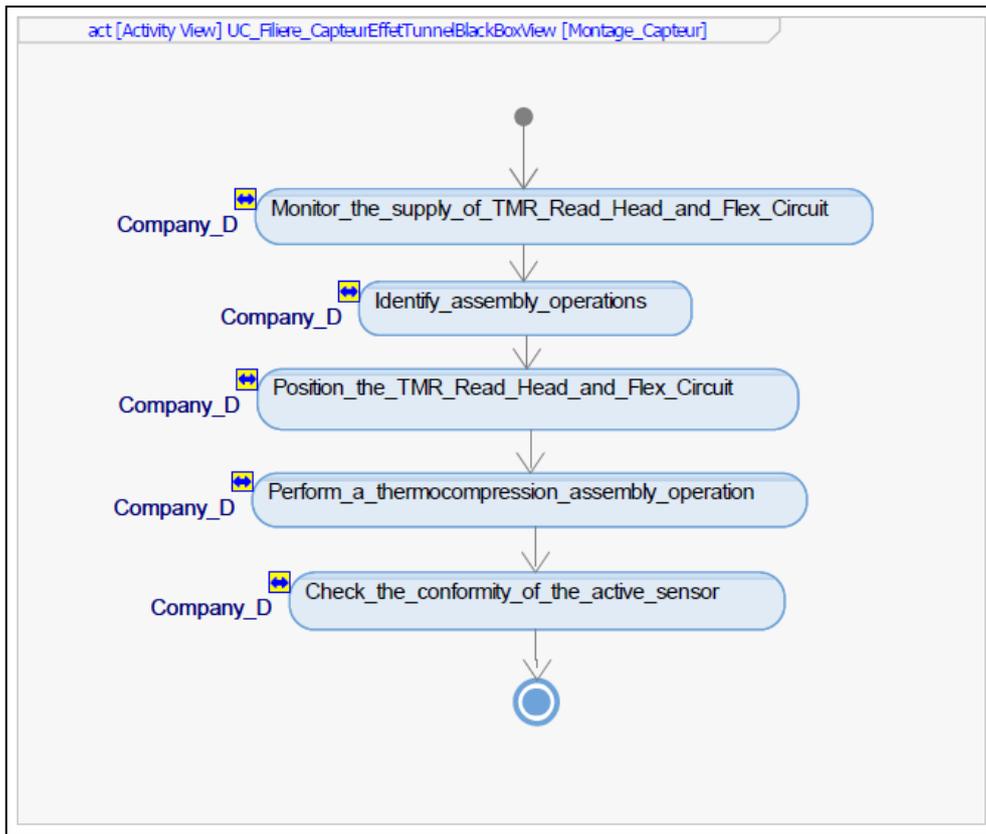


Figure 61: Activity diagram of the “Adjustment and manufacturing assembly” process

Modeling of the supply chain scenarios

We model as many supply chain diagrams as scenarios considered. To obtain scenarios of the entire supply chain, it is only necessary to integrate the activity sequences of each use case (Supply, Manufacture and Sales) within the same activity diagram.

The overall supply chain of the innovative product is modeled in the figure 62.

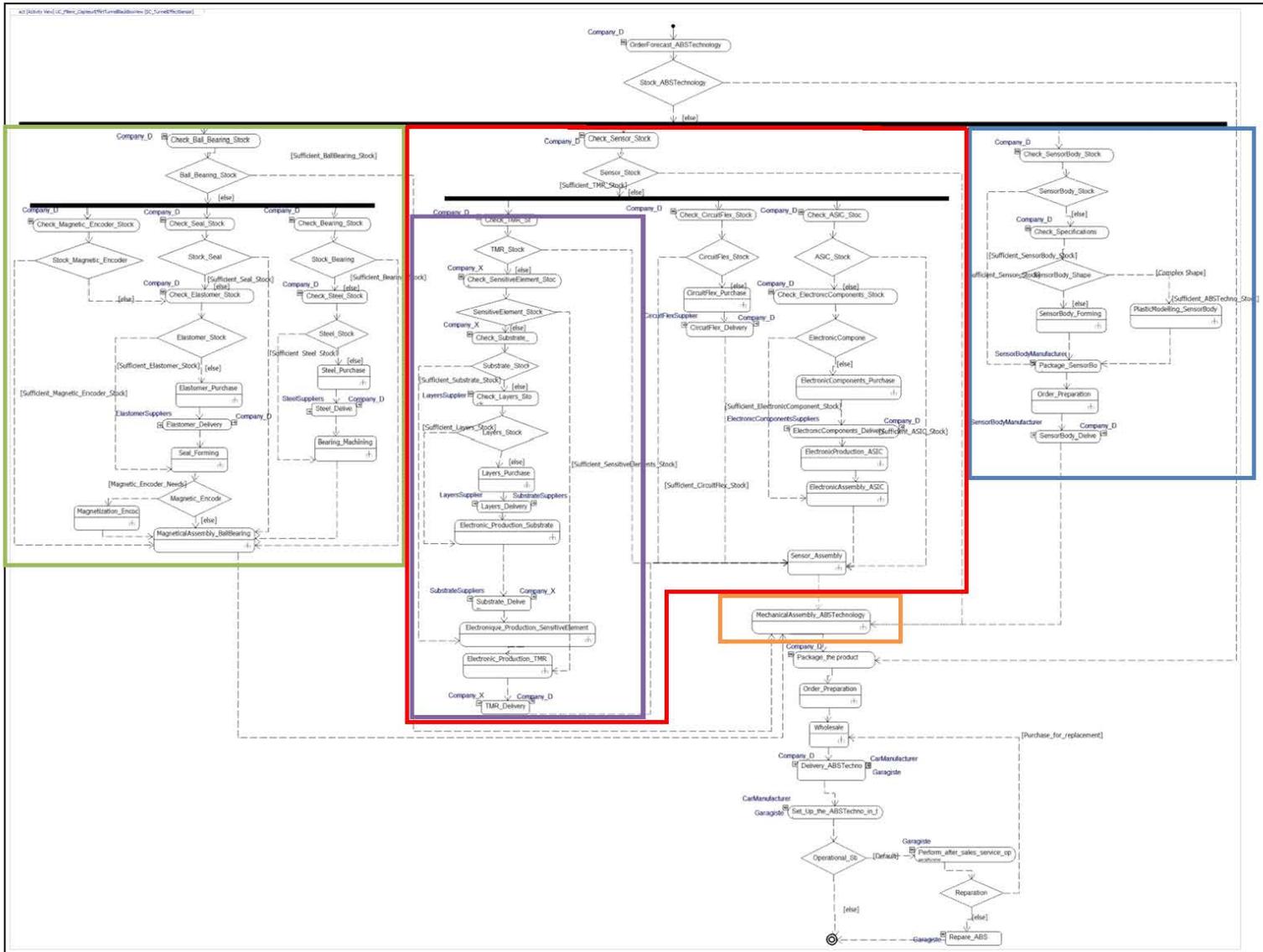


Figure 62: Activity diagram of the overall supply

This diagram shows that the production of ABS technology is based on three independent sub-supply chains:

- The one of the bearing (in green);
- The sensor (in red) including the TMR production (in purple);
- The sensor body (in blue).

These three sub-supply chains join within the “Assembly_ABSTechnology” process (in orange) leading to the production of ABS technology. This stage is then followed by the sales, and after-sales service processes.

8.3.4 The behavior pillar

The sequence diagram is generated from the different activity diagram generated previously. It highlights the interaction between the stakeholders of the supply chain. The direction of the message exchange corresponds to the one defined in the *ActorPin* of the relevant activity in the activity diagram³⁶.

In our example, the sequence diagram called “Sensor_production” including the “Adjustment and manufacturing assembly” process is presented in figure 63. This sequence diagram presents a broader view of the sensor assembly to highlight the interactions between Company D and Company X. Thus, this diagram illustrates the behavior of the process sequence from sensor production order and “TMR production” process (in green) to “sensor adjustment and manufacturing assembly” process (in red).

³⁶ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.



Figure 63: Sequence diagram of the “Sensor production”

8.3.5 Synthesis of supply chain modeling

Several diagrams are necessary to arrive at a scenario of the supply chain adapted to the product. The figure 64 shows the process recommended by our engineering in order to obtain a supply chain scenario from the product data.

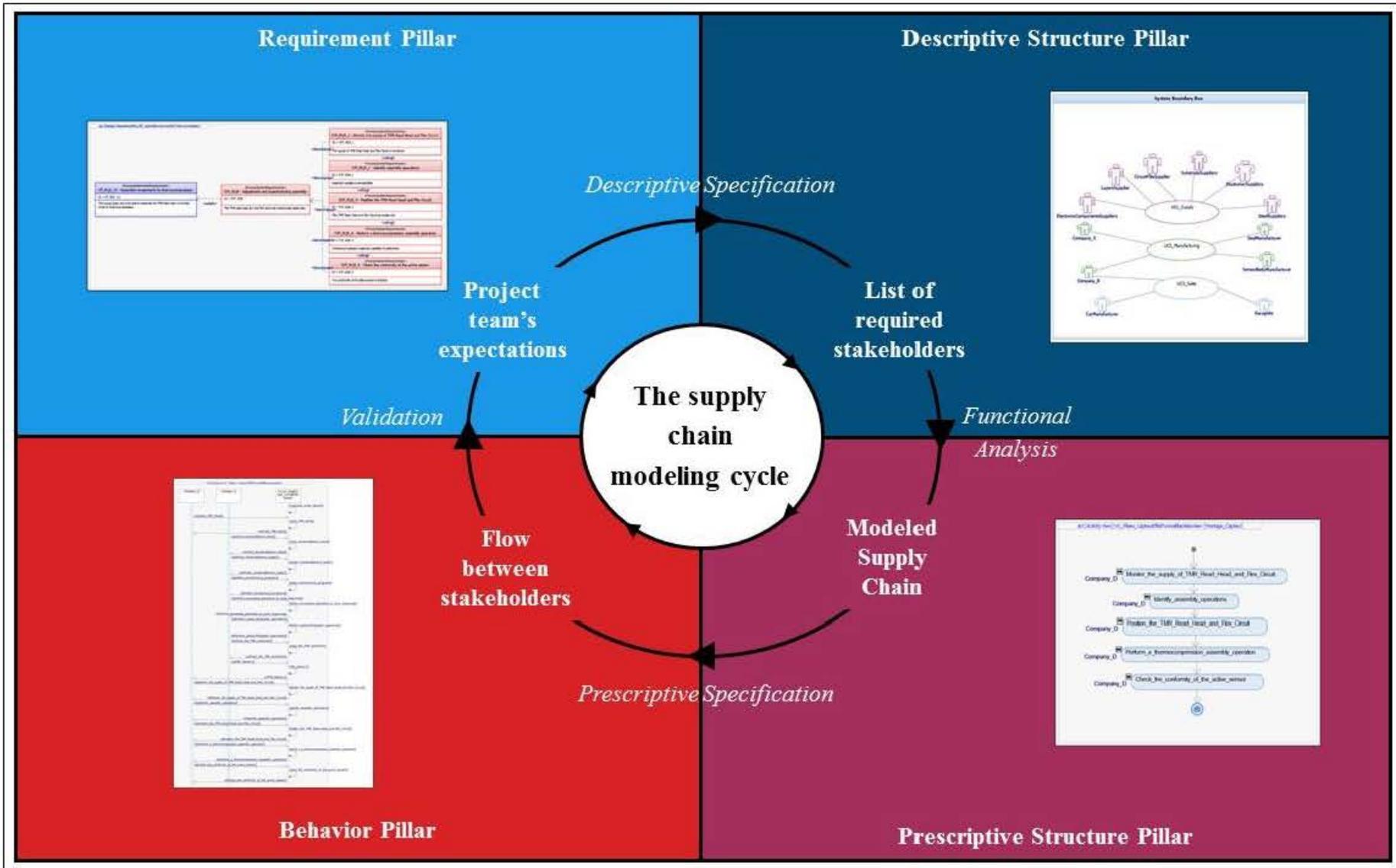


Figure 64: Synthesis of the supply chain model

8.4 Evaluate the supply chain scenarios

8.4.1 Changes within the supply chain

This product is an alternative to ABS technology based on a Hall sensor: company D makes the choice of sensors (Hall Effect or tunnel effect) to its customers, which means that the supply chain of ABS technology based on a Hall Effect sensor remains. Only one part of the global product, the sensor, is impacted by innovation, but it requires the implementation of a new adapted process. Thus, the two supply chains are distinguished at the sensor production level (and more particularly, the read-head production processes are new and must be integrated and implemented in the supply chain) and at the sensor body level (whose shape and process may not mobilize the same actors as in the initial supply chain). Consequently, we can conclude that:

- Stakeholders involved in the manufacture of ABS technology based on the Hall Effect Sensor remain involved in the supply chain. Indeed, the Tunnel Effect sensor is not considered as a substitute product for the Hall Effect Sensor in our case;
- Three new stakeholders (Company X, suppliers of layers and substrate) emerge to manufacture the Tunnel Effect Sensor due to their skills, their equipment, their mastery of the processes selected by the project team and their production capacity. Note that the company can use different suppliers of layers or substrates: the information provided by the project team does not allow to estimate if one or more suppliers will be necessary and consider to procure the same product;
- Depending on the preferred process, the companies in charge of protection will remain the same (machining process) or new stakeholders will be integrated into the supply chain (3D printing process).

Therefore, it seems to be more accurate and realistic to represent on this diagram the production of both types of sensors and to highlight the process supporting the customer's choice. For readability reasons, we have decided to present here only the supply chain of ABS technology including our innovative product. However, we consider that the customer can choose the most relevant solution for him, which is proof of the supply chain's agility.

8.4.2 Typology of the supply chain

Modeling gives an overview of the typology of the supply chain.

Indeed, the modeling underlines that:

- The proposed supply chain can supply two different products (a Tunnel Effect sensor and a Hall Effect sensor);
- The assembly is postponed to allow differentiation;
- The “ball bearing” part is entirely managed and controlled by company D;
- The new supply chain serves the same market despite product innovation.

Based on the differentiation between lean, hybrid and agile supply chains (Table 6—section 4.2.1), these observations underline that the global supply chain obtained is of **hybrid type**.

8.4.3 Strategic and technological decisions

Several decisions impacting the supply chain of ABS technology have been made.

On the technological level, decisions on the sensors lead to the industrialization of the manufacturing processes defined during prototyping, notably the assembly of the read head on the flex circuit. These decisions mainly concern company D and company X. Concerning the manufacturing process of the sensor body, no information on the final decision was given to us.

On the strategic level, discussions with the project team focus on the “sensor” part of the supply chain and provide clarification regarding the organization implemented at launch, essentially between Company D and Company X. Thus, the decisions taken by the company D influence the typology of the supply chain. Consequently, the implemented supply chain is characterized by several characteristics specific to an agile supply chain³⁷:

- A market sensitivity: the possibility of choosing one component, direct sale to the customer, a reflection based on a market study or a limited number of companies involved in the manufacture of the product;
- A digital dependency: data capitalization, information sharing, collaborative platform and common patent;
- A level of integration needed: subcontracting, alliances;
- A network operation: contractualization, contact with experts to support the product launch, common objectives sharing.

The decisions implemented by the company D are described in table 24. As the supply chain implementation cannot be based exclusively on process analysis, this step looks at what the company can do to implement the different scenarios and make the supply chain agile. As a result, managerial actions are highlighted to detect whether the supply chain in question has agile characteristics.

This analysis reveals that the “sensor” part of the supply chain seems to be more agile than the rest of the supply chain. Consequently, the global supply chain is **hybrid** with a **lean part** (dedicated to the manufacture of the ball bearing) and an **agile part** (dedicated to the manufacture of the innovative sensor).

Note that decisions concerning collaboration period between Company D and Company X are linked to the exploitation duration of the licenses. For a period of 5 years, Company D buys TMR Read Head exclusively from Company X. After this period, the Company D can use other subcontractors. Therefore, the typology of the supply chain will be impacted.

³⁷ As a reminder, see section 4.2.2 (Chapter 4)

Evolution of the supply chain		Implemented decisions		
Initial supply chain	Future supply chain	Operational	Tactical	Strategic <i>(agile characteristic)</i>
The supply chain has well-defined skills	The supply chain has new specific skills	Company D collaborates with Company X to produce the new sensor	Company D subcontracts activities that it does not master	Process integration
		Company D is in regular contact with research laboratories and funding bodies	Company D is surrounded by experts	Network-based
The production is mass-oriented	The production is mass-oriented	The supply chain is able to produce different combinations of products (Tunnel Effect sensor or Hall Effect sensor)	The supply chain is able to design different production systems	Network-based
The added value is essentially captured by Company D	The added value is essentially captured by Company D and Company X	Company D and Company X fill a patent	The new sensor is co-produced by Company X and Company D	Process integration
		Company D and Company X have set common objectives: valorize the new sensor to integrate new market	A part of the supply chain cooperate to manage the supply chain	Network-based
The stakeholders are well-known	The stakeholders are new	Company D collaborates with Company X to produce the new sensor	Company D subcontracts activities that it does not master	Process integration
		The relations between Company D and Company X are contractualized	Company D creates partnerships with Company X	Network-based
The target market for company D is well-known	The target market for company D is well-known	Company D offers car manufacturers the choice of the sensor with ABS technology	The supply chain supports a modular product	Market-sensitive
		The ABS technology is assembled at the end of the supply chain and managed by Company D	Product differentiation is delayed and downstream in the supply chain	
		Company D directly sells the ABS technology to car manufacturers	There is no intermediary between Company D and the car manufacturers	
		Company D pays particular attention to after-sales service to improve its product	A part of the supply chain considers customer feedback	
The data are managed by Company D	The data are managed by Company D and Company X	Company D implements a monitoring process at the supply chain level through a study of the target market and patents	A part of the supply chain capitalizes data	Digital
		Company X and Company D exchange information through a collaborative platform	A part of the supply chain share information	

Table 24: Evolution within the ABS technology and implemented decisions

8.5 Empirical discussion on case 4

8.5.1 Observation before/after innovation

Following the observation tasks, some changes emerge within the supply chain after the emergence of the Tunnel Effect Sensor.

Typology of the supply chain:

The development of this new sensor enhances a range of sensors used by ABS technology. The integration of this new substitutable component leads to the integration of a “substitutable” ramification within the supply chain of this technology. The analysis provided by our engineering methodology shows that this part has a more agile behavior than the rest of the supply chain to support the emergence of this new sensor. As a result, we found that the typology of the supply chain is not uniform throughout the supply chain. A lean supply chain can have hybrid or agile parts and vice versa. This finding will be developed further in Chapter 9.

Position within the supply chain:

By proposing a new sensor in the supply chain of ABS technology, Company D increases its influence and we could consider that it “governs” this supply chain. Indeed, it strengthens its position of:

- Suppliers to car manufacturers by its power of proposals (it enriches its range of sensors spontaneously);
- Manufacturers by requesting parts of the supply chain that can meet customer demand, i.e. it requests either the hall sensor sub-supply chain or the tunnel sensor sub-supply chain.

The scenarios obtained by our engineering methodology show the predominant position of company D within the ABS technology supply chain.

Market integration:

Company X’s involvement in product development and the associated supply chain enables it to enter a new market, i.e. the automotive market. In the medium term, Company D can decide to take advantage of its partnership with Company X to enter new markets, such as household appliances, for example. This would mean integrating the supply chain of the tunnel sensor into the supply chain of another product.

8.5.2 Feedback on the MBSCE

This case study was used to implement the MBSCE in a project involving several manufacturing companies. In addition, our engineering methodology was applied to the cases presented in Chapter 5. Overall, our proposal provided interesting and clear results. In the latter case, product/supply chain co-design has generated a lot of curiosity and the fact of obtaining simultaneous results encourages companies to start new innovation projects.

However, this analysis underlines that an interlocutor, currently the researcher, is essential to conduct the approach, interpret the results obtained and propose action plans adapted to the request of the innovative company. Indeed, to obtain consistent results, this methodological engineering has to be exploited by a competent person because it requires a significant step back, and a good control of the Rhapsody tool to draw relevant information from it. Currently, only the researcher manages the design and analysis of the supply chain. A proposal is formulated at the end of these documents to clearly integrate supply chain analysis and design into the innovation process.

8.5.2.1 The main advantages of the MBSCE

A possible customization of the supply chain analysis

To conclude, this engineering allows the study of the supply chain to be structured according to the needs of the innovative company. Indeed, depending on the type of product studied, the company may decide to study the global supply chain or only part of it. This leads to the customization of the supply chain analysis. Indeed, in some cases, a more localized study seems to be more constructive in order to better understand the problem and emerging phenomena. However, it is still important to apprehend the behavior of the global supply chain to obtain an analysis adapted to the context.

In the sensor case, only the supply chain of ABS technology has been analyzed in depth. However, understanding the overall functioning of the car's supply chain is necessary for different reasons:

- Identify the most influential companies, i.e. the companies that “govern” the supply chain;
- Determine the general typology of the supply chain. Here, it is a lean-oriented supply chain;
- Visualize the supply chain position of the technology ABS supply chain within the overall supply chain;
- Understand the context in which this new technology occurs;
- Visualize if the emergence of ABS technology can significantly impact and transform the overall supply chain.

A constructivist methodology

Our engineering is mainly designed to accompany companies in the choice and implementation of a supply chain by proposing tactical and operational action plans. This case study underlined that the scope of this engineering goes beyond the simple framework of support. It encourages project teams and companies involved questioning the future supply chain of their product, to anticipate it and to develop a prospective vision. The MBSCE approach is a constructivist methodology.

A stakeholder-oriented approach

Our engineering gives a clear vision of the stakeholders involved in manufacturing and selling the innovative product. The use case diagram identifies the necessary stakeholders, the activity diagram positions them within the supply chain and the sequence diagram describes their interactions. As a result, it is possible to quickly visualize a company's influence on the supply chain and this can lead us to question its governance. In the fourth case, the ABS technology can be broken down into three modules and we observe that the supply chain can also be decomposed in three parts characterized by three manufacturing companies:

- Company D is mainly in charge of the target magnet manufacture;
- Company X is mainly in charge of the detection device manufacture;
- An undefined subcontractor will be in charge of the protection manufacture.

These three branches of supply chain meet at the level of technology assembly, managed by company D. In the study of this case, the complete manufacturing of a module can be explained by the size of the company or by its expertise in the field. Indeed, Companies D and X are large companies whose expertise is recognized. This seems to make it easier for them to manage several different processes and product lines. The MBSCE is also a supply chain stakeholder oriented approach.

Scenario-oriented approach:

Our engineering help to provide an original solution to remove the company's uncertainties by proposing a reflection based on processes. Indeed, it is possible to model each envisaged supply chain scenario, i.e. to represent a supply chain model for each proposed technical solution. These modeled scenarios do not reveal which technical choice would be best suited, but they allow the company to visualize and think about the solutions that would seem most appropriate strategically, tactically and operationally. For example, in our case, the complexity degree of shape influences the manufacturing process of the sensor body: a complex shape would involve 3D printing, while a simple shape would require conventional machining. As a result, there is an uncertainty regarding the selection of the company or companies to be mobilized to produce the sensor body. In a first stage, our engineering methodology can reveal if the envisaged scenarios are feasible. In a second stage, the innovative company can visualize that machining can be realized by the current sensor body manufacturer (i.e. the one involved in the manufacture of the Hall Effect sensor body) whereas 3D printing leads to find new subcontractors. Obviously, the nature of the first criterion of choice will be technical but a strategic reflection should be considered. The MBSCE is a scenario oriented approach that helps in decision-making.

A management methodology

This engineering requires the involvement of the company manager or/and the project team in several parts: data collection, validation of data processing or in the choice of the preferred scenario. The main objective is to give meaning to the results obtained. The product/supply chain link is studied, but it has to be contextualized (competitive environment, freedom to

operate for innovative firms and so on)³⁸. Indeed, the company manager or the project team leader is involved from beginning to end and corrects or guides the results. The MBSCE is a management methodology integrating designer and decision takers.

8.5.2.2 The limitations of the MBSCE

The Model-Based Supply Chain Engineering has some limitations.

Generalization and computerization:

In our research, we sought to simplify a complex concept to better understand it. The study of the supply chain is rich, strategically very important and at the heart of the complexity. Consequently, it seems difficult to develop software able to valorize our engineering in order to generate supply chain scenarios and associated action plans. Indeed, it is important to study the supply chain in its context and therefore, to have a pragmatic analysis of the supply chain. Human and strategic dimensions are necessary to develop a supply chain: preferred suppliers/distributors, choice by affinity, willingness to design a local supply chain among others. Especially since there are few or no tools for selecting suppliers (Rezaei and Ortt, 2013). In the sensor case, the integration of the Company X into the project and the supply chain depends on company X—specific criteria and influence the supply chain:

- Its experience in magnetic layer deposition processes;
- Its ability to industrialize the future sensor within its factories;
- The availability of its production tool;
- Its qualified staff.

Scale of application:

Moreover, this engineering is relevant for national applications for two reasons:

- At the technical level: the development of processes is based on the “Répertoire des Métiers” provided by a French institution, the *Pôle Emploi*. Our engineering recommendations are therefore more oriented towards French companies.
- At the strategic level: the search for partner companies is more complicated at the international level because of the language or of the regulatory constraints specific to each country.

