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Joint-design of products and supply chain in a context of innovation

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Abstract— Designing an innovative product that will be well adapted to the context of the company is a key success factor. In particular, the supply chain composed of suppliers (upstream) and all stakeholders up to the final customers (downstream) has to be adapted to the emerging product and all their technological new aspects. Within the scientific literature, product innovation and supply chain are generally considered in terms of a causal vision. This vision seems too limited to consider all the variables impacting the technical design of the product and the organization of the supply chain, especially when considering the first phases of the New Product Development Process. To describe the interrelations that take place between design decisions and external requirements all along the new product development process the product and its supply chain are defined as a couple. Based on the notions of dialogue and recursiveness, product design and supply chain design are considered as two complementary activities within the innovation process to increase the product's chances of success on the market. A managerial approach is proposed which integrates the joint-design of the product/supply chain couple in companies.

Keywords— *innovation; supply chain, complexity, new paradigm, innovation process*

I. INTRODUCTION

The links between the characteristics of a product and its industrial system have been studied in the literature [1]–[3]. This industrial system (often also called supply chain or “*filière*” in the French literature) is part of the ecosystem around a product: it concerns the suppliers (upstream) and all stakeholders up to the final customers (downstream) [4]. The supply chain, the term used in this article, defines the set of interconnected stakeholders and processes required, starting from raw materials up to a final product targeting particular customers [4]. The material, financial and informational flows between stakeholders are also considered. Moreover, the corpus of common knowledge shared by these supply chain members is considered: customer requirements and standards among others.

There is a causal relationship between the product and the supply chain: the product impacts the supply chain just as the supply chain impacts the product [5]. During the innovation process, designers study the market needs, find solutions about the product specifications, and, finally look

for a set of suppliers and downstream intermediaries to launch the product on the market [6]. In the environment of the company, the suppliers also adapt their activities to new constraints given by their innovative clients. In parallel, distributors adjust their organization when launching the new product. Thus, product characteristics such as life cycle, modularity, complexity, degree of innovativeness, cost, quality and physical properties will influence the design of the associated supply chain [7]. Therefore, the impact caused by the product on the supply chain could be observed and the causal influence is attested from the product to the supply chain, the supply chain having to adapt to the product. The development of innovative products leads to the emergence of new models and new logistics organizations. The supply chain definition becomes important for the success of the new product [8], [9]. Therefore, it also requires special attention from the designers at a strategic level (sourcing, collaboration and postponement), at a network level (capabilities of suppliers and manufacturing companies, capabilities of the storage and the transportation), at a local level (flows, storage areas, materials handling equipment, packaging...) and at a planning level (demand forecasting, inventory management, capacity planning...) [7].

More recently, the scientific literature has emphasized that a simple causal approach does not consider the full complexity of the interrelation between the product and the supply chain [8], [9]. Indeed, their relationship can be influenced by external environmental factors such as the size of the companies involved (including size diversity), the sector, the type of product, the influence of innovative companies within the supply chain and regulations [10]. As a result, the product and the supply chain influence each other and must adjust to each other [8], [9]. Thus, there is a bidirectional, dynamic and evolving relationship between the product and the supply chain. This relationship must be anticipated and considered when designing a new product.

In this paper, we propose to describe the product/supply chain couple under the complexity paradigm. In other words, we want to emphasize that product design and supply chain design can be seen as complementary activities in the overall innovation process, creating a

virtuous circle between the product and the supply chain. Therefore, this article is a managerial contribution, aiming to make practitioners aware of the need to co-design the product and the supply chain and to support them in this co-design approach. Indeed, there is a lack of a coherent overview of the joint product/supply chain activities that can be conducted during the innovation process. Filling this knowledge gap should help practitioners design appropriate supply chains for products before they reach the market.

This paper is organized as follows. The first part focuses on the theoretical background, addressing the complementarity of a systemic descriptive approach to the interrelation between a product and a supply chain. It also addresses the notion of co-design. Considering that a practitioner can perceive a standard as a guide, the second part proposes an improvement of the French standard FD X50-271 on innovation management [11] to highlight the existence of activities allowing a co-design approach of the product/supply chain couple.

II. THE LINK BETWEEN PRODUCT AND SUPPLY CHAIN: A THEORETICAL APPROACH

A. *Theoretical approaches to the product/supply chain link*

Some researches [1]–[3] describe four major variables impacting the product/supply chain couple: supply and demand uncertainties, customer expectations and time dimensions (product life cycle). Depending on the type of products considered, supply chain categories are proposed in order to better understand the bidirectional nature of the relationship between the product and the supply chain.

