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Diana Sofia Melendez Gonzalez

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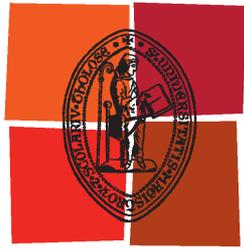
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**PROPOSAL OF AN EXPERIENCE FEEDBACK APPROACH TO IMPROVE
COLLABORATION IN INDUSTRIAL PROCESSES**

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1. INTRODUCTION

1.1 General context of this research project

The cooperation and exchanges between the public and private research sectors are crucial for the advancement of research. In an attempt to reduce the historical barriers between those two worlds, the French education ministry has created the CIFRE (*Conventions Industrielles de Formation par la Recherche*) thesis. By this mean, the French research community can come together to promote shared interests and seek solutions to address the issues that interfere with the advancement of research application in the industry. This alliance provides a process to debate among all relevant participants so that academic researchers propose original solutions to the problems of the industrial partners. This thesis originates from a long-lasting partnership between the company Axsens-bte and the laboratory LGP-ENIT (*Laboratoire Génie de Production – Ecole Nationale d’Ingénieurs de Tarbes*) as shown in Figure 1. Axsens-bte is an international consulting and training company, which combines skills in the field of consulting in Industrial Organization, Supply Chain & Logistics, Lean & Industrial Methods, Quality - with a reference framework of practices at the tactical, operational and execution levels - with field experience in Industrial Organization, Quality, Methods and Industrialization. In the company, the research is carried out within the department “Research and Methods” (R&M). The R&M business unit aims at defining innovative and practical solutions for Axsens-bte customers through applied research and collaborative projects.

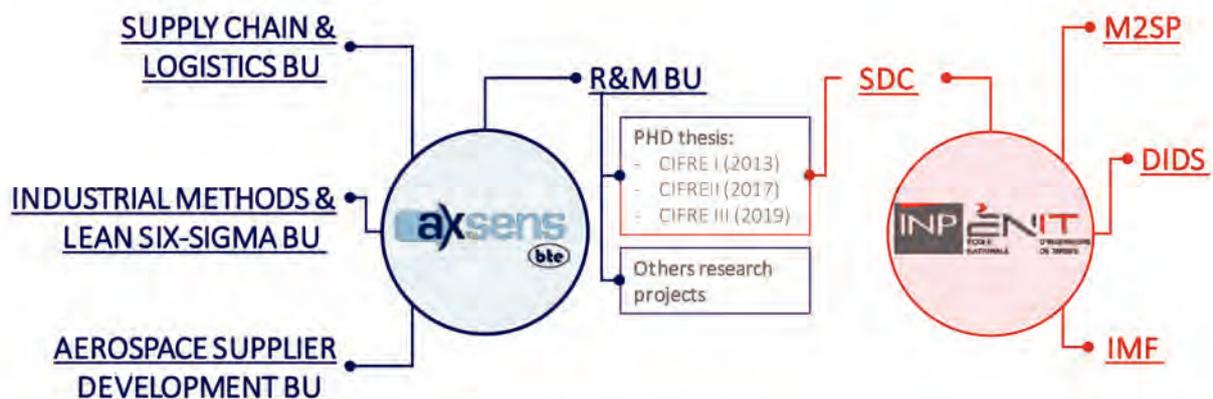


Figure 1. General context

On the other hand, the LGP is the laboratory of ENIT, a public engineering school integrated in the University of Toulouse and linked to the “*Institut National Polytechnique de Toulouse*” (INPT). This research was conducted within the “*Systèmes Décisionnels et Cognitifs*” (SDC) team, one of the four research teams of the laboratory. The domains of research of the SDC team are: Experiences, Knowledge & Competencies (ECC in French); and Uncertainty, Risk & Decisions (IRD from French). Furthermore, two Ph.D. thesis have already been carried out between Axsens-bte and ENIT: “*Collaborative problem solving within supply chains: General framework, process and methodology*” (Romero Bejarano, 2013), and “*Towards an agile methodology for industrial problem solving*” (Llamas, 2017). In such a context, Axsens-bte and LGP-ENIT have been dealing with strong industrial issues for many years. Organization, modeling, optimization, methods and tools are needed to face these issues. That is why Axsens-bte and LGP-ENIT are collaborating via the CIFRE framework to provide new paradigms.

1.2 Collaboration in industrial processes

In today's industrial and commercial environment, the organizations are more open, globalized, and competitive. Changes in these conditions oblige organizations to become involved in various kinds of industrial networks in order to maintain their business efficiency. Different forms of networks are emerging continuously and progressively, and their structure is becoming more flexible. The capacity of networked enterprises to adapt and react rapidly to market developments is the key factor that ensures their survival. As a result, organizations have to continuously improve their processes in order to achieve higher levels of effectiveness and efficiency and to deliver the expected business results, while increasing their quality and flexibility to satisfy their stakeholders' expectations.

(Davenport, 1993) defines a business process as a structured set of activities designed to produce a specific output, previously called goal. In other words, a process implies an emphasis on how work is done between and within organizations. Thus, individuals who work for organizations must collaborate in order to reach specific outputs, as shown in Figure 2.

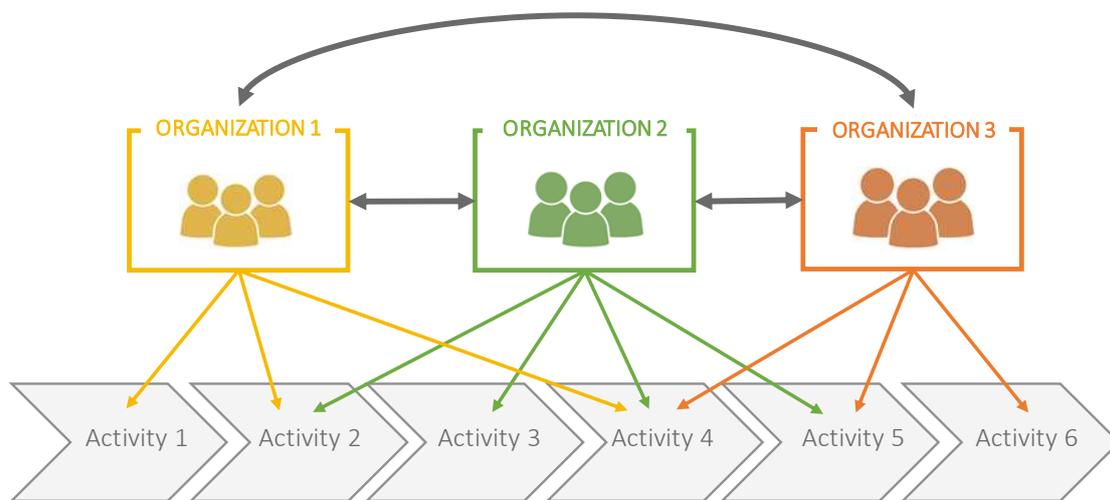


Figure 2. Collaboration in industrial processes

According to (Thomson et al., 2009), collaboration in an inter-organizational context is a term used by scholars and practitioners to describe a process that can emerge as organizations interact with one another to create new organizational and social structures. In this regard, (Agranoff and McGuire, 2004) suggest that collaboration is about selecting actors and resources, shaping the network, and developing ways to cope with strategic and operational complexity. (Poocharoen and Ting, 2015) distinguish collaboration from cooperation and coordination. Cooperation involves sharing information, reciprocities, and exchanges of resources without necessarily having mutual goals. Coordination is the orchestration of organizations towards a particular goal that provides shared rewards in the long term. Then, (Poocharoen and Ting, 2015) define collaboration as a closer relationship between the parties where new structures emerge and social and organizational capital is built. Collaboration involves a willingness of involved parties and stakeholders to improve their capacity for mutual benefits. According to (Himmelman, 2001), the parties share risks, responsibilities, rewards, invest substantial time, share common goals, and have high levels of trust. In this regard, there is a need to improve future collaborations based on past experiences and lessons learned.

1.3 Experience feedback

Experience feedback is a structured approach which allows to capitalize and to exploit information from the analysis of positive and negative events. Hence, it is a method for collecting, organizing and storing relevant information that allows:

1. To characterize past experiences, i.e., important information from the organization and execution of implemented activities to respond to a given event or objective,
2. To generalize these experiences in business knowledge, i.e., in rules or proven working procedures,
3. To inject this experience and knowledge to facilitate decision-making for the organization and execution of future activities.

Therefore, the objective of Experience Feedback is to take advantage of the past, in order to minimize the repetition of errors and dysfunctions and to increase the performance of organizations. According to (Bergmann, 2002), experience feedback can be perceived as a tool derived from knowledge management.

For several decades, companies concerned about preserving their intangible capital have integrated Experience Feedback into their continuous improvement plans. Intangible capital relates to the intellectual capital of the company, i.e., the information and knowledge derived from the knowledge and skills of staff and culture company (Bertin, 2012).

Furthermore, Experience Feedback has demonstrated its effectiveness to facilitate decision making in many sectors (Duffield and Whitty, 2015). As a result, there are many examples of success in various areas such as health, nuclear energy, railways, aviation and space among others. Moreover, in the partnership between LGP and Axsens-bte, experience feedback has been applied to problem-solving in supply chain (Romero Bejarano, 2013) and agility (Llamas, 2017).

Besides, experience feedback is based on concepts extracted from knowledge management, such as data, information and knowledge. The data, initially considered to be simple scattered facts will once be linked and interpreted, become information. This information, once contextualized (according to a process context), will constitute an experience, the answer to a given event. Finally, once generalized and expressed according to a pre-established framework or model specific to the profession in question, this experience can contribute to generate knowledge (Argote and Ingram, 2000).

Thus, to improve collaboration in an industrial context, organizations should be able to easily use past experiences and good practices acquired during previous processes executions. The need to capitalize on positive experiences (good practices) and negative ones (failures) is no longer to be demonstrated. Their reuse is an essential source for continuous improvement.

1.4 Problem statement and research questions

According to (Thomson and Perry, 2006), collaboration arises over time as organizations exchange formally and informally through interactions in order to negotiate, develop commitments, and execute those commitments. In this regard, collaboration is an organizational characteristic that has become a crucial factor that determines the success of business and process objectives. Collaboration has several definitions, although one of the most generally accepted is that it is the way that two or more entities work together toward a shared goal (Frey et al., 2006) and irrespective of geographical separation (Durugbo et al., 2011). This goal is often beyond the capabilities of the organizations involved in the collaboration and hence, they closely work together based on durable relationships and strong commitments to a common goal. This creates inter-organizational networks, but little attention is paid to the characteristics of organizations hosting these networks (Goossen, 2014). Indeed, organizations are often considered as closed environments that are internally homogeneous.

Collaboration has also been studied from a team point of view. In this context, (Bronstein, 2003) defines collaboration as *“an effective interpersonal process that facilitates the achievement of goals that cannot be reached when individual professionals act on their own”*. Among the individuals who work towards a common goal, maintaining proper collaboration is a major challenge. When an industrial process is executed, professionals from multiple organizations must participate by using their respective knowledge, skills, and abilities to achieve the common goal. However, the characterization of the collaboration in industrial processes from both organizational and individual points of view remains a major challenge. Considering that knowledge coming from past experiences is a strategic resource providing a decisive competitive advantage to organizations, this research is carried out in the framework of a partnership between the LGP Laboratory and Axsens-bte. Indeed, Axsens-bte is strongly interested in the application of this type of knowledge in order to improve collaboration in industrial contexts. Therefore, a dedicated study needs to be undertaken to propose an experience feedback process to capitalize experiences of collaboration within industrial processes in order to be able to reuse them to define future collaborations. In order to tackle the research problem, two global objectives are defined in our work:

1. *How to characterize and memorize collaboration during an industrial process taking into consideration organizations and actors who work for them?* It implies the definition of a conceptual collaboration model corresponding to a generic experience frame that allows capitalizing how individuals collaborate. This collaboration model is based on the execution of an industrial process. This question will be answered on the basis of characterization and measurement of collaboration between actors who interact during an industrial process and then propagate them to the level of organizations.
2. *How to define and improve future collaborations based on past experiences?* It requires the specification of an experience reuse approach able to suggest future collaborations in industrial contexts. This question is positioned at the meeting point of collaboration in process and knowledge management disciplines.

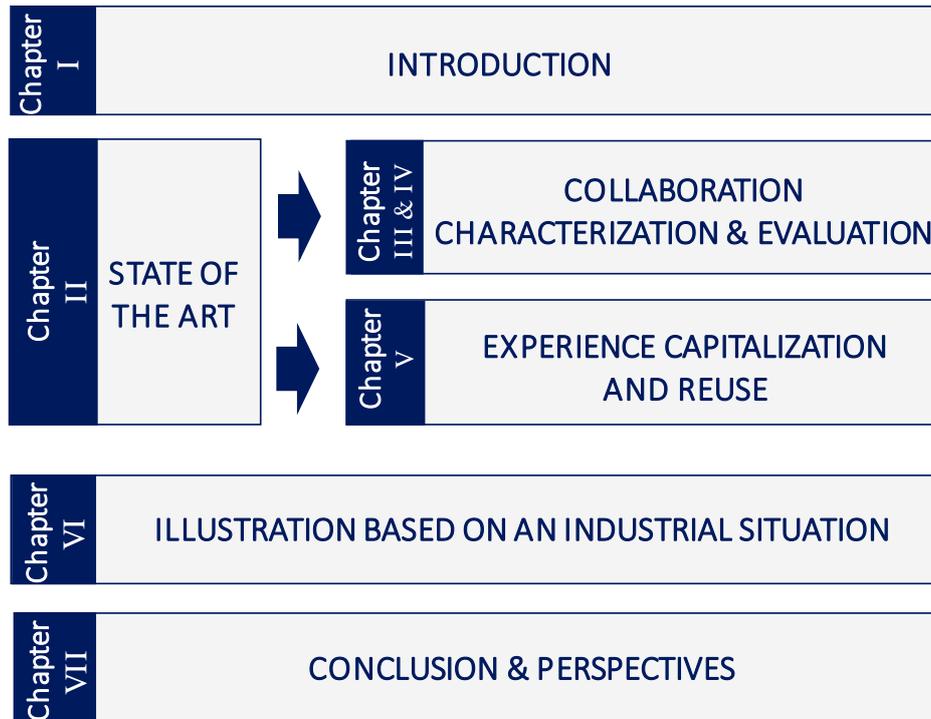


Figure 3. Structure of the document

Thus, the document is organized in seven chapters as follows (Figure 3):

- **Chapter 1 - Introduction:** the current chapter presents and positions the general context and the scientific disciplines in which this PhD thesis is carried out (i.e. Collaboration in industrial processes and Experience Management). Furthermore, the problem, the research questions and the structure of the document are presented.
- **Chapter 2 - Conceptual framework:** this chapter presents the state-of-the-art and covers research background related to the research questions. It is divided into two research pillars which are necessary to position the main contributions of our work. First, different approaches for collaboration characterization in industrial processes are described. Second, the concepts of Knowledge Management and Experience Management are developed. The application of these two concepts to collaborative processes is also discussed.
- **Chapter 3 - Information model:** the collaboration model is introduced in this chapter. The elements which allow to characterize collaboration in processes are detailed. Moreover, a taxonomy is developed in order to facilitate a standard characterization and future retrieval of the collaboration experiences.
- **Chapter 4 - Indicators of the information model:** this chapter presents a proposition of a collaboration evaluation of actors in terms of communication, cooperation and coordination, as well as a method to evaluate the performance and collaboration between organizations which participate in an industrial process based on the interaction of actors who work for these organizations.

- **Chapter 5 - Experience reuse for collaboration in industrial process:** in this chapter the experience reuse approach which allows to reuse past experiences is described.
- **Chapter 6 - Illustration based on an industrial situation:** an application of the method on an industrial context is introduced in this chapter. It was conducted in the context of Axsens-bte company and it intends to clarify the collaboration model and the concepts of experience capitalization and reuse through industrial and research projects application.
- **Chapter 7 - Conclusion and perspectives:** this last chapter summarizes the contributions of this work and outlines future research directions.

2. CONCEPTUAL FRAMEWORK

This research focuses on the study of the reuse of collaboration experiences in industrial processes. This chapter presents a background of two major scientific areas of study and their intersection, as shown in Figure 4. First, this chapter develops the different approaches of collaboration characterization in industrial processes. Second, the concepts of Knowledge and Experience Management are developed. Finally, the intersection between these scientific areas is presented in order to identify the concepts that will be the base of the proposed collaboration model.



Figure 4 Conceptual framework axes

Section 2.1 outlines the characterization of collaboration industrial processes. Then, three approaches for collaboration modeling are presented in section 2.2 as follows: collaborative business processes (section 2.2.1), collaboration in engineering (section 2.2.2) and collaboration networks (section 2.2.3). In section 2.3, some collaboration maturity models are developed. In section 2.4, the domain of knowledge and experience capitalization and reuse is presented. In section 2.5, some applications of experience management to collaboration in industrial processes are described. Finally, in section 2.6, the synthesis of this chapter and the contributions of this work with regard to this background are presented.

Definitions and insights of collaboration in industrial processes which have been identified in the literature are presented next.

2.1 Insights of collaboration in industrial processes

The paradigm of competition between organizations is based on the constant striving for individual profits. As a result, the survival of organizations is determined by strategies that reinforce their competitiveness and especially focus on the creation of individual competitive advantage. Taking into consideration today's fast-changing business environment, collaborative behavior between organizations has become a more and more relevant strategy to be adopted by organizations in order to ensure their survival on the market (Rostek, 2015). The adoption of collaboration strategies can bring synergy, expanding the individual benefits for each one of the parties by waiving confrontational attitudes. In the context of today's challenges for organizations, such as growing globalization, intensifying competition and the

need to keep up with technological development, cooperation enables them to reinforce their own competitive potential (Danik and Lewandowska, 2013). The dissemination of collaboration effects and overcoming resistance to it are more visible in the current economy. In today's market, traditional competition tends to decrease; instead, oligopolistic structures (association of two or more organizations that aim to dominate the market), agreements and cooperation networks are formed. That implies that organizations are ordered through the networks of developing interrelations and that they are supported by strategic collaboration (Thomas and Pollock, 1999).

As discussed above, organizations are dynamic systems performing in an environment where markets frequently change. Hence, their own re-thinking and restructuring is a key factor in order to survive in a competitive global market. A single organization model is not adequate to cover all the aspects of customer and market satisfaction due to the complexity of the markets. Hence, organizations are trying to build collaborative networks with other organizations, and subsequently, developing networked enterprises contributing to a common business goal. Competitive advantage is achieved through strategic alliances and networks of collaboration through the fusion of resources, skills, competences, and sometimes, infrastructures (Sroka and Hittmár, 2013).

