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A collaborative tool to design the product/supply chain couple in a high-tech environment: application to an electromagnetic sensor

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Abstract— The emergence of innovative products involves several stakeholders and impacts the supply chain. Innovation is often a collective and open process. As the product is interlinked with its supply chain, companies involved in the innovation process have a strong interest in focusing on the product/supply chain pair rather than on the product alone. However, there are many collaborative tools dedicated to product design but they are not necessarily adapted to the design of the product/supply chain couple. Therefore, we suggest in this article that an instantiated supply chain model can help companies collaborate to design their product/supply chain couple. A case study illustrates our proposal and highlights the importance of digital tools in the innovation process.

Keywords— *Supply chain; Innovation; Collaborative tools; Case Study*

I. INTRODUCTION

New products become more and more complex, involving an increased number of stakeholders. Consequently, innovation cannot always be driven by the company alone [1], it is often a collective and open process. Indeed, the new product often requires new resources, a new mode of delivery, and a distribution of tasks of realization between several companies. Therefore, innovation occurs within wide collaborative systems between customers and suppliers [2] or between final customers and manufacturers [3]. Thus, it is important to have a vision of the sequence of stakeholders involved in the launching of an innovation [1], i.e. a vision of the supply chain of the product.

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 [4]–[6], because the structure of the supply chain is influenced by the technical choices made to manufacture the product [7], [8]. The product is both the cause and the effect of the supply chain. So, the product and the supply chain are interrelated. Hence in a context of innovation, collaboration between companies could facilitate the achievement of an "optimal" product/supply chain couple. This collaboration may help to consider the complexity inherent in the product/supply chain relationship (regulatory constraints, specific skills, available technology among others).

However, at present, many collaborative tools facilitate product design such as computer-aided design software or augmented reality [9], [10] or project management tools without being adapted to supply chain design. Thus, this article raises the following question: How to extend collaborative tools to the product/supply chain couple? This research shows how the instantiated supply chain model [11] can support collaboration between companies designing the product/supply chain couple.

This article is structured as follows. Initially, existing theories related to our research work will be proposed. Then, the methodology is presented and the results are detailed. The model is described in detail. Finally, the analysis and conclusion of this research are presented.

II. RELATION TO EXISTING THEORIES AND WORK

A. Characterization of the studied system: the product and Supply Chain couple

This study integrates two closely related and interacting subjects: the product and the supply chain. The product is the result of a sequence of processes that also characterizes the supply chain. So, the product and the supply chain are linked by activities and tasks [12] within processes involving specific skills, equipment, decisions and know-how

Whatever the innovation is (product, service, processes, organization, way to sell...), the supply chain is impacted following the changes within the innovation. An innovation can lead to consequential changes requiring a partial or complete reconfiguration of the supply chain [13].

The choice of a supply chain is directly linked to the expected results in terms of value creation. However, each supply chain evolves in an environment with external factors (political, economic, socio-cultural, technological, ecological and legal) to be considered because they can change and have an impact on operations in the supply chain [13]. 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 [14]. Thus, the functioning of the supply chain depends on the balance between all these components. So, there is a mutual dynamic influence between the product and the supply chain: the product and the supply chain form a couple and evolve in a complex environment.

The product/supply chain couple is a part of a larger Technology Innovation System, containing both social and technical elements, 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 [15].

Thus, when designing the product/supply chain couple as part of the innovation process can help to consider the complex interactions with the environment [15]. Indeed, the link between the product and the supply chain is possible through the processes that make it possible to produce the product and define the supply chain. This vision is complementary to a "Concurrent Engineering" (CE) approach of the 90s that is intended for "designing concurrently a product and its processes, such as: manufacturing, assembly, test, support and recycling" [16]–[18]. Consequently, as multiple stakeholders are involved in the co-design of a product/supply chain tools are developed to collaboratively design and implement the product/supply chain.

B. Importance of the collaboration for the adjustment between Product and Supply Chain

Companies rely on R&D collaborations to access external sources of knowledge which can represent a substantial part of the complementary inputs necessary for the development of successful innovations [19], [20].

R&D collaboration for innovation offers a number of substantive benefits, such as the possibility for mutual knowledge sharing, combining complementary skills with partners, scale economies in research, as well as the sharing of costs and risks [21], [22]. A large body of literature has shown that R&D collaboration can contribute to different outcomes such as innovation [23]–[25], patenting [26], organization growth [27] and manufacturing procurement efficiency [28]. There are differences between institutional (universities and research institutes), vertical (buyers and suppliers) and horizontal (competitors) R&D collaborations [22].