In his pioneering work, Fisher [1] shows that innovative products whose demand is difficult to predict and functional products satisfying basic needs for which demand is predictable do not have the same supply chain requirements. Fisher addresses the concept of “match” by exploring how the nature of the company’s products fits the organization of the company’s supply chain [12], [13]. In addition, he considers that a predictable demand requires physically efficient processes, while an unpredictable demand (as is the case for innovative products) requires market-responsive processes, i.e. more adaptive processes.

In his work, Lee [2] extends the scope of uncertainties by suggesting that companies have to understand the uncertainties regarding both the supply and demand of their products in order to try to match these uncertainties with the right supply chain strategies. Complementary to Fisher’s efficient vs adaptive notion, Lee [2] stressed that supply chains can evolve or be stable in a context of innovation. A new product can stem from a stable supply chain (purchasing and manufacturing process of the stakeholders are known and mastered, underlying technologies are mature for example) or an evolving supply chain (purchasing and manufacturing processes of stakeholders and underlying technology are still under development and are rapidly changing). These statements lead to two new types of supply chain: risk-hedging and agile supply chains. A risk-hedging supply chain tries to prepare for possible risks, including keeping extra stock or developing extra supplier relationships to safeguard the

supply of components. An agile supply chain is also risk-hedging but at the same time deals with changing product characteristics that put constant pressure on the supply chain. Finally, the strategy implemented by an innovative company depends on the maturity of the supply chain processes. More mature supply chains have over time developed optimal conditions to achieve objectives of supply chain partners [14].

The organization and, consequently, the design of a supply chain depends on the characteristics of the product and the expectations of the downstream supply chain partners and end customers [1], [15]–[17]. [3] suggest that customer expectations may evolve and thus are considered throughout the product life cycle. Three types of product can be distinguished [3]: standard products (stable demand and slow evolution), innovative products (uncertain demand and quick evolution) and hybrid products (a combination of standard and innovative products). This product classification leads to the following typology: (i) Lean supply chains, in which stakeholders individually focus on eliminating non-value adding steps and collectively seek to optimize the supply chain to improve performance [2]. This type of supply chain complicates adaptation to changes in the environment (e.g. in standards or customer demand), (ii) Agile supply chains, in which stakeholders individually understand customer requirements [2], [18] through an interface with the market and have a collective knowledge that is expressed through joint activities (meetings within professional structures, a research program within a shared entity) or bilateral activities (customers—supplier), in order to be able to adapt quickly to future changes, or (iii) Hybrid supply chains, where a supply chain can be adapted and take on the characteristics of each of the previous types, thereby forming becoming hybrid.

The dynamic nature of present supply chains suggests that, the products’ characteristics have to be quickly adjusted as products move through their life cycle [12], [13]. Thus, the match between product and supply chain is considered as a perfect and dynamic 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) [19]. Then, Vonderembse et al. [3] propose a supply chain classification of product types and product life cycle as a matrix.

These different approaches underline that there is a close link between product and supply chain that needs to be considered during the design stages. The following sections will focus on the link and its consequences within the innovation process.

B. *Towards a vision in terms of circularity for a joint design of the product and the supply chain*

Several approaches are presented in the literature, based on a paradigm that can be considered as causal. These theories are not conflicting but underline the complexity of the phenomena.

Considering the product and the supply chain as subsystems can help to explore the link between these two entities as a systemic approach facilitates the study of

objects in their complexity. De Rosnay [20] defined a system as “sets of elements in a dynamic interrelation, organized according to a goal” that helps to solve a complex problem [21]. A product is composed of independent elements performing functions, organized as a whole where each element function contributes to defining the global function of the expected product. A supply chain defines the set of interconnected stakeholders and processes required starting from raw materials to a final product targeting particular customers [4]. It is then the system supporting the industrialization of the product. Therefore, the product and the supply chain are considered as two interdependent objects of study in the same dialogical and recursive duality, i.e. these two poles form a virtuous circle (recursiveness) where the two elements are united without the loss of a duality (dialogism). Moreover, the systemic approach is based on the recognition that there are many possible organizations to cope with the environment. Therefore, there is not just a single way to achieve positive results [22] and in our case different configurations are possible and reliable for the product/supply chain couple. More precisely this couple may be analysed considering the four precepts: (i) relevance (there is no ideal combination between the two considered systems), (ii) globalism (one improvement on one of the systems will have a greater effect if there is a combined improvement on the other one), (iii) teleology (the couple is influenced by the objectives of the stakeholders) and (iv) aggregation (as the situations to be studied are numerous and challenge comprehensiveness) [23].

Considering the complexity of the reciprocal interrelations, the notion of circularity may be proposed. Refusing to reduce complex data treatment, circularity means that the causes and effects of a phenomenon influence each other. Thus, the effects of the product and those of the process, here the supply chain, are to be considered simultaneously as co-generators and co-causing [24], [25]. Therefore, evolution over time of the product and the supply chain is represented by a set of cause-effects in the shape of virtuous circles that improve their relationship.