In this context, collaboration in a business network can be seen from two perspectives: horizontal and vertical (Rostek, 2015). The vertical perspective is a natural process which proceeds along the production—distribution—sale chain between the supplier—producer—distributor—client. The horizontal perspective is related to organizations which remain market competitors. This perspective combines competitiveness and collaboration approaches between organizations. This type of collaboration can be seen as competitive collaboration, this concept was introduced to management sciences in 1996 under the term of “coopetition” (Nalebuff and Brandenburger, 1997). “Coopetition” combines competition and cooperation between market competitors (in a repeatable way) which are organizationally separated. Their main objective is to reach their own individual strategic goals through the integration of their activities.

Any of the strategies explained above involves managed relationships. Therefore, contract governance, mutual commitments and management procedures play a key role in collaboration strategies (Halvey and Melby, 2005). The establishment of contract alliances allows organizations of different sizes to potentially enlarge their shares in the global market (Arrais-Castro et al., 2018). In this context, collaboration occurs over time, as organizations interact formally and informally through repetitive sequences of negotiation, development of commitments, and process execution (Thomson and Perry, 2006). This implies the formation of collaborative networks between organizations.

In collaborative organizational networks, nodes can be individual or collective, such as teams, departments, divisions, subsidiaries, and organizations (Paruchuri et al., 2019). Moreover, the collaboration in networked organizations can be seen as a network of individuals who work for them (Goossen, 2014). Accordingly, teams have emerged as a requirement for business success enablers, allowing organizations to improve their offer and competitiveness. [Figure 5](#) shows the approach where organizations networks are seen as multilevel networks, in which two or more companies establish a collaboration and their employees cooperate via joint project teams.

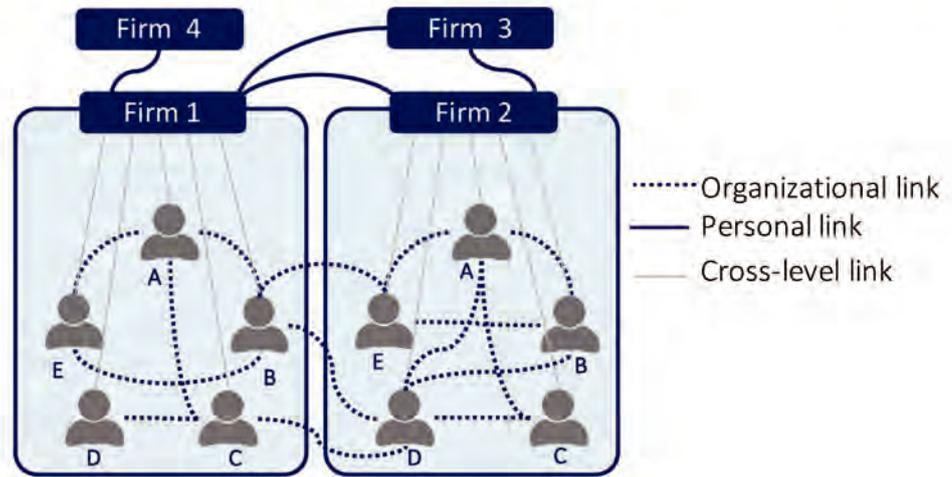


Figure 5. Example of a fully nested cross-unit uniplex network (Paruchuri et al., 2019)

According to (Rostek, 2015), the literature on organizations networks has shown that companies are networks of individuals who have their own characteristics. This means that organizations are internally heterogeneous and the effects of interorganizational collaboration vary from one organization to another. It also means that the collaboration between individuals will affect the collaboration between organizations, according to the roles of individuals and their intra-organizational networks.

In the literature, several definitions about collaboration are provided. According to (Bryson et al., 2006), collaboration is the linking or sharing of information, resources, and capabilities by organizations to achieve jointly an outcome that could not be achieved by a single organization. Also, collaboration is the coming together of diverse interests and people to achieve a common purpose via interactions, information sharing, and coordination of activities (Jassawalla and Sashittal, 1998).

At an individual level, there is collaboration when individual goals are subordinated to a collective achievement (Kelly and Schaefer, 2014) and when people “work informally together, share ideas, information, resources and work together as a team” (Ellinger, 2000). In (Borsato and Peruzzini, 2015), collaboration is described as a process where people are working together and interdependently to achieve a goal that is impossible for any individual to accomplish alone. In a fully connected society, collaboration is ubiquitous in all professional activities.

In an inter-departmental context, collaboration implies common goals, shared values, mutual commitments, and collaborative behaviour (Blomqvist and Levy, 2006). In (Kahn and Mentzer, 1996), collaboration is “the willingness of departments to work together, which emphasizes working together, having mutual understanding, having a common vision, sharing resources, and achieving collective goals”.

Following (Tyler, 2001), collaboration consists of information processing, communication, knowledge transfer and control, management of intra and inter-unit coordination, trustworthiness or the ability to engender trust, and negotiation skills. For (Kasvi et al., 2003), team collaboration involves trust, commitment, communication and joint problem solving.

As stated by (Sivadas and Dwyer, 2000), collaboration competency is defined as “the ability of the partners to trust, communicate, and coordinate”. Furthermore, collaboration competency of companies is influenced by three key capabilities: social networking capabilities, management capabilities and learning capabilities (Niemelä, 2004). Collaboration is a “process by which individuals, groups, and organisations come together, interact, and form psychological relationships for mutual gain or benefit” (Smith et al., 1995).

Collaboration capability is defined as the capability of actors to build and manage network relationships based on mutual trust, communication and commitment (Blomqvist and Levy, 2006) . Collaboration is a social phenomenon that involves several individuals when the action of only one does not achieve the expected result. (Knoben and Oerlemans, 2006) define collaboration in terms of efforts and purpose: “Collaboration is making a joint effort toward a group goal”.

Collaboration is defined as a process in which two or more agents (individuals or organizations) share resources and skills to solve problems so that they can jointly achieve one or more goals. During this process, the agents communicate with each other to coordinate their tasks. It means that team members effectively communicate (i.e. process), reach shared understanding (i.e. information), and adjust their tasks (i.e. management and process), behaviors (i.e., people), and means (i.e. technology and information) to produce high-quality outcomes (Boughzala and De Vreede, 2015).

Collaboration is often seen as an activity that involves team members working together on a project. However, true collaboration is more than an activity. It is a process with associated behaviors that can be taught and developed, and governed by a set of norms and behaviors that maximize individual contribution while leveraging the collective intelligence of everyone involved (Kelly and Schaefer, 2014). From the definitions above, we summarize in [Figure 6](#) the main characteristics of collaboration in processes.

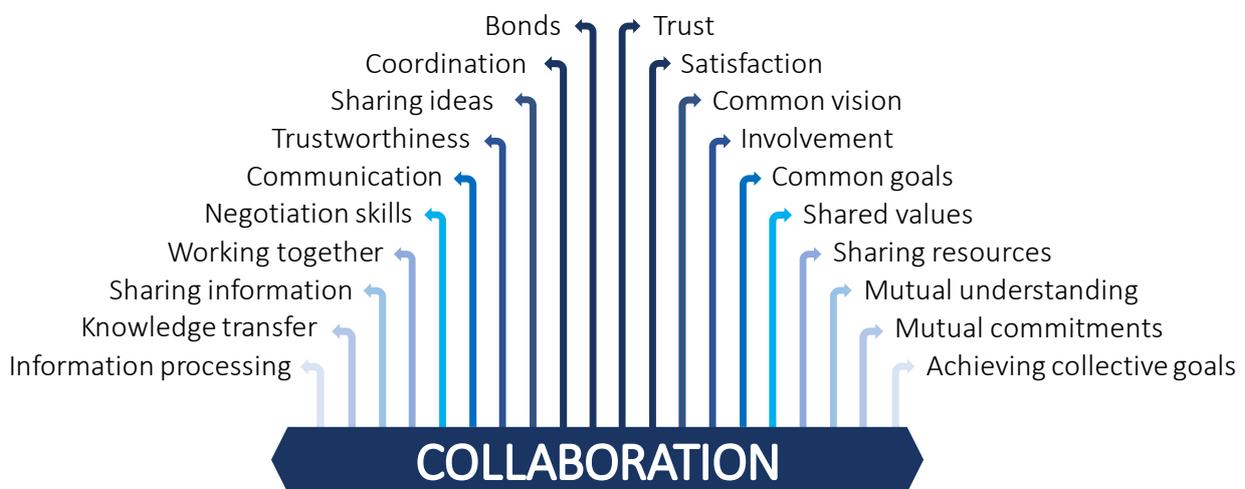


Figure 6. Main characteristics of collaboration in processes

[Table 1](#) summarizes the main characteristics of collaboration found in the literature. This table provides a generic perspective of collaboration to this research. Collaboration can be characterized by a list of elementary characteristics which are present in an individual perspective and/or an organizational perspective.

| | | MAIN CHARACTERISTICS OF COLLABORATION IN PROCESSES | | | | | | | | | | | | | | | | | | | |
|---------------------------------|----------------------------------|--|--------------------|---------------------|------------------|--------------------|---------------|-----------------|---------------|--------------|-------|-------|--------------|---------------|-------------|--------------|----------------|-------------------|----------------------|--------------------|----------------------------|
| | | Information processing | Knowledge transfer | Sharing information | Working together | Negotiation skills | Communication | Trustworthiness | Sharing ideas | Coordination | Bonds | Trust | Satisfaction | Common vision | Involvement | Common goals | Sharing values | Sharing resources | Mutual understanding | Mutual commitments | Achieving collective goals |
| REFERENCES | (Bryson et al., 2006) | | | ○ | | | | | | | ○ | | | | ○ | ○ | ○ | | | | |
| | (Jassawalla and Sashittal, 1998) | ○ | | ○ | | | | | ○ | ○ | | | ○ | | ○ | | ○ | | | | |
| | (Kelly and Schaefer, 2014) | | | | | | | | | | | | | | | | | | | | ○ |
| | (Ellinger, 2000) | | | ⊗ | ⊗ | | | | ⊗ | | | | | | | | | ⊗ | | | |
| | (Borsato and Peruzzini, 2015) | | | | × | | | | | | × | | | | | | | | | | × |
| | (Storbacka et al., 1994) | | | | | | ○ | | | | ○ | | ○ | | | | | | | ○ | |
| | (Wieselquist et al., 1999) | | | | | | | | | | | × | × | | | | | | | | |
| | (Blomqvist and Levy, 2006) | | | | × | | | | | | | | | | | × | × | | | × | |
| | (Kahn and Mentzer, 1996) | | | | ⊗ | | | | | | | | | ⊗ | | | | ⊗ | ⊗ | | ⊗ |
| | (Gupta et al., 1985) | | | ⊗ | | | | | | | | | | | ⊗ | | | | | | |
| | (Tyler, 2001) | × | | | | × | × | × | | × | | × | | | | | | | | | |
| | (Kasvi et al., 2003) | | | | | | | | | | | ⊗ | | | | | | | | ⊗ | |
| | (Sivadas and Dwyer, 2000) | | | | | | ○ | | | ○ | | ○ | | | | | | | | | |
| | (Niemelä, 2004) | | | | | | | | | | | ○ | | | | | | | | ○ | |
| | (Smith et al., 1995) | | | | ⊗ | | | | | | | | | | | | | | | | ⊗ |
| | (Knoben and Oerlemans, 2006) | | | | × | | | | | | | | | | × | | | | | | × |
| (Boughzala and De Vreede, 2015) | × | | × | | | × | | | × | | | | | | | | × | × | | × | |

Table 1. Summary of main characteristics of collaboration in literature

As stated by (Kelly and Schaefer, 2014), organizations have conventionally applied collaboration to teams or organizational levels (such as senior leadership) to break down silos, to foster cross-functional activities and to encourage better innovation. Collaboration can yield positive results. In addition to increasing innovation, collaboration increases employee energy, creativity and productivity, which generally leads to less stressed, happier, and more engaged workers.

According to (Perrault et al., 2011), there are three main success factors for collaboration:

- Mobilizing competences and expertise that add value for partnerships to achieve success.
- Sharing a goal and working together towards common objectives.
- Building bridges and establishing trust, taking ownership and providing leadership, assuming responsibility and being open to external input.

Moreover, the business networks are dynamic and constantly changing. In this context, the benefits of collaborative networking are considered to be a consequence of the following characteristics (Camarinha-Matos et al., 2008):

- Business partners can quickly and easily come together to benefit from a business opportunity, fulfill the need and then disclose the collaboration;
- Application of collaborative network in early stages of product life cycle, speeds up and gives more efficiency to engineering and design;
- Increasing customer collaboration and logistics enhances market understanding and reduce delivery times and times to market;
- Customer collaboration in after delivery networks enables new form of support activities over the life-cycle of the delivered product or service;
- Efficiency relies on capability for companies to co-operate despite different infrastructures, business cultures, organizational forms, and languages;
- Business networks themselves continuously change.

To conclude, many scientific approaches regarding the characterization of collaboration in processes have emerged in order to study the collaboration complexity at human and organizational levels. Some of these approaches focus on the collaboration modeling in order to improve collaboration in industrial processes; these approaches will be described in the next section.

2.2 Collaboration modeling

This section is structured in three subsections. Firstly, the analysis of collaboration through Business Process Management is presented. Secondly, collaboration in engineering is described. Finally, the main concepts of collaboration in complex networks are developed.

2.2.1 Collaborative Business Process Management

Business Process Management (BPM) is defined as “supporting business processes using methods, techniques and software to design, enact, control and analyze operational processes involving humans, organizations, applications, documents and other sources of information.” (Ko et al., 2009). BPM has emerged as an inclusive consolidation of disciplines sharing the belief that a process-centered approach leads to substantial improvements in performance and compliance of a system (Vom Brocke and Rosemann, 2010). BPM is a key factor for organizations because it allows the achievement of organization’s objectives through the improvement, management and control of essential business processes (Jeston, 2014).

According to (Lindsay et al., 2003), BPM recognizes the involvement of humans in the processes execution. BPM assumes the existence of crucial notions such as process knowledge and human participants as rational decision makers cooperating to achieve agreed and clearly defined goals. This description of business processes introduced the actors/roles and the collaboration between them. It is worth clarifying that BPM is a process-oriented management discipline and not a technology. Business processes are described as “a series or network of value-added activities, performed by their relevant roles or collaborators, to purposefully achieve the common business goal” by (Ko et al., 2009). In this context, BPM strives to better understand the key mechanisms of a process in order to ensure consistent outputs and managing to produce added value for an organization (Lindsay et al., 2003).

Although there are many types of business processes Essentially they can be either private or public. On one hand, private business processes are internal to the enterprise. On the other hand, public business processes involve external organizations (e.g. delivery of goods, ordering of materials, etc.) (Ko et al., 2009). According to (Ko et al., 2009) public business processes are also commonly known as collaborative Business Processes (cBPs). They are becoming more important because of the need for fast information transfer and quick decision making between organizations which participate in industrial processes. In this regard , BPM is not only relevant for inter-application integration, but also focuses on successfully managing and executing cBPs (Lippe et al., 2005).

For the design and analysis of cBPs it is necessary to consider that processes are modelled from different perspectives because cBP is negotiated between partners. This means that a successful modeling of CBPs requires that partners link their existing internal processes and resources to achieve an agreed interaction model (Lippe et al., 2005). In this context, collaboration could be understood as a mean to secure the adaptiveness of business processes to a changing environment. The task of managing collaboration in BPM becomes increasingly important. Managing BP networks is an integral part of the maturation of an organization in its BPM activities (Niehaves and Plattfaut, 2011). Researchers recognize the relevance of cBP model understandability in the context of BPM. cBP can be seen as the management of cBPs across organizational boundaries involving actors from inside or from outside an organization (Hermann et al., 2017) .

According to (Liu et al., 2009), collaborative business processes are used to facilitate collaborations between organizations. Thus, a collaborative business process runs across multiple organizations and, therefore, reporting becomes particularly important for a

participating organization to measure the performance of collaboration. Nevertheless, in the context of cBPM, such a reporting is complicated by the cardinality of participating business processes, and the correlation of collaborating process instances (Liu et al., 2009). All collaborative business processes form a complex network, and each business process in this network may participate in multiple collaborations in order to reach a common goal. However, the cBPM approach concerns information transfer of two or more systems or components to exchange information and to use the information that has been exchanged for decision-making (Lippe et al., 2005). Furthermore, cBPM mainly deals with interoperability issues between organizations and they are out of the scope of this research.

The second domain where collaboration has been modeled is product and software development. It is described in the following section.

2.2.2 Collaboration in engineering

Collaborative engineering builds upon the nature of cross-functional product development teams introduced in the domain of concurrent engineering. The scope of Concurrent Engineering (CE) is extended to include the new models of “Extended Enterprise”, “Virtual Enterprise” and “Concurrent enterprise” that have become commonplace during the last decade. The concept of Collaborative Engineering encompasses both supplier integration and advanced communication tools to cope with the product development process and extends the scope of CE, as shown in Figure 7.

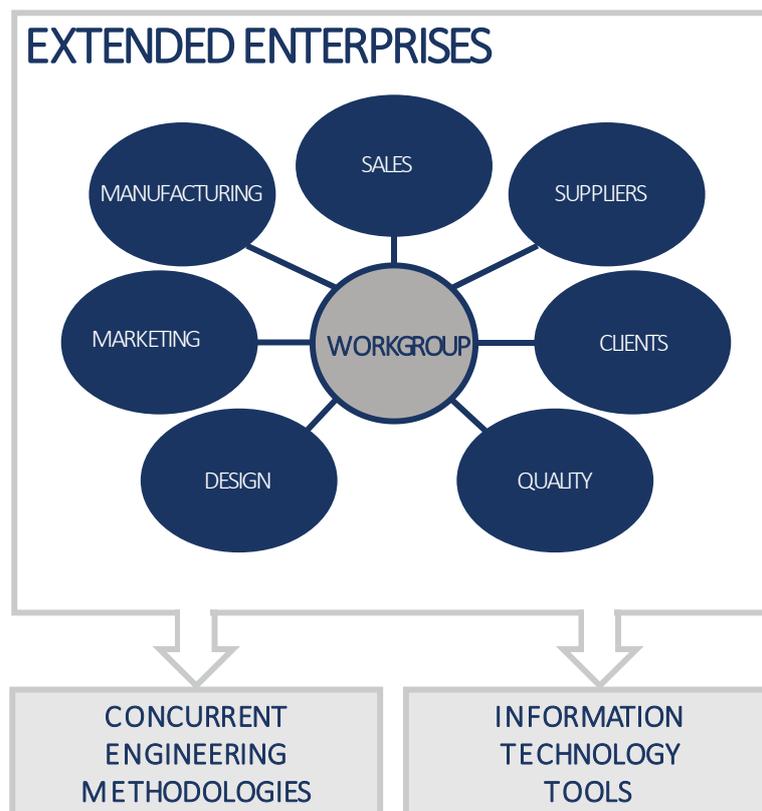


Figure 7. Collaborative Engineering model. Adapted from (Contero et al., 2002)

The workgroup is the central element of Collaborative Engineering model and Concurrent Engineering methodologies and Information Technologies tools support the Product and Processes Development. In this regards, collaboration among members who support the Product and Processes Development is essential to achieve the objectives of the workgroup (Contero et al., 2002).