Universities and research institutes are important centres for the creation and dissemination of scientific knowledge [29]. Suppliers have greater expertise and more comprehensive knowledge regarding the parts and components which may be critical to a company's new product development [30]. Customers can help to identify market opportunities for technology development but also reduce the likelihood of poor design in the early stages of development [30]. Furthermore, involving customers can help to gain new ideas about solutions

[31] and to identify market trends, thereby increasing the chances of new product development and success [30]. Finally, competitors can share technological knowledge and skills in order to produce a synergistic effect on solving common problems outside the competitor's area of influence [32].

In a co-design approach for the product/supply chain couple, vertical collaborations are particularly interesting because the stakeholders are likely to participate in the industrialisation of the product. As a result, vertical collaborations can be at the origin of the future supply chain of the innovative product.

Many tools have been developed to facilitate collaboration between several stakeholders, among others: (i) Digital tools to facilitate the exchange of information such as computer-aided design software or augmented reality [9], [10]; (ii) Organizational tools or methodologies to facilitate project management [33], [34] such as Enterprise Resource Planning tools [35], collaborative platforms or scrum methods [36].

However, there is a lack of strategic approaches characterizing collaboration and addressing important questions such as Why collaborate? How to collaborate? Under what conditions? How long?

So, characterizing collaboration prior to launch and defining its role in the future supply chain (i.e. anticipating its evolution) can be useful to increase the chances of success of the product on the market.

C. An instantiated supply chain model as a collaborative tool

Product design is a complex phenomenon that depends on the interaction between many stakeholders. Design research aims to understand what drives the improvement of the practice of product design in order to increase the chances of producing a successful product [37], [38]. Therefore, human interactions are an important part of the design process that contain main uncertainties [39], [40].

Collaboration results from these human interactions. Common models can help describe and implement collaboration by providing a common vision of the object to be created. However, in our case, the object to create is the product/supply chain couple. This couple is characterized by common descriptive elements such as processes, skills and activities. Thus, a collaboration set up before the launch of the new product contributes to the simultaneous design of the product and the supply chain.

However, although there are international standards and reference models for collaboration such as SCOR for supply chain management or ISO 10303-21 STEP for product information exchange, there is no collaboration model in the literature leading to the design of the product/supply chain couple. Based on a literature review and an observation campaign, Marche et al [11] created an instantiated supply chain model to detail the supply chain architecture of a product taking into account stakeholders, flows between stakeholders, processes and value at each step of the supply chain, one step being represented by a process.

This model is based on system engineering to represent the product/supply chain couple and its complexity and the relationships between the different constitutive elements [41] necessary for a coherent description of the studied couple. In the context of product and supply chain development, this approach breaks down the complex system into different layers, identifies and organizes activities and controls the information needed to develop the product and supply chain [41]. To transmit the information, the use of modeling language, standardized formalism, is required. UML are discursive languages where information is communicated as text [42]. 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. It is based on a decomposition of the model into “views”, represented in diagrams. Each view is dedicated to the representation of a particular aspect of the system: requirements, structures, behaviors [43]. In addition, MEGA International Software is a software solution for system modeling. It facilitates process definition, control of operations. To represent a model, the system engineering approach uses entities linked by relationships. Cardinalities and constraints give information to get as close as possible to reality.

Within the model, each stakeholder has a role: producer, influence, resources or specialist. The producer stakeholders are involved in a process using skills, resources and decisions to realize a product or a part of the product contributing to the flows within the supply chain. Each stakeholder is connected to the other ones through flows: financial flow, material flow or information flow. A process can be decomposed into at least one activity generating value [11].

Therefore, the supply chain is described as many times as there are processes. By accurately describing the supply chain, this model provides information for future collaboration: who does what, what skills/equipment are shared, what is exchanged, what value is generated? The description provided by this model is very precise but it has yet to be validated, which is the subject of this article.

III. RESEARCH APPROACH

The empirical approach considers that knowledge is constructed from the observation of phenomena, it is a discovery of the world through experience [44]. It contributes to the constructivist paradigm which considers that reality is constructed and that it is self-organized around a finality [44]. In a constructivist approach, observation is a phase in the progressive construction of a research project, and the definition of new representations [45], [46]. To collect and exploit data about the innovative product/supply chain couple, a case study approach was used.