This notion of circularity can be illustrated through a study of the Swatch case highlighting the impact of the product on the supply chain and vice versa [26]. In this case, these decisions concerns:

- **Knowledge and skills mobilized:** Some of the skills mobilized to design a product are common to those needed to describe how the current supply chain works. The development of the Swatch mobilized knowledge of the watch industry (operating in a cartel where each company is specialized) and skills in plastic injection. This same knowledge is necessary to understand the organization of the supply of raw materials (watch components) or marketing constraints (jewelry, etc.). When changes occur in the product or in the supply chain, new skills emerge as a way to adapt.
- **Partners:** Simultaneous engineering aims to integrate partners during the product design phase, these same partners can also be integrated into the supply chain of the future product. In the case of Swatch, the partnership with an equipment supplier, Branson,

allowed to select the technology, the ultrasonic welding at the heart of the future supply chain.

- **Technology/Equipment:** Some of the technologies mobilized to design a product are common to those needed to manufacture the product in today’s supply chain. In the case of Swatch, the partnership with the equipment manufacturer validated the choice of technology, ultrasonic welding. In addition, the patenting of a method for attaching the glass to the housing led to the consolidation of the product and the supply chain.

The circular causal link between the product and the associated supply chain emerges at the design stage and it continues to evolve during later stages. As mentioned by [24], as two systems are in a circular interrelation, the design of the two systems is characterized by complementary activities. Following on from the work of [9], [27], this research focuses on common product and supply chain design activities within the innovation process to ensure product success (Fig.1).

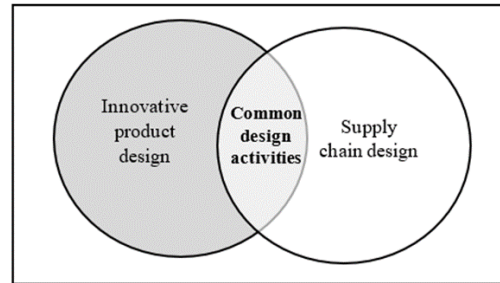


Fig. 1. Common design activities between innovative product design and supply chain design

The joint design of the product/supply chain couple groups activities whose implementation feeds both the product and the supply chain and which mobilize common skills and decisions. Therefore, this joint design can be seen as a complex thinking step in a new product development process. Indeed, complex thinking will help us to link the product and the supply chain while differentiating them, unlike disjunctive thinking which seeks to consider the product, on the one hand, and the supply chain on the other without looking at what connects them. It differs from “design for” or “concurrent engineering” approaches, which aim to develop a collective understanding of product design and production system by seeking to minimize manufacturing time, costs or operational difficulties [28]. Thus, the next section of this article will seek to provide practitioners with some elements to jointly design the product and the associated supply chain.

III. MANAGERIAL PERSPECTIVES: JOINT-DESIGN ACTIVITIES DESCRIPTION THANKS INNOVATION STANDARDS

To describe the product/supply chain joint-design activities, we took the opportunities of the recent publication of innovation management standards. Note that authors participated in the elaboration of these standards. Three standards exist: national standard like the French standard FD X50-27, the European CEN/TS 16555-1 and the international ISO 56002. In fact, all these standards are perfectly consistent. The choice of the FD X 50 271 is made for two reasons: (i) it is the first published and (ii) it

is the easiest way to get in contacts with experts, in particular thanks to the synoptic table presented below.

A. Description of the current French Innovation Management standard

The French Standards Association (AFNOR¹) has published a standard in Innovation Management FD X50-271. It is based on an implementation guide to “define for an organization, the actions, choices and structures within the framework of its general management, to promote 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 (mainly addressing top management involvement) and operational management of innovative projects (mainly concerning project managers and all people involved in design tasks)” (Fig.2).

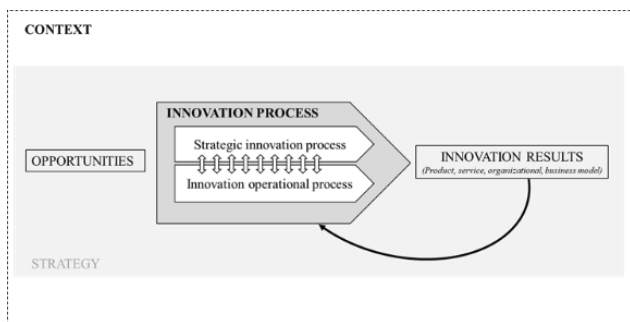


Fig 2. Simplified representation of innovation management based on the FD X50-271 standards

The strategic level can be divided into four stages [29]:

1. “*Exploration*” seeking to identify the contextual elements for action by providing a methodological approach;
2. “*Evaluation & decision*” seeking to validate the contextual element for action by providing a methodological approach;
3. “*Project management*” seeking to manage the strategic plan throughout its development;
4. “*Capitalization*” seeking to refine the relevance of the company’s strategic plan year after year.