In essence, Collaborative Engineering is the association of concurrent engineering to the concept of highly effective and well-supported team collaboration, including not only the act of collaboration itself, but also the infrastructures and environments that enable and nurture it. As such, collaborative engineering is an evolution of the principles and practices of concurrent engineering. While concurrent engineering has historically been concerned with the careful structuring of products, workflows, teams and organizations, collaborative engineering is, in contrast, more concerned with creating the environment for effective free-flowing and ad-hoc collaboration among peers whose insights complement one another and whose whole as a team is far greater than the sum of its individual parts (Mills, 1998).

Collaborative engineering is the practical application of collaboration sciences to the engineering domain. Its aim is to enable engineers and engineering processes to work more effectively with all stakeholders in achieving rational agreements and performing collaborative actions across various cultural, disciplinary, geographic and temporal boundaries. It has been widely applied to product design, manufacturing, construction, and software development. Collaborative engineering aims to integrate functional and industrial design. This goal requires integrating the design processes, the design teams and using a single common software platform to hold all the stakeholders contributions (Mas et al., 2014). A second definition by Lu et al (2007), expresses that Collaborative Engineering is the synergy between teamwork and task-work. Teamwork allows stakeholders to attain collective rationality, based on which global optimality of task-work can be attempted. In this context, collective rationality in teamwork should not be confused with global optimality in task-work.

It is important to mention that using a Collaborative Engineering approach, requires stakeholders to negotiate a single joint agreement, based on multiple decisions made by participating individuals and emphasizes the search for consensus, the need for sharing responsibilities and the achievement of complicity in results (Borsato and Peruzzini, 2015).

The traditional approach of collaborative engineering has been based on ways of supporting distributed collaboration technically through video conferencing, online workspaces, and through the real-time transmission, storage and retrieval of data (Karlsson et al., 2005). Additionally, this approach has been an enabler of product and service innovation. The product and service innovation changes the ways in which global collaboration is carried out. Thus, this changes the ways in which collaboration technologies and methods should be designed and applied in order to successfully support such collaboration (Löfstrand et al., 2005).

According to (Karlsson et al., 2005) current collaborative engineering practices and technologies must be adapted to the new drivers and the outcome will be new methods of work as well as new technologies. Collaborative engineering facilitates the understanding of market needs and it translates them into a functional product innovations. [Figure 8](#) shows the three levels of collaborative engineering: Integration (i.e. data management), Infrastructure

(i.e. ICT tools that help creating a shared workplace across locations) and Interaction level (i.e. interaction between people, and human-computer interaction). The figure also illustrates the communicative gap between them (Karlsson et al., 2005).

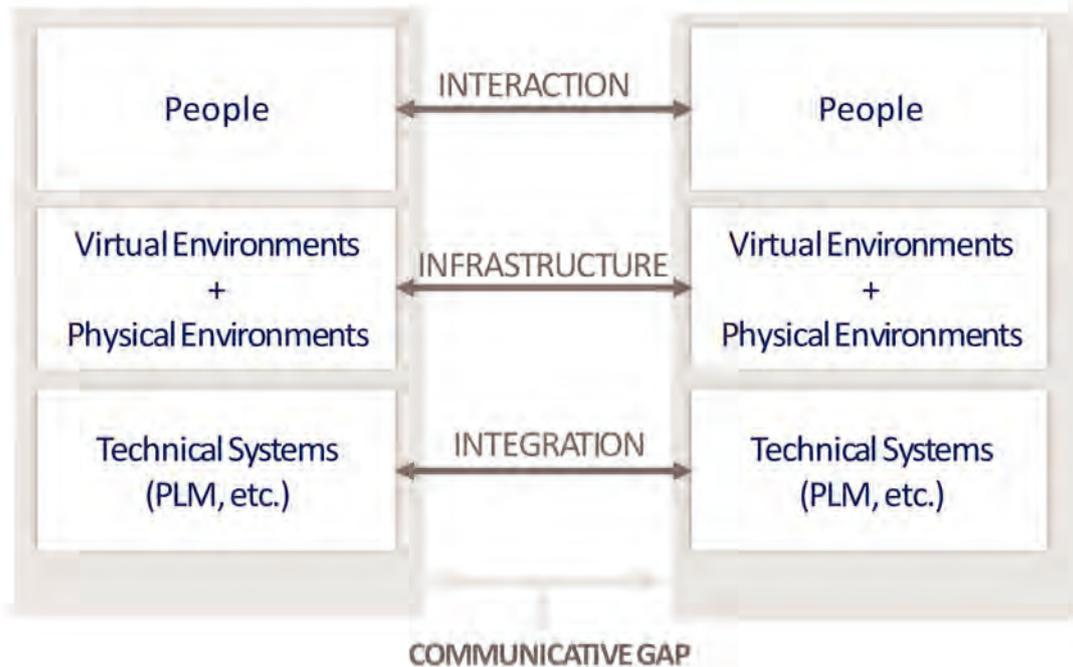


Figure 8. Levels of collaborative engineering. Adapted from (Karlsson et al., 2005)

The **integration level** is focused on the structure integration of low-level communication, involving the exchange and synchronization of data and information between different software and partners within the extended enterprise. In this level, the aim is to support the persistent storage of data, version control of design documents, and to show the current state of the design process. The use of standards for information exchange and product modeling is important since the product model provides a shared object for multiple participants to store all information about a product throughout its entire lifecycle (i.e. requirements, analyses and geometry). A requirement for collaborative engineering systems is that they must combine relevant data from many sources and present it in a form that is comprehensible to the users.

The **infrastructure level** includes the Information and Communication Technologies, a shared workplace with access to the relevant applications. This level includes collaboration tools for synchronous and asynchronous activities. It is important to support collaboration between distributed teams of engineers using highly heterogeneous environments.

The **interaction level** is focused on the people's perspective of collaborative engineering. It means, the interaction between individuals and groups using ICT (human-human interaction), and the interaction between people and ICT (human-computer interaction).

According to (Lu et al., 2007), the problems for which the collaborative engineering approach is the most important in industry have the following characteristics:

- The problems are ill defined (i.e. solutions depend on problem formulations; hence, there are disagreements about how to define the problems).
- Due to various resource and knowledge limitations, the problems are open-ended and characterized by technical complexities and/or scientific uncertainties.
- Unilateral efforts using traditional methods to deal with the problems have been proved insufficient.
- The stakeholders have diverse interests, expertise and access to information about the problems; hence, they often perceive the problems differently.
- These differing perspectives often result in, at least initially, incompatible (or adversarial) opinions and positions among the stakeholders.

Collaborative engineering analyzes the interactions in the engineering process in order to make the collaboration easier during the process. Moreover, collaborative engineering is becoming a topic of great interest in recent years due to the emerging trend of internet technologies (ElMaraghy, 2009). In this regard, information technology tools are a central topic of interest for collaborative engineering. This allows to facilitate the interactions between actors in a collaborative process, although it does not ensure effective collaboration among the actors involved. Hence, the 3C model, which proposes three criteria in order to characterize collaboration, is presented next.

In view of computational support for collaboration, (Gerosa et al., 2006) adapt the collaboration model of (Ellis et al., 1991) and then, the 3C model appears frequently in the literature as a mean to classify collaborative systems (Fuks et al., 2008). It is based on the idea that to collaborate, members of a group communicate, coordinate and cooperate as shown in [Figure 9](#). (Gerosa et al., 2006) propose the use of 3C based components as a mean of developing extendable groupware whose assembly is determined by collaboration needs. The following are the three pillars that underlie the 3C collaboration:

- **Communication** involves the exchange of messages and the negotiation of commitments (Fuks et al., 2008). There is no collaboration without effective communication. Both employees and leaders must share and build ideas, constructively criticize, and provide feedbacks (Kelly and Schaefer, 2014).
- **Coordination** enables people, activities and resources to be managed so as to resolve conflicts and facilitate communication and cooperation.
- **Cooperation** is the joint production of members of a group within a shared space, generating and manipulating cooperation objects in order to complete tasks. Cooperation is performed when each person on a team develops his or her own plans and shares those plans with the team. There may be joint discussion, but the focus remains on individual actions and achievement rather than on a collective strategy (Kelly and Schaefer, 2014).

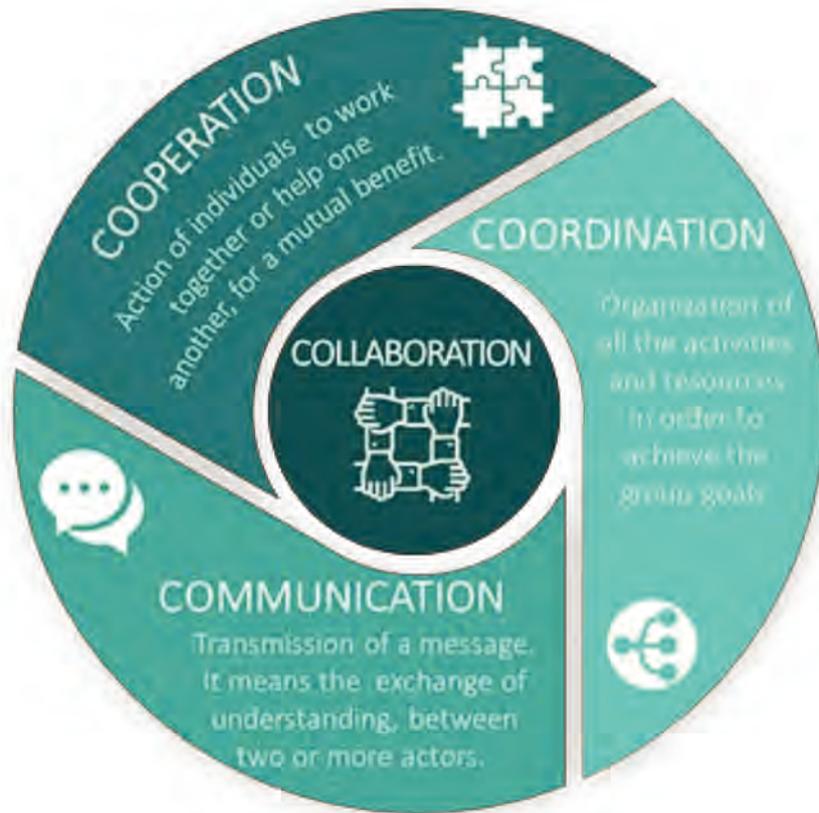


Figure 9. The 3C model. Adapted from (Ellis et al., 1991)

Despite their separation for analytic purposes, communication, coordination and cooperation should not be seen in an isolated fashion. There is a constant interaction between them as shown in Figure 9. To summarize, the 3C model is a general framework to better define collaboration in collaborative virtual environments. It allows to link the internal procedures of communication, cooperation and coordination in order to facilitate the achievement of the proposed objectives. For the purposes of this research, the characterization of collaboration in industrial processes will be based on the three pillars of the 3C model regardless of the existence of a virtual environment.

The last studied approach of collaboration modeling and collaborative networks is presented in the next section.

2.2.3 Collaborative Networks

The rapid progress on computer networks and pervasive computing has prompted the conditions for the establishment of a networked society where new forms of collaboration are being explored. A Collaborative Network (CN) is constituted by a variety of entities in order to collaborate to better achieve common or compatible goals, and whose interactions are supported by computer network (Camarinha-Matos and Afsarmanesh, 2005). CNs are complex systems and consist of many facets whose proper understanding requires the contribution from multiple disciplines. In fact, the various manifestations of this paradigm have been studied by different branches of science including computer sciences, computer engineering, management, economy, sociology, industrial engineering, law, etc. (Camarinha-Matos and Afsarmanesh, 2008).

As stated by (Camarinha-Matos and Afsarmanesh, 2005), during the last years various manifestations or variants of CNs have emerged such as: Virtual Enterprise, Virtual Organizations, Dynamic Virtual Organization, Extended Enterprise, Virtual Organizations Breeding Environment, Professional virtual community among others. It is important to highlight that the applications have evolved from a cell and shop floor point of view to inter-enterprise point of view.

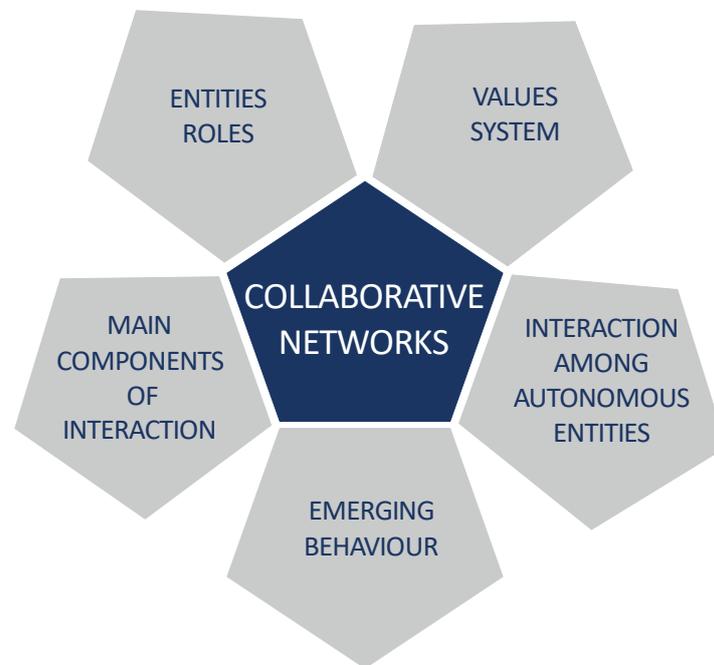
Some common elements can be observed in all these various applications. (Camarinha-Matos and Afsarmanesh, 2005) identify these common elements through the analysis of the following applications (Figure 10):

- *Breeding environment* represents an association or pool of organizations and their related supporting institutions that have both the potential and the aim to cooperate through the establishment of a long-term cooperation agreement and an interoperable infrastructure (Camarinha-Matos and Afsarmanesh, 2003).
- *E-Science* is about global collaboration in key areas of science, and the next generation of information and communication technology infrastructure that enables flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions and resources (Hey and Trefethen, 2003).
- *Virtual Organization* comprises a set of independent organizations that share resources and skills to achieve its mission/goal, but that is not limited to an alliance of enterprises for profit (Mowshowitz, 1997).
- *Professional virtual community* is an association of individuals identified by a specific knowledge scope with an explicit business orientation. It aims at generating value through members' interaction, sharing and collaboration (Bifulco and Santoro, 2005).

| Breeding Environment | E-Science/ Virtual Labs | Virtual Organization / Enterprise | Professional Virtual Community |
|---|--|---|---|
| <ul style="list-style-type: none"> - Long term association - Ready to collaborate | <ul style="list-style-type: none"> - Mix network people-organizations - Access to remote equipment | <ul style="list-style-type: none"> - Temporary network - Goal oriented consortium | <ul style="list-style-type: none"> - Network of people - Value creation |
| <p>Collaborative Networks</p> <ul style="list-style-type: none"> - Networks of autonomous organizations, people, resources or mixed - Common goals to be achieved by collaboration - Agreed principles of operation and interoperable infrastructures | | | |

Figure 10. Collaborative Networks characteristics (Camarinha-Matos and Afsarmanesh, 2005)

In essence, CNs are characterized by (i) networks of autonomous entities (organizations, people, resources or mixed) located in different locations, (ii) they are driven by common goals/intentions to be achieved by collaboration, and (iii) they are based on agreed principles and interoperable infrastructures to cope with their heterogeneity. In view of the elements set out before, [Figure 11](#) illustrates the main spotlights of CNs: the external interactions among autonomous entities, the roles of those entities and the main components that define the proper interaction among entities, the value systems that regulate the evolution of the collaborative association records, and the emerging collective behavior (Camarinha-Matos and Afsarmanesh, 2005).



[Figure 11](#). Main spotlights of CN. Adapted from (Camarinha-Matos and Afsarmanesh, 2005)

[Figure 12](#) exemplifies the importance of collaboration networks for industrial companies and their supply chain because there are several actors that collaborate in networks for the product or service delivery. This delivery involves one or more customers and some solution providers. The customer could be an individual consumer or an organization. In this regard, a customer and the solution providers could collaborate to jointly design and deliver the product or service which is known as value co-creation (Durugbo et al., 2010).

Also, two customers can cooperate to co-create value (with solution providers). However, in the example of [Figure 12](#), the main solution provider is Company A which deals with the customer A directly and, in turn, customer A deals with the final customer of the product or service (customer B). It is supported by a network of suppliers who are companies B, C and D. The industrial network may vary according to the strategies and alliances that companies B, C and D adopt. It means that these actors can interact in different ways and five different networks can be identified in this example as shown in [Figure 12](#).

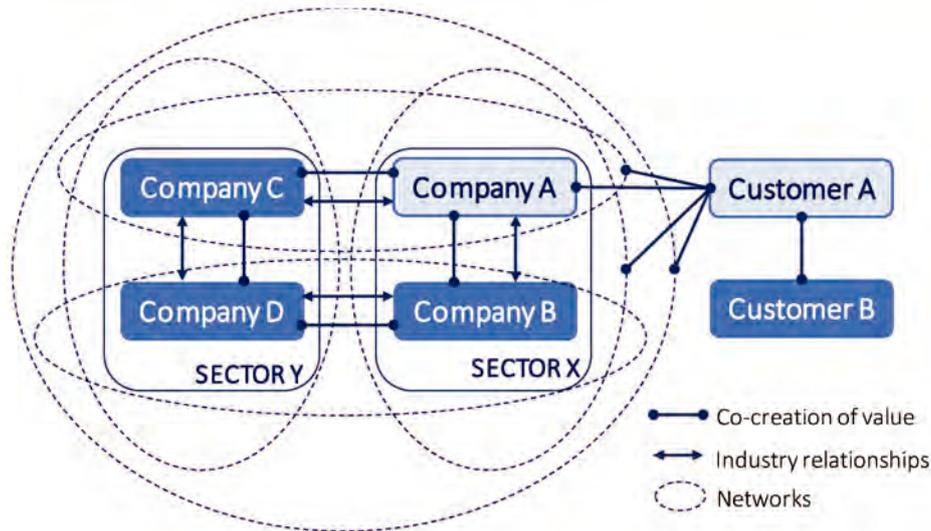


Figure 12. Industrial networks for collaboration (Durugbo, 2016)

The literature on interorganizational networks perceives organizations as individual, 'atomistic' entities but they are actually networks of individuals that have their own characteristics (Goossen, 2014). As stated before, a product or a service can be seen as value co-creation between two or several organizations. It means that this value co-creation is the result of collaboration between organization's individuals as shown in Figure 13.