A. Aim of the study

In this empirical study, we seek to validate the use of the instantiated supply chain model as a tool to describe and implement a collaboration. We mainly focus on the vertical

collaboration between two companies involved in the development and the launch of an electromagnetic sensor. This case study is chosen for the following reasons: (i) the product is obtained as the result of an inter-company collaboration; (ii) the collaboration evolves throughout the innovation process and product life cycle; (iii) the product and the supply chain are co-designed.

From the early stages of the project, collaboration was important: the preferred concept for the new product required concurrent engineering from the beginning of the collaboration and contributed to its sustainability.

Moreover, in this case, it can be said that collaboration is not limited to the development of a new product: the two main stakeholders are also willing to rely on each other to create new markets in the medium and long term. Indeed, based on their expertise and knowledge of new markets, these two companies are seeking to enrich their technological systems and business models.

The use of the instantiated supply chain model seems consistent with a constructivist approach because: (i) it facilitates decision-making; (ii) it is reproducible, adapts to different situations and makes it possible to characterize situations.

B. Methodology

1) Data collection

The research includes a collection of data compiled throughout the innovation process through interviews and work sessions. The data highlight how product design impacts the relationships and collaboration between companies in the supply chain. The instantiated supply chain model was used to collect data from the two companies studied.

Indeed, the model enables to translate product design data into supply chain design data. At each stage of the supply chain, the model must be completed to accurately describe how the supply chain works and to consider the form of possible collaboration during the product launch.

2) Data processing

During data processing, several dimensions are considered such as skills, processes, stakeholders, added value and equipment. This step aims to identify the processes and/or activities that could enrich collaboration.

In order to describe scenarios of a supply chain for the product, a detailed description of each process involved in the production of the future product was proposed thanks to the instantiated supply chain model. In this article, the process highlighting the outcome of the collaboration will be detailed. This supply chain study has several advantages: (i) it describes in detail on which elements (processes, equipment, skills) possible collaborations are based; (ii) it considers possible collaborations based on the value (financial, strategic for example) generated within the supply chain.

The model is completed as follows: (i) the product has been decomposed into modules and components; (ii) each module or component has been decomposed into processes; (iii) activities have been assigned to each process; (iv) skills, resources and decisions were assigned to each activity; (v) actors have been defined according to the skills and resources used to carry out the activities (related activities assigned to actors are seen as tasks); (vi) the generated value of the assembly operation has been determined.

Using the instantiated supply chain model, the functioning of the supply chain is analysed to visualize when collaboration can emerge. It can be based on a specific combination of skills from both companies, on the sharing of equipment or specific know-how or on high value-added activities for both partners.

3) *Result from data processing*

Following the data processing, the partners can decide on the type, intensity and timing of collaboration strategies.

IV. FINDINGS

Firstly, following a presentation of the case study, the instantiated supply chain model will be used to illustrate its interest in setting up a collaboration between two companies. Secondly, we will look at the collaborative strategy favoured by the two companies within the framework of this project.

A. *Factual description of the innovative project development*

1) *Brief description of the product*

The innovative product is an electromagnetic sensor integrated into ABS technology. The Automatic Break System (ABS) is used in the automotive industry. It consists of a magnet and a sensor, sensitive to the external magnetic field to vary the electrical resistance of the assembly. The 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 magnetic sensor, based on a magneto-resistive element and an integrated electronic part.

2) *Origin of the project*

Company A is at the origin of this project, it is a company specializing in ball bearings for the automotive industry. It designs and develops different ranges of bearings, encoders and seals for vehicles. These products need to be combined with sensors to provide data to drivers.

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. More than 100 million sensors are used in ABS systems in vehicles (25 million vehicles being equipped on each

wheel). Based on its current production and by considering that it is outcompeting alternative systems and the company is not challenged by another company, this enables company A to make fairly accurate production forecasts: a daily mass production is envisaged.

The research and development focus on a Tunnel Magneto Resistance sensor and involve two stakeholders in addition to company A, selected according to their expertise: (i) **Jean Lamour Institute** (University of Lorraine) is an academic research laboratory specialized in material sciences. It is in charge of the scientific supervision; (ii) 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.