The third stage of the strategic level, i.e. “*project management*”, is the interaction between the **strategic level** and the **operational level**. The operational level ensures the coherence and good progress of projects in line with the objectives of the strategy. It is at the strategic level that choices and priorities are made.

The **operational level** consists of four stages in project management adapted to innovation, and are referred to as “*formulation*”, “*feasibility*”, “*development*” and “*launch*”. It offers a structured innovation management methodology to ensure feasibility and profitability of innovation projects [29].

The strategic and operational management of innovation are then structured with four major areas of engineering to be implemented and coordinated by companies to ensure

the completeness of this management. The risks and opportunities described at this stage are [29]:

- The **Marketing** and sales part concern the contribution of knowledge about customer needs as well as knowledge about the maturity of the market with regard to innovation and it also deals with the identification of exploitable prospects.
- The **Commercial** activities are also concerned with the customer feedback and niche opportunities to be explored.
- **Technology** relates to expertise and innovation methodology. It gives insights into the required know-how to design an innovative artefact and the mastery of the techniques and methods that the company has at its disposal.
- The **Legal, Normative and Financial** aspects focus on the protections, guides and drivers of the innovation portfolio management strategy. This refers to the tasks of employees involved with legal issues and more precisely to the monitoring of intellectual property and the search for risks, opportunities and regulatory monitoring.
- **Management and organization** focus on the operational activities needed to manage innovation portfolios and innovation projects. It deals with the supervision tasks and decision taking. This includes: value analysis, planning, responsibility sharing and internal communication.

As a result, the standard provides a guiding scheme representing the innovation process where each task is presented in the form of best practice sheets in order to improve companies’ ability to innovate by increasing their project quantity, and degree of novelty and diversifying the types of projects.

B. What could be a product and supply chain joint-design?

The proposal consists in adapting the process described in the French Innovation Management standard by integrating activities related to the supply chain in order to support innovative companies in this process. Two notions are important during integration of product and supply chain: iteration and integration. More precisely, iteration is represented by a close alternation between study phases focusing on the product and those targeting a better description of the supply chain, and integration refers to phases where data concerning the two domains are simultaneously mobilized.

1) Strategic Innovation Management

Strategic reflection on the supply chain help to promote emergence of and decisions regarding the launching process. It should be noted that a joint design approach for an innovative product and the associated supply chain depends on the innovative company’s willingness to open up, i.e. its willingness to initiate partnerships (companies, laboratories) and to design new supply chains [30], [31]. Within the scope of this standard, strategic innovation management in the product/supply chain couple area is as follows (aspects dedicated to the product are marked with

¹ Association Française de NORmalisation

a “P” and “SC” for the supply chain. Finally, an “I” is used when integration is applied):

“*Exploration*”: It identifies the contextual elements that need to be considered for action. At this stage the aim is to consider contextual data (sector, size of companies, size of the supply chain, competitive environment, experience of the current supply chain, etc.) in order to select the opportunities that the company supply chain(s) can seize thanks to its potential (technologies, knowledge and know-how) and to the list of external contributions available to be incorporated. This integrates the identification of available know-hows (*P*) for future products and their owners (*SC*), potential partners (*SC*) and potential competitors (*SC*).

“*Evaluation and decision*”: It validates the contextual elements for action. This phase relates to the identification of 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. This consists of technical studies (*P*), benchmarking (*I*) and multi-criterion decision-making processes including make or buy decisions (*I*) [32].

“*Project management*”: This step ensures 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. From the specifications about the product (*P*), the production processes (*P*) and the supply chain (*SC*) and sales activities (*SC*), competencies are listed and their availability is ensured (*I*) (training in companies or mutualized training sessions within the sector, individual or collective research programs...).

“*Capitalization*”: This step seeks to ensure that the information provided by the supply chain analysis is safeguarded. This corresponds to capitalize on the technologies (*P*), knowledge and know-how held by the supply chain companies (*SC*) in order to remobilize them in new projects, enrich the databases (technologies, skills or know-how) for future innovation projects [33] and facilitate the design of future supply chains (*SC*).