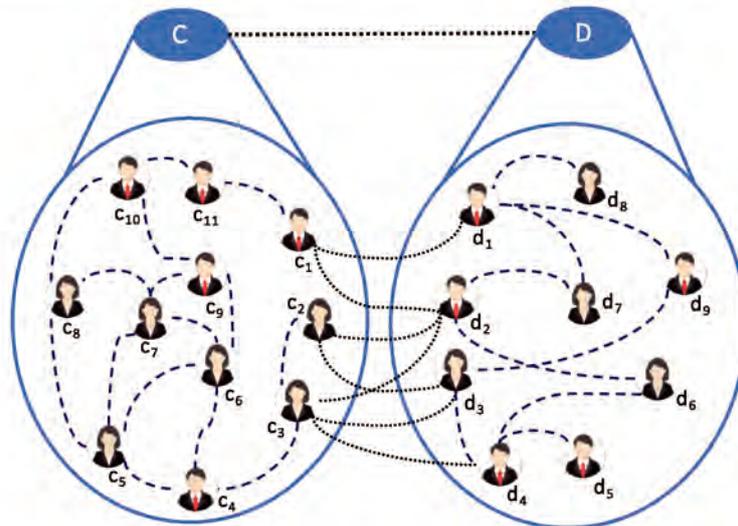


Figure 13. Multilevel model in interorganizational collaboration (Goosser, 2014)

According to (Durugbo et al., 2011), the approach of viewing organizations as networks is considered in research as a useful method for promoting organizational flexibility and adaptability, particularly in the quality and sharing of information. Networks can be represented as a matrix or a graph. In graph representations, the vertices represent the actors within networks and the edges indicate the relationships between the actors. Hence, complex networks offer useful insights into how people work together based on communication media that influence information sharing in order to execute one or several activities, as illustrated in Figure 14. Within complex networks research, Social Network Analysis (SNA) is the main approach to study and understand relationships, social roles and social structure in organizations (Durugbo et al., 2011).

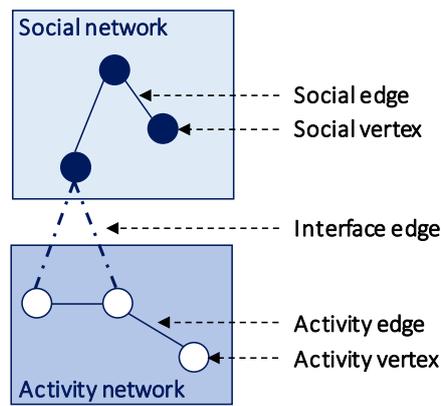


Figure 14. An intra-organizational collaboration model as a hypergraph

(Durugbo et al., 2011) propose an application of SNA as a diagnostic tool for managers attempting to promote collaboration and knowledge sharing in organizational networks. SNA are effective in promoting effective collaboration within a strategically important group; supporting critical junctures in networks that cross functional, hierarchical, or geographic boundaries; and ensuring integration within groups following strategic restructuring initiatives.

Figure 15 presents the modeling of collaborative design based on the theory of complex networks. On one hand, collaboration in collaborative design processes is characterized by having linked processes and interconnected groups. From the point of view of complex networks that could be modeled by a hypergraph of activity network, social network interfaced by edges. On the other hand, they proposed three main indicators of collaboration performance: teamwork scale, decision making and coordination. The first indicator (decision scale) measures the ease with which social vertices can make choices. The second indicator (teamwork scale) measures the ease with which social vertices can pool resources and the third indicator (coordination scale) measures the ease with which social vertices can harmonize interactions. These indicators are derived as sums of existing SNA measures: clustering coefficient, closeness and degree of centrality, as shown in Figure 15.

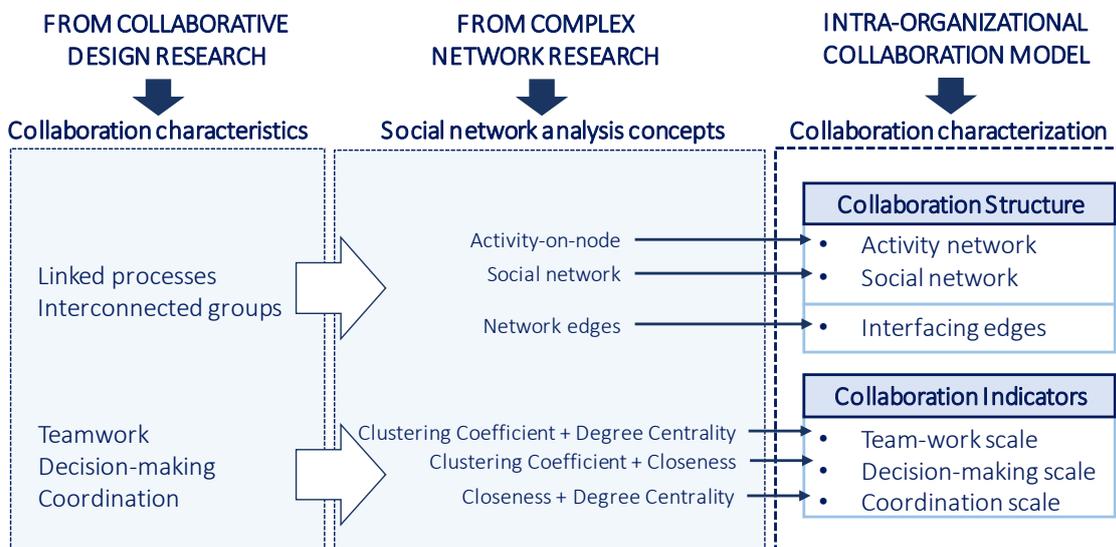


Figure 15. Collaboration Model conceptualization (Durugbo et al., 2011)

In this context, (Durugbo et al., 2011) propose a mathematical model that enables to analyze how individuals in organizations work together. The three quantitative indicators proposed (team-work scale, decision-making scale and coordination scale) are based on the process network structure. These indicators can vary depending on several factors such as skill levels, staff knowledge and experience, working hours, study/sick leaves and involvement in multiple projects. However, the model does not propose a methodology to clearly identify how these characteristics could affect the results. Instead, the high values of collaboration indicators for vertices suggest high potentials for working together and low collaboration indicators could imply high independent work. Consequently, collaboration indicators could offer a useful path for planning staff availability, implementing staff covers and backup and establishing multiple information access points (Durugbo et al., 2011).

To conclude, in the networked production organizations context, the concept of value has a great relevance specifically in the definition and implementation of performance management systems (Cunha et al., 2008). Information and knowledge sharing and communication play a major role in new forms of organizations, such as integrated supply chains and production networks. Besides, the performance of a network reflects itself in each member's performance, perceived from their own performance measurement system. However, the view from one member's perspective is partial in an organizational network. Therefore, its performance evaluation requires the consideration of other dimensions besides the individual one. Considering the collaboration issues within networks, in order to develop performance management systems for production networks, the following requirements should be satisfied:

- The indicators definition should be a collaborative activity to be performed during the network set-up, and they must be redefined periodically during the operation phase.
- The defined indicators should illustrate the performance evaluation of the collaborative aspects in the network.
- The vision of each stakeholder of the network should be taken into account and the individuals' performance measurement systems should be embedded in process performance. Thus, a network level and a member level should be considered.
- The technological design of the performance system should provide an architecture flexible enough to support members entering and leaving the network.

A methodology to define a structured set of performance measures is important for the management activity of networked production enterprises. [Figure 16](#) illustrates the methodology proposed by (Cunha et al., 2008). This methodology has two levels to analyze the performance of a network: an individual level and a cooperation level.

On one hand, at individual level, the performance of member organizations is evaluated. It means that each organization has its own objectives and indicators that, although being different, characterize their performance in a similar and compatible way with others members. These indicators must be related to the operational process. On the other hand, a similar approach is used for the network evaluation, which is a second level. All members are stakeholders in the network and each one of them indicates what they expect from the network (strategic factors).

According to (Cunha et al., 2008), this requires to bring to this level the performance measures, common to all members. At this level, performance measures are set on strategic factors such as responsiveness, innovativeness, versatility, re-configurability, information exchange and communication.

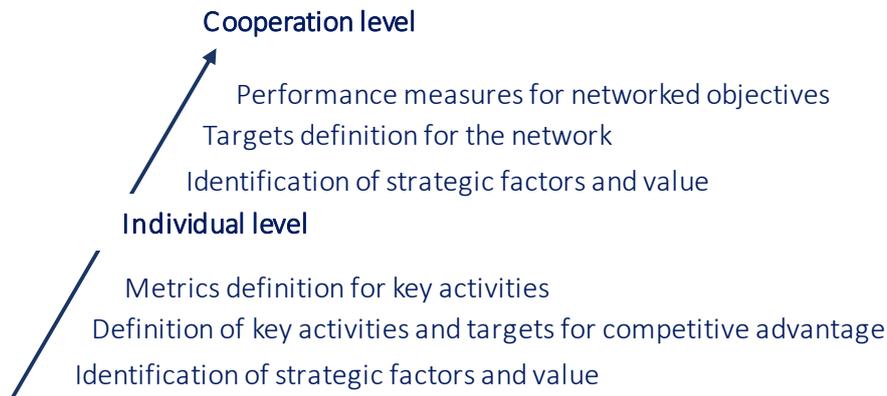


Figure 16. Step toward performance measure definition (Cunha et al., 2008)

Collaborative Networks are formed through interactions either between organizations or between the individuals who work for them. The Collaborative Network approach proposes that individuals, as well as organizations, evaluate the performance of the Collaborative Network. Nevertheless, there are no performance measures regarding the quality of collaboration between members of the Collaboration Networks. Thus, the collaborative network approach is considered and adapted to our work, in order to facilitate the assessment of collaboration based on the actors who participated in the network, and who are employees of the organizations involved in the network. Furthermore, the use of collaboration maturity models is an interesting way to assess collaboration between organizations. Collaboration maturity models are described in the next section.

2.3 Maturity Models for collaboration assessment

Maturity models define structured frameworks that describe, for a specific area of interest, the characteristics of effective processes. For the purpose of this research, the specific area of interest is the collaboration assessment in industrial processes. It determines what is to be done, and it is used mainly to achieve two objectives (Santanen et al., 2006):

- To set process improvements and priorities through methodological guidance in order to ensure stable and capable processes,
- To appraise organizations for the sake of improvement.

Collaboration Maturity Models are seen as important improvement tools for organizations (Van Looy et al., 2013) in order to reach business process excellence. They are evolutionary tools to periodically assess and improve defined characteristics of a process (Van Looy et al., 2011). According to (Magdaleno et al., 2011), these models are usually divided in hierarchical maturity levels, allowing organizations to plan how to reach higher maturity levels and to evaluate their outcomes on achieving that.

The first collaboration maturity models were developed for software development with topics covering, for instance, data quality, software maintenance, and testing. Nevertheless, other issues like IT alignment, the use of enterprise resource systems, technology and knowledge management or collaboration processes are becoming more important. (Wendler, 2012). For the purpose of this research, a summary of the main existing research publications about collaboration maturity models are presented, as shown in Figure 17.

| | |
|--|--------------------------------|
| CEMM | (Santanen et al. 2006) |
| CEMM is a model for evaluating the maturity of collaboration engineering. This model is based upon established standards within the field of software engineering. The model provides an overview of the CE approach, and its development. | |
| CollabMM | (Magdaleno et al. 2009) |
| CollabMM organizes collaboration practices to be introduced in business processes. The maturity model was defined based on well-known group supporting aspects: communication, coordination, awareness and memory. | |
| ECMM | (Alonso et al. 2010) |
| ECMM process improvement approach conceived as a maturity model for collaborative networked organizations, in which organizations participating in a network are assessed, both as a stand-alone company and with respect to the network. | |
| Col-MM | (Boughzala and De Vreede 2015) |
| Col-MM allows to assess an organization's team collaboration maturity as a first step toward a generalizable solution. It is intended to be sufficiently generic to be applied to different organizational and team settings and usable for conducting self assessments. | |

Figure 17. Collaboration maturity models

The main Collaboration Maturity Models are described in the next sections.

2.3.1 The Collaboration Engineering Maturity Model (CEMM)

The Collaboration Engineering Maturity Model is a maturity model for assessing and improving Collaboration Engineering (CE) processes. The model aims to introduce the evolution of CE processes within an organization. The capability assessment dimension of the model is derived from the ISO/IEC 15504 assessment approach (Santanen et al., 2006).

According to (Santanen et al., 2006), there are five major phases of the Collaboration Engineering approach that must be followed in sequence in order to properly design and deploy a collaboration process : (1) Field Interview, (2) Design, (3) Transition, (4) Practitioner Implementation, and (5) Sustained Organizational Use. These phases allow organizations to sustain and successfully support collaboration practices. Consequently, the objective of the CEMM is to assess the maturity level of each phase of the CE. The CEMM model proposes four collaboration maturity levels: “*provisional*”, “*managed*”, “*predictable*” and “*optimized*”. For each maturity level, there is a set of criteria derived from the ISO 15504 assessment approach.

At the first level (*provisional*), the collaboration process has been constructed or implemented at some basic level. It is often only temporary and likely to require extensive changes or even total replacement as the CE process continues to grow and mature, and serves as an important and useful starting point along the collaboration engineering process.

At the second level (*managed*), formal statement of objectives is defined for each phase of the CE approach. Specific methods or models that support the collaboration engineer objectives are created. The collaboration engineer, together with organizational stakeholders can begin to evaluate the collaboration process against the respective set of objectives or models.

At the third level (*predictable*), the CE approach has been sufficiently refined and documented such that it now has the potential to achieve its desired outcomes.

The collaboration engineer can fully trust the established CE approach and its building blocks to realize the anticipated outcomes

Achieving the fourth level (*optimized*) denotes that the success and predictability of the CE approach for the task at hand has been implemented and is well understood by the collaboration engineer and the organizational stakeholders. The mechanisms that make the approach successful are further researched and documented with an effort to optimize the results that are achieved as a result of the engineered process.

Before carrying out the maturity assessment, it is necessary to characterize and understand what happens in each phase of the CE. The first phase is “Field Interview”. During this phase, several interviews may occur with the primary organizational actors from various organizational units.

The second phase is the “Design Phase”, this phase includes the set of activities during which the collaboration engineer designs the recurring collaboration process for the specific task, organization and practitioners. Also, the design can then be validated as a whole in order to determine whether it meets the requirements set in the previous phase.

The phase “Transition” involves the transferability and reusability of the collaboration process design. Furthermore, additional goals for this stage include the development of a standardized method for knowledge transition.

In the next phase, “Practitioner Implementation”, the organizational practitioners execute the collaboration process. Over time, the organization then begins to fully implement the collaboration engineering process. In other words, the practitioners now assume the role of the facilitator and begin to run the collaboration sessions on their own. Also, organization management should stimulate the execution of the process as it has been designed and support the collaborative processes.

The last phase is “Sustained Organizational Use”. In this phase, the overall organization assumes full responsibility for and ownership of the processes. Practitioners are the resident experts and have taken complete control of the engineered processes.

The previous descriptions of each phase correspond to the definition of the collaborative processes. This means that if the company meets these characteristics, the first level of maturity is reached.

According to (Santanen et al., 2006), as the collaboration process becomes more evolved, it needs to be carefully managed and controlled. Thus, the implementation of formal evaluations is required in order to provide some feedback and inform how the collaboration process may be better managed. This allows the identification of guidelines or methodologies to improve collaboration processes. Depending on the reached Managed maturity levels, different methods may be used for each phase, to manage and control the collaboration process.

Predictable maturity level implies that the practices and outcomes are to some extent predictable in each phase. Therefore, collaboration processes can be more successfully designed and deployed. However, reaching this level of maturity is more difficult for some phases such as “Field Interview”. This is due to the competitive rather than co-operative culture in organizations among the internal stakeholders, various levels of hidden agendas, and personal interests that will undermine the predictability of eligibility. To establish predictable requirements, the collaborative engineer requires good interview and negotiation skills.

Lastly, in order to judge the relative achievement of each level of process maturity, CEMM use the following ordinal scale that rates maturity levels from zero to one hundred percent of the ISO 15505 standard:

- Not Achieved: A measure of 0% to 15% indicates that there is little or no evidence of achievement of the defined attributes or objectives of the CE process. This means that the CE approach is at the provisional maturity level.
- Partially Achieved: A measure of 16% to 50% indicates evidence of a systematic approach to and limited achievement of the defined attributes of the CE process. This means that the CE approach is at the managed maturity level.
- Largely Achieved: A measure of 51% to 85% indicates evidence of a systematic approach and significant achievement of the defined attributes of the CE process. This means that the CE approach is at the predictable maturity level.
- Fully Achieved: A measure of 86% to 100% indicates systematic and full achievement of the defined attributes of the CE process. This means that the CE approach is at the optimized maturity level.

ECCM proposes four levels of maturity which provide a type of “checklist” for the collaboration engineer that will help the collaboration processes to be improved in specific and beneficial ways. However, this model does not provide a collaboration quality assessment throughout the execution of a given process.

2.3.2 The collaboration maturity model “CollabMM”

CollabMM is a maturity model proposed by (Magdaleno et al., 2009) as an attempt to organize a set of practices which can enhance collaboration in business processes. CollabMM describes a way in which processes can achieve a progressively higher maturity on collaboration, while changing from one level to a higher one.

According to (Magdaleno et al., 2009) a first issue arising in the attempt to define CollabMM is the identification of the main relevant aspects for collaboration to be considered in a business process: communication, coordination, awareness and group memory. These aspects facilitate the characterization of collaboration in a business process and therefore allow to identify the maturity level of the business process.

The CollabMM proposes four collaboration maturity levels: “*ad hoc*”, “*planned*”, “*aware*” and “*reflexive*”.

At “*ad hoc*” level, collaboration is not explicitly represented in business processes. It means that Collaboration may happen, but it is dependent on individual initiative and skills, and its success depends on the relationship and/or affinity among people.

At “*planned*” level, business processes start to be formalized, aiming at including basic collaboration activities. For example, formalizing groups, roles and responsibilities and defining the appropriate communication channels among group members. Coordination is a strong aspect at this level because groups need leadership and management in order to work harmoniously. The role of a coordinator is needed in the process to centralize and manage activities, and to foster commitment, encouraging members to accomplish their goals.

At “*aware*” level, the process includes activities for monitoring and controlling how collaboration occurs. Each team member is aware of tasks and responsibilities and is committed towards them. They understand the process in which they are engaged, its main objectives, their roles and responsibilities and how their activities are related with others to perform these objectives.

At “*reflexive*” level, processes are designed to provide self-understanding, identifying the relevance of the results which has been produced and sharing this knowledge inside the organization. Processes must be formally concluded and their results communicated. Lessons learned are captured, strengths and weaknesses are analyzed, success and challenges are shared, ideas for future improvements are collected. Process tacit knowledge is shared through ideas, opinions and experiences. Finally, group members are aware of collaboration manner during process execution.

2.3.3 Enterprise collaboration maturity model (ECMM)

ECMM presents a process improvement approach conceived as a maturity model for collaborative networked organizations in order to assess the participation of each organization (Alonso et al., 2010). The result of this assessment provides two elements: (i) a picture of processes’ maturity regarding the collaboration structure and (ii) an improvement roadmap plan which will help the company to improve its collaboration maturity. In other

words, ECMM aims to assess the readiness of organizations for collaboration and interoperability and helps them establishing a roadmap to improve their practices.

In (Alonso et al., 2010), four maturity levels have been defined: “*innovating*”, “*standardized*”, “*managed*” and “*performed*”.