3) *Description of the collaboration during the innovation process*

This project is the result of the desire of company A and the Jean Lamour Institute to industrially develop the magnetoresistance with a tunnel effect (TMR), controlled in the laboratory. The industrial stakeholder, i.e. company A, has developed a network of R&D partners to develop the new product. Company A being in charge of the manufacture of ball bearings, Company X has joined this network in order to develop the product/process specifications. The choice of Company X was based on several criteria: (i) existing facilities and skilled staff; (ii) experience in thin magnetic layers deposition and process; (iii) industrialization solution for the future sensor; (iv) partner already present and recognized in the sensor market.

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 A, 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** (secondary stakeholder not involved in product development) by the Jean Lamour Institute for three reasons: (i) study and model the future supply chain of ABS technology; (ii) study the role and future relationships between the stakeholders involved in the development project; (iii) reflect on the collaborative strategy to be put in place to facilitate the industrialization of the product.

The functioning between the main stakeholders of the project are described in figure 1.

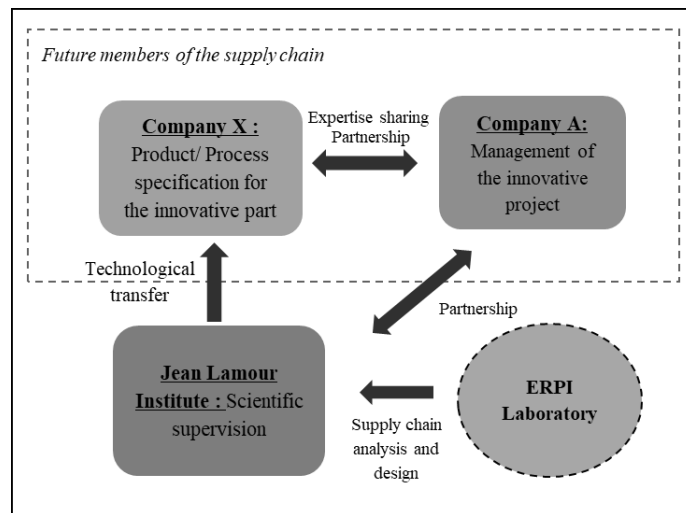


Fig 1. Overview of the functioning between the main stakeholders during the development of the project

B. Factual description of the supply chain design decisions

The organisation of the supply chain is the result of decisions taken before the innovation process.

Company A manages the manufacture of the ball bearing integrating magnetic encoders. From the outset of the project, company A 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 company X 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 A and Company X for at least five years. The figure 2 represents the material results of the collaboration between companies A and X.

To better understand the role of the instantiated supply chain model, we focused on the “thermocompression assembly” process because the ABS technology is the result of the assembly of TMR Read Head and a Flex circuit by

thermocompression. The thermocompression assembly process is a necessary step to obtain the active sensor.

The active sensor is composed of several components who are need to be manufactured prior to assembly. To achieve this, three stakeholders have to work in a coordinated manner: company A, the read-head manufacturer (company X) and the electronic components supplier, the latter not being an essential stakeholder in the development of the innovative product given the availability of electronic components on the market. Company A implements this process by means of the following activities: (i) reception of the necessary components (TMR Read-Head, Flex circuit equipped with differential amplifiers, electronic components and copper threads); (ii) positioning the read-head on the flex circuit; (iii) assembly of the read-head and flex circuit by thermocompression on copper threads; (iv) 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.

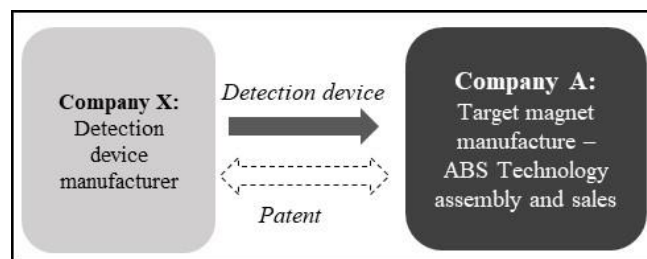


Fig 2. Material results of the collaboration between companies A and X

Figure 3 shows the application of the model to the example “thermocompression assembly process”.

In a context of innovation and when stakeholders desire to create sustainable collaborations, the instantiated supply chain model can be considered as the functional specifications of collaboration, highlighting the foundations on which it is based, clarifying the role and technical contributions of each stakeholder. It is used as a collaborative design tool.