TABLE I. ASPECTS DEDICATED TO PRODUCT, SUPPLY CHAIN OR INTEGRATION OF BOTH AT THE STRATEGIC LEVEL

Step	Variable	P	SC	I
Expl	Know-how about product	X		
	Know-how about companies		X	
	Potential partners		X	
	Potential competitors		X	
Eval	Technical studies	X		
	Benchmarking			X
	Multi-criterion decision			X
Proj. Man	Product specification	X		
	Production processes	X		
	Supply chain process		X	
	Sales activities		X	
	Competencies			X
Cap	Technologies	X		
	Knowledge and Know-how of partners		X	
	Technologies and skills of partners		X	

2) Operational innovation management

Within the scope of the standard, operational innovation management in the product/supply chain couple area is divided in four aspects:

“*Project formulation*”: It consists of reviewing industrial processes and identifying possible solutions on the market. This step makes an inventory of the industrial processes to be considered in view of a possible industrialization of the product (*I*), identify the missing processes in the current supply chain or in the environment of the innovative company (*SC*) [34], and highlight the possible industrial solutions (*I*). Reflections on industrial solutions also lead to questions about the supply of raw materials (type of raw materials, availability) which will participate in the choice of the industrial solution (*SC*).

“*Project feasibility*”: It studies the functional feasibility. This phase focuses on the study and validation of the functional realization of the product (*I*), i.e. the modelling of each supply chain scenario (*SC*) integrating reflections on physical flows (geographical location of stakeholders, single or multiple supply...) and defining the different actions for the implementation of each scenario (*I*). The creation of a scenario is used to identify the type of collaboration to be implemented to secure the industrialization of the product according to the value generated by each potential partner (*SC*). The creation of these scenarios then leads to the identification of potential partners to include in the development of the product according to their skills, their technologies (degree of mastery, patent), their location, their positioning in a market.

TABLE II. ASPECTS DEDICATED TO PRODUCT, SUPPLY CHAIN OR INTEGRATION OF BOTH AT THE OPERATIONAL LEVEL

Step	Variable	P	SC	I
Proj. form	Industrialization of the product			X
	Missing processes		X	
	Industrial solution			X
	Supply of materials, solutions		X	
Proj. feas	Functional realization of the product			X
	Supply chain scenarios		X	
	Reflection on flows and implementation of the supply chain			X
Prod. dev	Value generation for each partner		X	
	Industrialization			X
	Decision-making concerning technologies and supply			X
	Validation of supply chain scenario		X	
	Implementation of the supply chain			X
	Patent registration	X		
Launch	Relationship between stakeholders		X	
	Deployment of the supply chain		X	
	Launch of the product on the market			X

“Product development”: It develops the functional solution. At this stage, a strategic decision is made to define the best product/supply chain couple configuration. The development of the functional solution will make it possible to refine the supply chain scenarios and to determine the future stakeholders involved in industrialization among others (*I*). Supply chain scenarios can then influence the decisions to be taken during the product design on the technological level (location, degree of control, availability, capacity), on the supply level (location, source, availability, capacity) (*I*). Companies try to strengthen and validate the favored supply chain scenario (*SC*) for the final product and assess the risks [35]. The actions to be implemented within the supply chain are listed to form an action plan (*I*). Following product development, protection mechanisms [36] such as patent registration (*P*) can then be used to strengthen relations between several stakeholders in the future supply chain (*SC*).

“Product launch”: It qualifies the supply chain and its implementation. This step seeks to organize the deployment of the supply chain able (*SC*) to support the manufacturing and sales of an innovative product. The actions implemented aim to ensure the launch of the product (*I*). This last step seeks to concretize the supply chain (and therefore the product according to the companies involved in industrialization). This involves specifying the capacities of each partner (suppliers, manufacturers), specifying logistics strategies (storage,

production on demand, transport), organizing production and the exchange of physical, informational and monetary flows between stakeholders (planning, demand forecasting, inventory management) [7].

The global proposal is illustrated in Fig.3 in which the middle row of the strategic and operational level management, the red row, is added to represent the important aspects of the supply chain and product couple.

IV. APPLICATION OF OUR PROPOSAL TO THE DESIGN OF AN ELECTROMAGNETIC SENSOR AND ITS SUPPLY CHAIN

A first test of the proposed joint-design approach was carried out on an electromagnetic sensor and proved to be conclusive. For reasons of confidentiality, the name of 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 designers.