At the first level (*performed*), collaboration with external entities is done, but in an ad-hoc and chaotic manner. Collaborative tasks and processes usually exceed budget and schedule, their past success cannot be repeated, and the potential of the technology is not used properly.

At the second level (*managed*), the objective is to create a management foundation for collaboration. Network technologies are used to collaborate and interoperate.

At the third level (*standardized*), the objective is to establish a common business strategy and business process infrastructure for collaboration. Business collaboration is facilitated through interoperability technologies and use of standards.

At the fourth level (*innovating*), the objective is to manage and exploit the capability of the networked organization process infrastructure to achieve predictable results with controlled variation. Additionally, another objective is the continuous improvement of the networked organization processes and the resulting products and services through continuous capability, and planned innovative improvements.

2.3.4 The collaboration maturity model “Col-MM”

Col-MM focuses on team-level collaboration between individuals. Col-MM aims to be generic for all types of collaboration and can be used to assess the overall collaboration maturity of a given team. Additionally, it supports the development of recommendations to define and prioritize improvement actions of collaboration quality and thus organizational performance (Boughzala and De Vreede, 2015).

(Boughzala and De Vreede, 2015) propose four collaboration maturity levels: “*ad hoc*”, “*exploring*”, “*managing*” and “*optimizing*” levels.

At the first level (*ad hoc*), processes are chaotic and information/knowledge is not managed. Team success depends on the competence of some individuals. Teams produce products and services, but they exceed the budget and the schedule of their projects is not respected. Moreover, the management of the collaboration practices is not based on a clear strategy.

At the second level (*exploring*), processes are characterized but not always respected or understood and information/knowledge is partially managed. Teams produce products and services but they are not effective. Although collaboration strategy management is announced, it is not always followed. In essence, individuals work together with the means at their disposal but they are faced with many collaborative challenges.

At the third level (*managing*), processes are well characterized and understood and information/knowledge is managed. Teams are able to accomplish products and services of good quality. Thus, the collaboration maturity of teams is good nevertheless there is still room for improvement.

Finally, the last maturity level (*optimizing*) has a robust management of processes information and knowledge. In sum, teams are collaboratively mature and the management of collaboration is based on a proven and effective strategy.

Col-MM aims to assess the overall collaboration maturity of a given team evaluating through collaboration criteria. For each criterion there is a question which allows to evaluate the level of maturity. This evaluation is obtained by scoring each question on a scale from 1 to 4. The level of collaboration maturity of a team is obtained by calculating the weighted average of collaboration maturity values for each criterion. This calculation provides the level of maturity: ad hoc (< 20%), exploring (20% – 50%), managing (50% –80%), and optimizing (80% –100%).

2.3.5 Synthesis

Four Collaboration Maturity Models have been introduced along with their main characteristics. [Table 2](#) summarizes the characteristics of each Collaboration Maturity Model levels. Each one of the four Collaboration Maturity Models has four maturity levels, ranging from an unstructured collaboration to a formal, structured and documented collaboration that can be continuously improved. The identified collaboration maturity models are global and they are not based on factual feedback. Therefore, the recording of collaboration experiences and their future reuse allow to improve the collaboration maturity assessment. In this regard, the principles of Knowledge and Experience Management are presented in the next section.

| | CEMM | CollabMM | ECMM | Col-MM |
|----------------|---|---|---|--|
| LEVEL 1 | <ul style="list-style-type: none"> - Collaboration process has been constructed or implemented at some basic level. - Processes are temporary and require extensive changes. - Processes serve as an important starting point along the collaboration engineering process. | <ul style="list-style-type: none"> - Collaboration is not explicitly represented. | <ul style="list-style-type: none"> - Collaboration with external entities is done, but in an ad-hoc and chaotic manner. - Collaborative tasks and processes usually exceed budget and schedule. - Their past success cannot be repeated, and the potential of the technology is not properly used. | <ul style="list-style-type: none"> - Chaotic processes. - Information is not managed. - Teams are collaboratively immature. |
| LEVEL 2 | <ul style="list-style-type: none"> - Objectives are defined for each phase of the CE approach - Specific methods or models that support the collaboration engineer objectives are created. - The collaboration process is evaluated against the respective set of objectives or models. | <ul style="list-style-type: none"> - Business processes basic activities for collaboration - Planning group work - Planning comprises formalizing groups, roles and responsibilities (social awareness) | <ul style="list-style-type: none"> - Creation of management foundation for collaboration. - Network technologies are used to collaborate and interoperate. | <ul style="list-style-type: none"> - Processes are characterized but not always respected. - Information is somehow managed although not completely. - Teams produce products and services but they are not effective. - Weaknesses in terms of collaboration quality. |
| LEVEL 3 | <ul style="list-style-type: none"> - The CE approach has been refined and documented. - The collaboration engineer can fully trust the established CE approach and its building blocks, to realize the anticipated outcomes. | <ul style="list-style-type: none"> - Process includes activities for monitoring and controlling how collaboration occurs - The information is distributed - Knowledge is explicitly shared | <ul style="list-style-type: none"> - Business strategy and business process infrastructure are defined for collaboration. - Business collaboration is facilitated through interoperability technologies and use of standards. | <ul style="list-style-type: none"> - Processes are well characterized and understood. - Information is managed. - The collaboration management is based on a clear strategy. |
| LEVEL 4 | <ul style="list-style-type: none"> - Success and predictability of the CE approach. - CE is understood by the collaboration engineer and the organizational stakeholders. - The mechanisms that make the approach successful are documented in an effort to optimize the results of the process. | <ul style="list-style-type: none"> - Processes are formally concluded and their results communicated. - Lessons learned are captured, strengths and weaknesses are analyzed - Group members are aware of the manner in which the group collaborates during process execution | <ul style="list-style-type: none"> - Management and exploitation of the capability of the networked organization process. - Continuous improvement of the networked organization processes and the resulting products and services. | <ul style="list-style-type: none"> - Processes are continually improved, and information is very well-managed. - Individuals work together optimally and are able to produce high-quality products and services. |

Table 2. Summary of Collaboration Maturity Models levels

2.4 Knowledge and Experience Management

In this section, the principles behind Knowledge Management (KM) are first presented. Then, the notions of Experience Management (EM) are detailed with a focus on experience reuse and Case-Based Reasoning (CBR), a technique that allows to reuse knowledge contained in past experiences. Finally, a statement of collaboration knowledge representation ontologies and EM applications for collaboration in business processes is developed.

2.4.1 Knowledge Management

According to (Inkinen, 2016), the ability to manage knowledge is crucial in today's knowledge economy. Knowledge creation and diffusion have become increasingly important factors in competitiveness. An organization in the Knowledge Age is one that learns, remembers and acts based on the best available information, knowledge, and know-how. Knowledge of an organization is not intended to replace individual knowledge; instead, it is intended to complement it by making it stronger and more broadly applied. Knowledge management represents a purposeful and systematic approach to ensure the accurate utilization of the knowledge base of an organization, coupled with the potential of individual skills, competencies, innovations, and ideas to create a more efficient and effective organization (Dalkir, 2013).

In the 1990s, Knowledge Management was initially defined as the process of applying a systematic approach to the capture, structuring, management, and dissemination of knowledge in order to work faster, reuse best practices, and reduce costly rework from project to project as stated by (Dalkir, 2013). Knowledge Management solutions have proven to be most successful in the capture, storage, and subsequent dissemination of knowledge that has been rendered explicit, particularly lessons learned and best practices.

According to (Schneider, 2009), Knowledge Management has roots in philosophy, epistemology and in several other disciplines, and it extends to formal languages and computing. In this regard, it is important to highlight that to make an effective use of the techniques and tools, an overview of related concepts is crucial. Another key aspect is making people knowledgeable, it brings innovation and continues the ability to create and deliver products and services of the highest quality. It also requires effective knowledge capture, reuse, and building upon prior knowledge. For that, (Wiig, 1997) identifies five basic knowledge-centered strategies that organizations may attempt in order to derive the best business value from their existing knowledge-based assets or try to create new competitive knowledge-related assets where that is required as shown in [Figure 18](#).

As stated by (Wiig, 1997), **knowledge strategy as a business strategy** focuses on “*knowledge creation, capture, organization, renewal, sharing and use to have the best possible knowledge available – and used – at each point of action*”. **Intellectual asset management strategy** focuses on “*knowledge enterprise-level management of specific intellectual assets such as patents, technologies, operational and management practices, customer relations, organizational arrangements, and other structural knowledge assets*”. **Personal knowledge asset responsibility strategy** focuses on “*personal knowledge responsibility for knowledge-related investments, innovations and the competitive state, renewal, effective use, and availability to others of the knowledge assets within each employee's area of to obtain new*”

and better knowledge that will lead to improved competitiveness accountability to be able to apply the most competitive knowledge to the enterprise's work". **Knowledge creation strategy** focuses on "knowledge learning, basic and applied research and development, and motivation of employees to innovate and capture lessons learned". **Knowledge transfer strategy** focuses on "knowledge systematic approaches to transfer – obtain, organize, restructure, warehouse or memorize, repackage for deployment and distribute – knowledge to points of action where it will be used to perform work. Includes knowledge sharing and adopting best practices".



Figure 18. Basic knowledge-centered strategies. Adapted from (Wig, 1997)

As aforementioned, Knowledge Management is the deliberate and systematic coordination of an organization's people, technology, processes, and organizational structure in order to add value through reuse and innovation. This is achieved through the creation, sharing, and application of knowledge as well as through the feeding of valuable lessons learned and best practices into corporate memory in order to foster continued organizational learning.

As stated by (Liao, 2003), knowledge is an important resource for preserving valuable heritage, learning new things, solving problems, creating core competences, and initiating new situations for organizations. The management of an organization knowledge has become an important issue in the past few decades, and the knowledge management community has developed a wide range of technologies and applications for academic research and practical

applications. In addition, the Knowledge Management research community has made considerable efforts to explore Knowledge Management's nature, concepts, frameworks, architectures, methods, tools, functions, and business implementations with the objective of demonstrating Knowledge Management technologies and their applications.

From an organizational perspective, corporate memories can act as a tool for knowledge management on three types of learning in organizations: individual learning, learning through direct communication and learning using a knowledge repository (Van Heijst et al., 1997). Applying knowledge and experience management to business processes can have the following impacts: facilitate the execution of activities, improve the quality of processes, recognize possible problems faster, increase the ability to handle difficult and complex tasks and deal with difficult cases, clients, customers, suppliers, or colleagues easily. The main motivation for knowledge management is simple: a smarter company reacts better to the demands of customers and markets. When a customer requests an improvement or a solution to a problem, a smarter company will be able to provide it faster and at better quality. This is a fundamental added value of knowledge management.

A more intelligent behavior of an organization is often achieved by a better use of existing knowledge rather than by more knowledge. Thus, it is not only the knowledge that makes the difference but also the representation of knowledge and where it resides. Dissemination is the most visible part of knowledge management but it is not the most crucial one. According to (Liao, 2003), to make an organization smarter, many members of the organization should be empowered to use existing knowledge. There are several prerequisites for such reuse. First of all, each experience must be processed and validated. Second, knowledge must be evaluated and organized (i.e., structured and linked). Third, experience should be transformed into readily usable material. Finally, related experiences and pieces of knowledge can be combined, reworked and rephrased.

From the computer-science discipline, the term "knowledge" is related to the triplet: data, information and knowledge (Bergmann, 2002). According to (Zins, 2007), data is *"the representation of concepts or other entities, fixed in or on a medium in a form suitable for communication, interpretation, or processing by human beings or by automated system"*. Information is obtained by the interpretation of data. Knowledge is obtained by related information with pragmatics and it puts information into a context which is given by a certain goals. In this regard, data are the raw material for information, and information is the raw material for knowledge.

Moreover, (Belser, 2008) proposes the addition of experience to the triplet Data, Information and Knowledge as shown in [Figure 19](#). The gradual transformation (or hierarchy) information, experience, knowledge is explained in (Foguem et al., 2008): information corresponds to an event along with its context; an experience permits to formalize analysis and solution. Finally, when lessons learned, procedures, rules, etc., are implied from past experiences, knowledge is obtained. Knowledge and experience are both intelligent assets of human beings. Although these two concepts have a close relationship, their definitions are different. According to (Sunassee and Sewry, 2002), knowledge is the human expertise stored in a person's mind, gained through experience and interaction with the person's environment.



Figure 19. Positioning of an experience in the triplet Data-Information-Knowledge. Adapted from (Belser, 2008)

Experience is the type of knowledge a person or a group acquires by being involved. In a general sense, experience can be taken as pre-knowledge or skills obtained in everyday life (Schneider, 2009). In other words, experience is a form of pre-knowledge, which consists of problems one has met and the successful solution to them. Therefore, experience can be considered as a specialization of knowledge. By consequence, Experience Management is a special kind of knowledge management that is restricted to the management of a specific knowledge: the experiences. EM will be explained in more detail in the next sub-section.

2.4.2 Experience Management

Experience Management deals with collecting, modeling, storing, reusing, evaluating, and maintaining experiences. As stated by (Bergmann, 2002), experience is “valuable, stored, specific knowledge that was acquired by a problem-solving agent in a problem-solving situation”. In this research, we define experience from a more general point of view: experience is a specific knowledge drawn from being involved in an activity or an event. Therefore, several experiences refer to chunks of that specific knowledge, gained in one or more activities or events.

Knowledge and experience management can establish links and support learning on individual and organizational levels. Experiences have a number of properties that make them special and that require special treatment. According to (Schneider, 2009), when it comes to planning and optimization, experience is treated as “soft stuff” that resides inside individuals and is not accessible to a team or a company. It means, experience is a delicate material, and it takes dedicated techniques to handle it well. They are similar but not identical to the approaches used in knowledge management.

According to (Bergmann, 2002), the general activities related to knowledge management are the base for the specific activities for experience management (see Figure 20):

1. **Collecting Experience:** The experience to be shared must be collected. Experience may be already available in a documented form, for example, as text documents or as database entries. However, experience may also be only available in the memories of the experts. This experience must first be collected for reuse. Furthermore, new experiences arise continuously. They typically arise in the context of certain problem-solving situations. Mechanisms are required to collect such new experiences at the time they become available.

2. **Modeling Experience:** In order to manage experience, it must be modeled. Modeling is the core for selecting reusable experience and for reusing it. Modeling experience means finding appropriate ways for representing it and for formalizing it, if necessary. Different kinds of experiences and different problem-solving tasks may require tailored ways for experience modeling.
3. **Storing Experience:** The collected experience must be stored for future reuse. Such an experience memory can be either centralized or distributed.
4. **Reusing Experience:** Experience reuse is the ultimate goal of experience management. This requires (i) to get access to experiences and to select appropriate experiences for reuse, (ii) to assess the utility of the selected experiences in the context of a new problem to be solved, (iii) if necessary, to adapt experience to the new context, and (iv) finally, to solve the new problem (or to support the user to solve the new problem) by reusing experiences.
5. **Evaluating Experience:** During problem-solving by experience reuse, the reused experience can be evaluated in the context of the new problem to be solved. The evaluation can be in terms of appropriateness of the selected experience, or in terms of accuracy and actuality of the retrieved experiences. Such evaluation is important to continuously improve the process of experience reuse.
6. **Maintaining Experience:** Finally, the available experience must be updated continuously. Due to the rapidly changing environment, experience may have a limited lifetime. Invalid experiences must be identified and removed or updated. Also, the way in which an existing experience is modeled may be subject to changes. Experience maintenance can be triggered by a negative experience evaluation or can be performed precautionary.



Figure 20. Activities for experience management (Adapted from (Bergmann, 2002))

Figure 21 illustrates the notion of experience and its potential as a source of new knowledge. On one hand, past experiences can facilitate the resolution of a new problem or be a base for the definition of new experiences; on the other hand, they can be analyzed to enrich the organization's knowledge. According to (Jabrouni, 2012), these fragments of knowledge or specific knowledge (past experiences) located in a particular context require an effort to be generalized.



Figure 21. Experience as a source of knowledge

In order to support decision-making and improve the performance of industrial processes, capturing and storing past experiences is often considered much easier than capturing and storing more generic knowledge from experts, hence the interest of organizations in using experience-based approaches (Potes Ruiz, 2014). However, general knowledge has a greater scope than a specific experience, hence the importance of analyzing the information from the experience (Bergmann, 2002). Moreover, for operational actors, it is often easier to validate expertise extracted from real-life experiences than to describe generic knowledge out of context (Kolb, 2000). Experience reuse plays a key role in Experience Management, for this reason, this method will be explained in more detail in the in the following sub-section.

2.4.2.1 Experience Reuse

The systematic reuse of experience supports actors in processes to make better use of their own experience, and more important, to make use of experience which is made by a group or enterprise rather than which is made by a single actor. Experience reuse requires capitalizing past experiences in order to reuse them in future similar situations. According to (Rakoto, 2004), it implements a set of human and technological resources that must be managed to help reducing the repetition of errors and promote certain successful practices.

Therefore, experience reuse is a structured approach for collecting, organizing and storing relevant information allowing to characterize past experiences. In addition, it allows generalizing these experiences in knowledge and facilitating decision-making with regard to the organization and execution of future activities. The objective of experience reuse is to take advantage of the past to minimize the repetition of errors and dysfunctions and to increase the performance of an activity, process or company (Balmisse, 2005). (Rakoto, 2004) distinguishes two phases in experience reuse process as shown in Figure 22.



Figure 27. Experience reuse process

The first phase, capitalization, consists of building and maintaining an organization memory. This phase uses formalization, modeling, construction and collective management techniques to achieve effective sharing of capitalized experiences (Jabrouni, 2012). This phase includes several steps centered on the notion of strategic knowledge: the identification of knowledge sources, their formalization, their organization and storage, their distribution and their maintenance. The tracking consists in identifying and locating the information that will be capitalized in the experience base. Preservation makes it possible, for each type of experience, to establish the appropriate formalism for its representation and storage in the experience base. Knowledge translation makes it easy to access, disseminate and exploit the experiences acquired. Updating ensures the constant enrichment and improvement of the experiences stored in the system.

The exploitation phase is an essential part of experience reuse and allows enhancing the valorization of capitalized information. This phase can be carried out using a powerful search tool which can be directed according to one or more specific criteria related to the new experience (Corby et al., 2006). The basic concept of experience reuse is to provide the result of similar past experiences stored in an experience base in order to solve problems more efficiently and quickly, to integrate good practices (Corby et al., 2006) or the construction of new knowledge based on past experiences.

In order to facilitate experience reuse, a language common to all stakeholders is needed. However, developing a common language is a nontrivial problem (Fensel, 2001). For that, experience reuse can use semantic technologies such as ontologies. According to (Gruber, 1995) an ontology is a hierarchical structure that formalizes and structures the entire vocabulary of a given domain. This facilitates the formalization and structure of a common language (Chituc et al., 2008). According to (Hakeem and Shah, 2004), ontology is the formal specification of domain concepts and their relationships while taxonomy is the general categorization based on class/subclass relationships. Taxonomy goes from general concepts to more defined and specialized ones provides a complete, shared and common understanding of a given domain of application (Bergmann, 2002).