In the sensor case, company X is German but its integration into product development has not blocked the design of the supply chain (French/German relations are facilitated by their membership of the European Union). However, it is easily understandable that finding a major subcontractor, outside France, based solely on the processes they have mastered could have complicated the implementation of the supply chain.

Note that the equestrian obstacle case highlights these problematic because some of the components of its obstacles (notably hedges) are manufactured in England and firm B has encountered difficulties in finding a suitable subcontractor.

³⁸ The influence of the context on the product/supply chain link is detailed in chapter 9.

Details of recommendations and readability:

The MBSCE helps to highlight the transformations to be expected within the supply chain in terms of processes or types of stakeholders. However, it does not detail the characteristics expected of the different stakeholders (skills, mastery process, equipment, and so on), apart from their ability to implement the process. Therefore, engineering helps to define the activities that a company has to master. For example, in the sensor case, company D knows that the subcontractor expected to manufacture the sensor body must know how to master the machining and/or 3D printing processes, but it does not indicate the equipment and skills necessary to carry out these activities.

The results provided by our engineering don't provide precise action plans. We can state that our engineering methodology delivers supply chain plans but not the supply chain itself. It is possible to highlight the processes and stakeholders to be integrated as well as the axes to be developed to obtain an agile supply chain, but it does not generate precise action plans, i.e. action plans detailing with precision the appropriate partner and where the acquired agility can be evaluated.

For example, in the sensor case, we visualize the general form of the supply chain that may suit the product but the decisions to be taken, the actions to be implemented or the skills and equipment to be mobilized are not included.

Note that the scenarios obtained by our engineering are a simplification of reality, i.e. only the product flows and certain information flows (customer request, manufacturing order for example) are represented.

8.5.2.3 Perspectives for improvement of the MBSCE

In order to remove the limitations previously identified, several perspectives for improvement were considered.

Database development:

The MBSCE has been tested with manufacturing companies only and the results obtained by engineering seem to attest to a certain robustness. However, in order to make this tool more flexible and perhaps to generalize and computerize certain stages, it seems interesting, first of all, to be able to collect and manage a quantity of sufficient information to facilitate the description of the processes (to make computerizable the research of the process integrating a manufacturing process in particular by basing itself on the data of the *Pôle Emploi* for example). For that, the development of a database adapted to our engineering would be an interesting possibility. However, the analysis and the choice of the scenario depend on the company.

Deployment of action plans:

Currently, the MBSCE provides solutions in the form of information (intended for the supply chain) but these do not go as far as proposing recommendations and an operational action plan. One of the perspectives would then be to operationalize the recommendations made to the companies so as to lead to the proposal of concrete solutions to conceive a supply chain whose level of agility reached would ensure the success of the product on the market.

Assessing agility:

Engineering seeks to develop an agile supply chain capable of supporting the innovative product. At present, it is possible to determine whether the supply chain is agile and to determine which axes (market sensitive, network, digital, and integration process) can be strengthened. However, it would be interesting to be able to assess the supply chain's ability to adjust to the product.

Broadening the scope of analysis:

An interest in processing companies would broaden the scope of our engineering and lead to an improved and more robust engineering. In addition, it can help us to develop analyses by sectors in order to collect data from the context and study from another angle the decisions taken and the actions set up to implement a supply chain.

Conclusion of the Chapter 8

The objective of this section was to apply our engineering to an innovative product: a tunnel sensor integrated with ABS technology. This implementation is based on a qualitative validation method: the case study. Thus, in collaboration with the Jean Lamour Institute, the engineering was tested operationally and the relevance of the proposed result was discussed. Feedback on this engineering is encouraging, and this product/supply chain vision has generated interest.

This engineering allows innovative companies to customize their analysis and involve project teams. Within the generated scenarios, the stakeholders to be considered in the future supply chain is viewable based on the information provided by the project team. It turns out that the MBSCE is not only a tool facilitating the design of the supply chain, this role will be detailed in the next chapter. However, some limitations appear. The specific contexts of each company and supply chain prevent a possible generalization and computerization of our engineering. The human dimension is important for designing supply chains that meet the needs of project leaders. Moreover, our engineering seems more adapted to the French Territory in its current state. Finally, the recommendations generated could be further developed to facilitate business decision-making. Therefore, the MBSCE has to be further improved. However, we can consider that this is a promising first version in view of the reaction of our interlocutors on the sensor case. Several avenues are envisaged such as developing and deploying a database to store the information collected during each analysis, reinforcing recommendations and deploying action plans, evaluating the agility of the supply chain or extending the field of analysis to process companies.

Therefore, the next chapter will consist of two discussions. The first discussion will focus on our contributions with particular emphasis on the differences between theory and reality. The second discussion will focus on the perspectives, and limitations of the supply chain study based on the findings from each of our case studies.

IN BRIEF

- The **implementation** of the MBSCE is based in a **case study**: a Tunnel Effect Sensor integrated into the ABS technology developed by a manufacturing company.
- The project team is involved in the **collection** of information, in the **validation** of intermediate stages and in the **choice** of scenarios.
- **Feedback** on this engineering is **encouraging**, and the interest of the product/supply chain **co-design** was **emphasized**.
- The MBSCE can be further **improved** and its scope **broadened**.
- The engineering applied to this case study highlighted **changes** in the supply chain, **positioning** the company and visualizing its **influence** and some **strategic orientations** such as market relations or partnerships.
- The **agility** of the supply chain can be **localized**.

KEY FINDINGS OF THE CHAPTER 8

This chapter is an application of our engineering methodology presented in the previous chapter. Based on an ongoing innovation, this chapter illustrates each step of the engineering process, from the product study to the modeling of the corresponding supply chain scenario. Consequently, the contribution of this chapter lies in the validation of our theoretical and methodological contributions.

Introduction

The previous chapter has illustrated our theoretical and methodological contributions with the help of an on-going case. The chapter 9 provides a general discussion of our research:

- From a methodological perspective: by highlighting improvement with supply chain analysis methods;
- From a scientific perspective by underlining the usefulness and limitations of our contributions;
- From a pragmatic perspective by highlighting contextual elements that can influence the implementation of a supply chain.

In particular, this section contributes to the deepening of the empirical questions addressed in the previous chapters and especially in chapter 5:

- How to better understand the in-situ phenomena within the supply chain caused by the emergence of an innovative product?
- These phenomena can be occurred in both SMEs and large companies?

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9.1 Interest of supply chain analysis for the company

However, despite the difficulties faced by top management concerning the supply chain, it remains a relevant and effective approach for the innovative enterprise. The interest of the supply chain analysis can be demonstrated on several levels.

9.1.1 Supply chain analysis: a multiple side tool for a company

Supply chain analysis can be seen as a multiple side tool at disposal for the innovative company.

9.1.1.1 Supply chain analysis as a modeling tool

Indeed, supply chain analysis can facilitate a technical description of the product in order to know the sequence of technical activities necessary for its manufacture. Thus, it provides information on the expertise and equipment to be integrated in order to obtain the most suitable supply chain. For further research, we thought that supply chain analysis can facilitate a description of the economic relationships between supply chain members and determine the different customers of the supply chain.

Finally, functional focus is a first approach but a supply chain analysis requires more information than the functional information of products/manufacturing alone, such as competitors or context among others. An analysis of the supply chain can provide information on the strategy to be implemented according to the position of the innovating company within the supply chain and its specific characteristics. In this way, the latter can more easily determine the actions to be implemented to generate value and perpetuate its activity.

9.1.1.2 Supply chain analysis as a decision-making tool

When developing a new product, it may exist technical uncertainties that require decision-making. Joint supply chain analysis can be a useful tool to test the different technical and economic combinations and thus determine, for equivalent technical options, which supply chain will be the easiest to implement (proximity of stakeholders, existing partnerships for example) or the most value creation for the innovative company.

9.1.1.3 Supply chain analysis as a prospective tool

Supply chain analysis, based in particular on our instantiated model, can be used to integrate new technologies and changes (in terms of stakeholders or processes for example). Thus, it is possible to simulate future supply chains considering technological and/or environmental developments. This may be consistent with the evolution of the current supply chain and can provide information for potential product improvements.

Hence, supply chain analysis provides elements for processing prospective data and interpreting them in the form of different possible scenarios.

9.1.1.4 Supply chain analysis as a support for internationalization

A supply chain analysis can be a support for internationalization by providing a more global vision to the innovative company. Thus, it can quickly determine what process can be

managed by a foreign company to propose the innovative product on the market of a new country. In addition, if the innovative company is in the upstream part of the supply chain, it can determine which downstream company can become a partner to offer its product internationally.

9.1.2 Agile supply chain implementation practices

To conclude this research work, we propose a non-exhaustive list of “good practices” leading to the design and implementation of a supply chain scenario adapted to a specific product.

These practices are the main pragmatic actions taken by innovative companies to define their supply chain strategy, to manage and drive their supply chain and finally to make it evolve. The strategy adopted by companies depends on several factors including the sector or the size of the company.

These practices are derived from our bibliographical and exploratory research but are by no means a reference for implementing the supply chain of a new product.

To sum up we state that the product/supply chain co-design is based on five practices:

Data collect and process:

These practices concerns the way of collecting and processing information in order to co-design the product and the supply chain. Two tools are available to the CEO or the project team leader:

- The instantiated supply chain model that allows information to be collected during the innovation process;
- The Model-Based Supply Chain Engineering that allows information to be processed and modeled.

To collect information, a structured expert “supply chain centered” inquiry may be useful. Based on an interview guide or on a confrontation to a simplified supply chain model, an expert opinion collection could be achieved. Moreover, by questioning other future supply chain members (suppliers, subcontractors, and/or distributors) involved in the product design, it is possible to obtain more accurate and reliable information to model the supply chain. Hence, the supply chain model can be used as a systemic interview guide.

Capitalization:

This practice concerns the safeguarding of information resulting from the design and implementation of the product and the associated supply chain. Indeed, information from the design and launch phases is capitalized in order to preserve the experience stored by the supply chain. The instantiated supply chain model and the Model-Based Supply Chain Engineering help to organize, capitalize and share information so that it can be reused. Indeed, this information is useful for the functioning of the supply chain and for launching new innovative projects using the same supply chain.

Strategy:

This practice concerns the strategy implemented by the innovative company within the supply chain when the innovation is launched. This strategy integrates: the structure of the supply chain, how it works, the importance given to stakeholders and the responsibilities assigned to supply chain members. Defining the supply chain strategy allows to specify:

- Future activities and processes to be implemented;
- Stakeholders to be associated at each stage of the supply chain;
- Relations between members of the supply chain (partnership, subcontracting, exclusivity among others);
- The number of activities and processes managed by one company;
- The importance of the customer in the supply chain (market pull or technology push);
- Influential actors (competitors, institutions among others);
- The company or companies that make the decisions in the supply chain;
- The value distribution.

Resources management:

The supply chain needs particular human and material resources to operate. The development of a new product may require the integration of new skills or equipment to ensure that its production is possible inside the company and within the supply chain. Material resources support the manufacturing of the product. Human resources have to be able to carry out the processes, control the necessary equipment and manage the difficulties (threats from the environment for example) occurring within the supply chain.

Capitalization:

This practice concerns the safeguarding of information resulting from the design and implementation of the product and the associated supply chain. Indeed, information from the design and launch phases is capitalized in order to preserve the experience acquired. This information is useful for the functioning of the supply chain and for launching new innovative projects using the same supply chain.

Note that our approach focuses on the functional relationships between product and (manufacturing) process. However, to obtain a complete analysis of the supply chain, information and financial flows have to be considered.

Financing:

This practice concerns the ability of companies to invest in the supply chain and/or to mobilize a financial mechanism in order to limit financial risks when an innovative product emerges. Indeed, supply chain companies may need to find financing to acquire new

equipment, facilities or tools needed to manufacture the new product. Consequently, supply chain analysis is relevant for estimating the feasibility of a product in terms of manufacturing and production; for limiting the uncertainties inherent in the launch but in terms of the supply chain (production capacity, estimated reliability of the future supply chain); for drafting concrete and realistic investment plans in order to encourage financing organizations or potential partners to invest.

9.1.3 Conclusion

The benefits of a supply chain analysis are not limited to the design or proposal of supply chain scenarios adapted to the innovative product. It can support the company manager in his decision-making. In addition, there are invariant to consider when analyzing the supply chain that can assist companies in their innovation and co-design process. These invariant are presented as practices in order to help innovative companies to design and implement their supply chain.

9.2 Review of our research

9.2.1 Synthesis of our research

This research proposes five contributions:

- On a theoretical level: a new design paradigm (Chapter 3) and a framework to implement agility strategy (Chapter 4) based on a literature review;
- On an empirical level: an overview of phenomena occurring in a supply chain during the emergence of innovation (Chapter 5);
- On a methodological level: an instantiated supply chain model (Chapter 6) and a Model-Based Supply Chain Engineering (Chapter 7).

In order to validate that our results adequately address our research problem, we propose to cross-reference the contributions of each chapter in order to validate that we have answered our research question: How to model the **innovative product/supply chain interrelated couple** in order to identify the **adjustments to be implemented** within the supply chain by a (manufacturing) **company in a context of innovation?**

To do this, we examine each sub-question separately.

2.1. The theoretical dimension

- *How to better describe the interdependence between the characteristics of a product and those of the supply chain in the context of innovation?*

A system is the result of the arrangement of relationships between components or individuals, where the representation of this arrangement can be considered as the system architecture (Bonjour and Dulmet, 2006). **Hence, a product and its supply chain can be considered as systems** (Chapter 3).

Thus, the architecture of the product requires the involvement of several companies: each component, each interface requires a specific know-how. Thus, the set of components mobilizes processes and skills distributed between a set of actors, both able to master a phase but also to act collectively with others. As a result, the product architecture influences the architecture of the supply chain: **the product and the supply chain are two interrelated systems** (Chapter 2-3).

The supply chain companies are in charge of all processes required to the product manufacture, distribution and sale. Therefore **the product and the supply chain are linked by the process** (Chapter 2).

The product and the supply chain mobilize common processes, skills, knowledge and resources. Thus, joint design activities can be considered during the innovation process. Hence, we can consider **product design and supply chain design as two complementary and interrelated activities within the innovation process** (Chapter 3) **fostering the co-design of the product and the supply chain** (Chapter 3).

Thus, the development of an innovative product influences the development of the supply chain and vice-versa. For the development of an innovative product, an agile supply chain is expected (Vonderembse et al., 2006) because the supply chain has to be able to adapt quickly to changes in the environment and product uncertainties. Indeed, agility is an organizational response and means that the supply chain has dynamic ability to carry out pragmatic adjustment activities in order to fit product and supply chain. Therefore, **there is a link between the structure and the behavior of the product/supply chain couple**. In addition of the structural fit, **a strategic fit is expected** (Chapter 3-4).

- *For a particular product, how to model the corresponding supply chain?*

A supply chain is composed of different constitutive elements, some of which can be common with those of the product: processes, skills and equipment. Thus, by collecting data from the product development process, the innovative company can **model the functional-side of the supply chain** (Chapter 2).

To have a right vision of the product supply chain at a given moment, the innovative company has to consider constitutive elements, specific to the supply chain: the type of stakeholders, the relationships between companies involved in the product manufacture, the generated value and so on. Therefore, the innovative company has to consider the technical data from the product but also its strategy: the innovative company can **model the structural-side of the supply chain by taking strategic decisions** during the product development process. The structure stems from the companies strategies (Chapter 3).

Hence, **the supply chain model is the result of a technical vision and a strategic vision** (Chapter 6 – methodological contribution).

- *How to match the type of supply chain required for a type of product?*

The works of (Fisher, 1997; Lee, 2002) and the classification proposed by (Vonderembse et al., 2006) suggests that the innovative product has to evolve in an agile supply chain during its launch on the market. Therefore, the strategy of the innovative company has to transform the supply chain to ensure better performance (Chapter 3) if the innovative product does not fit the initial supply chain. Thus, the innovative company has to ensure that the future supply chain will support the new product using new characteristics that will guarantee **its agile character** (Chapter 4).

To support the new product, the innovative companies adjust the supply chain to meet the needs of the product. Hence, if an innovation emerges in a lean/hybrid supply chain, adjustments are then necessary (Chapter 4).

- *How can the adjustments required to transform/type the supply chain in the case of innovation be better understood?*

According to the theory of contingency, the supply chain has to meet to the product constraints by making strategic or structural adjustments (Chapter 3). Therefore, there is a mutation within the supply chain due to the strategy chosen by the company (Chapter 3).

Agility concerns the capacity of a supply chain to increase the agility level of the initial agile supply chain, transform the initial supply chain or create a new agile supply chain. The agility of a supply chain is its capacity to transform its configuration according to the innovative company's strategies: the adjustments depend on the capacity of the supply chain and result from decisions taken by the companies to make the supply chain more agile.

There are three types of decisions (Ansoff, 1965): strategic, tactical and operational. These decisions are actions implemented by the supply chain companies. Hence, the adjustments can be described in the shape of actions implemented within the supply chain (Chapter 4 – second theoretical contribution).

2.2. The methodological dimension

- *How to anticipate (if possible) the future supply chain needed for innovation?*

There is a gap between theory and reality and we find that companies lack the tools to anticipate and design their supply chain. Hence, we propose an engineering linking our theoretical results to the needs of companies (Chapter 6-7-8). This engineering considers the product data, the common processes and agility design to anticipate the supply chain functionally and managerially (Chapter 6-7-8).

- *From a specific product, how to design a future supply chain?*

The product requirements lead to the corresponding supply chain requirements; the supply chain requirement has the shape of processes. Hence, the manufacturing processes of the product are translated into supply chain processes using MDM matrix (Chapter 7-8).

These supply chain processes are ordered according to their function: supply, manufacture or sale. Thus, we can define the types of stakeholders needed for manufacturing and position them according to the functions to which they respond: the innovative company can position itself within its supply chain (Chapter 7-8).

Then, the supply chain can be organized in the shaped of a sequence by indicating the processes managed by the various stakeholders defined. In this model, we can represent the supply chain decisions taken during the design phase: all supply chain scenario from a specific product can be designed (Chapter 7-8). Thus, the top manager can visualize the impact of their decisions on the supply chain and decide to act in consequence to make the supply chain scenario more robust both functionally (sequence of processes) and managerially (supply chain strategy). An example of this engineering is proposed in the chapter 8.

2.3. The empirical dimension

- *Are there generic phenomena within the supply chain caused by the emergence of an innovative product?*

Through three case studies, the impacts of innovations on the supply chain were observed: an innovation influences the type of the supply chain, the value chain of the innovative company, processes, core competencies, the regulatory environment and the marketing for the product (Chapter 5). This creates a misfit between the requirements of the innovative product and what the current supply chain can actually do. Therefore, to deal with the different misfits caused by the emergence of an innovative product, we consider several strategic perspectives to anticipate the transformation of the supply chain: skills, market, stakeholders, activities and the environment (Chapter 5).

By considering these strategic perspectives, we note that innovative companies implement adjustments that are consistent with the results of chapter 3 and 4. However, these adjustments are company-specific. Thus, there are several ways to solve a misfit and it depends on the willfulness of the top manager. Indeed, the latter can be satisfied with minor changes in the supply chain to be able to ensure the manufacture of the product or have a real reflection in terms of supply chain (Chapter 5). Thinking about the supply chain before the product is launched provides information on the predictability of the supply chain, i.e. whether it can be predicted or whether it should be created gradually (Chapter 5).

However, reflection about the supply chain highlights that it strongly depends on the context. Hence, to obtain an accurate analysis of the supply chain, it is important to consider contextual elements like type of innovation, boundaries, size (company and sector), governance, experience or competitive environment.

- *Do these phenomena occur in both SMEs and large companies?*

In our study, phenomena within the supply chain caused by the emergence of an innovative product occur, regardless of company size (Chapter 5). Therefore, the supply chain items impacted by the emergence of an innovation are commons to the SMEs and large companies.

In both cases, the emergence of a product leads to a (re)structuring of the supply chain in line with the company's favored strategy. Following innovative product development, SMEs and large companies have to implement agility decisions to obtain a supply chain more agile.

In both cases, it seems that a supply chain design depends on contextual elements although due to its size, a large company seems to have more resources (humans, technical and financial) and influence to structure the supply chain. Therefore, SMEs and large companies seems to be influenced by the same contextual elements during the design of their product's supply chain, i.e. the type of innovation, the boundaries, the size of the sector, the governance, the experience or the competitive environment. However, based on our case studies, we assume that large firms may be more able to limit the influence of these external factors because of their ability and bargaining power. This hypothesis could be developed in future research where the study could then focus on the differences between SMEs and large companies during the design and implementation of supply chains.

Power balance and political strategic aspects are not part of my work but are important between companies and within companies. This choice is justified by the fact that we are initially seeking to study the product/supply chain link to facilitate its manufacture and ensure its launch on the market. This explains why our research does not give more indications on what is occurring between SMEs and large companies. These are topics for further research.

The usefulness and the limitations of each contribution are summarized in the table 25.

Initial findings	Theoretical		Empirical	Methodological
	Product/Supply Chain co-design	Agility definition and framework to implement agility strategy	Overview of phenomena occurring in supply chains during the emergence of innovation	Model-Based Supply Chain Engineering and the Instantiated Supply Chain Model
Usefulness	<ul style="list-style-type: none"> - Bring a new vision to product design; - Highlight complementarities between product design and supply chain design; - Product/Supply chain design can minimize implementation efforts; - Highlight that a product cannot exist without a suitable supply chain and vice versa; - Help find the requirements towards partners and suppliers - Accelerate the NPDP through collaboration. 	<ul style="list-style-type: none"> - Have a more precise vision of what “facilitates” the implementation of an agility strategy (possible actions); - Visualize actions that are tactical or operational; - Have a support for diagnosis of the strategy taking agility into account; - Have a support to determine if an innovative company is implementing decisions to make the supply chain more agile. 	<ul style="list-style-type: none"> - Have a better understanding of what is happening in situ, i.e. within companies and supply chains; - Confront theory and reality; - Capture of the context data complexity; - Have a critical view of our theoretical results, - Get a list of best practices. 	<ul style="list-style-type: none"> - Facilitate dialogue between the project team and the researcher, customization, constructivist approach; - Help to visualize the supply chain (in the form of a system), scenario-oriented approach; - Get a whole and unique representation of the global supply chain; - Describe the evolution of this supply chain; - Help to visualize design uncertainties; - Help to consider partnerships in a project, stakeholder-oriented approach; - Visualize and anticipate the problems the innovative company could encounter later during the launch of the product (management tool).

Table 25: Summary of the benefits of each contribution

Initial findings	Theoretical		Empirical	Methodological
	Product/Supply Chain co-design	Agility definition and framework to implement agility strategy	Overview of phenomena occurring in supply chains during the emergence of innovation	Model-Based Supply Chain Engineering and the Instantiated Supply Chain Model
Limitations	<ul style="list-style-type: none"> - Difficulty to collect some process information. 	<ul style="list-style-type: none"> - Theoretical and fixed framework; - Difficulty to estimate the degree of agility achieved: lack of metrology. 	<ul style="list-style-type: none"> - Limited generalizations due to the low number of case studies; - Wide study field; - Only successful decisions are observed. 	<ul style="list-style-type: none"> - <i>Pôle Emploi</i> database accuracy; - Visualization of the entire supply chain, recommendations and readability of results; - Supply chain typology not always explicit; - Difficulty generalizing and computerizing; - Focus on a functional perspective ignoring information flows, financial flows and political and strategic aspects; - Focus on specific levels of analysis (activities, processes) but not the entire ecosystem or the Technological Innovation System.
Perspectives	<ul style="list-style-type: none"> - Develop a methodology to apply the implementation of this design in companies; - Study of particular situations: sectors, new/old supply chain. 	<ul style="list-style-type: none"> - Develop an agility metrology; - Describe the agility degree at different levels within the supply chain (supply chain as a whole or parts); - Make agility in agility, i.e. improve and deepen this framework so that it adapts to changes in context and environment. 	<ul style="list-style-type: none"> - Select the critical elements to analyze (type of products, size of company for example) to see if a generalization is possible; - Understand why some strategies do not have the desired effect on the supply chain. 	<ul style="list-style-type: none"> - Complement engineering with other tools to make it accessible to companies; - Develop a database specific to our engineering in order to gain in accuracy and speed when processing results; - Deepen engineering (skills, equipment, activities and/or performance indicators) so that its use can help develop new products and seize new opportunities; - Assessing agility; - Broadening the analysis field (processing company).

Table 25: (Continued)

9.2.2 Discussion on limitations of our research

The crossing of these contributions highlights the existence of several limitations: theoretical, strategic and functional. We propose to discuss them on the following paragraph.

9.2.2.1 Theoretical limits

a. The supply chain concept—Limitation of generalization

In our research, we have identified several limits to the generalization of the supply chain concept:

A system is a mindset representation:

Each stakeholder has its own representation, its own vision of the supply chain. Thus, the structure of the supply chain depends on the representation that each stakeholder has of it. Hence, our proposition may be seen not as a way to get an individual “true” representation but a collective shared representation.