A. Description of the Company and the innovative product

The innovative company, called Company X, specializes in ball bearings 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. The innovative product is an electromagnetic sensor integrated into ABS technology as an alternative to the Hall Effect

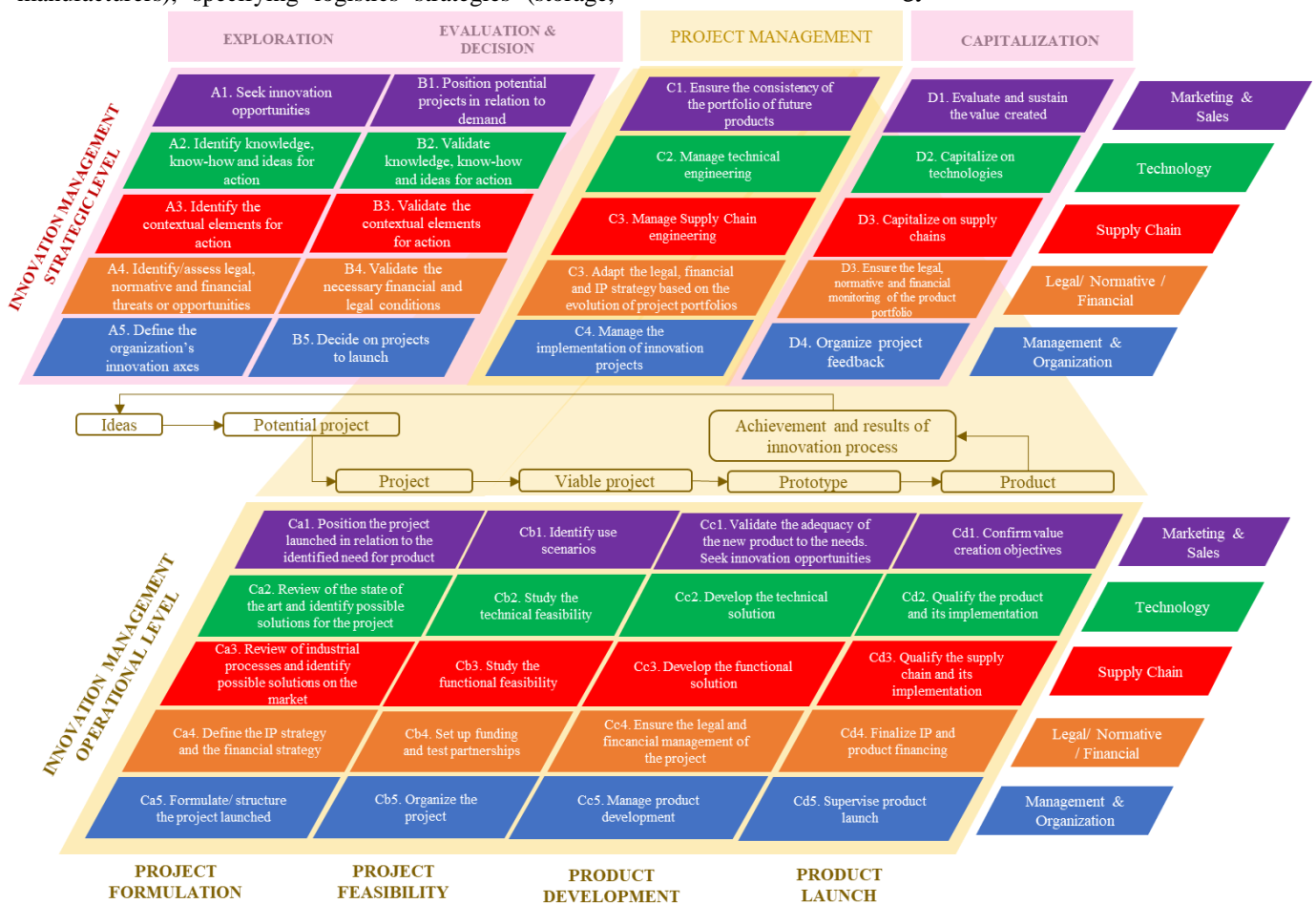


Fig. 3. Proposition of a new synoptic table of innovation management (added activities in the red boxes)

sensor. ABS technology is an assistance system integrated into a car to help the driver during braking so that the wheels do not remain locked. This innovative product consists of a magnet and a sensor, sensitive to the external magnetic field in order to vary the electrical resistance of the assembly. It is made of 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; particular attention is paid to this part in order to propose a relevant supply chain analysis.

B. Description of the joint-design project

From a product point of view, the product was started in response to a growing demand for a more accurate and complementary sensor. By exploiting the properties of the electron, Company X plans to offer a new range of sensors that can integrate new markets and supply chains. For this innovation project, Company X decided to integrate external partners and create a consortium. It relies on (i) the expertise of an academic research laboratory specializing in material sciences for scientific supervision and on (ii) the qualified personnel and infrastructure of a second company called Company Y for the specifications and industrialization of sensitive elements. The close collaboration between Company X and Company Y leads to the joint-design of the product/supply chain couple, with the two companies forming the basis of the future supply chain in charge of the manufacture of the innovative parts of the product, i.e. the target magnet and the detection device.