Once the experience reuse principles have been developed, a method that allows to carry out the experience reuse is required. In this regard, the Case-Based Reasoning technique is detailed in the next section.

2.4.2.2 Case-Based Reasoning (CBR)

As stated before, the objective of experience reuse approach is to define a way to capitalize past experiences and lessons learned in order to reuse them in future similar situations. In

this regard, a technique that facilitates the management of past experiences is needed. The Case-Based Reasoning (CBR) approach is a technique for solving problems based on the reuse of previous experiences (Aamodt and Plaza, 1994). It relies on a database of past cases or solved experiences, with the aim of solving new problems by reusing these stored experiences (Cordier et al., 2007). On one hand, this technique provides the reuse of the solution from the previous cases and on the other hand, the application of a solution adapted to the specificities of the current problem. According to (Bergmann, 2002), it provides techniques for representing, storing, indexing, finding and adapting experience. CBR provides a rich set of techniques which are highly relevant for experience management. As stated by (Aamodt and Plaza, 1994), the CBR method is composed of four phases (see Figure 23):

1. **Retrieve** similar cases or experiences to the problem description.
2. **Reuse** a solution suggested by a similar case.
3. **Revise** that solution to better fit the new problem if necessary.
4. **Retain** the new solution once it has been confirmed or validated. This phase allows to solving problems by using or adapting solutions to past problems.

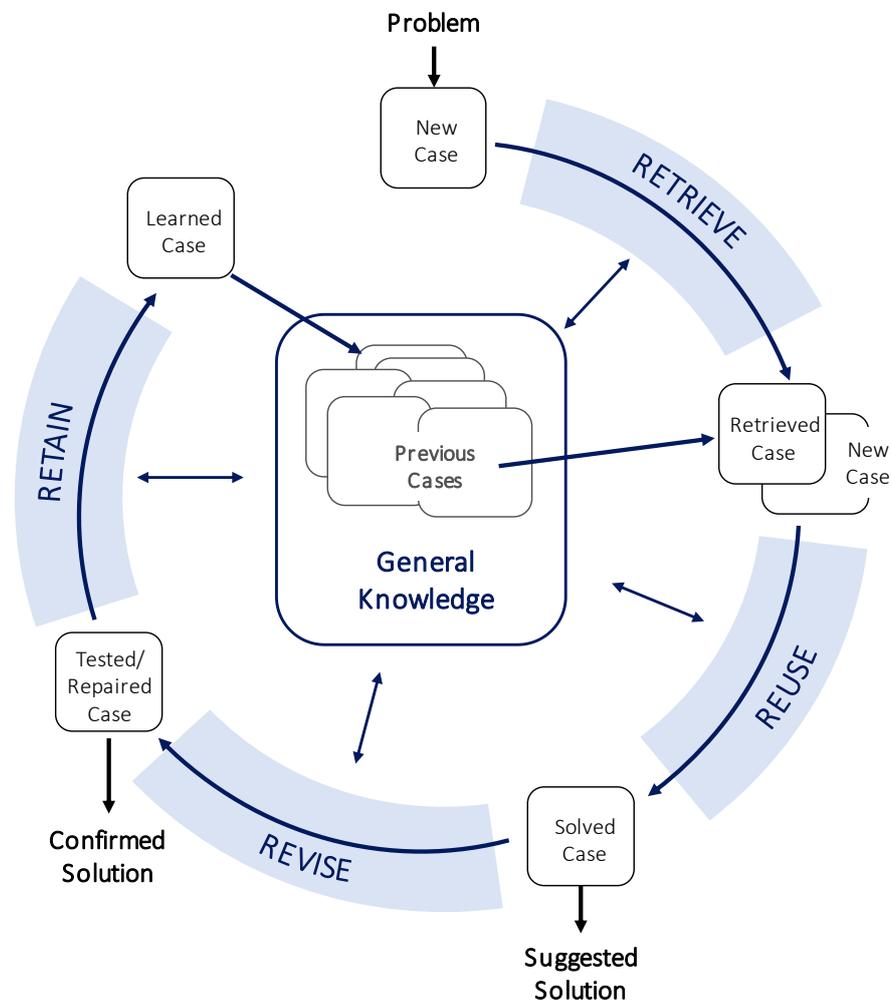


Figure 23. CBR cycle. (Aamodt and Plaza, 1994)

As stated before, the cycle starts with the **retrieve** phase. This phase begins when the user makes a new request on the system, indicating a new problem to solve, which includes the general problem description. The retrieve phase consists of finding, in the case or experience base, the cases that are most similar and relevant to the new case. The most commonly used method is to compare and to identify the correspondence between the descriptors that characterize the new case or experience with those in the case or experience base, by means of a similarity function (measurement of the degree of matching between two cases).

The **reuse** phase consists in reusing the solution of the most similar cases or experience to solve the current problem or to define the new experience based on the adaptation of similar past cases or experience. The adaptation process concerns the substitution of components or parts of the similar past case by the different components of the context of the current case.

The **revision** phase determines whether the selected solution achieves the objectives or if it needs to be corrected or improved. Indeed, the objective is to make an assessment of the result of the implemented solution before its recording in the system.

The last phase is **retain**. This phase consists of storing or adding the current case or experience in the base. The new stored case or experience becomes available for reuse in the resolution of future problems.

To conclude, CBR is an established system to improve process or activity performance based on the reuse of stored knowledge in one or more cases or experiences in general. However, the implementation of a CBR system constitutes a challenge for companies (Rakoto, 2004). Thus, this involves significant improvements in the organization's processes and provides valuable support to experts to support their decisions or to protect against past mistakes (Bergmann, 2002). Moreover, CBR principles are considered and adapted to our work in order to define an experience reuse approach for improve collaboration in industrial processes.

2.5 Experience Management for collaboration

In this section, some methods and tools of Knowledge and Experience Management for collaboration are presented. First, the use of ontologies to characterize collaborative processes are presented. Second, the experience reuse approach in order to facilitate collaboration in specific contexts such as supply chain and product design are developed.

2.5.1 Ontologies for collaboration process

As stated in section 2.2, collaboration is a complex and essential process for organizations. Because of this, it is crucial to conceptualize and formalize a common vocabulary to represent collaboration. Ontologies can provide a way to facilitate knowledge and experience management, by serving as a common conceptualization of collaboration characterization in industrial and business processes.

(Oliveira et al., 2007) study collaboration characterization based on the structure defined by the 3C Model presented in section 2.2.2. They propose an ontology to formalize knowledge of each component (communication, coordination, and cooperation) in order to provide a common vocabulary, promoting integration within the collaboration domain as shown in [Figure 24](#).



Figure 24 The Collaboration Ontology. (Oliveira et al., 2007)

Following the structure of the 3C Model, the Collaboration Ontology is divided into three sub-ontologies: Cooperation, Communication, and Coordination. Figure 24 describes the relation among sub-ontologies within the Collaboration Domain. However, (Oliveira et al., 2007) develop only cooperation and communication sub-ontologies (Figure 25 and Figure 26 respectively). The base of collaboration characterization is done during a Collaboration Session (CS). A CS is a kind of event that represents a period of time in which some actors collaborate for a given purpose. There are some important concepts related to a CS, such as participants, objectives, artifacts, coordination, and communication.

According to (Oliveira et al., 2007), participants are agents who contribute in a meaningful way to achieve the objectives of the session. Cooperation and interaction depend on the commitments of each of the participants. In addition to that, collaboration involves the sharing of specific information among members of a group that cooperate to create or consume information.

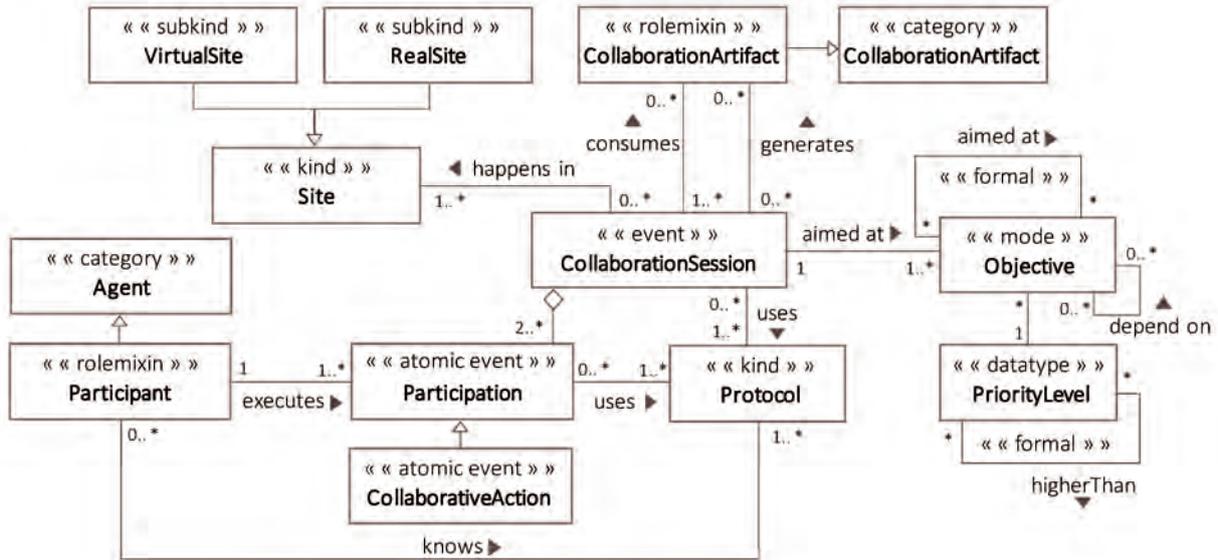


Figure 25 The Cooperation Ontology (Oliveira et al., 2007)

Finally, the CS happens in a place, defined in this model above as a site. The actions of a CS need some kind of coordination. In the presented model, this is represented by the protocol concept. During a CS, the participants exchange information. This is carried out by performing send and receive participation, which in turn, are essential parts of communication actions. These concepts are defined in the Communication Ontology depicted in Figure 26.

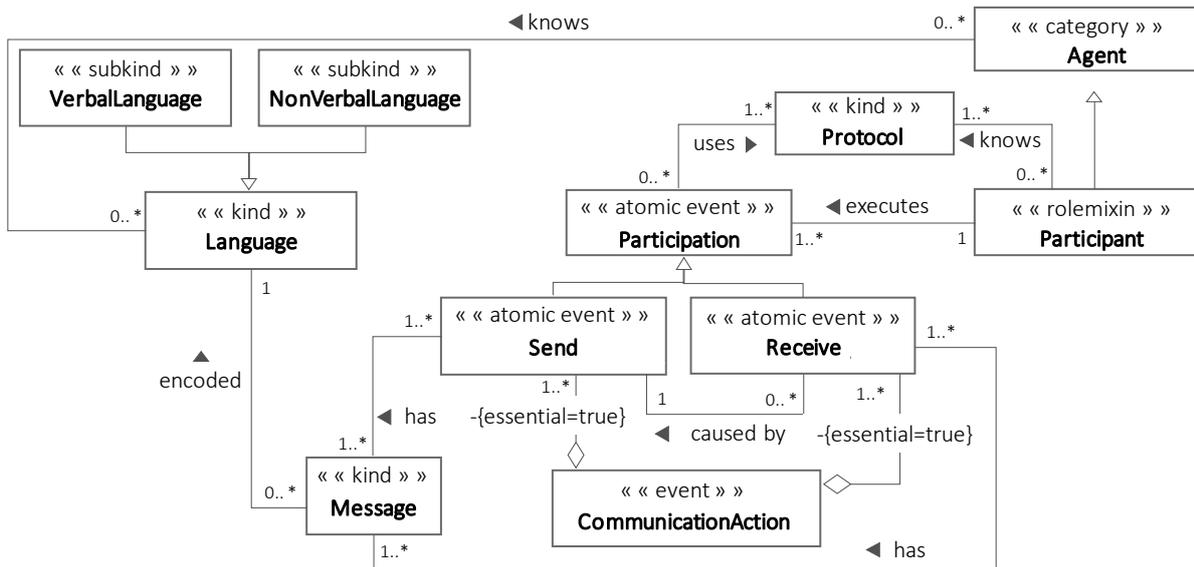


Figure 26. The Communication Ontology (Oliveira et al., 2007)

In this ontology, a communication action is composed at least of two participations executed by participants. Each participation event has one message that represents the exchanged information. A message is expressed through a language. It also uses one communication media that is the instrument used to carry out communication.

(Rajsiri et al., 2010) provide an ontology from a global perspective. They provide a knowledge-based system dedicated to the specification of a relevant collaborative process from a given collaborative situation. The collaborative process generated from this system can be used for developing an information system mediator.

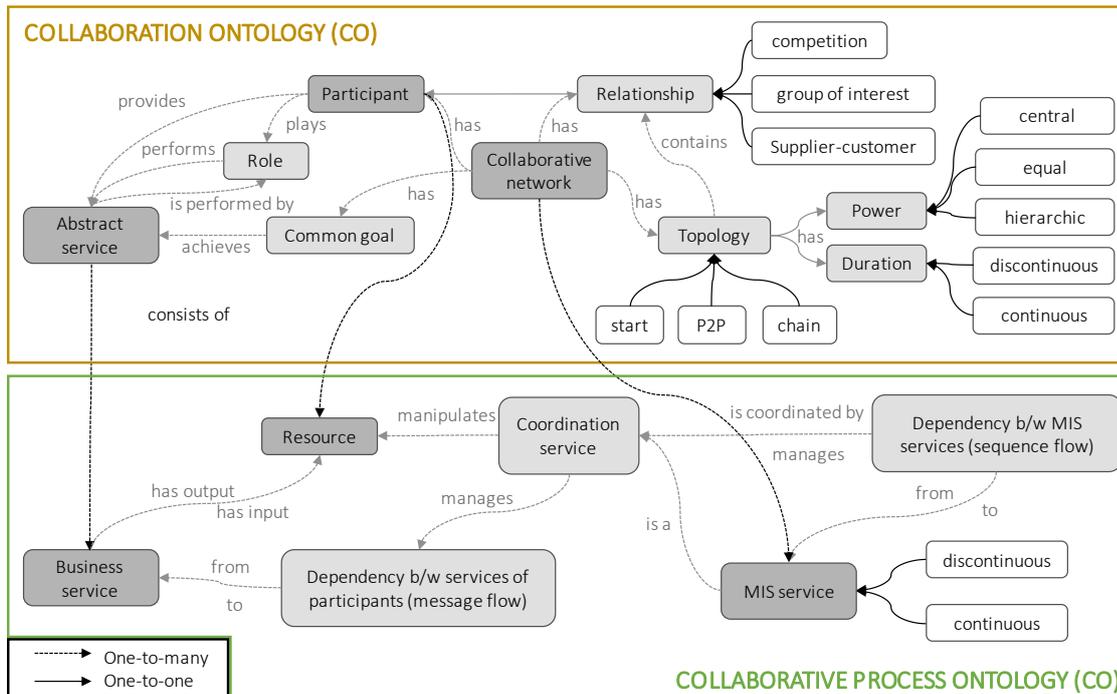


Figure 27. Collaborative Network Ontology and Collaborative process ontology (Rajsiri et al., 2010).

An ontology can be represented by a graph, in which the nodes represent concepts and where the links represent relationships between concepts. A representation of the Collaborative Network Ontology (CNO) is shown in Figure 27, in which the upper and lower parts represent the Collaboration Ontology and the Collaborative Process Ontology respectively. It deals with collaboration as well as providing common definitions in both collaboration and network domains. CNO includes the concepts of the collaborative network, their relations, and their properties. The ontologies in the CNO are 1) the Collaboration Ontology (CO) representing the elements of a collaborative network, and 2) the Collaborative Process Ontology (CPO) representing the elements of a collaborative process. (Rajsiri et al., 2010) developed an ontology-based approach by taking into account the mapping between collaborative network and process domains.

According to (Smith et al., 2011), a successful coordination mechanism facilitates mutually beneficial interdependencies while avoiding adverse outcomes. Agents need to communicate and reason about activities, resources, and their properties. In this context, (Smith et al., 2011) describe an ontological approach to coordination in which agents dynamically manage the interdependencies that arise during their interactions. Figure 28 provides an overview of the coordination ontology, illustrating the main concepts and relationships. The basic idea is to enable agents to reason about the relationships of their activities with the activities of other agents. The ontology provides a mean for describing activities and the interdependencies that may exist between them. This knowledge can then be used to coordinate the various activities with the other ones.

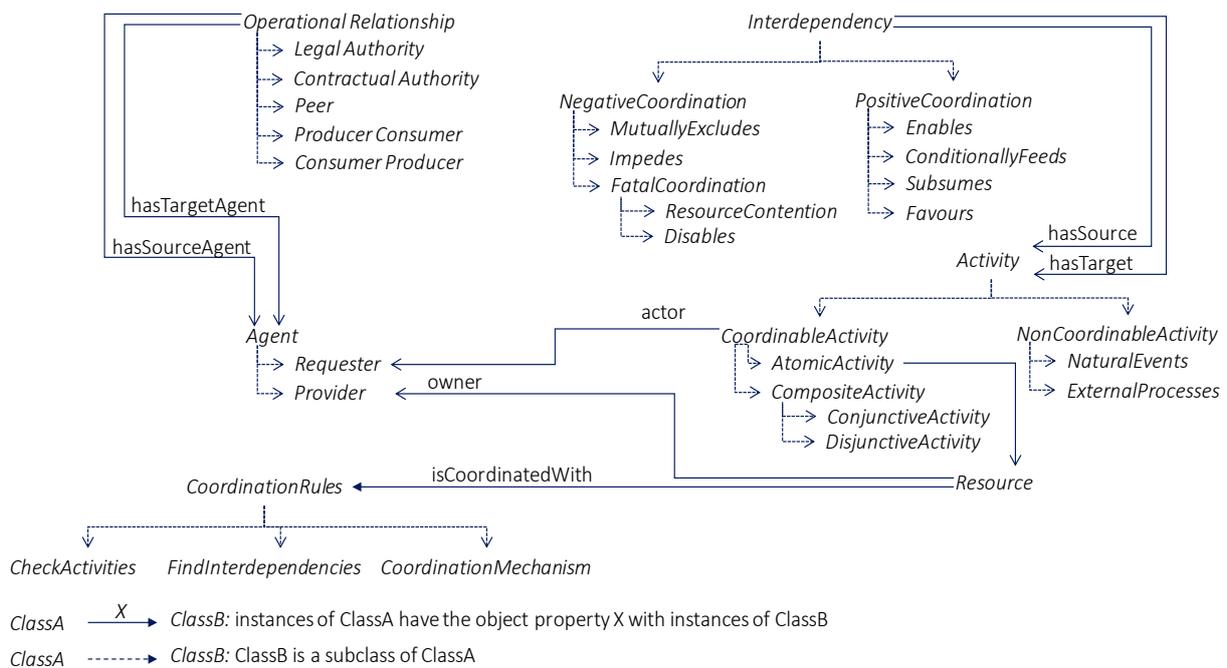


Figure 28. Coordination ontology (Smith et al., 2011).