The supply chain notion is data sensible:

The engineering and the instantiated model are based on the information provided by the project team and therefore on the stakeholders it considers relevant. Therefore, the project team seems to set the limits of the supply chain itself. Note, that the framework identifies decisions whose impact remains close to the innovative company.

The theory discusses a system with well-defined boundaries:

Our case studies have emphasized that the notion of “boundaries” is specific to each supply chain. For example, to obtain a relevant analysis of case D, we focused on the supply chain of the innovative component and not on the supply chain of the car although this technology makes up the car. Therefore, it is difficult to delineate a supply chain. Some definition may be given to qualify the distance between a supply chain member and the focal company, or, to define a grade as in the automotive sector.

In addition, it is not simple to determine the beginning of a supply chain. Thus, we may wonder about the relevance of considering:

- A supplier of raw material as oil in a supply chain that uses plastic powder (case B);
- A single supplier who has a monopoly on a raw material in the supply chain of the future product (Arcelor Mittal for example).

This raises several questions: Are the limits of the supply chain not linked to the scope of the decisions and actions of the most influential companies in the supply chain? Are the limits of the supply chain more strategic than functional? In this case, should another model be used?

b. Limits of the agility concept

A theoretical concept:

The notion of agility is still little discussed in the literature, so it is a concept that still needs to be clarified. Many authors have tried to explain how to implement agility but there does not seem to exist any real consensus. This research does not aim to precisely characterize this concept but rather to condense research on this subject in order to make it more accessible for a company by proposing an analytical framework in the form of observable phenomena from the literature. Therefore, to deepen this contribution, a field observation seems relevant.

What element is important to characterize a supply chain?

Moreover, the notion of agility refers to the typology of a supply chain (lean, hybrid and agile) where each case is defined by several different characteristics (types of alliances, types of organizational structures or types of product design strategy). However, we were able to note that a supply chain is composed of sub supply chain of different typology (as it is the case for the globally lean automotive sector with more agile links/parts).

Therefore, it questions how to characterize a supply chain globally and locally. Is it more important to consider the global behavior of the supply chain or to highlight its most agile links?

As a result, we may ask ourselves whether there are criteria to be favored when characterizing a supply chain in order to ensure that it is sufficiently agile to contribute to the success of the product on the market.

When is a supply chain defined as agile?

An agile supply chain is defined by its market sensitivity, virtuality, networking and process integration. However, we have observed that an agile supply chain does not develop its characteristics at the same level (example of cases B and D).

Therefore, we can question if:

- These characteristics are of equivalent importance when typifying a supply chain as agile;
- A supply chain must meet these characteristics equally to be qualified as agile;
- A strong response to one of these characteristics is enough to qualify a supply chain as agile;
- What if only particular parts of the supply chain attest of these characteristics?

In our research, we considered that the four characteristics had to be significantly impacted to be able to consider a supply chain as agile. But is that enough to make a difference in a competitive environment?

This leads to question the degree of agility to be achieved.

Is there a minimum degree of agility to achieve?

The degree of agility corresponds to the level of agility achieved by the supply chain to support the innovative product. It characterizes the gap between the initial supply chain and the expected agile supply chain and results from decisions implemented by supply chain companies.

The automotive supply chain is a good example to underline that. Within a lean supply chain, there are agile parts. Thus, it seems difficult to affirm that a lean supply chain has a degree of agility of zero or almost zero. The degree of agility seems to be influenced by contextual factors such as the size of the company, the sector or the competitive environment.

Thus, this raises the question of assessing the degree of agility:

- How to assess the influence of agility decisions on the supply chain?
- Is it possible to define the most “effective” decisions?
- Is it possible to estimate the level of agility achieved by a detailed action plan?

9.2.2.2 Strategic limits

a. Depending on the innovative company project team

The future supply chain is the result of the innovative company, the project team or the CEO which influences it in several ways:

By the skills at its disposal:

The skills of the innovative company play an important role in structuring the future supply chain. Indeed, if the knowledge necessary for the realization of the product is absent from the innovative company, several solutions are possible:

- Develop or acquire these skills internally through training, for example. This has little impact on the current supply chain;
- Integrate these skills externally through partnerships, subcontracting. This has a direct impact on the current supply chain.

A similar reasoning can be made in terms of processes, equipment and technologies. This highlights the importance of decisions in the implementation of the future supply chain.

By their decisions:

The results of our empirical study (Chapter 5) highlights that the implementation and the shape of the supply chain are decisions-dependent. For example, to integrate new skills within the supply chain, several solutions are available to the company: hire internally, subcontract or form a partnership. Thus, the obtained supply chain will not be the same according to decisions. This shows the unicity of each supply chain. However, this complicates the supply chains anticipation because the result depends of the project team/ CEO’s choices.

Knowing this, it is important to understand the CEO’s strategy when collecting data to provide action plans adapted to the company.

By the relevance and the accuracy of the information within their reach:

During product design, uncertainties arise regarding the future supply chain in terms of processes, skills or technologies. This information is not always available, which impacts the future supply chain. The more precise the information is, the easier it is for the innovative company to shape the future supply chain. However, it is important to translate this information into usual industrial language to ensure that skill, process and/or equipment requirements are available within companies to manufacture the product.

b. Unclear boundaries between activity decisions and supply chain decisions

As the instantiation tasks require a set of data, it is possible for us to determine two sets of data collected: an historical one concerning the present supply chain and a prospective one concerning the design of the future activity (products, business models, the launching...). These two sets have a common intersection, including particularly decisions (concerning activities/processes, skills and equipment, partners among others) common to both sets. Indeed, both the product and the supply chain are the result of decisions. Therefore, the data are interrelated: decisions about the product have an impact on the future supply chain and inversely. Studying this interrelation gives information about the predictability/unpredictability of the supply chain.

However, the boundary between activity-oriented decisions (i.e. strategic, tactical and operational decisions involved in the organization of the company following the innovative product development) and supply-chain oriented decisions (i.e. strategic, tactical and operational decisions involved in the implementation of the supply chain—see, “Framework to implement an agility strategy”) remains unclear and can be influenced by the CEO’s willfulness, i.e. his willingness to have a vision beyond the boundaries of his company. For example, it is not always easy to determine whether the choice of subcontracting is an activity-oriented decision or a supply chain-oriented decision.

Thus, the willfulness of the top manager is questioned and the framework (to implement an agility strategy) gives us information on this subject to identify if the decision is supply chain-oriented. Indeed, it is possible to see whether decisions concern supply chain or innovation process. For example, Company D’s decision not to manage the process on the layers had an impact on the supply chain.

In addition, it can happen that the strategies implemented in the innovation process have an impact on the supply chain. Indeed, for example, the decision to integrate company X into the innovation process also had an impact within the supply chain.

However, even with the framework, it remains difficult to identify the CEO’s intention behind a decision. It seems relevant to know the importance of the company manager to the supply chain to determine the direction of the decision.

c. Temporality of decisions

To elaborate our framework, one base is the breakdown of Ansoff's decisions:

- Strategic decisions: long term
- Tactical decisions: medium term
- Operational decisions: short-term

We have defined strategic decisions as decisions leading to the development of the characteristics of an agile supply chain.

According to (Vonderembse et al., 2006), a supply chain needs to be agile during the introduction and growth of an innovative product. So one question is the period when the kind of problematic we treat is accurate? More precisely, when do designers consider the problem of supply chain, during the project, after the project, during what period?

d. Assessment of the impact of decisions and derivation from the target supply chain

Within this research, only successful decisions are observed for several reasons:

- To understand the intentions of innovative companies during the new product supply chain design;
- To generalize the perspectives to consider during a supply chain development.

In addition, top managers rarely talk about their strategic mistakes or ineffective decisions.

Therefore, understanding why some strategies do not have the desired effect on the supply chain can also be a path to follow (Marche et al. 2017). For example, defective Swatch products have enabled new products to be improved. The importance of feedback can lead to unpredictable and positive results for the company and the associated supply chain.

However, it's difficult to assess the impact of decisions on the supply chain. Indeed, a decision can have different effects depending on the supply chain according to the context, the changes (weak or strong) that it operates in the supply chain, the influence of the company in the supply chain, the market targeted among others.

Hence, at the present time of our research, it's difficult to estimate if one decision is more advantageous than another.

Moreover, if a company encounters difficulties in implementing the supply chain scenario it has chosen, it is difficult to know the effects of a derivation of the supply chain. This can have an impact on its agility, on the value it generates, which requires indicators.

9.2.2.3 Functional limits

a. Data collection limits

A supply chain representation sensible to data collection:

The model of the supply chain is instantiated with data collected and observation outcomes. In some cases (such as case D), empty boxes within the model, i.e. the emergence of missing information, highlight the project team's questions, doubts and information lacks. Our case studies have highlighted that the lack of information can concern: the type of stakeholders on the market, industrialization of the process, production capacity with this process, relevance of skills among others.

As a result, even the lack of data provides information to the researcher, it indicates uncertainties regarding the supply chain and therefore difficulties to anticipate when launching the product. Hence, this model is interesting for collecting "functional" information.

Difficulty to obtain raw information:

The data collection is based on interviews, exchanges with the project team, and documents like the project report. The data obtained is not "raw", as a consequence our supply chains models are influenced by the project team's perception. In order to obtain relevant and reliable data (i.e. factual data), a long observation protocol is necessary and used in our research. In addition, depending on the case to study, immersion within the project team is necessary in order to better understand the subject.

b. Limits of data treatment

Difficulties with very specific product/supply chain couple

The information collected has to be processed for modeling purposes. We have chosen to rely on the databases provided by the *Pôle Emploi* to present our results in "usual" language. As previously presented, the data from the "Pole Emploi" are used as a reference to describe the main tasks associated with the most common processes in companies.

However, some processes concern very specific skills and tasks (cases C and D for example) and the *Pôle Emploi* database does not allow them to be addressed. It is rich but very generic. Therefore, with this database, we can sometimes consider that:

- Two actors have identical or complementary tasks due to the description of tasks is too generic;
- A stakeholder of the supply chain has to evolve or stabilize in the context of a global evolution of the supply chain, whereas a more detailed analysis would highlight evolution within the tasks of each stakeholder.

Hence, this database is not sufficiently complete and precise to model a "realistic" supply chain. In addition, as in data collection, the researcher has to acquire knowledge on the subject to translate the information as best as possible.

c. Limits of visualization

A graphical visualization:

The amount of information needed to characterize a supply chain requires step-by-step collection to describe the supply chain as accurately as possible. Consequently, the instantiated supply chain model is interesting to study the supply chain at a precise moment even if instantiation does not reflect the dynamic nature of a supply chain. Indeed, product flows and exchange between companies are difficult to visualize: one sheet of the model corresponds to a static moment in the supply chain. That's why, the instantiated supply chain model is coupled with DSM/DMM matrices and System Engineering to describe the supply chain and its behavior.

Moreover, for long and/or wide supply chains, the modeling of information collected via this instantiated model during interviews is spread over many pages: one sheet per process. Therefore, the more processes there are, the more sheets there are: the description of the supply chain can be compared to a stack of sheets whose sequence is not obvious. Therefore, the model can quickly become unreadable. In this case, we propose to decompose the supply chain to focus on the study of processes and stakeholders impacted by innovation.

A static visualization:

Engineering results highlight future product supply chain requirements in terms of stakeholders or manufacturing processes. As a result, it can be seen whether stakeholders already involved in the current supply chain are mastering the new processes to be integrated. Consequently, engineering leads to an inventory of what the supply chain needs to manufacture the future product and deliver it to the market.

Therefore, supply chain scenarios do not reflect the dynamic aspect of a supply chain, which is reinforced by the use of diagrams to describe it.

The dynamic aspect comes only from the possibility of supposing certain new processes leading to the construction of as many models as technological evolution scenarios, i.e. supply chain scenarios.

9.2.3 Conclusion

These several contributions help to make the link between theory, and reality operated at the present time by the researcher. From the company's point of view, these contributions seem to have an implicit educational aim because they encourage companies to ask themselves questions about the functioning of their supply chain and how they act or react within it.

However, the study of these contributions shows that a generalization seems difficult at the present time, the context being an important factor in any analysis of the supply chain. For this reason, we propose a pragmatic study of the supply chain in the following section.

With regard to the work carried out within this thesis, we propose a general analysis based on two findings.

Generalizability of the approach:

This research shows the importance of product/supply chain co-design for manufacturing products. Our analysis led us to identify some contextual elements limiting a generalization of our approach. However, a generalizability of our approach is possible: what type of innovation can be analyzed in this way? For what type of supply chain?

Thus, we propose a generalizability for:

- Complex technological products, i.e. products including high-technology components, new knowledge involved in production and several producers working together simultaneously (Hobday, 1998) in order to essentially remove the technological obstacles at the supply chain level and the uncertainties impacting the future industrialization of the product;
- Predictive or non-predictive supply chain. In the case of a non-predictive supply chain (because of changes in context due to the presence of other supply chain) and uncertainties in the supply chain, it is necessary to make more scenarios and constantly update models (see Figure 65).

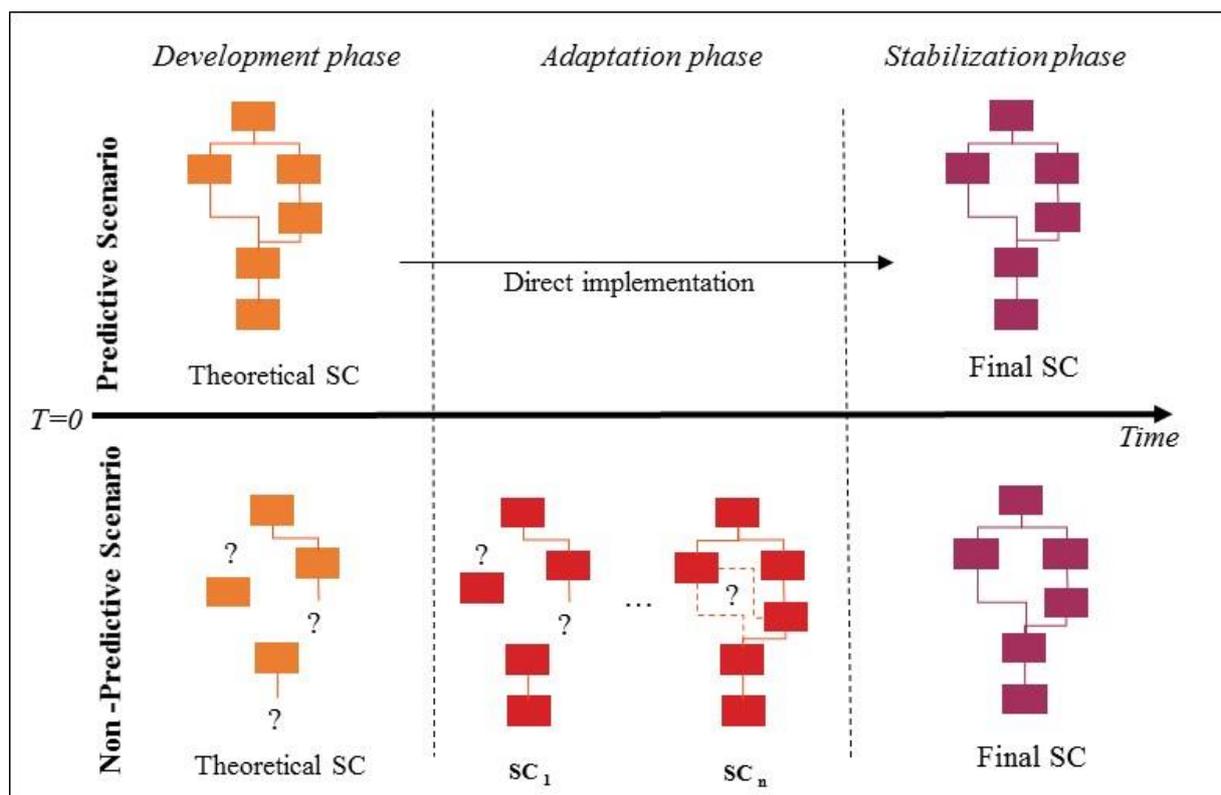


Figure 65: Predictable and unpredictable new supply chain

Considerations of changes and evolutions:

Our research problem was based on 6 statements. The first two emphasizing the uniqueness of the supply chain and its characteristic components have been clearly highlighted in this document. Nevertheless, clarification is needed regarding the other 4 statements, namely:

- Every product has its own supply chain and this couple is unstable and evolutionary;
- An innovation leads to a modification of the supply chain;
- Product/supply chain has a double dynamic influence;
- The product/supply chain couple has to adjust.

The results in the form of diagrams “freeze” the supply chain whereas we consider the supply chain as a system in constant evolution.

The flexibility needed to describe a supply chain is more about the method than the support of the results. Indeed, our engineering makes transformations possible: it is easy to add information on the initial supply chain already modeled to characterize the changes operating within the supply chain. The round trips between the stages are facilitated. Moreover, when modelling the supply chain, the software used encourages us to revisit the steps in chronological order (from requirements to behavior) in order to obtain robust and consistent results. This ensures a reflection on the supply chain but can take time.

9.3 Some concept to integrate with the supply chain research studies

9.3.1 Is there a link between the newness degree of the targeted innovative product and the impact on the supply chain?

To analyze innovations, (Garcia and Calantone, 2002) propose making a level distinction on two dimensions, namely at the micro and/or macro level and at the marketing and/or technological level:

- The macro versus micro perspective: from a macro perspective, the characteristics of innovation, its impact and its innovative character are new and felt by the world, the industry or the market. From a micro perspective, innovation has to be seen as new to the company or its customers;
- Marketing versus technological discontinuity: from a marketing perspective, an innovation may require new markets to evolve and/or new marketing skills for the company. On the other hand, it may require a paradigm shift in the science and technology used in the manufacture of the product, new R&D resources and/or new production processes for the company.

Based on this analysis scheme, (Garcia and Calantone, 2002) propose a classification of innovations (Figure 66) based on combinations of elements of these two dimensions:

- Radical innovations: these are innovations whose introduction results in discontinuity at macro and micro levels, as well as technology and marketing;
- Really new innovations: they produce either a marketing or technological discontinuity at the macro level but not both simultaneously and at the micro level any combination of marketing and/or technological discontinuity;
- Incremental innovations: these are innovations that only produce discontinuities at the micro level by affecting marketing and/or technology.

Thus, highly innovative products will be classified as radical innovations, moderately innovative products as really new innovations and weakly innovative products as incremental innovations (Assielou, 2008).

Inputs*: Discontinuities				Outputs: Innovation Type		
Macro-Marketing Discontinuity	Macro-Technology Discontinuity	Micro-Marketing Discontinuity	Micro-Technology Discontinuity	Radical Innovation	Really New Innovation	Incremental Innovation
1	1	1	1	1	0	0
1	0	1	0	0	1	0
0	1	0	1	0	1	0
1	0	1	1	0	1	0
0	1	1	1	0	1	0
0	0	1	1	0	0	1
0	0	1	0	0	0	1
0	0	0	1	0	0	1

*note: other combinations are not feasible, if an innovation results in a discontinuity on a macro-level, the discontinuity will also occur on a micro-level.

Figure 66: Typology of innovation (Garcia and Calantone, 2002)

Considering this approach to evaluate the newness degree of a targeted innovation, it could be hypothesized that the nature of the innovation has implications for the structure of the associated supply chain. Radical innovations impact the company's environment, including its supply chain, which will have to adjust to evolve towards new markets **while** integrating changes resulting from the adoption of new technology. This is the situation in cases A and C. Really new innovations see their supply chain adjusted to evolve towards new markets **or** transformed to integrate new technology. This is the situation in cases B and D. Finally, the supply chain of incremental innovations essentially evolves **locally** at the level of the company or its relationship with its customers. So perhaps, the transformation of the supply chain may be less important.

Thus, more research has to be driven about the intensity of the changes within the supply chain considering the newness degree.

9.3.2 How to define the supply chain limits?

The delineation of the supply chain is often fuzzy and depends on the way in which the top management perceives it. Definitions in the literature focus on the elements that make up a supply chain, but few elements are proposed regarding its delineation. All the appellations (French *filière*, supply chain or Global Value Chain) do not provide any details on this point.

9.3.2.1 **An inaccurate definition of the supply chain boundaries**

Several delineations can be envisaged according to the needs of our analysis: organizational, structural and in terms of complexity.

Organizational delineation leads to a subdivision of the system into subsystems. One subsystem is autonomous and can be considered independently of the rest of the supply chain (Lorino 2003) while being a constituent part of the system. An example of a subdivision is a description of the supply chain stakeholders in terms of their roles within the supply chain: suppliers, distributors, manufacturers, and so on. Thus, the supply chain can be delimited thanks to the rank of the stakeholders in relation to the focal company (tier 2 suppliers, tier 1 distributors for example).

Structural delineation makes it possible to identify boundaries based on artefacts. To determine the upstream limit of the supply chain, initial artefacts have to be identified. Depending on the study approach, a raw material may be the first point of entry. By choosing to include or exclude activities, the supply chain draws its contours. It should be noted that these outlines are quite malleable and specific to each supply chain. Finally, the internal structure of the supply chain will depend on production processes (Trognon, 2005). This approach remains fuzzy as many artefacts need some sub compound associated with long supply chain. Is it for example necessary to describe the steel supply chain when describing the automotive supply chain?

At last, (Mentzer et al., 2001) proposes to delineate the supply chain according to its degree of complexity (Figure 67). According to him, a supply chain is direct if it is composed of a company, a supplier and a customer involved in upstream and/or downstream flows. This approach is used among others in the automotive sector where suppliers are defined upon their positioning (range) towards the assembling company. A supply chain is defined as extended if, in addition to the direct supply chain, it includes suppliers of the direct supplier and customers of the direct customer. Finally, an ultimate supply chain encompasses all the organizations involved in the upstream and downstream flows from the ultimate supplier to the ultimate customer.

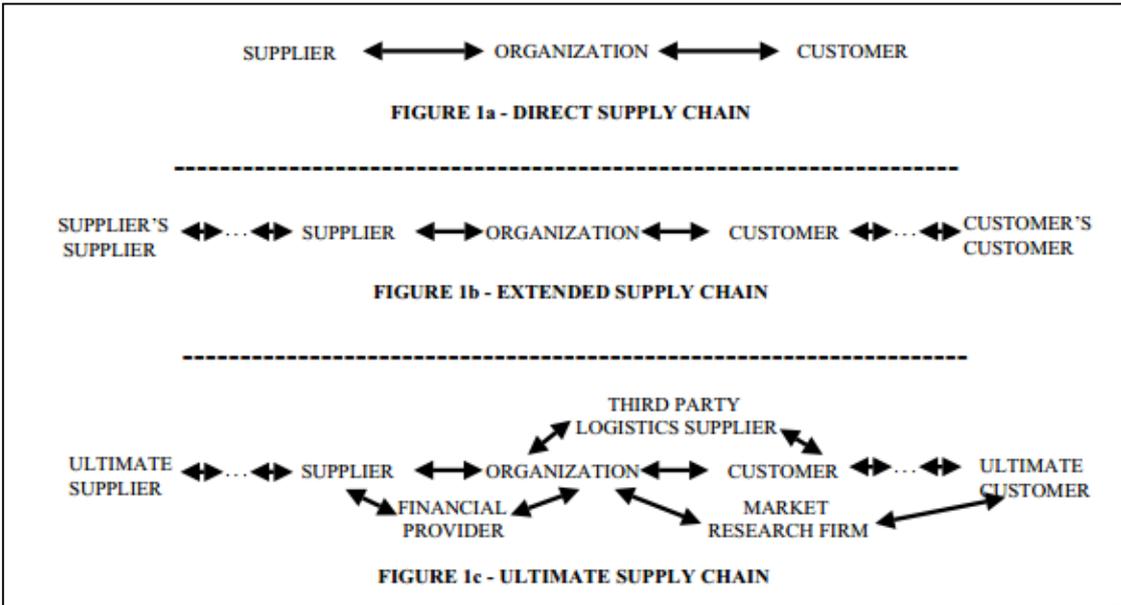


Figure 67: Delimitation of the supply chain in terms of complexity (Mentzer et al., 2001)

But all these criteria are difficult to apply in practice. In the case of company A, a plastic injection machine is used. When describing the supply chain, is it necessary to consider the suppliers of the machine as its design influences the performance of company A? The same uncertainty remains considering all software used by members of a supply chain. Priorities have to be applied to filter data, among others:

- The specificity of the inputs and the related stakeholders considering the project. A supplier of equipment will be integrated in the supply chain if this equipment is typical of the process of the future product;
- The impact on the value creation. It is proposed to focus on inputs, outputs and relating stakeholders that have a higher position in terms of value creation;
- The involvement of the stakeholders within the supply chain. It is proposed to focus on stakeholders whose participation in the supply chain is frequent and active.

9.3.2.2 The supply chain as a succession of value chains within an extended value chain

Each company has its own value chain (Porter, 1986). A supply chain is a succession of companies linked by flows, so the value chain of a company is linked to other value chains. The supply chain is defined as an extended value chain, connecting the value chains of the companies that make it up: the final value is the sum of these values (Trognon, 2005). Hence (Lysons and Gillingham, 2003) point out that there are few differences between the vision of the supply chain and the notion of the value chain developed by (Porter, 1986). As a result, a supply chain may be considered as a macro value-generating activities chain composed of micro value chains (at company level) (Heeramun, 2003; Hines, 1993).