The first steps of the collaboration between Company X and the research laboratory made it possible to identify and validate the knowledge to be mobilized for the success of the project, especially in spintronics and electromagnetism (steps A2 and B2). Once the project was launched, both partners were involved in identifying possible solutions based on their previous scientific research on tunnel magnetoresistance (TMR) (step Ca2). In collaboration with Company Y, they validated the technical feasibility of the proposed solution, the TMR sensing element (step Cb2). Company Y then validated with its suppliers the availability of the substrate compounds (Cb3) before participating in the development of the first functional prototype, the sensor structure (step Cc2). Companies A and X co-specified the product/process leading to the sensors and participated in the product launch (step Cd2) and data capitalization (step D2).

From a supply chain point of view, Company X has identified competing supply chains, those of the Hall effect sensors in particular and identified new markets that it could target, such as the household appliances or aeronautics sector and relevant partners, such as Company Y (steps A3 and B3). Once the product was launched, an inventory of industrial processes that could potentially be used in the future supply chain was carried out, including thin magnetic layer deposition and first solutions were identified (steps Ca3 and Cb3) in particular by validating the ability of suppliers to supply the compounds needed for the substrate as well as the ability of the chosen technologies to be mass-produced. The technical tests carried out by these three stakeholders made it possible to define the sequence of processes required to produce the

innovative sensor (step Cc3). Tests were carried out on a small scale to validate that the supply chain scenario was robust enough for mass production.

Finally, Company X and Company Y have contracted their collaboration, moving from the design stage to the industrial stage. One of the terms of the contract stipulates that Company Y must be the supplier of Company X for the sensitive part for a defined period of time. They have set up the supply chain scenario that they consider most appropriate by contracting their relationships with the other supply chain partners (Cd3). The supply of raw materials is divided between several specialized suppliers (steel, electronic components, elastomers). The manufacture of the layer supporting the detection device is subcontracted, as well as the manufacture of the plastic protection integrating the detection device and the target magnet. Company X takes care of direct sales to the car manufacturer. As a result, the supply chain of this new product is limited to a few stakeholders, with the majority of the activities being carried out by Companies X and Y. It should be noted that a patent has been filed for this innovation in order to consolidate the innovative part of the product at the base of the supply chain.

For the case of the electromagnetic sensor project, Table III illustrates how to organize the joint-design of the product/supply chain couple using our proposal based on standard FD X50-271.

C. Limitation of our proposal

The results obtained by joint-designing the product/supply chain couple are satisfactory: the product has been successfully launched on the market, in addition to the existing sensors. The couple product/supply chain joint-design helps to anticipate the deployment of the future supply chain and ensures that the innovative product could move from the prototype stage to the industrialized product stage. Companies are now integrated in the supply chain whose role are manufacturer of the detection device (Company Y) and manufacturer of the target magnet and ABS Technology assemble (Company X). This new proposal for the standard is a suitable response to support companies in their joint-design project of the product and the supply chain, offering operational, technological, organizational and strategic responses.

However, our proposal to transform the innovation standard seems insufficient to describe the complexity inherent in joint-designing the product/supply chain couple. Particular attention is paid to the competitive environment (study of competitors, market demand, etc.) but some factors may be added, including: the degree of novelty of the product, the size of the innovative company or the size of the global supply chain among others. Indeed, all these factors have an impact on the supply chain's functioning and behavior. The joint-design of the product/supply chain couple is therefore multi-scale and context-dependent. Moreover, the proposed approach does not reflect the dynamism inherent in the joint design of the product and the channel. The process is much more iterative and interactive.

TABLE III. SYNTHESIS OF THE JOINT-DESIGN APPROACH OF THE ELECTROMAGNETIC SENSOR COUPLE AND ITS SUPPLY CHAIN BASED ON OUR PROPOSAL DERIVED FROM STANDARD FD X50-271