Therefore, this knowledge can be used to coordinate the various activities with one another. For this purpose, a number of rules were developed. These rules are split into three groups: (i) rules to check activities; (ii) rules to detect interdependencies between activities; and (iii) rules to manage interdependencies between activities.

In summary, the aforementioned ontologies build a common vocabulary for the key concepts of collaboration and the relations and dependencies between them. For the purpose of our work, the following elements of ontologies, as well as their descriptions, are taken into consideration for the structure of the collaboration model that we propose for characterizing the collaboration in industrial processes: activity, actor or participant, organizations and commitment (common goal). However, these elements and their descriptions are not sufficient to properly characterize and measure the collaboration of an industrial process in order to reuse it for future collaborations. Other elements that allow to complete the characterization of the collaboration in an industrial context will be described in chapter 3.

2.5.2 Experience reuse for collaboration

As mentioned before, collaboration plays a key role in the execution of industrial processes, and taking into account experience reuse is an approach that facilitates decision-making with respect to the organization and execution of future activities. This subsection will introduce some research that uses this approach to facilitate organizational structure, decision making, and problem-solving processes in future projects based on past experiences.

Regarding the experience reuse to structured decision making and organization in design projects, (Dai et al., 2014) present a knowledge-oriented classification method in design project experience in order to enhance learning in organizations. Project memory is defined at the beginning, and afterwards a knowledge discovery method by classification according to different views of project memory is introduced to extract deep knowledge. The enhancement of learning from expertise and past experience is the main goal of project memory. In order to classify knowledge from different context for different learning intentions, (Dai et al., 2014) propose a general semantic network of project memory decomposed into four sub-networks as shown in [Figure 29](#).

The first sub-network, “Decision-making process” represents the most important activity of design projects. For that, the *issue* must be established. It is the major question or problem that is addressed, the *proposition* is a solution proposed to the issue, and *argument* evaluates the proposition by supporting or objecting it. Then, a *decision* is made by selecting the best proposition. Criteria tagging method is proposed to tag each argument with criteria to represent project context.

The second sub-networks is “Project organization making decision”, here, the concept *member* is added into the decision-making sub-network to represent the organizational dimension.

The third sub-network is “Project organization realizing project”. It offers a learning perspective on project realization with an organizational perspective.

Finally, the sub-network “decision-making process and project realization” shows a mutual influence of task arrangement and decision-making process. In addition, (Dai et al., 2014) develop important concepts and create an ontological class hierarchy for classification for each sub-network (see [Figure 29](#)).

In the context of product design, expertise represents an important capital in a company (Matta et al., 2011). The loss of this kind of knowledge has forced companies to look for a

mean to capitalize it in order to use it in the future. Indeed, in many companies, the design process generally learns from an old similar experience. This is due to the fact that the designers often develop an existent solution or try to retrieve an old solution in order to adapt it to a new requirement.

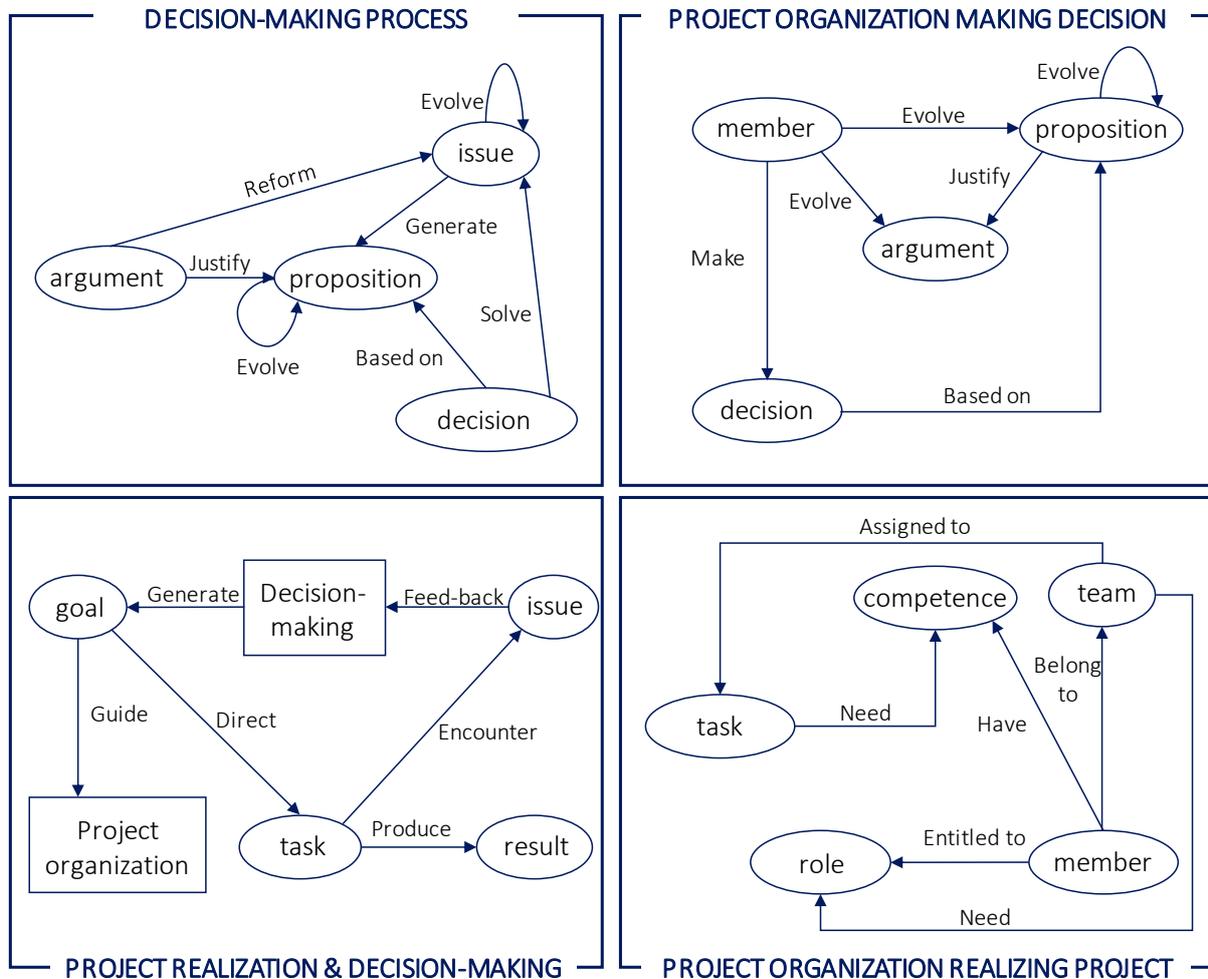


Figure 29. Sub-networks of project memory (Dai et al., 2014)

(Matta et al., 2011) propose techniques to extract and to represent experiences in a project memory, using Process Life cycle Management (PLM) tools. (Matta et al., 2011) describes project memory as "the history of a project and the experience gained during the realization of a project". Project memory must consider:

- The project organization: different participants, their competences, their organization in sub-teams, the tasks which are assigned to each participant, etc.
- The reference frames as rules, methods, and laws used in the various stages of the project.
- The realization of the project. It includes potential problem solving, the evaluation of the solutions as well as the management of the incidents met.

According to (Matta et al., 2011), there are interdependence relations among these elements. The knowledge used in the realization of the project is identified through the analysis of these relations.

Regarding experience reuse for problem-solving, (Romero Bejarano, 2013) defines a generic process to support the solving of problems occurring in a supply chain collaboration context taking into consideration the experiential knowledge as a key driver. This generic process is composed of four components: context, analysis, solution and generalization. The first component, context, provides a factual and standardized problem description and its context in order to compare problems. The analysis phase is performed on the basis of the context issued from previous phase. The objective is to identify the root causes at the origin of the cause-and-effect chain producing the problem. The solution phase strives for eradicating the root causes that have been identified and validated during the analysis phase in a way such that the problem is effectively solved and does not reoccur. Finally, all the corrective and preventive actions, as well as the rationale for their implementation and standardization, are stored into the experience entity during solution and generalization phases.

(Romero Bejarano, 2013) proposes an approach of reuse of past experiences stored in the experience base during the solving of new problems. In light of the distributed problem-solving process and taking into consideration the nature of the networks on which the problems occur, all these steps need to be reasonable not only in terms of similarities/distances in semantic taxonomies but also in terms of network configuration and problem-related attributes.

In this section, a selection of research works that reuse past experiences in order to: (i) structure decision-making and organization in design projects and (ii) facilitate problem solving were presented. In this regard, the experience feedback approach could be used for configuring future collaborations experiences. Experience feedback principles are used in this work in order to define a structured approach to capitalize experiences and reuse them to facilitate and improve future similar collaborations.

2.6 Conclusion and summary of contributions

In this chapter, we presented two areas of major interest for our research: collaboration in industrial processes and Knowledge and Experience Management. Firstly, the approaches for characterizing collaboration in business processes including the definitions, and characterization of collaboration methodologies have been addressed. With regards to the works, we identified the main characteristics of collaboration at organizational and individual level useful for our own contribution. Collaboration at individual level concerns the **actors** who collaborate in order to accomplish one or several **activities** of a **process**. On the other hand, organizational level concerns the **commitments** or goals, the **requirements** or engagements of each commitment and relationship between **organizations** related through one or several **contracts** as well as the **process**. Collaboration leads to set up a collaborative network which can be structured by the following elements: actors, activities, commitments, requirements, contracts, and organizations. These elements are related to the definition of collaboration. Furthermore, we use the 3C model to understand collaboration through its three pillars: 1) communication for exchanging information, 2) coordination for managing the

activities, actors and resources, and 3) cooperation in order to achieve the commitments of the process that have been established.

Enterprise knowledge can be acquired from experience. The knowledge that drives and supports collaboration are, for example, core competences of the enterprise, experiences from previous collaborations, decision-making support, etc. Normally, the knowledge required for collaboration is retrieved from experiences and best practices. The precision of collaboration characterization depends on the knowledge that can be retrieved from each experience at the individual and organizational levels. The capture of more knowledge with a better quality will lead to a more accurate characterization of the collaboration and the result will be closer to reality.

The challenge in the following chapters is to adopt the elements studied in this chapter to develop a collaboration model and a collaboration evaluation methodology for collaboration experience capitalization in industrial processes. The contribution of this thesis regards the proposition of a collaboration model which allows formalizing the collaboration in processes in order to capitalize and reuse experiences of collaboration. The model defined in this work is composed of an information model for collaboration characterization and of an experience reuse method, based on CBR principles, which allows searching similar experiences as an input to define a new experience.

Taking into consideration all the concepts and principles that have been introduced in this state of the art, the general objectives of this research can be defined as the following:

- Building an information model for collaboration in industrial processes that allows the measurement of collaboration maturity levels and the construction of process indicators to quantify the performance and collaboration levels.
- Propose an approach to implement *Experience Reuse* in collaborative industrial processes, through mechanisms and algorithms based on experience feedback principles. This will facilitate the definition and execution of processes by reusing similar past experiences.

3. INFORMATION MODEL FOR EXPERIENCES

3.1 Introduction

In this chapter, the information model which allows to describe a collaboration experience of an industrial process is described. This information model has been built based on the literature review presented in the previous chapter and the know-how of industrial experts (consultants within the Axsens-bte company). In this regard, this model allows to characterize the main elements corresponding to the collaboration context in processes in order to capitalize and reuse past collaboration experiences. First, the main elements describing the context as well as the relationships between these elements that appear throughout an industrial process or project are presented. Then, an illustration is proposed in order to exemplify the introduced concepts.

3.2 Collaboration model for experience characterization

In this section, the main elements of the context of a process which characterize the collaboration of an experience are presented. According to (Dumas et al., 2013), processes are the core system within organizations and in supply networks. Processes involve transforming inputs into outputs by means of capital and human resources that carry out a set of interrelated activities (Anupindi et al., 1999). Consequently, processes shape the future work of every resource along a business process. In this regard, processes allow to determine the capacity of an organization to adapt to new circumstances and to comply with a fast-growing number of market requirements (Dumas et al., 2013).

(Davenport and Short, 1990) define a business process as “a set of logically-related tasks performed to achieve a defined business outcome”. This outcome is a specified end result of process execution and it can be a product or a service. These outcomes are commitments which have been defined in advance by the organizations involved in one or more activities of an industrial process.

Therefore, the organizations which participate in an industrial process must collaborate in order to reach the process commitments. In an industrial context, the collaboration between two or more organizations is governed by contracts. Moreover, contracts frame and support what the stakeholders agree to do in order to achieve a common goal: the process commitments.

According to (Goossen, 2014), an organization consists of one or more actors. That means that an organization is a network of individuals on itself. When two organizations establish a collaboration, actors who work for both organizations will collaborate during the process execution as shown in [Figure 30](#). This creates interpersonal ties that cross organizational boundaries. Because of this, actors must work together based on durable relationships and strong commitments to reach a common goal with the aim of pooling expertise and standardizing tasks (Durugbo et al. 2011). The capitalization and use of past experiences is considered to be a key aspect in the improvement of industrial processes performance (Skyrme, 2007).

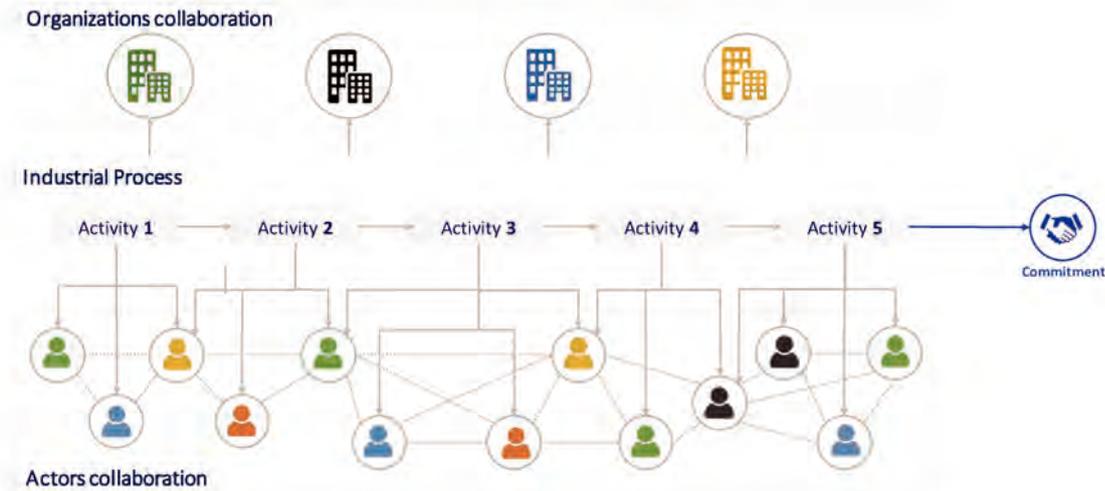


Figure 30. Collaboration in industrial processes

The main goal of this section is to propose an experience feedback process in order to capitalize experiences of collaboration performed in industrial processes and to reuse them in order to define future collaborations. The capitalization of an experience is done for all the activities of a process as shown in Figure 31. An experience is formalized using elements of a knowledge base in order to permit the experience standardization and facilitate the future reuse of past experiences (Meléndez et al., 2018).

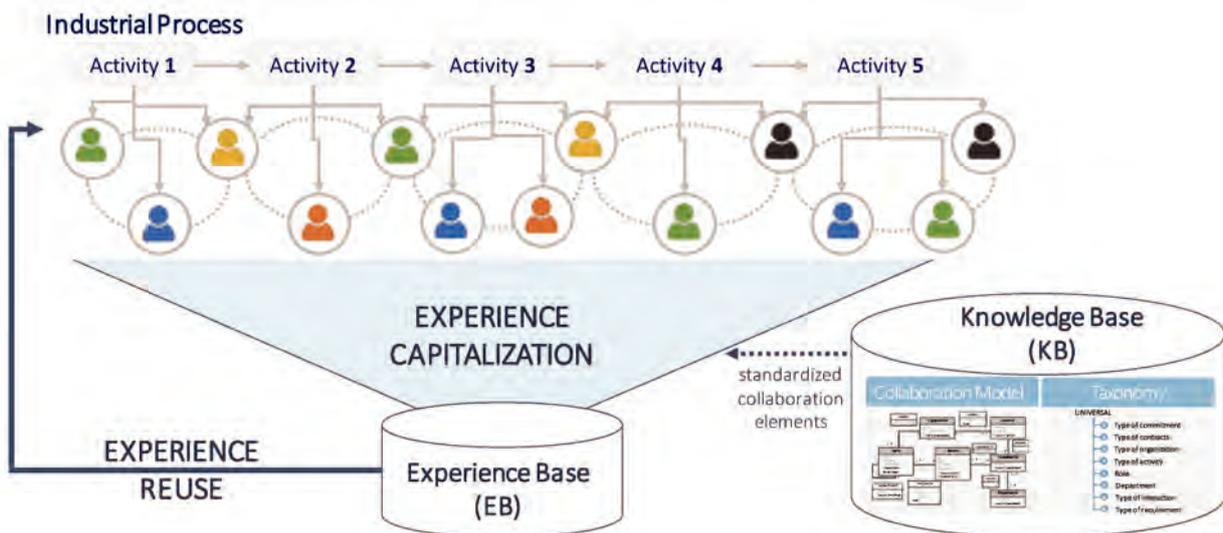


Figure 31. Overall experience feedback process

Some standardized elements are stored in the Knowledge Base. They allow to better define a collaboration experience and to capitalize it in the Experience Base. In order to facilitate the reuse of experiences, it is necessary to define a generic model of collaboration corresponding to a generic experience frame. This generic model of collaboration is stored in the knowledge base, and every collaboration experience will be an instance of this generic model. In order to define the characteristics of a collaboration experience without ambiguity, it is necessary to standardize the main concepts and to store them in a structured manner. Therefore, the

knowledge base also contains a taxonomy of concepts that are used to characterize the different parts of a collaboration experience.

Once a collaboration experience has been properly defined from the available knowledge, it is stored into the Experience Base. For an industrial process, the planned collaborations and the actual ones have to be memorized within an experience. This will allow to compute some performance indicators by comparing what was planned and what has been really done during the industrial process execution. When a process has to be defined and planned for a new execution, the prior experiences stored into the Experience Base which correspond to the activities of the process can be reused. The generic model of a collaboration experience and the taxonomy are described in the next sections.

3.3 Generic model of a collaboration experience

This section describes the proposed experience collaboration model that allows to standardize experiences and to facilitate experience feedback process.

The proposed experience collaboration model is based on the execution of an industrial process which involves the collaboration of different actors and organizations. This model is formalized by means of the UML model of Figure 32. Different organizations can contribute to the execution of several activities of an industrial process in order to reach some defined goals. These goals are represented in the model by commitments, and they must satisfy one or several requirements. In order to formalize the different participations of the organizations, they are governed by contracts.