9.3.3 The influence of the company size and the global supply chain size?

The size of the innovative company or the supply chain impacted by innovation is descriptive variables whose importance is questioned.

9.3.3.1 Size of the company

Research on Small and Medium-sized Enterprises has been based for more than thirty years on a paradigm of specificity (Churchill and Bygrave, 1989; Fillion, 1997; Marchesnay, 2016): a SME is not a reduction of the large enterprise, but an entity endowed with very specific functional and theoretical attributes. The paradigm of specificity is based in particular on the concept of “small structure” proposed by (Julien, 1990) that can be characterized as follows:

- A small size (refers to the company’s workforce);
- A centralized management;
- A low specialization of trades;
- An intuitive and short-term strategy;
- A simple and informal information system (internal and external);
- A local market.

Considering the concept of small structure, a problem arises when one identifies a company that does not respect any of these characteristics apart from small size: the SME is denatured

(Torrès and Julien, 2005). The denaturation considers that “small size” does not necessarily mean “small structure”, i.e. that a company with a small workforce can nevertheless “copy” the practices of large companies by implementing formalized management methods, decentralized management, defining a proactive strategy or expanding its market internationally among others. Then, this company is close to a “large miniature company” (Enjolras, 2016) although it remains more sensitive to environmental hazards and may be more vulnerable.

The design and implementation of a supply chain depend on the decisions taken by top managers. The innovative company’s ability to transform and govern the supply chain of its innovative product may be influenced by the size of its structure, but this is not necessarily a limiting factor: it is important to consider this company in its context (its sector for example).

It is difficult to determine whether an innovative SME needs to provide more energy to implement an agility strategy than a large enterprise. No proposition can be found in the literature. Perhaps the mastery of an extended functioning (division by service, mastery of digital tools, delocalized management for example) characteristic of large companies associated with easy access to resources (human or technical) may suggest that the latter have more facilities to transform or design the supply chain best suited to their innovative product. This hypothesis deserves to be studied in more depth on a panel of companies.

9.3.3.2 Agility and the size of the supply chain

The way to approach the supply chain depends on its size (considering that its boundaries are fuzzy—see 9.3.2.1). Indeed, an innovative company adapts its strategy according to the size of the global supply chain in which it evolves: an innovative company does not have the same impact within the supply chain of an electronic sensor as in the supply chain of an automobile. Case D is representative of this phenomenon, where the innovation developed has a strong impact on the ABS technology supply chain and a weak impact on the automobile supply chain.

The size of a product’s supply chain is directly linked to the diversity of its components and their numbers, but also to the number of processes involved in manufacturing the product.

Consequently, the large supply chain can be divided into sub-supply chains where these sub-supply chain corresponds to the supply chains of components.

Thus, the innovative company within one of these sub-supply chains focuses on the transformation of the supply chain of the component on which it operates, its actions are more localized and it has no control over global supply chain. As a result, agility decisions are often localized and restricted to the supply chain of the innovative product in question. Then, a global supply chain can be lean with agile ramifications.

More generally, we suggest that the classification of a supply chain as lean, hybrid or agile is possible even if parts of these supply chains belong to another category. A hybrid supply chain may for example contains lean sub supply chain. Hence, in case D, the sensor supply chain is an agile part of the lean automotive supply chain.

In our research, we consider that a supply chain is “**autotomous**”, by analogy with the phenomena observed with the lizards. Autotomy is the ability of some animals to lose a part of their body voluntarily. It is a defense strategy in a hostile environment. As part of a global supply chain, under the impetus of an innovative company, the corresponding sub-supply chain can be completely restructured, becoming more agile in order to adapt to the innovative product and thus becoming more efficient without having a strong impact on the rest of the supply chain. It is a so-called “Lizard theory” of the supply chain transformations.

9.3.4 The supply chain governance?

Every supply chain has its rules, so the governance can be applied in different ways:

Governance linked to the company’s ability to launch innovation:

The influence is linked with the capacity to launch innovations regularly. An innovative company boosts the supply chain and plays an essential role in the evolution of the supply chain. Thus people deciding to launch a new product may be considered as innovation decision makers both in their company and their supply chain.

In the case of volatile markets, the innovative company stimulates a dynamic by the development of its innovative products and by the induced supply chain modifications. This is particularly the case for supply chains supporting NICT-type products. In our research, it is possible to consider that company C governs its supply chain through regular launches of innovative products and through its associated strategies.

Governance linked to the regulatory authorities:

Regulatory authorities have a great impact on the coherence between the new product and the supply chain because of political legitimacy. They are concerned with designing environmental and safety constraints, among others. They can be considered as part of the governance of the supply chain.

Several cases can be highlighted:

- Patent filing that limits the use of technology, as is the case for seed;
- Government laws that impose constraints, as is the case for CO₂ emission for motor vehicles.

In this specific case, it is difficult to discuss direct governance because these external actors do not intervene in the supply chain, but they do have an impact on the organization of the supply chain by favoring certain know-how or certain standards, for example.

Governance linked to the position of the innovative company within the supply chain:

To create a value proposition for the end customer, companies upstream of the supply chain have to collaborate with companies downstream (Gandia and Gardet, 2012). As the latter are in contact with the market, they have greater negotiating power (Fonrouge, 2007). Obviously, the negotiating power depends on the number of stakeholders in the supply chain and reflects the company's influence on the supply chain. In the case of manufacturing companies, the companies in direct contact with the end customer may have more influence in the supply chain. Their positions are more appropriate to satisfy customer needs. This is the case, for example, in the automotive industry, where manufacturers influence the entire supply chain. However, there are cases where suppliers have a quasi-monopoly position and influence the supply chain significantly, as is the case for steel, chemical input or seed.

Consequently, the position of the innovative company in the supply chain has an impact on its structure and strategy. In fact, an innovative company will have to implement an agility strategy to limit its dependency and create more value. Note that the degree of dependence within a supply chain does not depend solely on the position of the innovative company. The resources, skills, size or proposed technology will influence dependency relationships.

9.3.5 The role of the company's experience?

Companies can be classified into four categories reflecting their attitude towards their environment: proactive, preactive, reactive and passive (Morel, 2007; Galvez, 2015). These attitudes are described as follows:

- **Proactive:** They are the most dynamic and offensive companies. They set up operations to induce change in their market. They have a long-term vision, by adopting a proactive strategy and a proactive attitude. They manage a network of innovation specialists. A substantial part of the turnover is achieved with new products. They have a very strong capacity to innovate because their management is a basic business in the company.
- **Preactive:** They are companies that do not induce change but anticipate it by developing an elaborate monitoring system. They have a medium-term vision and adopt an offensive attitude. They have staff and an organization designed to design products/services/processes.
- **Reactive:** They are companies that expect the changes to react. They are subject to external changes, and they do not anticipate changes. They have a short-term vision and therefore a defensive strategy of adaptation to the environment. They launch activities adapted to the new environment and they know how to organize staff to develop new products/services. They are never the first on the market.
- **Passive:** They are the companies that are in a survival situation in their environment. They do not anticipate change and are not able to react adequately. They have a vague

strategy or do not integrate innovation and develop, in fact, a defensive attitude. They are undergoing changes in their environment. They have a very low capacity to innovate, and they are mainly in adaptation.

As a result, it could be hypothesized that a company with a strong capacity to innovate is better able to transform and design the supply chain scenario best suited to its innovative product, in particular because of its experience. Indeed, an innovative company is often more regularly confronted with supply chain problems. It may be therefore better able to implement appropriate practices leading to the development of a supply chain. Thus, an experienced company in terms of innovation seems to have a positive influence in the implementation of a supply chain and the corresponding agility strategy, as is the case of the company C.

In addition, a supply chain whose members regularly work together to develop new products can be considered as experienced supply chain. Thus, it seems that the implementation of practices designed to transform the supply chain when launching an innovation is easier. Therefore, it is questionable whether the experience of a supply chain and the attitude of the company influence the pre-diffusion phase, i.e. the length of time the supply chain has to be agile to support the launch of its innovative product.

9.3.6 The role of the competitive environment?

A key feature of today's businesses is the idea that it is supply chains that compete, not companies (Christopher 2016) and the success or failure of supply chains is ultimately determined in the marketplace by the end consumer (Christopher and Towill 2001). Thus, within the same so-called industrial sector, there are several competing supply chains offering closely substitutable products.

The Positioning School, to which Michael Porter belongs, focuses on creating a competitive advantage that means finding a positioning that distinguishes it from its competitors. Heir to the industrial economy, Michael Porter proposes a systematic method of structural analysis of industry and competition (Porter 2008). This method, called the Five Forces of Porter (Figure 68), is essential for studying the structure of a sector, i.e. the nature and intensity of the competitive forces that determine its long-term profitability (Lehmann-Ortega et al., 2016). In this case, the term "structure" refers to the SSP paradigm of the industrial economy (see Chapter 2).

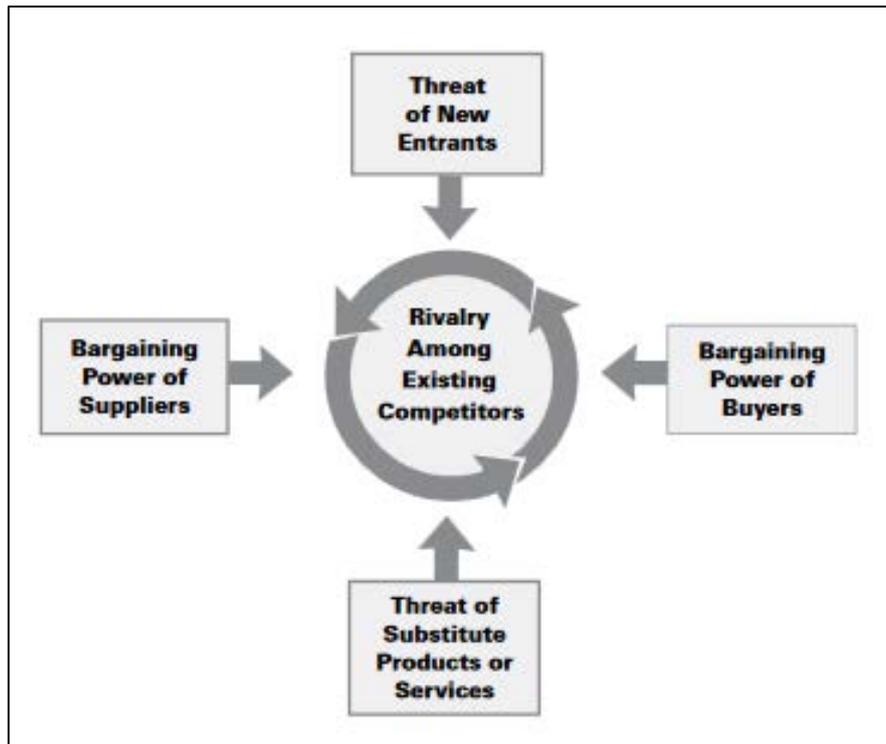


Figure 68: The Five Forces of Porter

Each of Porter's forces is detailed below based on the analysis provided by (Lehmann-Ortega et al., 2016) in the book "Strategor". This book, very popular in France, was written by academic and professional authors (consultants, managers and business leaders) in order to effectively combine theoretical knowledge, operational methods and real business cases. Of course, many authors have exploited Porter's work and illustrated it with business cases studies. However, we chose to adapt their analysis (which focuses on the company) to the supply chain in order to support a more pragmatic reflection on our research.

9.3.6.1 Intensity of the rivalry among existing competitors

The intensity of rivalry between existing competing supply chains is a strong determinant of a sector's profitability (Lehmann-Ortega et al., 2016). There are several criteria that promote the profitability of a supply chain:

The concentration of the sector

In our research, concentration consists in reducing the amount of supply chains for a given product. As a result, the higher the concentration is, i.e. the fewer competitors there are, the higher their market shares, the less intense the competition is, and therefore the more profitable the sector is (Lehmann-Ortega et al., 2016). For example, in the generic drug sector, small stakeholders are not able to compete with large companies in the sector. This is due to pharmacists choosing only two suppliers and rarely changing them (Lehmann-Ortega et al., 2016). Consequently, there is little supply chain competition.

Therefore, we can deduce that the agility strategy and associated actions implemented to design the supply chain depends on the concentration of the sectors.

The growth of activity

In a market in recession, strong tensions can arise between supply chains of closely substitutable products. These tensions are minimized in fast-growing markets. In mature sectors such as the automotive industry, there is intense competition between supply chains impacting their profitability (Lehmann-Ortega et al., 2016).

Therefore, the strategy adopted will depend on the growth of the activity. A market in deep recession may require a leaner supply chain in order to be competitive in terms of price and margin, while a market in strong growth will allow the supply chain to develop without seeking to lower prices and therefore without seeking to eliminate non-value-added stages.

The diversity of competitors

The supply chains present in a sector can be very similar (automotive for example) or, on the contrary, very different, because of their technological or sectoral origin, their size or their geographical location (Lehmann-Ortega et al., 2016). The more similar the supply chains are, the more collusive behavior tends to manifest itself, which favors the profitability of the sector. Collusive refers to tacitly coordinated strategies that give priority to profitability over competitive confrontation (Lehmann-Ortega et al., 2016).

In the 1950s and 1960s, the automotive market was segmented between Peugeot, Renault and Citroën, each brand producing cars with different characteristics. The openness to imports has destabilized this segmentation and weakened national manufacturers without eliminating collusive behavior (Lehmann-Ortega et al., 2016).

Therefore, supply chain behavior varies according to the diversity of competitors and the strategy adopted depends on the sector targeted.

The product differentiation

Product differentiation results from objective and subjective factors that limit product substitutability to the customers. It can be a brand, an after-sales service or physical characteristics of a product (Lehmann-Ortega et al., 2016). Therefore, product differentiation leads to supply chain differentiation. If this differentiation is strong, competition is monopolistic, i.e. each supply chain seeks to develop a mini-monopoly in a particular market segment. Then differentiation makes each supply chain unique and leads to improved profitability for the sector. For example, highly differentiated product supply chains such as luxury products are generally more profitable than paper or agricultural supply chains, even at equal concentration (Lehmann-Ortega et al., 2016).

Therefore, in our research, an agile supply chain offering product differentiation can limit the emergence of competing supply chains, so the implementation of an agility strategy can attenuate the intensity of competition.

In addition, differentiation has another positive effect, it also reinforces barriers to entry. A new supply chain will find it difficult to offer a different product in a sector where offers are

already highly differentiated (Lehmann-Ortega et al., 2016). Therefore, the design of an agile supply chain seems better suited to integrate sectors where products are highly differentiated, in particular by favoring a strong sensitivity to the market.

Moreover, in the case of a weak differentiation of the products supplied, the buyer may put his suppliers in competition. The buyers of standard products are therefore in a strong position. In the case of strong differentiation, it is difficult to substitute one product for another, which confers power on suppliers. For example, the automotive suppliers are striving to regain bargaining power by offering manufacturers high-value-added systems, as is the case for company D (Lehmann-Ortega et al., 2016). Therefore, product differentiation can influence supply chain governance and its typology.

9.3.6.2 Threat of new entrants

Within a sector, potential entrants may appear. If they can enter without difficulty, the competitive intensity will increase and the level of profitability of the sector will decrease. The higher the barriers to entry, the more likely the sector is to be economically profitable and the more sustainable supply chains in the sector can be.

There are several types of entry barriers:

The entrance tickets to the sector

The level of investment required to integrate the targeted sector is a first barrier to entry. Indeed, the higher the level of investment is, the more difficult the barrier to entry is to cross (Lehmann-Ortega et al., 2016). As a result, it is possible to assume that a supply chain including a large group will find easier to develop a product within an existing and highly structured sector than a supply chain including a start-up. Conversely, the supply chain including a start-up could develop a new product within an early-stage sector in which there are a variety of technological solutions or industrial choices. For example, investments in flat screen manufacturing units (like Sony or Samsung) are very high, which constitutes an important entry barrier and secures the supply chains already in place (Lehmann-Ortega et al., 2016).

Therefore, the size of the innovative company, and implicitly its functioning, can play a role in the design and the implementation of a supply chain for a new sector. If, this company has great and powerful position in this supply chain.

Economies of scale

A supply chain is subject to economies of scale when production volume is a significant factor in reducing unit costs. As a result, economies of scale create a barrier to entry as they confront new potential supply chains with a dilemma (Lehmann-Ortega et al., 2016):

- Either they enter with a reduced volume and higher unit costs than competing supply chains;
- Either they invest massively to minimize the unit cost by risking a very strong overcapacity before capturing enough demand.

This is particularly the case for the construction of large airlines, whose economies of scale linked to R&D discourage new entrants.

Note that experience can be considered. The case of the Xbox is significant, Microsoft had to sell at a loss for years to obtain sufficient volumes and face the low prices imposed by Sony and Nintendo. Indeed, by producing on a large scale, competing supply chains accumulate experience and develop productive, technical and commercial know-how (Lehmann-Ortega et al., 2016) that allows them to have lower costs than a new supply chain.

Hence, economies of scale can influence the typology of the supply chain and can lead to the implementation of supply chains with a high investment capacity. Thus, it would seem that an agile supply chain is not adapted to overcome economies of scale.

Cost advantages independent of size

In some sectors, regardless of economies of scale, existing supply chains have lower costs because they have managed to capture the least expensive raw materials or because their history in this sector makes copying their competitive advantage difficult and costly for new supply chains. As a result, it is more difficult for a new supply chain to reach the same level of competitiveness in the short term as supply chains that have been in place for many years (Lehmann-Ortega et al., 2016). A new supply chain wishing to offer a product similar to Coca-Cola would incur prohibitive costs that would make it vulnerable.

Consequently, cost advantages independent of size can lead to the implementation of a supply chains with a high investment capacity.

Access to distribution networks and suppliers

A new supply chain may have difficulty accessing the networks of suppliers and distributors in the targeted sector. Indeed, certain distribution or supply networks may have exclusive contracts with competing supply chains.

For example, ArcelorMittal has a monopoly on steel which complicates the emergence of a new supply chain integrating other steel suppliers.

Therefore, the design and implementation of a supply chain can be affected by the difficulty of integrating a network of suppliers and distributors. Thus, it can be difficult to integrate a sector where distribution and supplier networks have exclusive contracts within competing supply chain.

9.3.6.3 Threat of substitute products

Substitution consists in replacing one product by another, which fulfills the same function of use. The substitute product should not be confused with a new entrant. However, the pressure of substitute products in terms of the supply chain is quite similar to the threat of potential entrants: it limits prices, i.e. the pricing policy is more constrained. In addition, technical innovations can influence the emergence of substitute products and thus the emergence of

new supply chains. For example, smartphones and tablets are beginning to replace computers and are also threatening Nintendo and Sony game consoles (Lehmann-Ortega et al., 2016).

Therefore, the innovation strategy and the associated supply chain strategy can limit the emergence of substitute supply chain within a sector.

9.3.6.4 Bargaining power of suppliers and buyers

A supply chain is structured around the bargaining power of stakeholders. The outcome of this negotiation depends directly on the balance of power between buyers and sellers. The analysis of the bargaining power of suppliers and that of buyers are symmetrical so they will be confined within our research.

Several criteria are considered:

The relative concentration

In a supplier-customer relationship, the balance of power is established in favor of the most concentrated stage of the supply chain. Thus, within the sector, profit tends to migrate to the most concentrated stages. For example, a food store can easily put suppliers in competition, while conversely, a supplier has no interest in losing a contract with a food chain (Lehmann-Ortega et al., 2016).

Hence, the choice of suppliers or distributors can have an influence when designing the supply chain. Therefore, it is interesting to consider environmental elements to implement a supply chain scenario adapted to the innovative product.

The threat of vertical integration

The threat of possible vertical integration upstream or downstream creates a favorable power balance that improves the profitability of the supply chain. Indeed, the threat of integration consists in creating new competition, which is all the more credible on the barriers to entry in the upstream or downstream sector are low. For example, The Swatch Group has acquired well-known brands and is integrated upstream in the manufacture of mechanical movements for luxury watches. Thus, it supplies more than 60% of the movements used by Swiss watchmakers or major groups, which are therefore both its customers and its competitors. By threatening to limit component deliveries, Swatch forces its competitors to invest in the manufacture of mechanisms, increase their production capacity or buy component manufacturers (Leroy, 2012).

Therefore, the threat of vertical integration has an influence on the structure of the supply chain and on the typology of the supply chain (leading to a higher degree of agility for example).

The impact of input quality on output quality

The more decisive the quality of the input is for the buyer, the less price sensitive it is, which favors the supplier. For example, in the watch industry, major brands such as Hermès or Swatch are seeking to secure access to components (Lehmann-Ortega et al., 2016).

Hence, the structure of the supply chain and its typology can be influenced by the quality of the components necessary for the product. Governance can be moved within the supply chain depending on the quality of inputs required to manufacture the product.

The cost of replacing the partner

Replacement cost is a result of the two above factors and is measured by the expenses incurred by a change of supplier or distributor. A high replacement cost for a partner leads to greater bargaining power for that partner. For example, in the mobile telephony sector, customer transfer is facilitated by promotional offers provided by competitors and by number portability, but may be complicated by cancellation deadlines (Lehmann-Ortega et al., 2016).

Consequently, the structure and typology of the supply chain seems to be influenced by the cost of replacing a partner.

Conclusion of the Chapter 9

In this chapter, we seek to step back on all our results in order to study their benefits but also their limitations. For this reason, we also propose to deepen the benefits and limitations related to our study of the supply chain concept. We also go into deeper detail about the pragmatic aspects of our results. This does not question our work but it indicates that each new innovation project requires a thorough and personalized supply chain analysis. These different elements highlight the importance of context and environment in supply chain study.

Several ways of improvement are envisaged for our theoretical contributions and our engineering proposal. Our results have been tested with different manufacturing companies and the results obtained seem to attest to a certain robustness. However, we believe that our research could still be refined by expanding our fields of observation (to processing companies for example).

IN BRIEF

- The theoretical and methodological contributions seek to **clarify the different concepts** to make them accessible to businesses.
- The empirical contribution highlights the **complexity of our research**.
- The supply chain analysis can become a **tool** at top management disposal beyond an innovation context.
- Our research highlights **six supply chain design practices**: product/supply chain co-design, strategy, resource management, supply chain communication and capitalization.
- Difficulties in the implementation of the supply chain are due to **context**.
- Our research highlights the **presence of limitations preventing a generalization** of our work at the moment. These limitations are related to the nature of innovation, the size, the boundaries, the governance or the experience and the competitive environment.

KEY FINDINGS OF THE CHAPTER 9

In this chapter, we decided to overtake a critical perspective of our research findings in order to step back from our contributions and to propose perspectives for future research. As a result, the interest of supply chain analysis for the company is highlighted: it can be a useful tool for the company. Therefore, we propose some “best” practices allowing to implement a supply chain. However, the diversity of our case studies also underlines that the complexity of our subject interferes an eventual generalization of our engineering, the context being an important factor in any analysis of the supply chain. This chapter identifies the factors that we believe influence the implementation of the supply chain: the degree of novelty of the product, the boundaries of the supply chain, the size of the supply chain and the company, the governance of the supply chain, the company's experience in terms of innovation and the competitive environment in which it operates.

Overall Conclusion

1. Contributions

The assumption defended through this document consists in considering product design and supply chain design as two complementary activities within the innovation process. This suggests to co-design the product and the supply chain to anticipate the structure of the supply chain before the product is launched on the market. The supply chain structure results from the implementation of a specific strategy in order to have a supply chain adapted to the specifications of the innovative product.

Thus, this research work leads to a better understanding of the concepts of supply chain (structure) and agility (strategy). Our theoretical and empirical results are exploited and enhanced through the development of a supply chain engineering to encourage innovative companies to consider supply chain design as early as possible.

The design of the supply chain during the innovation process has to be considered as a new activity for innovative companies. Within the framework of the development of a new product, many tools are at the disposal of the companies to assist them in the different stages of the process. However, there are few tools focusing on supply chain design, so it becomes important to support innovative companies in their approach.

As part of our research, we propose to formalize the product and the supply chain simultaneously for several reasons:

- Check quickly if the technical choices for the product will be accessible within the supply chain at the time of industrialization;
- Have a clear vision of the different possible scenarios and determine which will be the most advantageous for the innovative company or for the current supply chain;
- Take into consideration as early as possible the external factors that could limit the product's chances of success when it is launched on the market;
- Anticipate the strategic actions to be implemented when designing the product to facilitate its industrialization and launch.

Thus, it seems relevant to link supply chain oriented-tools with product-oriented tools.

As part of our model-based supply chain engineering, we have chosen to use DSM and DMM matrices to structure product and supply chain design. This choice seemed relevant to us because these matrices allow us to reflect on the supply chain starting from the product specifications. They allow the product-supply chain transition to be initiated in a framed manner without loss of information. However, in our desire to model the supply chain in the form of a process, we have limited our matrices to product elements - manufacturing process - process. It is then possible to express and highlight the different design and manufacturing options.

Thus, this representation of information facilitates the modelling of different supply chain scenarios without loss of information.

When developing a new product, an innovative company is confronted with two situations concerning the supply chain:

- A transformation of the initial supply chain (increase in the degree of agility or mutation to an agile supply chain)
- A creation of the future supply chain.