C. Study of the evolution of the collaboration

In an innovation context, collaboration between different stakeholders may evolve, as may the supply chain [6]. The intensity of industrial collaboration may vary depending on the context. In our case, we note that R&D collaboration has led to a privileged relationship between stakeholders when the product is introduced to the market and evolves according to the product life cycle: the collaboration is gradually established and stems from the strategy. At the beginning of the project, Company X worked jointly with the Jean Lamour Institute to develop technical innovation. The collaboration between Company A and X was minimal. As technical decisions were made within the project where industrialization became possible, collaboration increased. When the product was launched on the market, Company A and X jointly filed a patent on the innovative product obtained, the result of their collaboration.

The industrialisation of the product (market launch, pre-diffusion phase and mass production) has led to several business guidelines: (i) companies A and X can sell the TMR sensor and/or use existing or new patented solutions for any customer in their own field or in "other fields"; (ii) company A

can purchase the TMR sensing elements exclusively from Company X.

These business guidelines are valid for 5 years. Beyond these 5 years, business guidelines evolve: (i) companies A and X can sell TMR sensor sensors and/or use existing or new patented solutions for any customer in their own field or in "other fields"; (ii) company A can purchase TMR sensing elements from any other manufacturer. Company X will allow Company A to use secondary sources for production with cost compensation for the transfer of processes and know-how; (iii) if third parties apply for a manufacturing licence, Companies A and X must agree on such a licence. Licensing costs are shared between companies A and X according to the number of patents each party contributes.

These business guidelines mark an evolution in collaboration around the industrialized product.

Based on our study [11], [15], the evolution could be represented as follows in figure 4 .

At the moment, the product is still in a growth phase. Two solutions are possible for the future:

1. Company A chooses new subcontractors and gradually orchestrates the end of the collaboration with company X;
2. Company A chooses to keep Company X as a subcontractor.

Other scenarios are possible, including a compromise that would consist in keeping Company X as a subcontractor while using other companies in parallel.

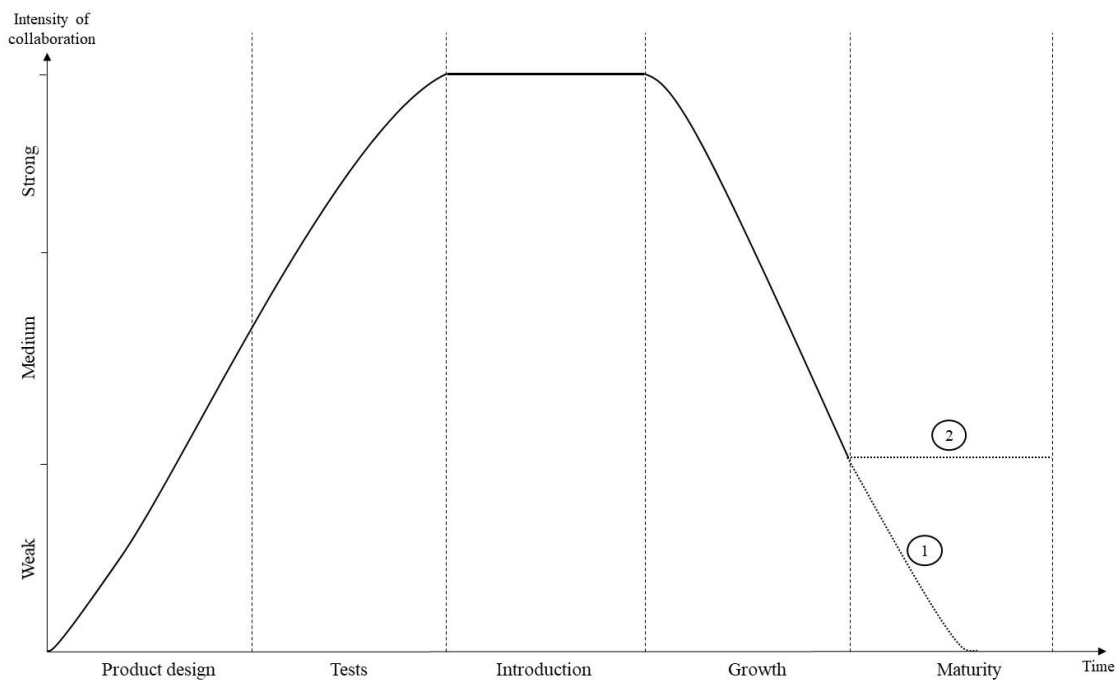


Fig 4. Evolution of the collaboration following the product evolution (our research)