STRATEGIC LEVEL	
EXPLORATION	
A2. Identify knowledge, know-how and ideas for action	For providing a high-precision detection and low power consumption sensor, two quantum properties of the electron are used: (i) the spin that makes it sensitive to the magnetic field and (ii) the tunnel effect which allows the electron to pass through insulating barriers
A3. Identify contextual elements for action	Study of global value and demand (competing supply chain, technological system involved, customer needs, market dynamism, etc.)
EVALUATION & DECISION	
B2. Validate knowledge, know-how and ideas for action	Validation of the concept selected at the previous stage in partnership with the research institute
B3. Validate the contextual elements for action	Validation of the possibility to design a new supply chain in this sector (profitability, value generated, satisfaction of customer needs, etc.)
CAPITALIZATION	
D2. Capitalize technologies	Drafting of an end-of-project report
D3. Capitalize on supply chains	Storage of contracts, invoices and documents provided by each partner
OPERATIONAL LEVEL	
PROJECT MANAGEMENT—PROJECT FORMULATION	
Ca2. Review of the state of the art and identify possible solutions for the project	Research on layer physics and tunnel magnetoresistance (TMR): possibility to develop TMR made of two ferromagnetic layers by a nanometric insulating layer for mass production and use in extreme conditions
Ca3. Review of industrial processes and identify possible solutions on the market	Choice of Company Y's processes to develop the sensor in partnership with Research institute because of its experience in thin magnetic layer deposition and process and its high-performance equipment
PROJECT MANAGEMENT—PROJECT FEASIBILITY	
Cb2. Study the technical feasibility	Production of TMR sensing elements under industrial conditions with controlled reproducibility and a yield fully compatible with future industrialization
Cb3. Study the functional feasibility	Validate the capacity of Company Y to produce the chosen TMR sensor with its machine park and employee skills
PROJECT MANAGEMENT—PRODUCT DEVELOPMENT	
Cc2. Develop the technical solution	Adaptation of the sensor structure to the process available on the industrial tool Optimization of the different layers of sensitive elements Choice and optimization of oxygen plasma oxidation Tests on the performance of the TMR sensor in terms of sensitivity and operating temperature Obtaining a prototype of the integrated sensor Filing a patent
Cc3. Develop the functional solution	Determination of specifications for the supply chain of the future product Definition of the characteristics of the stakeholders (skills, technological expertise, equipment) to be integrated into the supply chain Choice of stakeholders Definition of the tasks to be carried out by each partner and the relationships between them Obtaining different scenarios of supply chains suitable to the product production
PROJECT MANAGEMENT—PRODUCT LAUNCH	
Cd2. Qualify the product and its implementation	Development of product/process specifications that allow sensors to be developed according to customer specifications and industrialization to be started
Cd3. Qualify the supply chain and its implementation	Definition of the supply chain strategy Transmission of tasks to be carried out by each stakeholder involved in the supply chain Development of the sequence of processes to be followed (deadline, logistics, etc.). Contractualization of relations between supply chain stakeholders

V. CONCLUSION

Complex thinking provides a solid foundation for understanding the bi-directional, dynamic and evolving relationship between innovation and the supply chain. As a result, the integrated design of a new product and its supply chain is possible. This article proposes an improvement of the FD X50-271 standard in Innovation Management, aiming to raise awareness of the need to co-design the product and the supply chain and to support them in this co-design approach. A case study on the simultaneous design of an electromagnetic sensor and its associated supply chain is presented to illustrate the use of the revised standard by an innovative company. It shows that this proposition can help companies to design the product/supply chain couple by proposing a list of tasks and practical sheets to balance the aspects related to the innovative character of the product and the considerations related to the supply chain. This case study also reveals activities common to both product and supply chain design, such as the search for technical solutions and feasibility studies (technical for the product, industrial for the SC). The common development activities lead to the elaboration of supply chain scenarios based on the different prototypes in order to identify if the solution is feasible at the industrial system scale. Finally, the qualification activities of the product/supply chain pair involve the contract of the relationships resulting from the selected product/SC scenario in order to validate the product launch. These joint product design and supply chain activities rely on both cross-functional skills, such as project management, and specific skills (e.g. mechanics, IT, electromagnetics, etc.) to facilitate exchanges between the various partners. This managerial proposal of joint design of the product and the supply chain could go beyond the framework of innovation projects, in particular by helping practitioners to integrate thoughts of circularity in the design of products and the global organization of associated supply chains.

This case study also provides some important conceptual insights, including the value of approaching the product/supply chain pair from a complexity perspective. It highlights the importance of a more holistic view of the product design and supply chain process, considering the whole to be more than the sum of its parts by identifying common product design and supply chain activities within the innovation process in order to reduce the effort required to launch a product. The precept of teleologism is also respected by considering that the innovation/supply chain relationship involves a double action and leads to the creation of a virtuous circle. Following our first empirical observations, we can deduce that the precept of relevance is also respected in the context of the co-design because this vision leaves innovative companies free to act and considers the notion of intention of the innovation driver (the CEO, the R&D team, the innovative consortium, for example). Indeed, the product/supply chain couple being dynamic and evolving, it can easily consider the changes of perception of the actors involved in the innovation. Finally, the precept of aggregation is respected because this new paradigm deliberately considers the differences and variability of situations by considering the different factors (of the environment) influencing the product/supply chain

couple. Indeed, we insist on the fact that each product/supply chain pair studied is unique and that its specific contextual characteristics must be considered. However, the influence of this new paradigm on the success of the innovative product once it is launched on the market still need to be empirically tested.

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