To transform the initial supply chain, the innovative company must model the initial supply chain (either by breaking down the initial product, or through its knowledge of the supply chain in question) and the future supply chain in order to be able to compare them. The proposed engineering is indicated in both cases.

To create the future supply chain, the innovative company uses its product to design the appropriate supply chain. But if several scenarios emerge, the innovative company must be able to compare them.

Our work leads to obtaining these scenarios and allows a strategic analysis of the supply chain obtained. However, to become a real managerial tool within a company, this engineering can be completed with methods of comparison and evaluation facilitating decision making.

These methods of comparison belong to different perspectives: skills, market, stakeholders, activities, and environment. But these comparison methods must be supplemented by evaluation methods in order to estimate which scenario seems the most appropriate. This assessment can be based on the value created by each scenario, the social benefits of each scenario (i.e. the number of jobs impacted), the ease of implementation of each scenario (i.e. the valuation of relationships between companies already acquired) among others.

Thus, our engineering coupled with these different modalities would allow innovative companies to develop roadmaps and action plans in terms of supply chain. Supply chain design would then become a robust activity within the innovation process.

2. Perspectives

2.1. Managerial perspectives: interest of our research in the innovation management process

2.1.1. Description of the current French Innovation Management standard

The French Standards Association (AFNOR³⁹) has published a standard in Innovation Management, the FD X50-271 standards. This standard is based on an implementation guide for an innovation management approach in order to "define for an organization, actions, choices and structures within the framework of its general management, to promote

³⁹ Association Française de Normalisation

emergence, decide on the launch and successfully carry out its innovation projects. Innovation management actions and decisions are deployed at two levels of organizational responsibility: strategic innovation management and operational management of innovative projects.” (AFNOR FD X50-271 2013). In the guide of the FD X50-271 standard, the strategic and operational management of innovation is based on four engineering major areas to be implemented and coordinated to ensure the completeness of its management by companies (Huet-Kouo, 2015) :

- Marketing: knowledge of customer needs, knowledge of the market;
- Technology: expertise and innovation methodology;
- Legal, normative and financial: management of intellectual property, considering the normative framework and management of financial aspects;
- Management and organization: process management, resource management.

In order to describe the innovation process, the guide developed by the FD X50-271 standards represents it in the form of a synoptic diagram that aims to encompass all dimensions of innovation management. This diagram is described at two levels: a strategic level and an operational level. The third stage of the strategic level (project management) is the interaction between the strategic process and the operational process.

The original synoptic table of innovation management is presented in figure 69.

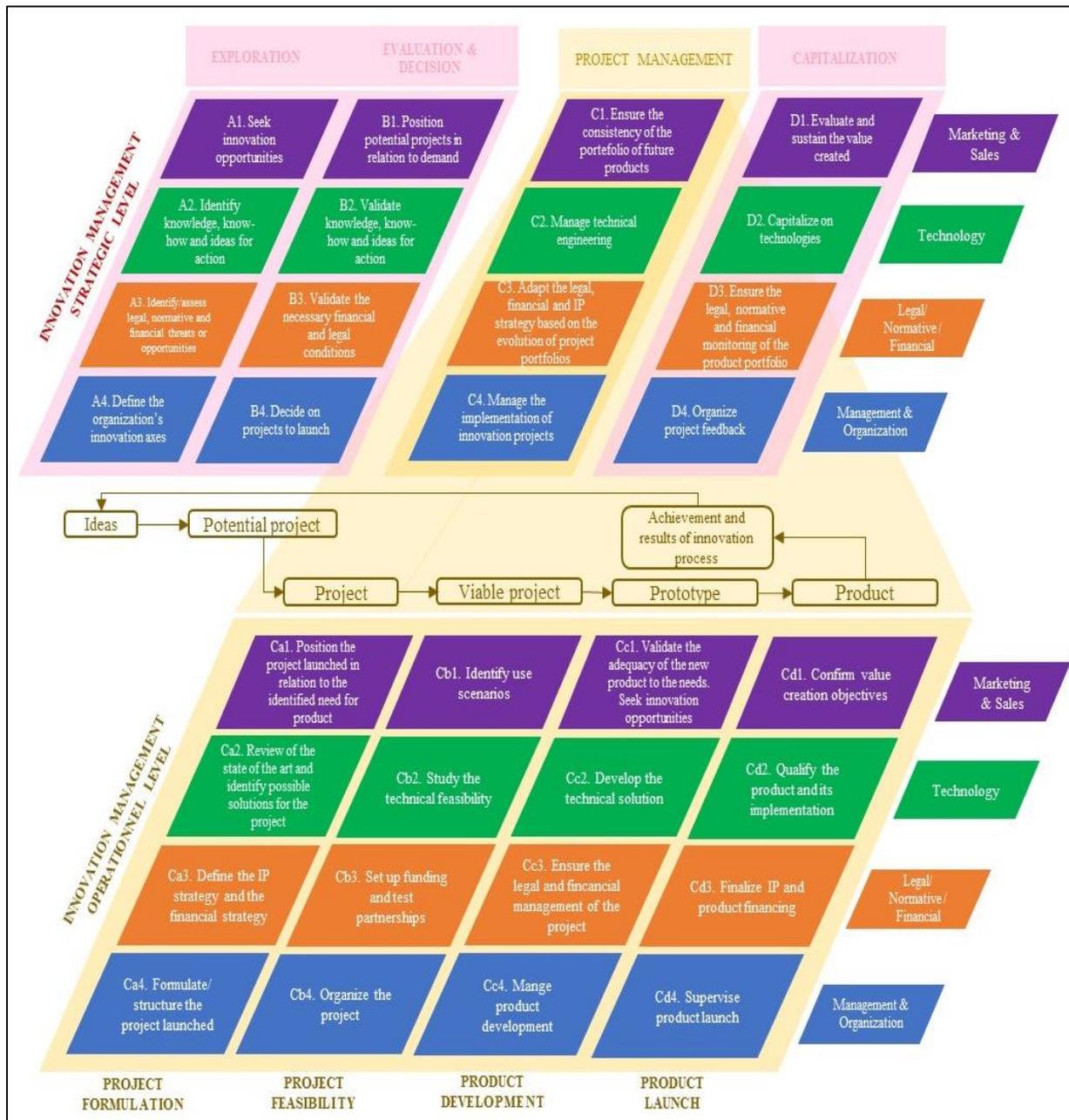


Figure 69: Synoptic table of innovation management (AFNOR, 2014)

Each task is declined in the form of “good practices sheets”, constituting a true “toolbox” of innovation management (Huet-Kouo, 2015). These activity description sheets explain why, how, with whom and with what, giving good practice for each activity to be carried out (Huet-Kouo, 2015).

2.1.2. Proposals for deepening the French Innovation Management standard

Our research proposes to integrate supply chain design activities into the innovation management process. We demonstrated that these design activities are linked to product design activities. Therefore, we propose to deepen the process proposed by the French Innovation Management standard by integrating activities related to the supply chain in order to support innovative companies in this process.

A. Strategic Innovation Management

Our research considers that strategic reflection of the supply chain can help to promote emergence, decide on the launch and successfully carry out its innovation projects. Within the scope of this standard, our strategic innovation management proposal in the supply chain area is as follows:

- Exploration: Identify the contextual elements for action

This step seeks to select by considering contextual data (sector, size of the company, size of the supply chain, competitive environment, experience of the current supply chain...) the opportunities that the supply chain(s) of the company can seize thanks to its potential (technologies, knowledge and know-how) or thanks to the external contributions that it is able to integrate.

- Evaluation and decision: Validate the contextual elements for action

This step seeks to have the best technologies, knowledge and know-how, under the best conditions, to enable the manufacture of its product and to be competitive with competing or substitute supply chains.

- Project management: Manage Supply Chain engineering

This step seeks to ensure the organization’s mastery of resources (human, technical) within the supply chain and their implementation, from the formalization of the innovative product to its launch and diffusion

- Capitalization

This step seeks to:

- Save the information provided by the supply chain analysis;
- Capitalize on the technologies, knowledge and know-how held by the supply chain companies in order to remobilize them in new projects;
- Enrich the databases (technologies, skills or know-how) for future innovation projects;

- Facilitate the design of future supply chains.

B. Operational innovation management

Our research considers that operational reflection of the supply chain can support innovative company to promote emergence, decide on the launch and successfully carry out its innovation projects. Within the scope of this standard, our operational innovation management proposal in the supply chain area is as follows:

- **Project formulation:** Review of industrial processes and identify possible solutions on the market

This step seeks to make an inventory of the industrial processes to be considered in view of a possible industrialization of the product, identify the missing processes in the current supply chain or in the environment of the innovative company and highlight the possible industrial solutions.

- **Project feasibility:** Study the functional feasibility

This step seeks to study and validate the functional realization of the product, i.e. the modeling of each supply chain scenario and define the different actions for the implementation of each scenario.

Our Model-Based Supply Chain Engineering would be a relevant tool for this step.

- **Product development:** Develop the functional solution

This step seeks to deepen and validate the favored supply chain scenario for the final product. The actions to be implemented within the supply chain are listed to form an action plan.

Our Model-Based Supply Chain Engineering would be a relevant tool for this step.

- **Product launch:** Qualify the supply chain and its implementation

This step seeks to organize the deployment of the supply chain able to support the manufacture and sale of the innovative product. The actions implemented aim to ensure the launch of the product.

Our proposal is illustrated in figure 70.

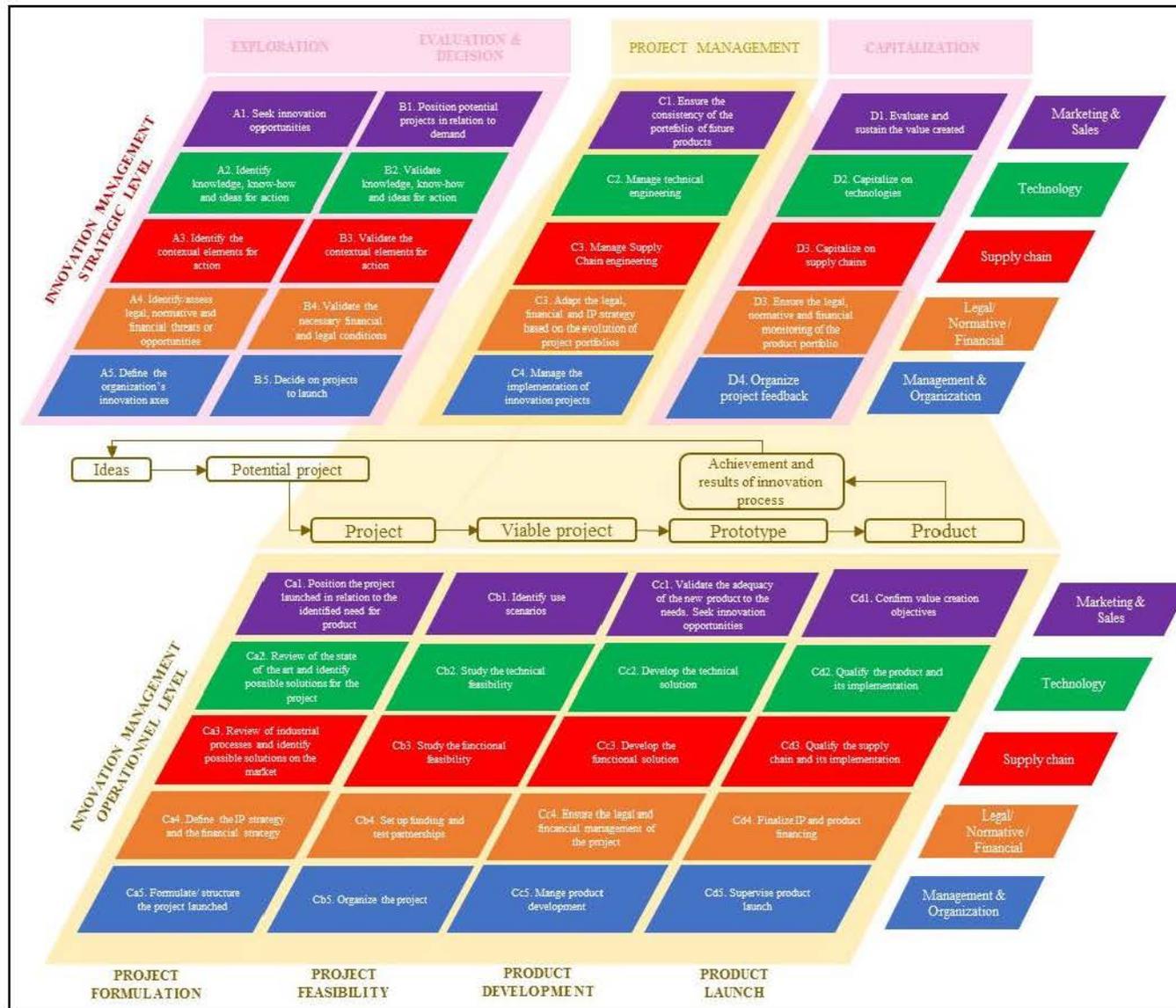


Figure 70: Proposition of a new synoptic table of innovation management (added activities in the red boxes)

Therefore, this research has made several contributions to product and supply chain design issues within manufacturing companies. From the point of view of scientific research, the several contributions concern:

- The proposal for a new vision of product/supply chain design: not in terms of impact on each other, but in terms of complementarities;
- The application of the complexity paradigm of product design/supply chain;
- The identification of common activities in product and supply chain design.

From the point of view of managerial implications, the development of model-based supply chain engineering has led to the highlighting of several observations to which we are trying to provide a solution through this research:

- Companies support is often characterized by methodological or financial support for the development of an innovation. However, the development of an innovation is not limited to the product itself but also integrates the evolution of its environment and more accurately, its supply chain. A supply chain design engineering to complement the current support provided to companies makes sense.
- The design of the supply chain depends on the context and intentions. Relying on the activities common to product and supply chain design then ensures a functional supply chain adapted to the innovative product, which reduces companies' efforts to structure their supply chain at the time of product launch. However, this analysis has to be placed in context so that the supply chain is in relation to its environment.

Therefore, the contributions of this research work concern both scientific research and the business world. The results obtained are promising and open up interesting research prospects.

2.2. Is the concept of supply chain still relevant?

In our research results, more attention is paid to the notion of processes and flows, and our experiments underline that a simple functional analysis is not sufficient to analyze our object of study in depth. Indeed, we have seen that strategies play an important role in the development and sustainability of the supply chain. However, this notion appears in a secondary way in the definition of the supply chain.

The concept of strategic community seems to be an interesting complementary concept. The concept of strategic community was developed through the work of (Kodama, 2001, 2005, 2006, 2007). The strategic community is a modality that brings together resources from various organizations to accelerate innovation in a sector of activity (Roy et al., 2011).

The Strategic Community is composed of four basic concepts (Kodama, 2007):

- A strategic community evolves in a common context in constant evolution in order to help companies to respond to dynamic changes. These changes occur in the market and technological environment or to spontaneously create new market and technological environments. (Nonaka and Konno, 1998; Nonaka et al., 2000).

- A strategic community is a community of practices (Wenger and Snyder, 2000) among the stakeholders that make up this community. This aspect promotes mutual learning within the community by gaining an understanding of the context.
- A strategic community provides pragmatic boundaries allowing stakeholders to transform existing knowledge (Carlile, 2004). In the organizational frontier (i.e. the pragmatic frontier) where innovation occurs, stakeholders demand the creation of new knowledge that goes beyond organizational learning or the transformation of existing knowledge (Kodama, 2007).
- A strategic community is composed of actors who dynamically link several different strategic communities and form networks between strategic communities (Barabasi, 2003; Kodama, 2005; Watts, 2004). These stakeholders are involved in knowledge integration and sharing.

Thus, a strategic community transcends the formal structures of the company. Therefore, (Kodama, 2005) describes the strategic community as “an informal strategic organization possessing qualities with both a resource-based (or knowledge-based) and a strategic view. The resource-based view is an emergent, learning view of the community in a shared context, while the strategic view is a planning view that aims to establish a desired position in the target market”.

Finally, in our research, we tried to go beyond the supply chain concept with its flows with a more dynamic and extended vision that is the strategic community. The latter would then be a temporary structure of inter-organizational collaboration, composed of suppliers, manufacturing companies, distributors, customers, etc., whose mandate consists in manufacturing, launching and ensuring the sustainability of an innovative product on the market.

This description of the strategic community seems to be complementary but not substitutable to our definition of the supply chain. By its conceptual foundations, the notion of strategic community complements that of supply chain by highlighting the importance of the context and stakeholders and by the clarifications they provide on borders. However, our object of study lies at the crossing of the notion of supply chain and strategic community.

Nowadays, companies evolve in constantly changing contexts. It therefore becomes important to consider the supply chain as a whole, i.e. by integrating functional, human, technological and strategic aspects. Thus, the notion of supply chain has to evolve.

Our research has studied in depth the functional aspect but the human, technological and strategic aspects would require further study. This opening to strategic communities provides opportunities to explore regarding the role of people, technology and strategy within our object of study. Thus, the notion of strategic communities underlines the importance of the stakeholder in this system and its influence on it. It considers that the company can play the role of mediator. Moreover, this notion pays great attention to the context which has proven to be a significant factor in our research (Chapter 9).

In fact, a coalescence of supply chain and strategic community concepts could lead to the emergence of a more complete definition of our object of study, i.e. a definition considering the sequence of processes, actors, knowledge, strategic actions and so on that lead to the launch, manufacture, sale and sustainability of an innovative product on the market.

Considering this new vision of the supply chain, the capitalization of all this information and knowledge generated seems crucial to facilitate the emergence of innovation.

2.3. Towards the metrology of agility?

Our research introduces the notion of agility, but the latter requires more investigations.

Consequently, we have chosen to position our frame as an analysis tool. Indeed, it allows us to have a factual vision when modeling the supply chain and thus to understand the inter-company operation envisaged by the innovative company when designing the product.

Thus, we think that it would be interesting to develop an agility metrology to support innovative companies in the implementation of agile supply chain.

Our proposal would be as follows:

The development of a tool based on decisions and actions that promote the implementation of agility. By analogy with the work done on the Potential Innovation Index (PII) (Camargo et al., 2015), our proposal would be summarized in four phases:

- Identify “good practices” that have a positive impact on the agility of a supply chain and define an evaluation method;
- Establish a global agility reference system;
- Establish a multi-criteria assessment leading to a comparison of supply chains in terms of their level of agility;
- Elaborate recommendations allowing innovative companies to increase the agility of their supply chain.

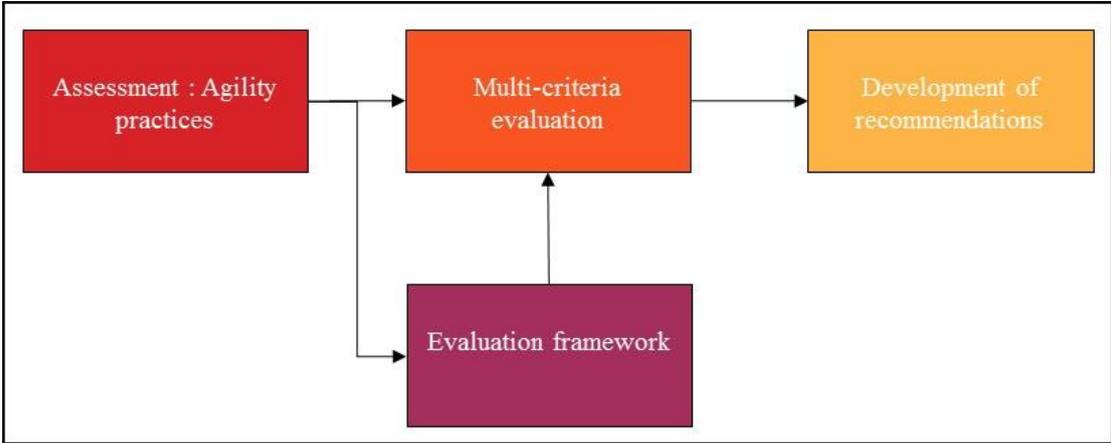


Figure 71: Step of creating an agility measurement tool (inspired by [Camargo et al., 2015])

This metrology would be based on the identification of activities promoting the implementation of agility through a literature review (improvement of our framework proposal). Its application to different case studies would also validate it experimentally. These studies would define a grouping of activities in the form of agility practices (the current grouping within the framework is perhaps not the most appropriate). There are several methods to evaluate these practices. At first sight, the maturity grid seems interesting because it highlights all the steps necessary to reach the maximum level of a phenomenon to measure, here agility. The use of a maturity grid as an evaluation method would notably enable to develop the supply chain's capacities and skills, to compare it with other supply chains, to define progressive stages, to choose the prioritization of practices and the improvement of processes thanks to the comparison with good practices (Lemieux, 2013), all in terms of agility.

2.4. Capitalization to facilitate the emergence of innovation?

An underlying perspective of our research is capitalization. Indeed, supply chain analysis generates a large amount of information whose storage may prove to be relevant for companies. Consequently, the development of a database seems judicious in order to collect the processes, skills, technologies mobilized in the supply chain.

In our case, the interest of a database is multiple:

- Facilitate the search for industrial processes during product design;
- Store results from all scenarios provided by our engineering;
- Save the results of a technological survey;
- Accelerate the data collection and processing phase of our engineering;
- Find substitution processes based on a specific activity (an activity that can occur in several processes).

To design this database, the MERISE method (Tabourier, 1986; Tardieu et al., 1984) seems interesting. Indeed, it is a computer method dedicated to modeling that analyses the structure to be computerized in terms of the system, here the supply chain. It has a number of models, spread over three levels:

- The **conceptual level** describing the operation of the system to be computerized;
- The **logical or organizational level** proposing a logical implementation of the previous level;
- The **physical level** proposing a concrete and usable construction of the previous point, a database.

Currently, the instantiated supply chain model presented in this document can serve as a specification in the design of this database, i.e. at the conceptual level, for several reasons:

- It gathers all types of data to be integrated into the database (processes, activities, type of stakeholders, skills, equipment, decisions and so on). This information will be used to determine the tables and fields present in the database;

- It offers a visual representation of our database. Each box in the diagram represents a table in the database;
- It highlights the relationships between the tables. Cardinality plays an important role. For example, a process requires several activities.

The Pôle Emploi's referential is a good source of information for the most common processes. This reference framework was developed by the Pôle Emploi teams and supported by a large network of partners (companies, branches and professional unions) in order to identify the usual processes and analyze the associated activities and skills. As a result, it helps to propose a study based on the field and allows a solid base for the elaboration of a possible supply chain. However, it is not adapted for specific processes as we noted during the study of case D. Consequently, the database has to be completed as our analyses progress in order to facilitate the preliminary analysis work.

Currently, the database obtained could be updated by the researcher during these analyses. In the medium and long term, it would be interesting for supply chain companies to update this database themselves. Consequently, block chains could prove to be an interesting solution for processing this information on a large scale.

2.5. Towards a supply chain 4.0?

Block chain is a technology for storing and transmitting information. This technology is defined in particular by three major characteristics (Badinet, 2016), it is:

- Transparent because each stakeholder can consult all the exchanges registered on a block chain since its creation;
- Secure because every transaction requires a private key, is subject to a mining process that consists in certifying certain elements (authenticity of transactions, identity of parties...) without having recourse to an intermediary or a central authority and requires replication on each of the network nodes;
- Without a control organ, since the block chain is based on peer-to-peer relationships.

In concrete terms, a block chain is a forgery-proof digital database on which all exchanges between its users since its creation are recorded. Unlike a traditional database, a block chain is a distributed database (Badinet, 2016).

There are public block chains (open to all) and private block chains (access and use limited to a certain number of actors). Private block chains have certain advantages such as simplified governance, known stakeholders, reduced costs, speed, confidentiality among others (Badinet, 2016).

According to (Badinet, 2016), there are three types of block chain uses:

- Asset transfers (shares, bonds, property titles, voting...);
- Block chain as a register (traceability and certification issues);
- Smart contracts: stand-alone programs that automatically execute pre-defined conditions.

Thus, due to its characteristics, a block chain guarantees the traceability of products from end to end, from the manufacturer to the consumer (by ensuring transparency and conformity of data) (Hug, 2017). Based on this finding, we assume that a block chain can support the functioning of a supply chain. Indeed, the actions carried out on the product are declared at each stage of its supply chain, from its production to its final use (for example: its origin, its manufacturing or storage conditions, its transport...) (Hug, 2017). Then the product contains the information of all its components and raw material. Thus, at the end of the supply chain, the consumer can have access to all the information concerning the product but also the characteristics of its supply chain. The supply chain becomes more **transparent**.