Describing the supply chain and therefore the collaboration requires a large amount of information to be considered in order to make the most appropriate decisions for the context and strategy of companies. The instantiated supply chain model can be used throughout the product life cycle to describe the relationships between companies. Then, modelling provides a framework for future collaboration: it highlights the contributions of each stakeholder in terms of skills, resources, it stipulates the tasks performed by each stakeholder, the value generated and thus facilitates contractualization between the stakeholders. Its use is useful when making critical decisions such as launching the project, launching the product on the market or ending the collaboration because it reflects the impact of these decisions on the supply chain. For example, the disappearance of a major stakeholder implies changes that need to be compensated to ensure that the production of the product will always be effective. The instantiated model therefore provides information on the characteristics of the stakeholders to be integrated.

Like the model, collaboration is built phase by phase. Thus, the instantiated model describing the supply chain at time t reveals the technical and organizational evolutions of the planned collaborations. The business guidelines appear in the "decisions" box of the model. Thus, by superimposing each model of the same process at a given time in the supply chain, it is possible to study the evolution of collaboration.

Collaboration and its evolution over time are the result of the strategy of the companies involved: it goes beyond the boundaries of the individual company. Thus, strategic decisions impact the supply chain of the product and the functioning of stakeholders. There are therefore organizational, operational and temporal repercussions.

V. CONCLUSION

The results presented here highlight the importance of a good knowledge of what characterizes collaboration between two or more companies: Which actors? Which processes? What decisions? What types of flows? What added value? However, this process is time-consuming and requires a significant amount of information that is not always easy to collect and capitalize. Indeed, the use of this model requires to describe the collaboration at each moment.

Collaboration can be considered as the beginning of the supply chain of a new innovative product. In the literature, collaboration is addressed in several ways: (i) a legal contractual aspect based on trust and the contractualization of relationships. Many technologies such as blockchain support this aspect by guaranteeing the transparency of exchanges; (ii) a flow aspect of the supply chain based on logistics and the exchange of products and information between the various partners. This aspect is considered in supply chain management; (iii) an organizational aspect emphasizing the importance of network configuration to create strong and sustainable relationships.

However, the literature reveals a lack of information regarding the implementation of these collaborations. Consequently, this article proposes an engineering approach as a functional

approach to support companies in the implementation of collaborative relationships in a context of innovation. The use of the instantiated supply chain model has highlighted the logical link between collaboration and supply chain, as collaboration can lead to the initiation of a supply chain. In order to encourage and support companies to collaborate with each other, it seems particularly appropriate to describe collaboration from a functional point of view and to facilitate decision-making and to anticipate the usage scenarios in order to reduce the gap between "perceived needs and real needs".

Two perspectives are then possible.

First, the development of a database seems judicious in order to collect the processes, skills, technologies mobilized in the supply chain supporting the collaboration. 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: (i) 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; (ii) it offers a visual representation of our database. Each box in the diagram represents a table in the database; (iii) It highlights the relationships between the tables. Cardinality plays an important role. For example, a process requires several activities.

Secondly, block chains could prove to be an interesting solution for processing this information on a large scale. It is a technology for storing and transmitting information by being transparent, secure and without a control organ [47].

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 [47]. It can be used as an information collection network shared between nodes that are all known and individually identified [48], i.e. stakeholders involved in the collaboration (suppliers, manufacturing companies, distributors and even institutional among others). This technology is interesting because it considers the legal, flow and organizational aspects while supporting the functional aspect of collaboration, as the instantiated supply chain model can serve as the specifications for the architecture of the future blockchain by: (i) guaranteeing the transparency of relations; (ii) storing a lot of relevant information for the companies involved (product data, source of raw materials, skills used, added value, etc.); (iii) highlighting the relationships between different companies; (iv) tracking the processes used to design products.

Thus, the collaboration is simplified by improving information transfer between the stakeholders and by fostering collective intelligence through a better distribution of resources and by distributing more fairly and transparently the value generated by the collaboration.

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