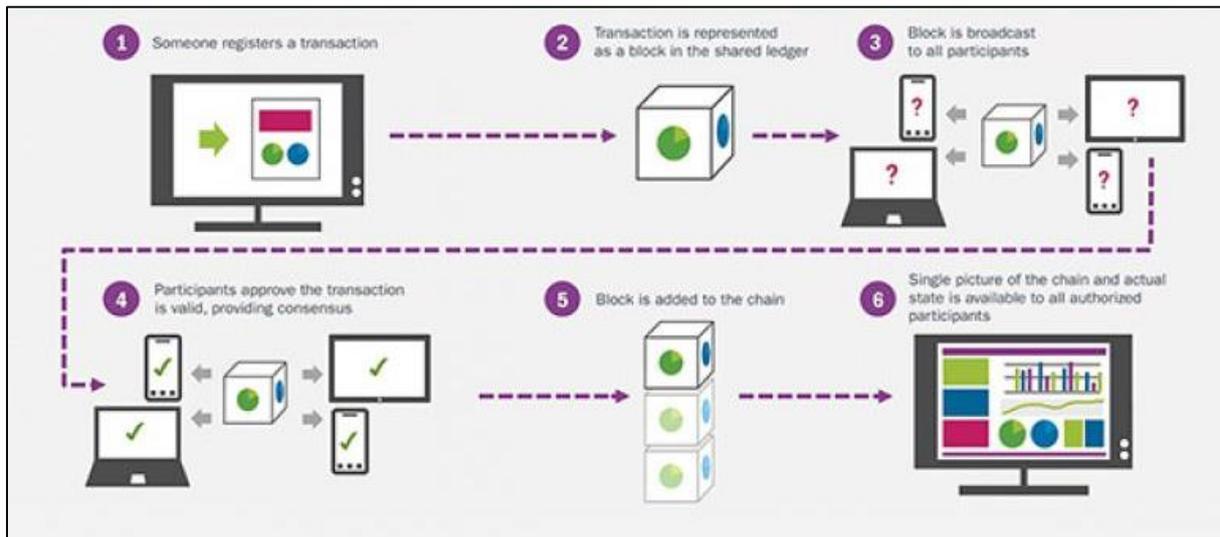


Figure 72: How a block chain works (source IFS) ⁴⁰

Consequently, in the case of a supply chain, the block chain can be used as an information collection network and highlight the digital identity of the product (origin and content). This collection network is shared between nodes that are all known and individually identified (Hug, 2017), i.e. supply chain stakeholders (suppliers, manufacturing companies, distributors and even institutional among others). Thus, each stakeholder actively participates in the supply chain of its product.

Thus, the block chain revolutionizes the transfer of information, like the invention of TCP/IP, the origin of the Internet, which revolutionized the cost of information. It certifies the transfer of information. Consequently, it reinforces the anthropological revolution that has been growing for some time, there is more and more agile organization and holacratic model that forces organizations to be flattered (Badinet, 2016). The supply chain is no exception. This questions the capacity of communities to empower themselves. The block chain thus has the capacity to horizontalize what leads to rethink the organization of human communities (Badinet, 2016).

Today, all decision-making is influenced by the market, only competition matters. The case of the pharmaceutical industry is a good example: each laboratory seeks to be the first without

⁴⁰ <https://www.ifsworld.com/se/>

seeking to join forces to satisfy customer needs. As a result, competition prevents a judicious allocation of resources, paralyzing collective intelligence (De Filippi, 2016). Once again, the block chain is interesting because it is a tool capable of leading us towards a collective intelligence through its capacity to transform and propose new forms of economic organization and governance (De Filippi, 2016). Thus, according to (Davidson et al., 2016), block chains are more what are called “spontaneous organizations” that allow and facilitate transactions that go further than mere exchange.

In the case of a supply chain, this perspective is interesting because it would facilitate the implementation of agile supply chain, by impacting:

- Its virtual aspect: by improving information transfer between all supply chain stakeholders;
- Its sensitivity to the market: by guaranteeing transparency to the customer, it becomes a stakeholder in the supply chain and can acquire the product in conscience;
- The integration of its processes: by making visible the interconnections between processes through transactions and thus between companies;
- Its network aspect: by fostering collective intelligence through a better distribution of resources within the supply chain by distributing more fairly and transparently the value generated by the supply chain.

Hence, the block chain seems to be an interesting alternative to facilitate the launch of an innovative product on the market.

Our approach to supply chain modeling can be used as part of a block chain. Indeed, as it occurs during the design phase, it can establish the basis of the future block chain: each stakeholder, defined according to its processes, is a block. The block chain preserves the decisions and processes that characterize the supply chain. However, the block chain helps to highlight financial and information flows. Especially since information flows are becoming more and more important, hence the need to digitize them. Thus, through the use of a block chain, governance would be shared between companies in the supply chain and no longer by the innovative or most influential company. In addition, the use of the block chain facilitates supply chain design and development: the addition or creation of new blocks is visible to all supply chain members and it may be easier to integrate existing sub-supply chains (in the case of public block chain). An example is presented in figure 73.

Thus, through the influence of the development of a 4.0 industry, the supply chain will evolve, leading to a supply chain 4.0 where the use of a block chain increases stakeholder involvement. It is a new supply chain operation, more digital, more flexible where each company participates in its development. The flexibility of this supply chain directly influences the hierarchy within the supply chain which becomes more horizontal: companies participate at the same level, collaboration and contribution are paramount. Data transfer within this supply chain is facilitated and transparent, which is particularly beneficial in terms of time and accessibility. Moreover, the supply chain 4.0 also impacts the end customer, who becomes a consumer actor and participates in the implementation and operation of the supply

chain through his choices. Consequently, the supply chain 4.0 is a contributory or “liberated” supply chain based on a participative operation and digital tools where each company is a real driving force.

The use of a block chain encourages the development of agile supply chain for any type of product, thus reversing current operations where profit is preferred to customer needs.

To conclude, the block chain will allow a return of the human in the digital ecosystem with real opportunities for choice, sharing, freedom of purchase or sale, independent work, with at the same time the catalysis and development of collective creativity (Blockchain France, 2016).

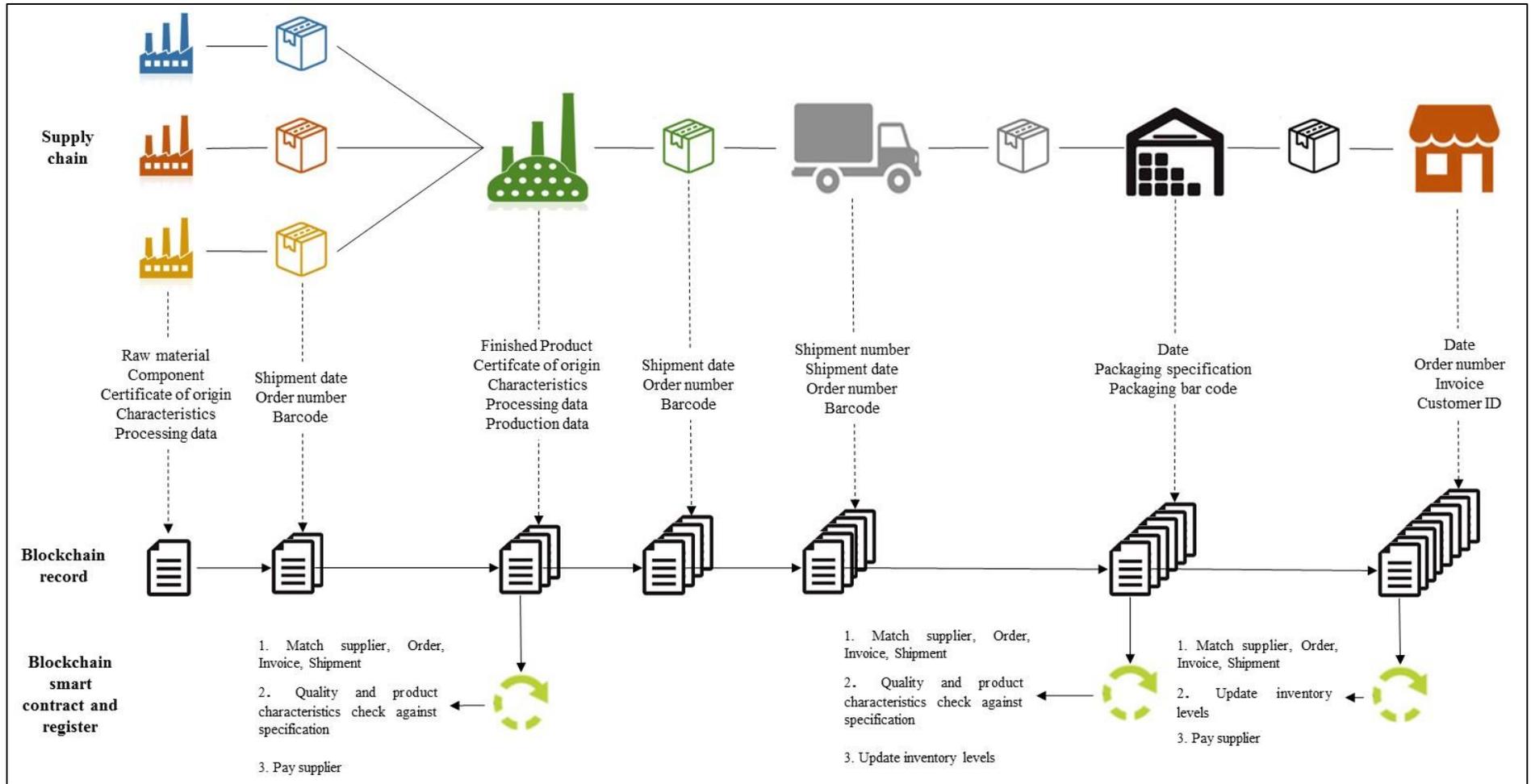


Figure 73: Example of the use of a block chain to support the operation of a supply chain ⁴¹

⁴¹ Adapted from the representation proposed by IRC Group Ltd

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APPENDIX

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APPENDIX 1: Framework to implement an agility strategy

Strategic decision	MARKET SENSITIVE				
	The supply chain is closely linked to marketing trends, it is close to the customer (Christopher and Towill, 2001)				
Dimensions	Orientation				
	The orientation concerns a set of practices to quickly build standards or customized products on the basis of spontaneous orders received without forecasts, inventory or purchase lead time (Kumar Sharma and Bhat, 2014)				
Tactical decisions	The supply chain seeks to delay differentiation to allow customization (Braunscheidel and Suresh, 2018)	The supply chain favors modular, specialized or custom manufacturing of the product (Hoek, 2001; Stavrulaki and Davis, 2010)	The supply chain has few/no intermediaries between the innovator and the end customer (Stavrulaki and Davis, 2010)	The supply chain is composed of few companies (Stavrulaki and Davis, 2010)	The supply chain manufactures the product in response to customer demand (Stavrulaki and Davis, 2010)
Operational decision	<ul style="list-style-type: none"> • The supply chain includes processes dedicated to customizing the product (assembly, colorization...) (Lee, 2004) • The customization processes are at the end of the product manufacturing process (Lee, 2004; Mesnard and Pfohl, 2000; Stavrulaki and Davis, 2010) 	<ul style="list-style-type: none"> • The processes in the supply chain depend on the choice of customers in terms of components or product (Mesnard and Pfohl, 2000) • The supply chain provides alternative processes to meet the customer's needs and to satisfy it (Braunscheidel and Suresh, 2018) 	<ul style="list-style-type: none"> • The innovative company directly sell to end customers (Stavrulaki and Davis, 2010) • The innovative company select a limited number of resellers (Stavrulaki and Davis, 2010) 	<ul style="list-style-type: none"> • The commercial services seek to have few retailers or resellers (Stavrulaki and Davis, 2010) • The manufacture of the product is managed by a limited number of companies (Stavrulaki and Davis, 2010) 	<ul style="list-style-type: none"> • Production is linked to commercial activity (the purchase order is equivalent to a production order) (Stavrulaki and Davis, 2010) • Production is discontinued according to customer demand (Stavrulaki and Davis, 2010) • The customer can requests the innovative company to design a product that meets their needs (Meredith and Francis, 2000; Mesnard and Pfohl, 2000)

Strategic decision	MARKET SENSITIVE The supply chain is closely linked to marketing trends, it is close to the customer (Christopher and Towill, 2001)		
Dimensions	Market opening—Responsiveness Set of practices that enable the supply chain to read and respond to actual demand (Sharma et al., 2017)		
Tactical decisions	The supply chain use a market data to create new product	The supply chain disseminates market data to all its members (Braunscheidel and Suresh, 2018)	The supply chain takes account of customer feedback
Operational decision	<ul style="list-style-type: none"> Members of the supply chain conduct marketing intelligence and market research (follow-up of market developments) (Ayadi, 2009; Meredith and Francis, 2000) The end customer participates in consultations or investigations (Meredith and Francis, 2000; Mesnard and Pfohl, 2000) 	<ul style="list-style-type: none"> The supply chain members have information on the level of demand (Lee, 2004) The innovative company or distribution centers adjust delivery of products according to demand (Lee, 2004) Resellers/retailers inform the supply chain of product requirements (Lee, 2004) 	<ul style="list-style-type: none"> The supply chain pays particular attention to after-sales service (Braunscheidel and Suresh, 2018) The supply chain sets up feedback processes to retrieve customer comments (Fundin and Bergman, 2003)
Dimensions	Supply and demand integration Set of processes by which the supply chain creates value for its customers by moving goods and information through marketing channels: demand-driven and supply-side processes (Esper et al., 2010)		
Tactical decisions	The customer is actively involved in the product development process (co-design) (Braunscheidel and Suresh, 2018)	The supply chain operations are impacted by market information	The supply chain has contingency plans in place to deal with supply-side uncertainties and disruptions (Braunscheidel and Suresh, 2018)
Operational decision	<ul style="list-style-type: none"> The client participates in working groups, product testing (Meredith and Francis, 2000; Mesnard and Pfohl, 2000) The client shares his ideas and needs with the commercial and/or R&D departments of the innovative company (Fundin and Bergman, 2003; Mesnard and Pfohl, 2000) 	<ul style="list-style-type: none"> The level of demand and its fluctuations are visible throughout the supply chain (Braunscheidel and Suresh, 2018) The supply chain recovers customer feedback on quality and delivery performance (Braunscheidel and Suresh, 2018) The supply chain organizes and improves its processes based on customer feedback (Fundin and Bergman, 2003; Garel and Mock, 2012) 	<ul style="list-style-type: none"> The supply chain informs customers of stock levels and production plans (Braunscheidel and Suresh, 2018) The supply chain informs customers of the shipping and delivery status of orders (Lee, 2004) The commercial department is in constant contact with the market to resolve litigation (Fundin and Bergman, 2003)

Strategic decision	DIGITAL The supply chain relies on information shared through all partners in the supply chain (Christopher and Towill, 2001)	
Dimension	Information sharing and accessibility Set of practices for accessing relevant data (Gligor et al., 2013)	
Tactical decision	The supply chain capitalizes on the data	The supply chain disseminates and shares information (Christopher and Lee, 2004)
Operational decision	<ul style="list-style-type: none"> • A monitoring process is implemented at the supply chain level (study of target markets, standards, legislation, trends, patents, geopolitics...) (Ayadi, 2009; Meredith and Francis, 2000) • The members of the supply chain actively exchange information (Braunscheidel and Suresh, 2018) 	<ul style="list-style-type: none"> • Members of the supply chain actively and regularly exchange information (Braunscheidel and Suresh, 2018) • Information is disseminated and shared through communication systems between members of the supply chain (Jahre and Fabbe-Costes, 2005) • Information is shared through computer and Internet tools (Agarwal et al., 2007; Braunscheidel and Suresh, 2018; Soni and Kodali, 2012) • Information on products, inventory levels, shipment status and production requirements is provided in real time (Radstaak and Ketelaar, 1998)
Dimension	IT integration / Virtual integration Set of practices in which information technology is used to coordinate and integrate information in the functions of the innovative enterprise and with the corresponding supply chain companies (Swafford et al., 2008)	
Tactical decision	The members of the supply chain frequently exchange (Lee, 2004; Sanders and Premus, 2005)	The members of the supply chain have a common reflection on the information technologies to be used
Operational decision	<ul style="list-style-type: none"> • Collaborative interdependencies exist between supply chain members (Lee, 2004; Sanders and Premus, 2005) • Information technologies facilitate collaboration between members of the supply chain (Giunipero et al., 2006) 	<ul style="list-style-type: none"> • The members of the supply chain set up computerized data exchange systems (purchase orders, invoices, delivery notes, etc.) (Min and Galle, 1999) • The members of the supply chain use connected, compatible and modular information technologies (Ngai et al., 2011)

Strategic decision	PROCESS INTEGRATION The supply chain has a high degree of interconnected processes between the members of the network (Christopher and Towill, 2001)
Dimension	Strategic sourcing All procurement network design and management processes that are consistent with operational and organizational performance objectives (Narasimhan and Das, 1999a, 1999b)
Tactical decision	The supply chain sets up alliances between suppliers and buyers to meet a varied demand (Qrunfleh and Tarafdar, 2013)
Operational decision	<ul style="list-style-type: none"> • The supply chain creates buffer stocks to cope with supply disruptions and increased demand (Braunscheidel and Suresh, 2018; Lee, 2004) • The level of inventory is visible throughout the supply chain (Braunscheidel and Suresh, 2018) • The supply chain uses rapid response initiatives such as continuous replenishment, vendor-managed inventory, collaborative planning, forecasting and replenishment (Braunscheidel and Suresh, 2018) • The members of the supply chain know how to manage manufacturing resources: raw materials, components... (Ngai et al., 2011)
Dimension	External integration Set of practices to coordinate the flow of information and goods with upstream and downstream members of the supply chain (Braunscheidel and Suresh, 2009)
Tactical decision	The activities of the innovating company are coordinated with those of its suppliers and customers (Stock et al., 2000)
Operational decision	<ul style="list-style-type: none"> • The innovative company has joint planning with its suppliers to facilitate purchasing and production (Braunscheidel and Suresh, 2018) • The innovative company shares information on inventory levels with its suppliers (Braunscheidel and Suresh, 2018) • The innovative company develops a long-term relationship with its suppliers (Braunscheidel and Suresh, 2018)

Strategic decision	PROCESS INTEGRATION	
	The supply chain has a high degree of interconnected processes between the members of the network (Christopher and Towill, 2001)	
Dimension	Internal integration	
	Set of practices that enable functions within an organization to coordinate and cooperate with each other (Braunscheidel and Suresh, 2009)	
Tactical decision	The company's activities are reliable and optimized or outsourced.	The company sets up cross-functional teams (Braunscheidel and Suresh, 2009)
Operational decision	<ul style="list-style-type: none"> • Methods are used to optimize activities (process mapping...) (Brandenburg and Wojtyna, 2006) • The company collaborates with subcontractors to carry out activities/processes that it does not control (Wiendahl and Lutz, 2002) • The company uses customer feedback to optimize and improve the reliability of its activities/processes (Garel and Mock, 2012) 	<ul style="list-style-type: none"> • Internal meetings are organized (Braunscheidel and Suresh, 2009) • The company sets up teams based on the expertise of its employees (Gotteland and Haon, 2011) • Information share among team members, between different departments of the company (Gotteland and Haon, 2011)
Dimension	Supply chain integration	
	Set of practices used by a company to collaborate with its supply chain partners and jointly manage intra- and inter-organizational processes (Flynn et al., 2010)	
Tactical decision	The product is jointly developed (Christopher, 2000) or according to a concurrent engineering	The supply chain plans contingency plans to address operational uncertainties and disruptions (Braunscheidel and Suresh, 2018)
Operational decision	<ul style="list-style-type: none"> • Companies in the supply chain work in collaboration with their suppliers (Christopher, 2000) • Companies in the supply chain share a common information system (Christopher, 2000) • The innovative company develops its new products jointly with its suppliers and customers (Braunscheidel and Suresh, 2018) 	<ul style="list-style-type: none"> • The supply chain creates buffer capacities to cope with potential disturbances (Braunscheidel and Suresh, 2018) • The members of the supply chain continuously learn to prepare for a disruption in the environment (Ngai et al., 2011) • The members of the supply chain are able to make quick decisions in response to change (Ngai et al., 2011)

Strategic decision	NETWORK-BASED	
	The supply chain gains in flexibility by using the strengths of specialized stakeholders (Christopher and Towill, 2001)	
Dimension	Resilience : includes the notions of flexibility and adaptability (Samuel and Ruel, 2017) Set of practices that organizations implement to adapt to any type of event and to reorganize quickly and in a coordinated manner after a major disruption (Sheffi, 2005)	
Tactical decision	The members of the supply chain are able to design production systems that can accommodate multiple products (Rice and Caniato, 2003).	Supply chain members are able to produce at different levels of production and change production quantities quickly and cost-effectively (Zhang et al., 2003)
Operational decision	<ul style="list-style-type: none"> • The members of the supply chain have the opportunity to move quickly from one component/product production to another according to the customer's demand (Braunscheidel and Suresh, 2018; Lee, 2004) • The supply chain ensures the flexibility of its supply networks, operations and distribution networks thanks to alternative routing capacities (Braunscheidel and Suresh, 2018) • The members of the supply chain are able to produce different combinations of products (Zhang et al., 2003) 	<ul style="list-style-type: none"> • The production planning is flexible (Christopher and Lee, 2004) • The members of the supply chain adopt internal flexible practices: flexibility of machines, flexibility in material handling, and flexibility of work... (Zhang et al., 2003) • The members of the supply chain adopt flexible external practices: volume flexibility, range flexibility (Zhang et al., 2003)
Dimension	Collaboration Set of practices promoting bilateral relations between supply chain partners (Narayanan et al., 2015)	
Tactical decision	Supply chain members exchange information and knowledge (Narayanan et al., 2015)	The members of the supply chain cooperate and participate in the management of the supply chain (Narayanan et al., 2015)
Operational decision	<ul style="list-style-type: none"> • Supply chain members maintain close and coordinated relationships with their main trading partners (suppliers, manufacturers and distributors) (Kisperska-Moron and Swierczek, 2009; Ngai et al., 2011) • The members of the supply chain exchange market information (Braunscheidel and Suresh, 2018) • The members of the supply chain share information about production, supply or customer demand (Braunscheidel and Suresh, 2018) • The members of the supply chain share so-called agile methodologies (SCRUM...) (Trudel and Boisvert, 2011) 	<ul style="list-style-type: none"> • The supply chain members have set common objectives (Narayanan et al., 2015) • The supply chain members make joint efforts to integrate social, environmental, technological or political considerations into their economic decisions (Seuring and Gold, 2013)

Strategic decision	NETWORK-BASED The supply chain gains in flexibility by using the strengths of specialized stakeholders (Christopher and Towill, 2001)	
Dimension	Skills enhancement Set of practices for applying knowledge and performing a task that depends on context (Le Deist and Winterton, 2005)	
Tactical decision	The members of the supply chain have a common reflection on the skills to be acquired	The members of the supply chain know how to surround themselves with experts
Operational decision	<ul style="list-style-type: none"> • The members of the supply chain have access to training (in and outside the fields of competence) (Dries et al., 2012) • The members of the supply chain recruit people by taking into account the skills needed to manufacture the product (Dries et al., 2012) • The members of the supply chain know the current and future availability of skills and resources (Jahre and Fabbe-Costes, 2005) 	<ul style="list-style-type: none"> • The members of the supply chain are integrated into clusters, into institutional networks (competitiveness cluster) (Camarinha-Matos and Afsarmanesh, 2006) • The members of the supply chain collaborate with research laboratories (Camarinha-Matos and Afsarmanesh, 2006) • The members of the supply chain are in regular contact with funding bodies (Katz, G., 2007)
Dimension	Relation integration Set of practices shared between customers and suppliers regarding business-to-business dependency and collaboration principles (Stank et al., 2001)	
Tactical decision	Innovative company creates partnerships with other members of the supply chain	
Operational decision	<ul style="list-style-type: none"> • Innovative company forges partnerships based on a network of reliable suppliers and distributors (Jahre and Fabbe-Costes, 2005) • The relations are contractualized (Mesnard and Pfohl, 2000) 	

APPENDIX 2: Fundamentals and justification of the “Modelling of the supply chain scenarios” part of our engineering

A Model-Based System Engineering approach (Estefan, 2007) for innovation purposes (Castro et al., 2008) is used to valorize collected data (manufacturing operations, the architecture of the product).

1. Interest of System Engineering

System Engineering (SE) is an interdisciplinary methodology, to formalize and control the design and the implementation and integration of processes within complex system (BKCASE Editorial Board, 2017). This approach integrates the contributions of the different disciplines involved in the design and integration phases of a system, considering the different requirements of the stakeholders (needs, constraints) (Meinadier, 2002b).

In order to applied a MBSE approach for systems engineering purposes, the language SysML has been developed by the Object Management Group⁴² at the initiative of the International Council on Systems Engineering (INCOSE)⁴³. This modeling language aims to support the specification, analysis, design, verification and validation of complex systems.

As a result, System Engineering seems to be an appropriate answer to our problem as it allows the representation of the supply chain in the form of an evolutionary system where product needs and external constraints can be considered in order to have a global view of the supply chain throughout its life.

2. What is SysML

SysML is adequate to represent the overall high-level of the system to be developed. These high-level models are appropriate in the early life cycle phases, to elaborate requirements, develop concepts, assess feasibility, and perform trade studies (Eisenmann et al., 2009).

The SysML is a language specifically developed to support a system engineering approach and can support the specification, analysis, design, verification and validation of complex systems such as a product supply chain⁴⁴. It is a pictorial illustration of semantics for describing a model representative of a given system.

⁴² Object Management Group, *OMG Systems Modeling Language (OMG SysML™), V1.0, OMG Available Specification*, <http://www.omg.org/spec/SysML/1.0/PDF>, 2007.

⁴³ www.incose.org

⁴⁴ “OMG Systems Modeling Language” *The Official OMG SysML Site*. Web 2014. <http://www.omgsysml.org/>

SysML supports system life cycle activities such as requirements specification, modeling of different components with their structure and behavior, integration as well as scenario specification for verification and validation. Thus, SysML diagrams have been categorized according to four pillars: requirements, behavior, structure and parameters, which is the cornerstone of the modeling reasoning of a complex system. There are four of them, each pillar provides the modeler with the diagrams needed to model the point of view expressed by the pillar. Thus, there is a “pillar” describing the requirements that a system can satisfy, a “pillar” describing the structure of the system to operate, a “pillar” describing the behavior of this system to ensure its main function and a “pillar” modeling the various parameters to achieve the purpose of the system (Castro Espiritu, 2010).

Modeling a supply chain involves describing it from these four points of view. SysML relationships between the different diagrams ensure their coherence to build the supply chain model (Roques, 2011).

3. Choice of Harmony Methodology

Several books and articles have been published about SysML, the standardized language for model-based systems engineering⁴⁵. But in most cases, the question of how to apply it in an integrated systems and software development process has not been addressed. Consequently, IBM offers a methodology called *Harmony* to close this gap. Based on the tool Rational Rhapsody®, this methodology provides a step-by-step guide using SysML in a way that allows seamless transition to subsequent system development⁴⁶.

The V-cycle is used to describe the life cycle of a project by focusing on the essential stages of development.

⁴⁵ SysML 1.0 Specification—<http://www.omgsysml.org>

⁴⁶ “Systems Engineering Best Practices with the Rational Solution for Systems and Software Engineering”—Hans-Peter Hoffmann, February 2011.

Consequently, *Harmony for System Engineering*, which is used in this research, focuses on the first steps of the classic “V” diagram, i.e. on the left leg of the “V” describing the top-down flow.

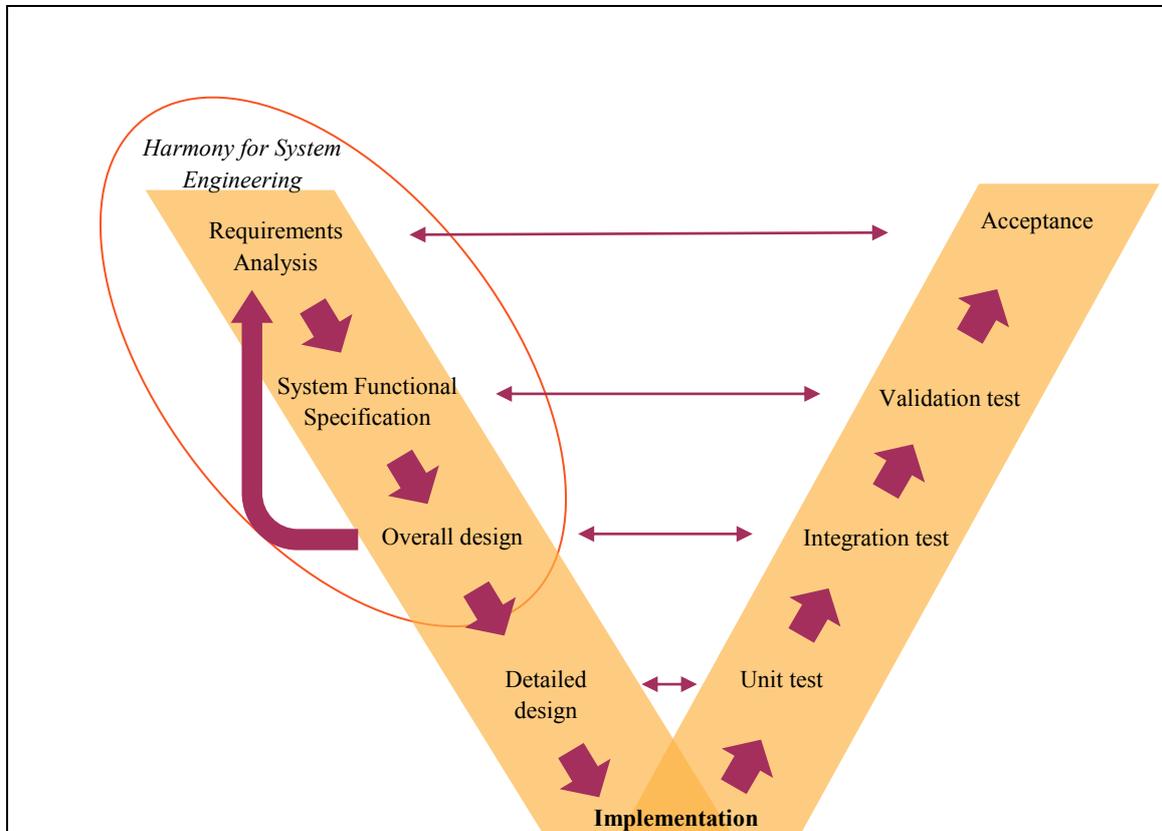


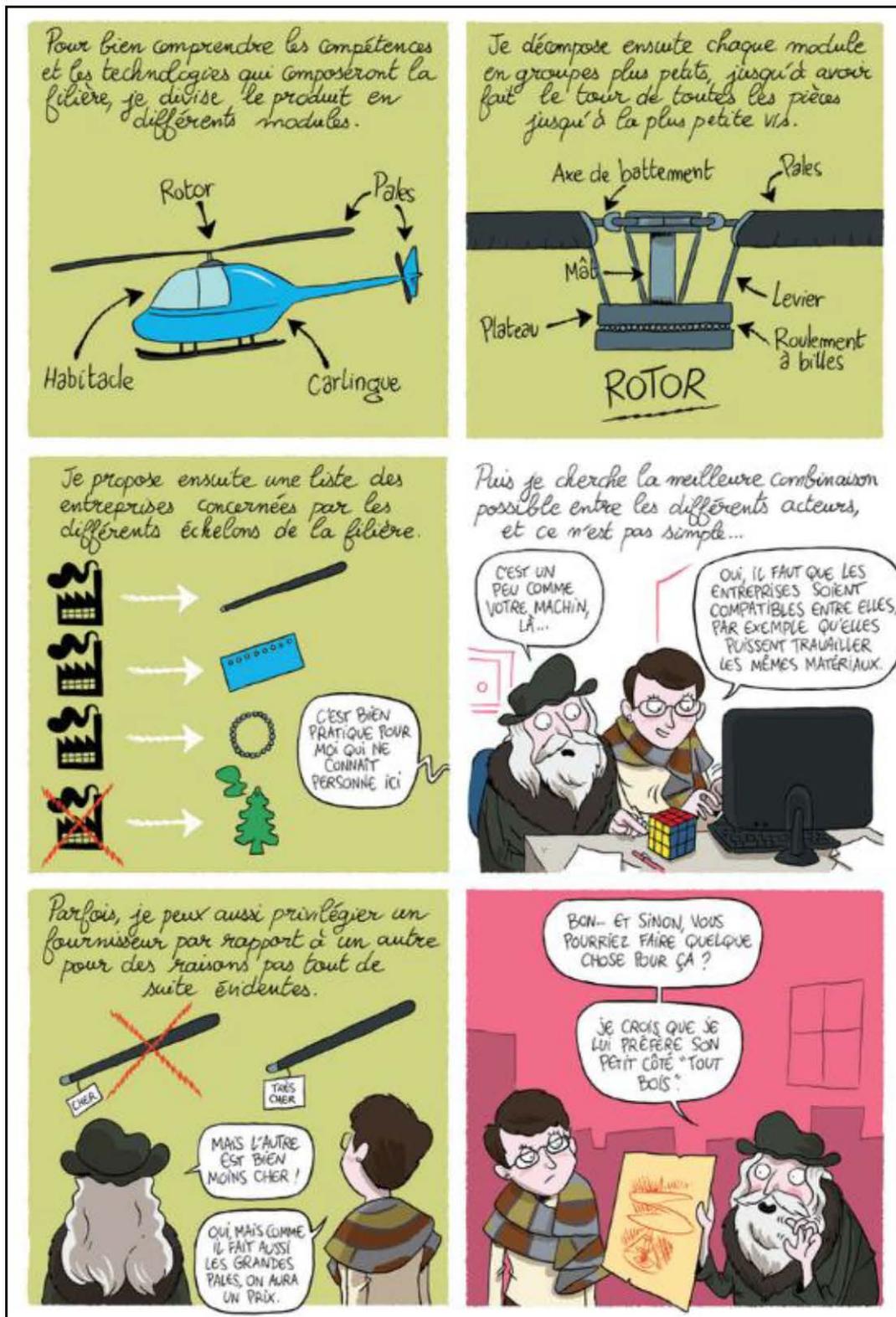
Figure 74: Supply chain design through Harmony for System Engineering process

The *Harmony for System Engineering* process supports Model-Driven Development (MDD). In a model-driven development, the model is the central work product of the development processes, encompassing both analysis and design. Each development phase is supported by a specific type of model.

APPENDIX 3: “Ma thèse en 180 secondes”

This thesis was the subject of a participation in the competition “Ma Thèse en 180 Secondes”, Finale de l’Université de Lorraine, Edition 2017:





Peb&Fox/MT180s/Université de Lorraine

Link to the video of the event—Finale of the Université de Lorraine 2017:

<https://videos.univ-lorraine.fr/index.php?act=view&id=4611>

APPENDIX 4: Summary of thesis in French

1. Introduction

La thèse que nous soutenons repose sur une vision commune et complexe du produit et de sa filière. Nous présentons une nouvelle perspective sur l'ingénierie de l'innovation en tenant compte de la conception simultanée du produit et de la filière correspondante, l'objectif étant d'augmenter le taux de réussite lors du lancement d'un produit innovant sur le marché. Au cours de cette recherche, des collaborations avec des entreprises innovantes ont été organisées afin de confronter les apports théoriques à la réalité.

Une étude " Nielsen Breakthrough Innovation Report " portant sur environ 12 000 lancements de produits en Europe occidentale entre 2011 et 2013 montre que 76 % des lancements de nouveaux produits échouent au cours de leur première année, soit environ trois produits sur quatre. Johan Sjöstrand, directeur général de la pratique d'innovation de Nielsen Europe et co-auteur de l'étude, souligne que "*innovation success is never just a remarkable coincidence*". Ainsi, une étude des facteurs clés de succès de l'innovation issus des ouvrages de référence en management de l'innovation a été réalisée. Une première observation apparaît : le lancement et les conditions de lancement d'un produit ne sont pas mentionnés dans les études de facteurs de succès (Tidd and Bessant 2013; Trott 2008; Kahn 2013). (Tidd and Bessant 2013) traite brièvement du concept de réseau, (Trott 2008) souligne les relations avec le réseau et les fournisseurs et (Kahn 2013) inclut un paragraphe sur la filière dans le chapitre consacré au réseau soutenant le produit innovant. Ainsi, l'organisation de la filière lors du lancement d'un produit innovant ne semble pas être considérée comme un facteur clé de succès. Sur la base de notre expérience passée, ce manque d'intégration de la structure de la filière lors du lancement du produit innovant représente une sérieuse limite. Ainsi, dans cette thèse, l'un des enjeux industriels majeurs est d'anticiper la conception de la filière d'un produit innovant afin de définir, au stade de la conception, une filière adaptée capable de supporter ce nouveau produit. Ainsi, sur la base d'un cadre théorique robuste et original, nous proposons une méthodologie pour concevoir et ajuster la filière lorsqu'un nouveau produit est développé par une entreprise manufacturière. Les entreprises manufacturières sont définies comme des entreprises qui fabriquent des biens par assemblage (fabrication de machines, d'équipement, de produits informatiques, de produits électroniques, d'automobiles, etc.). Ces entreprises produisent des biens qui peuvent être mécaniquement démantelés ou démantelés. Cette thèse se concentre donc sur ce type de produit innovant.

Le concept d'innovation est directement lié à celui d'une entreprise (Giget 2007). Dans un contexte industriel en constante évolution, l'innovation contribue au succès et à la pérennité des entreprises (Galvez 2015), qui ont la capacité de concevoir et de commercialiser de nouveaux produits ou de modifier la façon dont ces produits sont fabriqués et livrés aux clients. Elle est considérée comme le moteur du développement de l'entreprise en créant une dynamique permanente basée sur la nouveauté (Boly, Camargo, and Morel 2016). Elle conduit à des avantages concurrentiels: meilleure performance, meilleurs prix, meilleure

adaptation aux besoins entre autres. En effet, l'innovation est une nouvelle façon de créer de la valeur pour les clients, les utilisateurs et l'entreprise innovante elle-même (Garel and Mock 2012). Cependant, malgré des avancées significatives dans sa compréhension et sa formalisation, la maîtrise du processus d'innovation est loin d'être acquise (Toledo 2014). Le succès d'un produit innovant reste donc très incertain.

De plus, les nouveaux produits deviennent de plus en plus complexes, impliquant un nombre croissant de parties prenantes. Par conséquent, l'innovation ne peut pas toujours être portée par l'entreprise seule (Boly, Camargo, and Morel 2016), c'est souvent un processus collectif et ouvert (Garel and Mock 2012). En effet, le nouveau produit nécessite souvent de nouvelles ressources, un nouveau mode de livraison, et une répartition des tâches de réalisation entre plusieurs entreprises. En conséquence, l'innovation se produit au sein de grands systèmes de collaboration entre clients et fournisseurs (Maniak and Midler 2008) ou entre clients finaux et entreprises (Garel and Mock 2012). Il est donc important d'avoir une vision de la séquence des acteurs impliqués dans le lancement d'une innovation (Boly, Camargo, and Morel 2016).

Une filière regroupe toutes les entreprises impliquées dans la production et la distribution d'un produit final (B to C) ou d'un produit fini/semi-fini (B to B). La filière est considérée par certains auteurs comme un objet d'étude en soi (Christopher 2016, 1998, 2000; Fisher 1997; Lee 2002; Fixson 2005; Vonderembse et al. 2006). Ces auteurs étudient les caractéristiques de la filière, son fonctionnement, son évolution, etc. La notion de filière n'est pas fixée dans le temps. De nombreuses définitions existent pour décrire ce concept; elles varient en fonction de la dimension étudiée, ce qui élargit le champ de recherche sur la notion de filière. Néanmoins, une filière comme une entreprise est gérée et a une orientation stratégique. Une filière est dynamique, elle peut évoluer et s'adapter au produit qu'elle soutient afin d'être efficace et efficiente. En fait, une filière organisée, coordonnée et adaptée à un produit particulier mène à un avantage concurrentiel.

L'émergence d'un nouveau produit entraîne parfois des changements dans l'environnement de l'entreprise qui innove et a un impact sur l'organisation de la filière: la relation entre les parties prenantes change, certains apparaissent et d'autres disparaissent, les compétences évoluent... La conception d'un nouveau produit nécessite d'anticiper ces changements sur l'environnement actuel et la façon dont il modifiera les relations des principales parties prenantes (utilisateurs, distributeurs, fournisseurs). Le manque de sensibilisation à ces changements peut menacer le développement et la commercialisation future du produit (Boly, Camargo, and Morel 2016). Connaître ces changements et surtout les anticiper devient fondamental pour le succès du nouveau produit.

Basé sur l'innovation, nos recherches portent sur deux sujets étroitement liés et en interaction: le produit et la filière. Deux perspectives complémentaires sont prises en compte. Du point de vue de la recherche, nous cherchons à mieux comprendre les processus d'innovation au niveau du produit et de la filière. D'un point de vue industriel, notre intérêt particulier porte sur les décisions prises par l'entreprise quant à la position de son nouveau produit dans la filière et sur toutes les décisions et actions visant à faire en sorte que la filière corresponde au produit.

Par conséquent, cette recherche a les objectifs suivants. Premièrement, elle permet de mieux comprendre les liens entre un produit innovant et la filière associée. Deuxièmement, elle souligne dans quelle mesure l'adaptation de la filière au produit est un facteur clé de succès. Ainsi, la filière doit s'adapter aux exigences du produit final/fini ou le produit doit être adapté à l'ancienne filière.

Pour mener à bien cette recherche, une approche constructiviste a été choisie. Une recherche constructiviste diffère de l'interprétativisme en ce sens qu'au-delà de la compréhension, elle est orientée vers les objectifs. L'observation et la modélisation sont des phases dans la construction progressive d'un projet de recherche et la définition de nouvelles représentations (Le Moigne 1994; Boly 2000). Pour recueillir et exploiter les données sur le couple produit innovant/filière, une approche d'étude de cas multiples a été examinée.

Compte tenu du contexte et de la littérature présentée précédemment, cette recherche révèle six constats :

- Toute filière comporte des constituants spécifiques;
- Toute filière est unique;
- Chaque produit a sa propre filière et ce couple est instable et évolutif;
- L'innovation conduit à des modifications de filière;
- Le couple produit/filière atteste d'une double influence dynamique;
- Le couple produit/filière doit s'adapter à la nouveauté.

Ces six constats soulignent que notre recherche est multi-échelle et multi-acteurs et que les relations entre les objets de notre étude (produit et filière) sont complexes et dynamiques. Dans un contexte d'innovation, la filière, le produit et l'entreprise peuvent évoluer individuellement mais aussi conjointement. Le tryptique produit/entreprise/filière évolue également afin de répondre à la nouveauté. Compte tenu de tout ce qui précède, notre question de recherche est formulée comme suit :

Comment modéliser le **couple produit innovant / filière** afin d'identifier les **ajustements à mettre en œuvre** au sein de la filière par une **entreprise** (manufacturière) **dans un contexte d'innovation ?**

2. Apports scientifiques

Le système « filière » fait partie d'un système d'innovation technologique plus large, contenant des composantes sociales et techniques qui doivent toutes être alignées : prix et performance du produit, production, produit/service complémentaire, parties prenantes (sous-traitance, approvisionnement, fabrication, distribution, ventes...), clients, institutions, technologie et application des connaissances, ressources financières, humaines et naturelles, contexte économique, stratégique ou socioculturel, événements inattendus, entre autres. La conception de la filière est donc un vaste sujet, de sorte que cette recherche se concentre sur une description détaillée de certains niveaux particuliers et d'aspects particuliers : la performance du produit, la production, le produit complémentaire, les parties prenantes et le contexte stratégique.

La revue de la littérature a conduit à une clarification de différents concepts (innovation et filière) en relation avec notre problème, dans le but de poser des bases théoriques solides. Toutefois, il est difficile de donner une définition simple et complète de ce qu'est réellement l'innovation, étant donné sa complexité inhérente. De même, la séquence des entreprises soutenant la fabrication et la distribution d'un produit est définie par différentes appellations (supply chain, filière ou Global Value Chain) en fonction du contexte et de sa portée. Cependant, le concept de filière est un concept récurrent dans la recherche scientifique, la variété des appellations et des définitions démontrant sa complexité. En limitant notre recherche aux produits innovants, nous avons pu mettre en évidence que le lien entre le produit innovant et la filière associée est créé par la détermination des processus de fabrication.

Sur la base de notre revue de la littérature concernant le lien entre l'innovation et la filière, nous avons souligné les limites de ce domaine de recherche. Le lien entre la conception de l'innovation et la conception de la filière est souvent considéré sous l'influence d'un paradigme causaliste. Cependant, elle ne se limite pas à une relation de cause à effet. Par conséquent, nous proposons d'appliquer le paradigme de complexité à la conception de la filière en raison du fait que l'ajustement de la filière et du produit est un phénomène dynamique et multi-échelle et qu'il existe de nombreuses interactions complexes entre un grand nombre de variables. En effet, la pensée complexe met en évidence des éléments unificateurs et communs sans fusionner l'ensemble, elle connecte tout en distinguant. Plus précisément, il s'agit de considérer la conception d'une innovation et la conception de la filière comme deux activités complémentaires dans le processus d'innovation. Ainsi, l'entreprise innovante co-conçoit son innovation et la filière associée. Par conséquent, notre première contribution d'ordre théorique consiste à proposer **une nouvelle vision de la conception des produits et de la filière, à travers le paradigme de la complexité.**

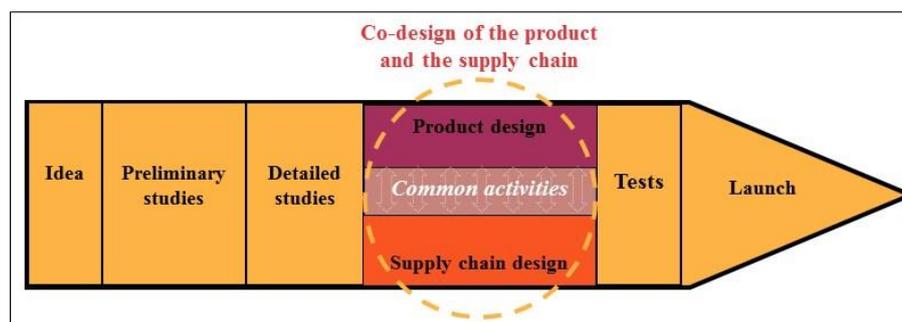


Figure 1: Conception du produit et de la filière comme deux activités complémentaires au sein du processus d'innovation

Ainsi, une entreprise innovante doit mettre en œuvre des stratégies pour adapter le produit et la filière ou pour ajuster la filière actuelle afin d'en obtenir une plus appropriée. La conception de la filière nécessite donc une vision managériale se concentrant sur les ajustements au sein de la filière: soit les entreprises agissent pour changer la filière en même temps que le produit, soit elles mettent en œuvre des actions pour changer la filière après la conception du produit. Le produit et la filière sont constamment ajustés. Plusieurs recherches soulignent qu'une filière agile semble plus adaptée à un produit innovant (Fisher 1997;

Vonderembse et al. 2006; Lee 2002). Ainsi, la stratégie de la filière privilégiée dans le cas du lancement d'un produit innovant est une stratégie d'agilité. La mise en œuvre de l'agilité est un sujet récent dans la littérature et il manque un cadre théorique. Par conséquent, l'illustration du lien entre la structure de la filière et la stratégie dédiée est au cœur de notre seconde contribution théorique. Un référentiel basé sur les phénomènes observables de la littérature a été développé. Ces phénomènes mettent en évidence les décisions individuelles ou collectives prises par l'entreprise innovante concernant la filière. Il constitue une base pour estimer l'agilité à mettre en œuvre pour obtenir une filière agile. En effet, avec ce cadre, il est possible d'analyser les actions de l'entreprise et d'évaluer si la filière peut être plus agile. Par conséquent, la transformation de la filière devient concrètement concevable.

Pour observer les conséquences de l'émergence d'une innovation sur la filière, une recherche empirique basée sur trois études de cas a été réalisée. Cette étude souligne que le résultat final d'un processus d'innovation reste incertain, car la réussite de la mise en œuvre d'une filière dépend des orientations stratégiques choisies par les entreprises, des contraintes environnementales, du comportement des parties prenantes ou de la relation avec le marché. Par conséquent, la création d'un processus d'ajustement pour faire correspondre les besoins des produits innovants avec leur filière est nécessaire pour optimiser la performance. En examinant les différentes variables affectant la filière (y compris la chaîne de valeur, les compétences, les processus, les parties prenantes, l'environnement et le marché), plusieurs phénomènes sont apparus mettant en évidence les limites de la recherche. Bien que l'étude soit exploratoire, l'identification de divers inadéquation et les ajustements associés permettent de constater que certains événements sont prévisibles et peuvent être facilement anticipés. D'autres événements sont spécifiques à l'entreprise, à l'environnement ou au marché. La contribution de cette étude exploratoire réside dans une meilleure compréhension des phénomènes in situ au sein de la filière (Marche et al. 2017) et une première observation des différences entre les PME et les grandes entreprises. Cette étude empirique met en évidence un écart important entre la théorie et la réalité : l'importance de la filière dans le lancement du produit mis en évidence par la littérature semble être sous-estimée par les entreprises.

Afin de combler cet écart, nous proposons deux contributions méthodologiques afin de soutenir les entreprises innovantes dans la conception de leur supply chain. En effet, il a été constaté que de nombreux outils d'accompagnement faciliteraient la conception de produit mais peu s'intéresse à la conception de filière.

La première contribution méthodologique porte sur le développement d'un modèle instancié de la filière (Marche et al. 2017), une représentation basée sur la réalité afin de mettre en évidence :

- Les éléments constitutifs de toute filière (parties prenantes, flux, processus, valeurs entre autres) et les relations et l'influence entre eux;
- Le caractère multi-échelle d'une filière (entreprises, processus, activités);
- Le fonctionnement de la filière doit tenir compte de toutes les échelles pour être efficace.

Le choix de la modélisation basée sur l'Ingénierie Système permet une capitalisation de l'information. Ce modèle est destiné à être utilisé comme un outil de collecte de données pour les entreprises qui conçoivent un produit innovant, il s'agit d'une description de la filière à un moment donné.

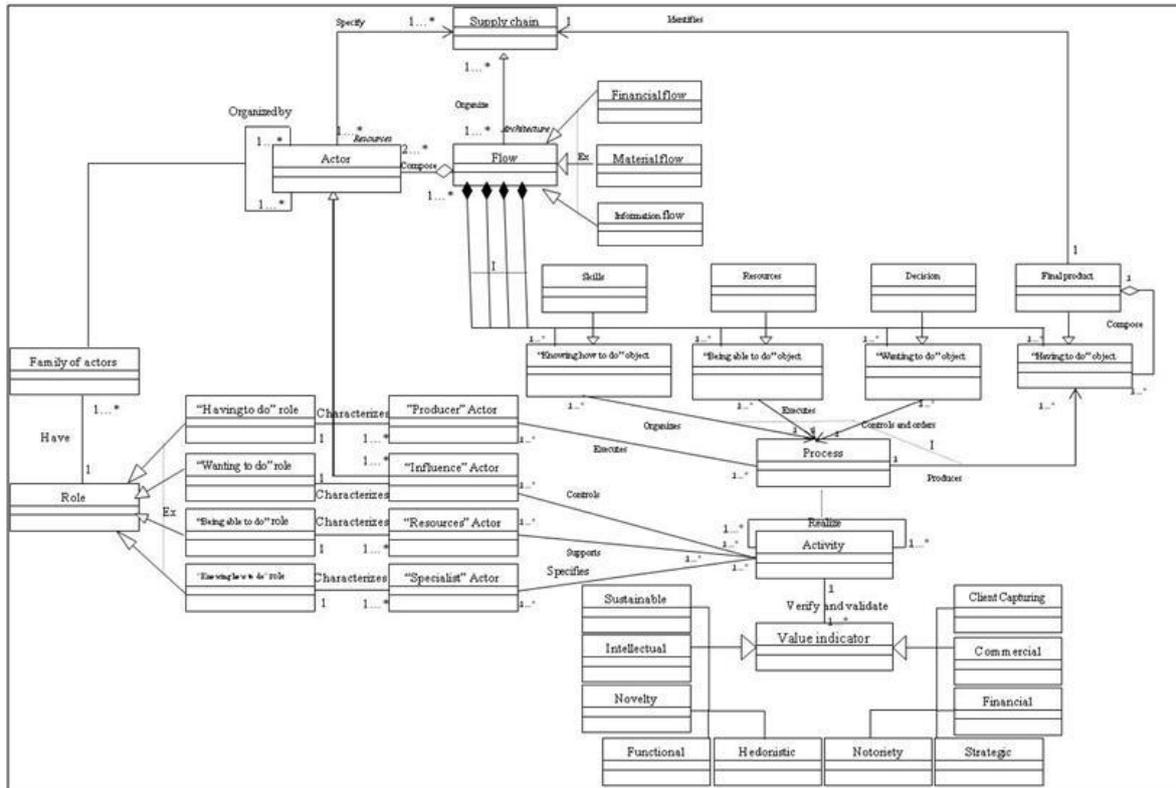


Figure 2 : Un modèle instancié de filière (Marche et al. 2017)

Notre deuxième contribution méthodologique cherche à favoriser la co-conception du produit et de la filière à travers le développement d'une ingénierie de filière basée sur les modèles. Elle conduit à la conception de la filière d'un produit innovant en particulier. Cette ingénierie comprend une étape de collecte de données (réalisée à l'aide de notre modèle instancié de filière), une étape de traitement des données (à l'aide de matrices) et une étape de modélisation. L'étape de modélisation utilise la méthodologie *Harmony for Systems Engineering* couplée à l'outil Rational Rhapsody®. L'étape de modélisation permet de déterminer les besoins de l'entreprise innovante en ce qui concerne son futur produit et la filière correspondante, de définir ce que fera la filière en question et les parties prenantes qui la composent, de déterminer comment elle fonctionne (séquence des processus et mise en évidence des décisions stratégiques, tactiques et opérationnelles mises en œuvre) et ce que les parties prenantes devront faire pour positionner finalement la filière dans le temps. La représentation finale obtenue aide à analyser la filière sur le plan managérial en visualisant si les décisions prises mènent à une filière agile (grâce à notre cadre théorique facilitant la mise en œuvre d'une stratégie d'agilité). Différents scénarios peuvent être envisagés avec une description des actions d'agilité mises en œuvre et peuvent aider l'entreprise innovante à prendre des décisions techniques concernant le produit.

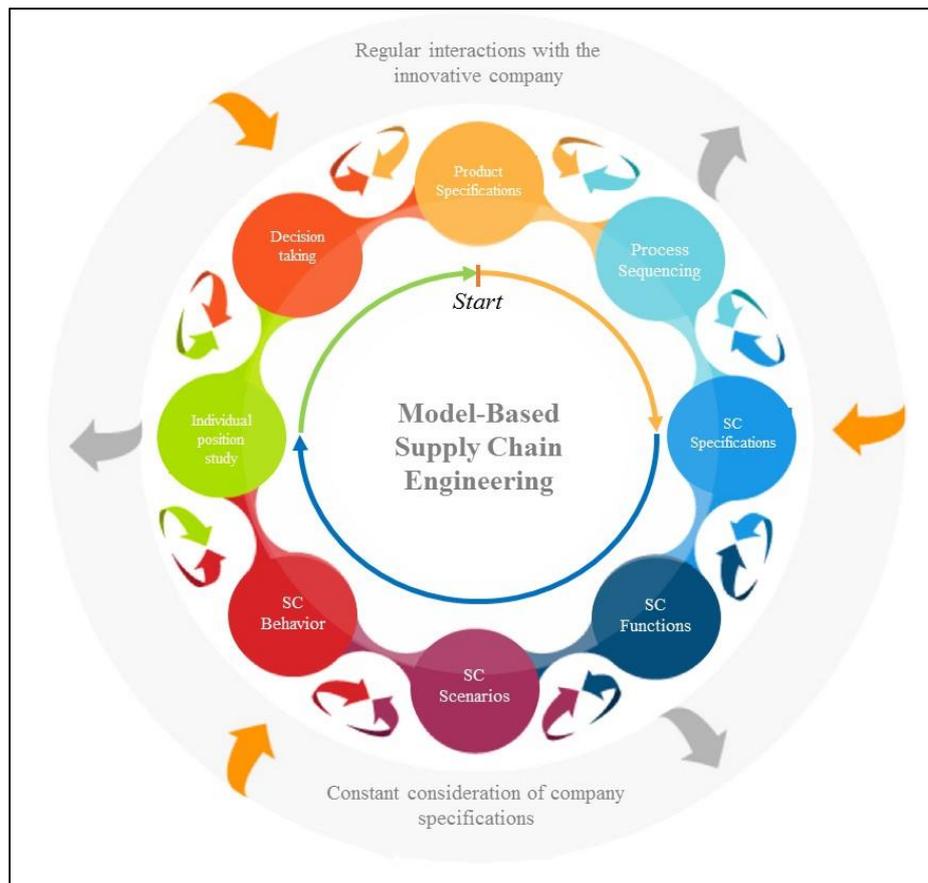


Figure 3 : Une ingénierie de filière basée sur des modèles

Le modèle instancié de filière et notre ingénierie ont été testés et validés sur un cas d'étude : la conception de la filière d'un capteur électromagnétique à effet tunnel.

La diversité de nos études de cas souligne que la complexité de notre sujet interfère avec une éventuelle généralisation de notre ingénierie, le contexte étant un facteur important dans toute l'analyse de la filière. Différents facteurs contextuels influençant la mise en œuvre de la filière ont été identifiés : le degré de nouveauté du produit, les frontières et la taille de la filière, la taille de l'entreprise, la gouvernance de la filière, l'expérience de l'entreprise en termes d'innovation et l'environnement concurrentiel dans lequel elle opère.

3. Limites et perspectives

Nos différentes contributions ont été testées et validées sur une étude de cas. Néanmoins, nous sommes conscients qu'il reste encore des points à développer et que ces contributions présentent certaines limites. Le tableau ci-joint résume l'utilité de chaque contribution ainsi que leurs limites et les perspectives envisagées.

	Théorique		Empirique	Méthodologique
	Co-conception produit/filière	Définition de l'agilité et cadre pour mettre en œuvre une stratégie d'agilité	Aperçu des phénomènes survenant dans les filières pendant l'émergence de l'innovation	Ingénierie de conception de filière et modèle instancié de filière
Utilité	<ul style="list-style-type: none"> - Apporter une nouvelle vision à la conception du produit ; - Mettre en évidence les complémentarités entre la conception du produit et la conception de la filière ; - La conception de la filière peut minimiser les efforts de mise en œuvre ; - Souligner qu'un produit ne peut exister sans une filière appropriée et vice versa. 	<ul style="list-style-type: none"> - Avoir une vision plus précise de ce qui " facilite " la mise en œuvre d'une stratégie d'agilité (actions possibles) ; - Disposer d'un support pour le diagnostic de la stratégie en tenant compte de l'agilité. 	<ul style="list-style-type: none"> - Mieux comprendre ce qui se passe in situ, c'est-à-dire au sein des entreprises et des chaînes d'approvisionnement ; - Confronter la théorie et la réalité ; - Avoir une vision critique de nos résultats théoriques. 	<ul style="list-style-type: none"> - Aide à la visualisation de la filière (sous la forme d'un système), approche scénarisée ; - Décrire l'évolution de cette filière; - Aider à visualiser les incertitudes de conception ; - Aider à envisager des partenariats dans le cadre d'une approche de projet axée sur les parties prenantes ; - Visualiser et anticiper les problèmes que l'entreprise innovante pourrait rencontrer plus tard lors du lancement du produit (gestion de l'entreprise).
Limites	<ul style="list-style-type: none"> - Difficulté à recueillir certains renseignements sur le processus. 	<ul style="list-style-type: none"> - Cadre théorique et fixe ; - Difficulté à estimer le degré d'agilité atteint : manque de métrologie. 	<ul style="list-style-type: none"> - Généralisation limitée en raison du faible nombre d'études de cas ; - Large champ d'étude ; - Seules les décisions couronnées de succès sont observées. 	<ul style="list-style-type: none"> - Lisibilité des résultats ; - La typologie de la filière n'est pas toujours explicite ; - Difficulté à généraliser et à informatiser ; - Se concentrer sur des niveaux spécifiques d'analyse (activités, processus) mais pas sur l'ensemble de l'écosystème ou du système d'innovation technologique.
Perspectives	<ul style="list-style-type: none"> - Développer une méthodologie pour appliquer la mise en œuvre de cette conception dans les entreprises. 	<ul style="list-style-type: none"> - Développer une métrologie de l'agilité ; - Décrire le degré d'agilité à différents niveaux de la filière. 	<ul style="list-style-type: none"> - Sélectionnez les éléments critiques à analyser (type de produits, taille de l'entreprise par exemple) pour voir si une généralisation est possible ; - Comprendre pourquoi certaines stratégies n'ont pas l'effet désiré sur la filière. 	<ul style="list-style-type: none"> - Développer une base de données spécifique à notre ingénierie afin de gagner en précision et en rapidité dans le traitement des résultats ; - Approfondir l'ingénierie afin que son utilisation permette de développer de nouveaux produits et de saisir de nouvelles opportunités.

Tableau 1 : Synthèse des avantages et limites de chacune de nos contributions

4. Conclusion et perspectives

Cette recherche a apporté plusieurs contributions aux problèmes de conception de produit et de la filière au sein des entreprises manufacturières. Du point de vue de la recherche scientifique, les différentes contributions concernent :

- La proposition d'une nouvelle vision de la conception de produit et de la filière: non pas en termes d'impact l'un sur l'autre, mais en termes de complémentarité;
- L'application du paradigme de complexité de la conception de produit et de la filière;
- L'identification des activités communes dans la conception de produit et de la filière.

D'un point de vue managérial, le développement de l'ingénierie de la filière basée sur des modèles a conduit à la mise en évidence de plusieurs observations auxquelles nous essayons d'apporter une solution par le biais de cette recherche :

- Le soutien aux entreprises se caractérise souvent par un soutien méthodologique ou financier pour le développement d'une innovation. Cependant, le développement d'une innovation ne se limite pas au produit lui-même, mais intègre également l'évolution de son environnement et, plus précisément, de sa filière. Une ingénierie de conception de la filière pour compléter l'appui actuel fourni aux entreprises a donc du sens.
- La conception de la filière dépend du contexte et des intentions. S'appuyer sur les activités communes à la conception des produits et de la filière assure ensuite une filière fonctionnelle adaptée au produit innovant, ce qui réduit les efforts des entreprises pour structurer leur filière au moment du lancement du produit. Toutefois, cette analyse doit être replacée dans son contexte afin que celle-ci soit conforme à son environnement.

Les contributions de ces travaux de recherche concernent donc à la fois la recherche scientifique et le monde de l'entreprise. Les résultats obtenus sont prometteurs et ouvrent des perspectives de recherche intéressantes.

Le concept de supply chain est-il encore pertinent ?

D'après les résultats de nos recherches, notre définition de la filière est peut-être trop étroite. Une plus grande attention est accordée à la notion de processus et de flux, mais nos expériences soulignent qu'une simple analyse fonctionnelle ne suffit pas pour analyser en profondeur notre objet d'étude. En effet, nous avons vu que les stratégies jouent un rôle important dans le développement et la pérennité de la filière. Cependant, cette notion apparaît de manière secondaire dans la définition de la filière

Le concept de communauté stratégique semble être une alternative intéressante. La communauté stratégique est une modalité qui rassemble les ressources de diverses organisations pour accélérer l'innovation dans un secteur d'activité (Roy et al. 2011). Ainsi, une communauté stratégique transcende les structures formelles de l'entreprise. Par conséquent, (Kodama 2005) décrit la communauté stratégique comme « une organisation stratégique informelle possédant des qualités à la fois basées sur les ressources (ou basées sur le savoir) et une vision stratégique ».

Dans notre recherche, nous avons essayé d'aller au-delà du concept de filière avec ses flux avec une vision plus dynamique et plus étendue qu'est la communauté stratégique. Cette dernière serait alors une structure temporaire de collaboration interorganisationnelle, composée de fournisseurs, d'entreprises manufacturières, de distributeurs, de clients, etc. dont le mandat consiste à fabriquer, lancer et assurer la pérennité d'un produit innovant sur le marché. Cette description de la communauté stratégique semble complémentaire mais non substituable à notre définition de la filière. Par ses fondements conceptuels, la notion de communauté stratégique complète celle de filière en soulignant l'importance du contexte et des acteurs et par les clarifications qu'ils apportent aux frontières. Cependant, notre objet d'étude se situe au croisement de la notion de filière et de communauté stratégique.

En fait, nous nous demandons si une fusion des concepts de filière et de communauté stratégique ne conduirait pas à l'émergence d'une définition plus complète de notre objet d'étude, c'est-à-dire une définition considérant la séquence des processus, des acteurs, des connaissances, des actions stratégiques et ainsi de suite qui mènent au lancement, à la fabrication, à la vente et à la durabilité d'un produit innovant sur le marché. Pour s'adapter au contexte actuel, le concept de filière semble devoir être redéfini.

Vers une métrologie de l'agilité ?

Nos recherches introduisent la notion d'agilité mais cette dernière nécessite un véritable approfondissement. Par conséquent, nous avons choisi de positionner notre contribution comme un outil d'analyse. En effet, elle nous permet d'avoir une vision factuelle lors de la modélisation de la filière et donc de comprendre l'opération inter-entreprise envisagée par l'entreprise innovante lors de la conception du produit.

Ainsi, nous pensons qu'il serait intéressant de développer une métrologie d'agilité pour soutenir les entreprises innovantes dans la mise en place d'une filière agile.

Nous proposons de développer un outil basé sur des décisions et des actions favorisant la mise en œuvre de l'agilité. Par analogie avec le travail effectué sur l'indice d'innovation potentielle (PII) (Camargo, Morel, and Boly 2015), notre proposition serait résumée en quatre phases :

- Identifier les " bonnes pratiques " qui ont un impact positif sur l'agilité d'une filière et définir une méthode d'évaluation ;
- Établir un système de référence global d'agilité ;
- Établir une évaluation multicritère conduisant à une comparaison des filières en termes de leur niveau d'agilité ;
- Élaborer des recommandations permettant aux entreprises innovantes d'accroître l'agilité de leur filière.

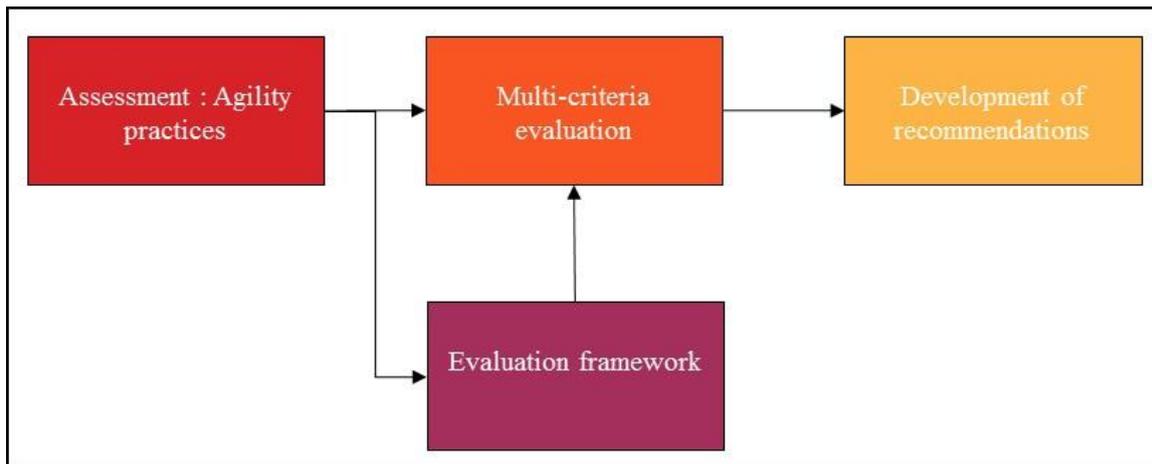


Figure 4 : Etape de création d'un outil de mesure de l'agilité

Cette métrologie serait basée sur l'identification des activités favorisant la mise en œuvre de l'agilité à travers une revue de la littérature (amélioration de notre contribution). Son application à différentes études de cas permettrait également de le valider expérimentalement. Ces études définiraient un regroupement d'activités sous la forme de pratiques d'agilité (le regroupement actuel dans notre contribution n'est peut-être pas le plus approprié). Il existe plusieurs méthodes pour évaluer ces pratiques. A première vue, la grille de maturité semble intéressante car elle met en évidence toutes les étapes nécessaires pour atteindre le niveau maximum d'un phénomène à mesurer, ici l'agilité. L'utilisation d'une grille de maturité comme méthode d'évaluation permettrait notamment de développer les capacités et les compétences de la filière, de la comparer avec d'autres filières, de définir des étapes progressives, de choisir la hiérarchisation des pratiques et l'amélioration des processus grâce à la comparaison avec les bonnes pratiques (Lemieux 2013), le tout en termes d'agilité.

Vers une filière 4.0 ?

La blockchain est une technologie de stockage et de transmission de l'information. Concrètement, une blockchain est une base de données numérique infalsifiable sur laquelle sont enregistrés tous les échanges entre ses utilisateurs depuis sa création. Contrairement à une base de données traditionnelle, une blockchain est une base de données distribuée (Badinet 2016).

Ainsi, en raison de ses caractéristiques, une blockchain garantit la traçabilité des produits de bout en bout, du fabricant au consommateur (en assurant la transparence et la conformité des données) (Hug 2017). Sur la base de cette constatation, nous supposons qu'une blockchain peut soutenir le fonctionnement d'une filière. En effet, les actions menées sur le produit sont déclarées à chaque étape de sa filière, de sa production à son utilisation finale (par exemple : son origine, ses conditions de fabrication ou de stockage, son transport...) (Hug 2017). Le produit contient alors l'information de tous ses composants et de la matière première. Ainsi, à la fin de la filière, le consommateur peut avoir accès à toutes les informations concernant le produit mais aussi les caractéristiques de sa filière. Elle devient plus transparente.

Ainsi, sous l'influence du développement d'une industrie 4.0, la filière évoluera, conduisant à une filière 4.0 où l'utilisation d'une blockchain augmente la participation des parties prenantes.

C'est un nouveau fonctionnement de la filière, plus numérique, plus flexible où chaque entreprise participe à son développement. La flexibilité de cette filière influence directement la hiérarchie au sein de la filière qui devient plus horizontale : les entreprises participent au même niveau, la collaboration et la contribution sont primordiales. Le transfert de données au sein de cette filière est facilité et transparent, ce qui est particulièrement bénéfique en termes de temps et d'accessibilité. De plus, la filière 4.0 a également un impact sur le client final, qui devient un consommateur et participe à la mise en œuvre et au fonctionnement de la filière à travers ses choix. Par conséquent, la filière 4.0 est une filière contributive ou "libérée" basée sur une opération participative et des outils numériques où chaque entreprise est un véritable moteur.

PUBLICATIONS

Peer-reviewed journals:

Marche, B., Boly, V., Morel, L., Camargo, M., and Ortt, J.R. (2017a). Overview of phenomena occurring in supply chains during the emergence of innovation. *Supply Chain Forum Int. J.* 18, 150–165.

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To be published shortly:

Marche B., Boly V., Morel L., Mayer F., Ortt R. (2019) Agilité et conception de filière : le cas de la montre Swatch. *Techinnovation*

Marche B., Boly V., Morel L., Mayer F., Ortt R. (2019) Agility and product supply chain design: the case of the Swatch. *Journal of Innovation Economics & Management*

International conferences:

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RESUME

Ce travail contribue à la recherche scientifique à travers différents aspects. Tout d'abord, le couple produit/filière, traditionnellement pensé de façon causaliste, a été envisagé à travers le prisme du paradigme de la complexité. Cette contribution théorique souligne la nécessité de co-concevoir le couple produit/filière afin d'atténuer les efforts associés au lancement d'un produit innovant sur le marché et de s'assurer de son succès. Cependant, une étude empirique a souligné que peu d'entreprises tenaient compte de la filière lors de la conception de leur produit innovant. Dans ce contexte, une ingénierie de conception de filière a été élaborée en se basant sur les données de conception du produit afin de concevoir, spécifier, valider et mettre en œuvre la filière d'un nouveau produit. Cette ingénierie se décompose en trois étapes majeures : une étape de co-conception, une étape de positionnement et une étape d'évaluation. L'étape de co-conception vise à collecter et à traiter les données de conception du produit fournies par l'équipe projet. Un modèle instancié de la filière a été développé afin de collecter les données nécessaires à la conception de la filière qui sont ensuite traités pour faciliter la modélisation. L'étape de positionnement vise à souligner le rôle de l'entreprise innovante au sein des différents scénarios de filière obtenus. Basée sur le processus *Harmony for System Engineering* et son outil Rational Rhapsody®, cette étape détaille la filière d'un point de vue exigences, acteurs, processus et comportement (chacun représenté par différents diagrammes) afin d'élaborer différents scénarios. Enfin, la dernière étape vise à évaluer ces scénarios de filière afin d'établir une stratégie cohérente. En effet, de nombreux chercheurs ont montré qu'une filière agile était plus apte à supporter un produit innovant lors de son lancement afin de s'adapter plus rapidement aux changements (organisationnels, tactiques, marketing, environnementaux...). Par conséquent, une trame basée sur des phénomènes observables a été développée afin de faciliter la mise en œuvre de stratégie d'agilité, ce qui permet d'évaluer la typologie de la filière actuelle et de décider des actions à mettre en place pour obtenir une filière plus agile. Cette ingénierie a été testée auprès d'entreprises manufacturières.

Mots-clés : Innovation, Filière, Co-conception, Agilité, Ingénierie basée sur des modèles, Entreprises manufacturières

ABSTRACT

This thesis contributes to scientific research through different aspects. First of all, the product/supply chain couple, traditionally thought of in a causalistic way, was considered through the prism of the complexity paradigm. This theoretical contribution underlines the need to co-design the product/supply chain couple in order to mitigate the efforts associated with launching an innovative product on the market and to ensure its success. However, an empirical study has pointed out that few companies consider the supply chain when designing their innovative product. In this context, supply chain design engineering was developed based on product design data in order to design, specify, validate and implement the supply chain of a new product. This engineering is divided into three major stages: a co-design stage, a positioning stage and an evaluation stage. The co-design stage aims to collect and process the product design data provided by the project team. An instantiated supply chain model was developed to collect the data needed to design the supply chain which is then processed to facilitate modeling. The positioning stage aims to highlight the role of the innovative company within the various supply chain scenarios obtained. Based on the *Harmony for System Engineering* process and its Rational Rhapsody® tool, this step details the supply chain from a point of view of requirements, stakeholders, processes and behavior (each represented by different diagrams) in order to elaborate different scenarios. Finally, the last step aims to evaluate these supply chain scenarios in order to establish a coherent strategy. Indeed, many researchers have shown that an agile supply chain is better able to support an innovative product when it is launched in order to adapt more quickly to changes (organizational, tactical, marketing, environmental...). Consequently, a framework based on observable phenomena has been developed to facilitate the implementation of an agility strategy, which makes it possible to evaluate the typology of the current supply chain and decide which actions to implement to obtain a more agile supply chain. This engineering has been tested with manufacturing companies.

Keywords: Innovation, Supply Chain, Co-design, Agility, Model-based engineering, Manufacturing companies