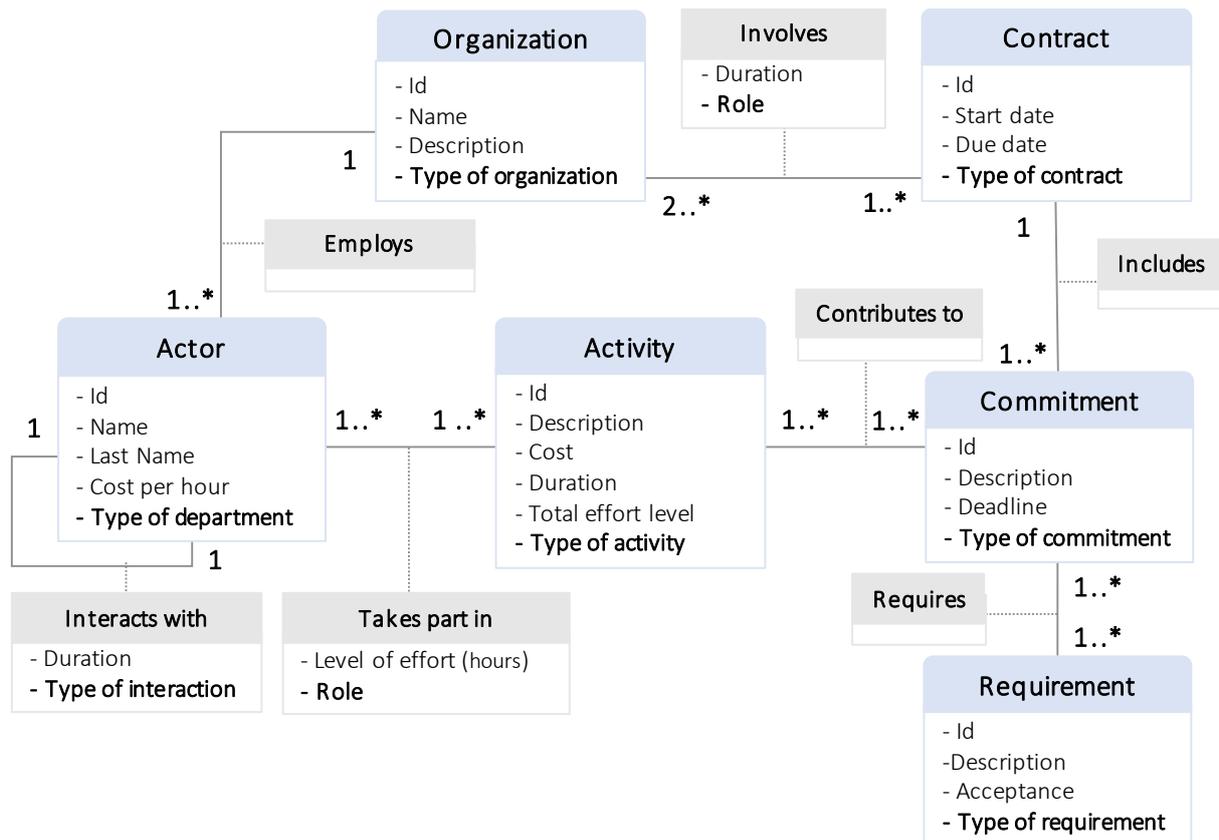


Figure 32. Collaboration model frame

The UML model of [Figure 32](#) contains classes representing the entities of an experience and relations between them. Some attributes are represented in bold, and their values will be chosen in the taxonomy (section 3.4). The entities are:

- *Organization*: an organization is a group of people structured in a specific way to achieve shared goals which in a legal context are named commitments (Katz and Kahn, 1978). An organization can collaborate with other organizations in order to meet the commitments specifications. It is characterized by its name, description and type.
- *Contract*: a contract represents one or several agreements where an organization provides products or services to another organization. These agreements can be verbal (they allow to start collaborative activities without a written contract) or written. It is characterized by the start date, the end date and the type of contract.
- *Commitment*: a commitment represents the output of a process. It is characterized by a description, a deadline and a type. In order to define an accurate typology of commitments, the type of commitment taxonomy is based on the European Classification of Products by Activity “CPA”. The CPA distinguishes between goods produced for own account and the services performed on goods on a fee or contract basis (see appendix 1).
- *Requirement*: a requirement is a specific need that the commitments have to meet. It describes the engineers’ perception of a need and their understanding of the solution (Roman, 1985). There are two families of requirements: functional and non-functional requirements (also called constraints). The functional requirements capture the nature of the interaction between the component and its environment. The non-functional requirements restrict the types of solutions one might consider. (Roman, 1985) proposes a taxonomy of requirements which will be used in this generic collaboration experience (see appendix 1). It is characterized by a description, an acceptance and a type.
- *Activity*: the interaction between the organizations to fulfill the commitments of a contract engenders an industrial process. It is a structured, managed and controlled set of activities with the purpose of transforming inputs into specified outputs (Davenport and Short, 1990). The following attributes characterize an activity: the cost, the duration, the total effort level, and the type. The cost attribute includes the cost of all actors who participate in the activity and others cost such as material cost, transportation cost, etc. The duration attribute is the difference between the start date and the finish date. The total effort level is the sum of all workloads (in person × hours) needed to carry out the activity.
- *Actor*: an actor is a person who participated in one or more activities of an industrial process (Hermann et al., 2017). The entity actor is characterized by its name, its cost per hour and its department.

For the relations between entities, the main relations are: “Includes”, “Requires”, “Involves”, “Employs”, “Interacts with”, “Takes part in”, and “Contributes to”. The characteristics of the relations are the followings:

- *Includes*: this relation represents the links between the commitments and the contracts. A contract includes one or more commitments, and a commitment is included into one contract.
- *Requires*: this relation represents the link between a commitment and a requirement. A requirement is linked to one or more commitments.
- *Involves*: this relation represents the link between an organization and a contract. A contract involves two or more organizations which collaborate in order to achieve one or several commitments. An organization (if it appears in the experience) is involved in one or more contracts. The relation *involves* is described by the duration of the collaboration and the role of the organization with respect to the contract.
- *Employs*: an organization employs one or more actors and an actor is employed by only one organization for the experience.
- *Interacts with*: within an experience, the actors are going to collaborate. If an actor interacts with another actor during the collaboration experience, an association is created. This association is described by its duration and by the type of interaction (see appendix 1).
- *Takes part in*: this relation represents the participation of actors to one or more activities of the industrial process. An activity is realized by one or more actors. The association of an actor who takes part in the realization of an activity is described by the level of effort (i.e. the number of hours required by the actor to execute his/her contribution) and by his/her role. During the execution of the process activities, actors collaborate contributing to the process commitments. Every actor has different roles and contributes to one or several activities throughout the process (Anupindi et al., 1999).
- *Contributes to*: this relation represents the link between activities and commitments. It indicates which activities contribute to a commitment. Then, this relation allows to link an activity to several commitments and several activities to one commitment.

Some attributes can be standardized in order to facilitate the future reuse. They are represented in bold in the UML model of [Figure 32](#). A taxonomy of concepts allows this standardization and it ensures an accurate capitalization of knowledge about collaboration. This taxonomy is described in the next section.

3.4 Taxonomy

A taxonomy is a hierarchical structure described through relations between concepts included in the hierarchy (Van Rees, 2003). Taxonomies create a consistent representation of concepts through their structuration into a tree according to a “*is-a*” hierarchical relation (Jabrouni et al., 2011; Rich, 1992). According to (Roman et al., 2005), a concept constitutes the basic element of the agreed terminology for some domain.

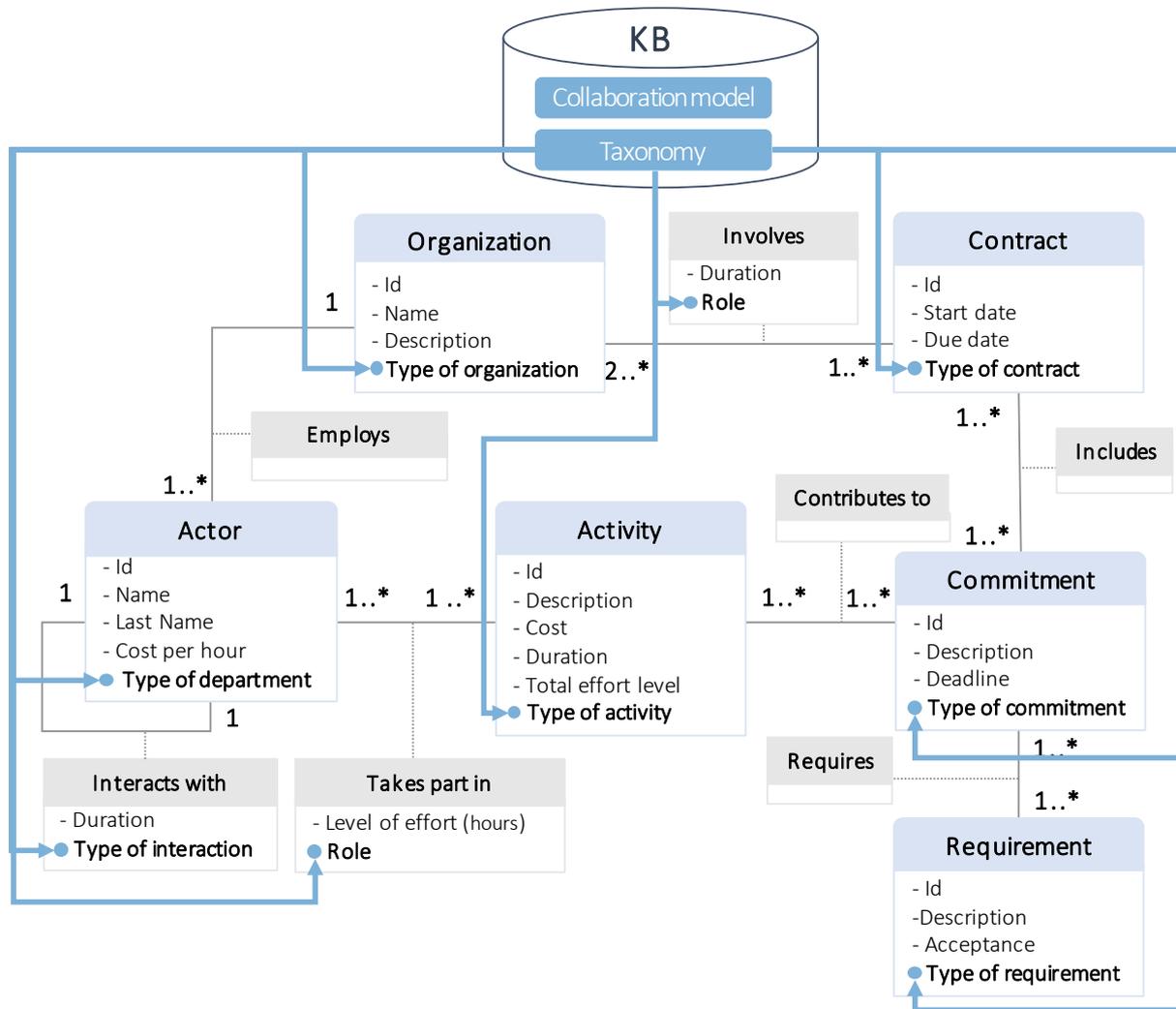


Figure 33. Utilization of the taxonomy for the standardization of different attributes values

In our work, taxonomies define possible values for several attributes (in bold in the experience model) in order to characterize the collaboration experiences (Figure 33) and facilitate their retrieval from the experience base where all experiences will be stored. The more generic concept is named “Universal”. The closer a concept is to the “Universal” concept, the more generic it is, and the furthest it is from the “Universal” concept, the more specialized it is. An illustration of a partial collaboration experience taxonomy is represented in Figure 34. Only general concepts are represented and each one of them can be specialized.

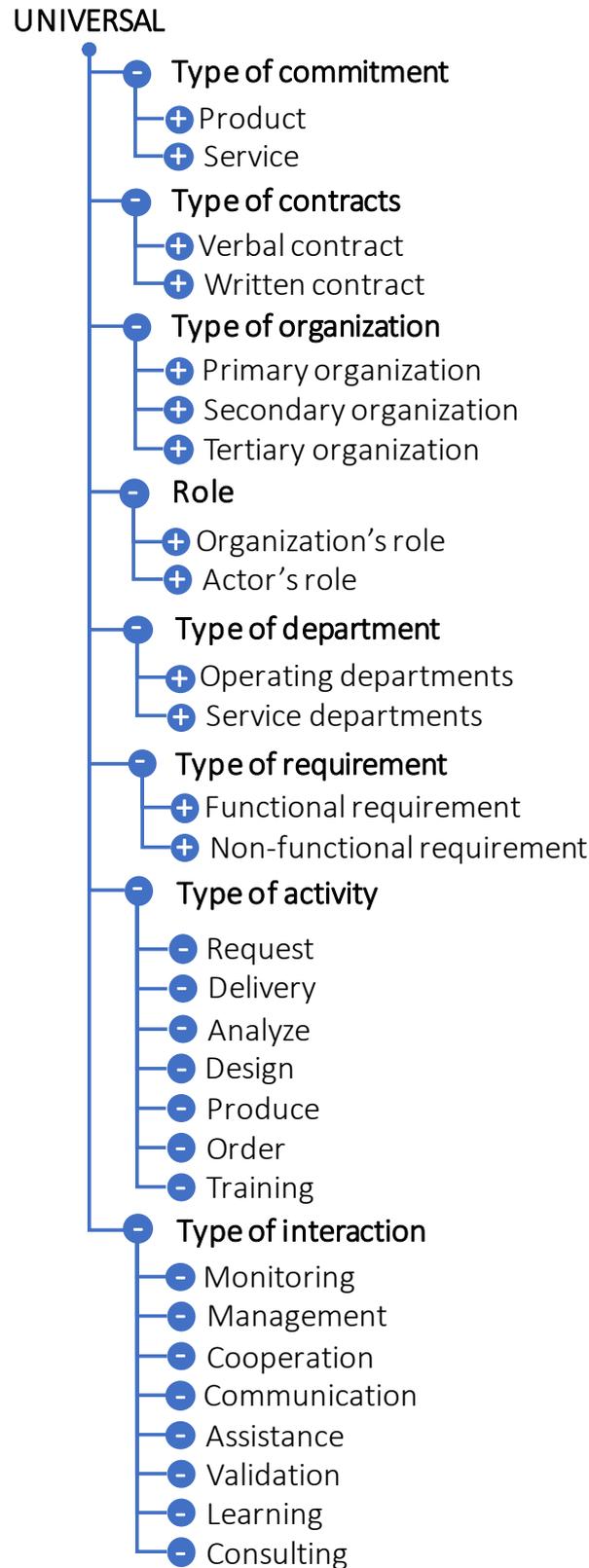


Figure 34. First level of the taxonomy

The taxonomy which allows the standardization of different attributes values of the collaboration experience (section 3.3) has been presented. Then, the collaboration experience building is described in the next section.

3.5 Collaboration experience building

In order to build a collaboration experience the elements of the knowledge base are used. These elements are: i) the collaboration experience model, which has to be used to structure a collaboration experience, and ii) the taxonomy of concepts which will permit to tag, by means of validated and standardized concepts, all the elements of a collaboration experience. The KB is essential in the proposed model because it facilitates the experience formalization and reuse. In addition to the different elements and their interactions previously described, it is necessary to distinguish two parts in the collaboration experience: the planned collaboration and the actual collaboration.

The first part is the **planned collaboration** where all the necessary actors, activities, commitments, requirements, contracts and organizations of the process to execute are included. All these elements have to be planned a priori. An example of an instantiation for one actor and one activity is shown in Figure 35. Some attributes values will be found in the taxonomy (appendix 1). For the activity Act₁, the value of the attribute named “type of activity” is “Production”; for the actor a₁, the value of the attribute named “department” is “Quality” and for the link “Takes part in” between the actor a₁ and the activity Act₁, the attribute named “Role” is “Monitor”. These values are coming from the taxonomy of concepts.

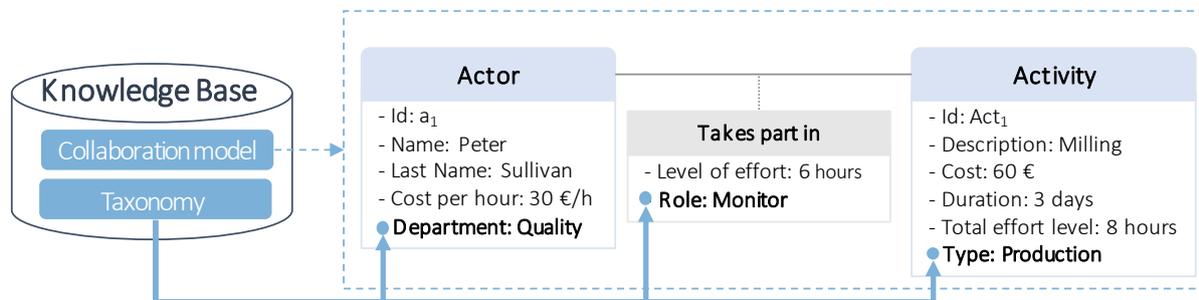


Figure 35. Example of instantiation of two elements from the collaboration experience model and the taxonomy

The second part is the **actual collaboration**. It means the actual information about the collaboration obtained after the process has been executed. Both parts allow to compare what was planned with the actual information and to analyze the differences. Conjointly with the collaboration experience building, collaboration and performance indicators are calculated. They are developed in the chapter 4.

The second step of the proposed approach is the storage in the Experience Base (after validation) of the planned collaboration experience, the actual collaboration experience and the performance indicators. Once they are capitalized, the experiences can be reused to facilitate the decision-making process of future collaborations. The reuse of experiences is described in chapter 5.

3.6 Illustration of an experience collaboration elaboration

In order to illustrate the instantiation of the model, the construction of a collaboration experience corresponding to an industrial process is proposed in this section. The planned collaboration experience and the actual collaboration experience are shown.

3.6.1 Planned collaboration experience elaboration

The industrial process taken into account is a standard process of consulting in the domain of lean management. Company E_1 contracted company E_2 (contract C_1) to carry out a time study and a Lean Improvement Plan for an aircraft painting activity. Nevertheless, company E_2 did not have all the necessary resources to carry out the project. Thus, company E_2 contracted company E_3 (contract C_2) to define a Lean Improvement Plan. In this regard, the time study is set as commitment 1 (com_1) and Lean Improvement Plan for the aircraft painting activity is set as commitment 2 (com_2) as shown in Figure 36. As stated before, this illustration is based on a real industrial case where company E_3 represents the Axsens-bte company (the names of organizations E_1 and E_2 are not disclosed due to confidentiality clauses).

In Figure 36, the concepts of the information model elements that come from the taxonomy are presented in blue. Company E_1 is a manufacturer organization, company E_2 is an engineering company and company E_3 is a consulting company. Then, the type of involvement of each organization for each contract must be defined. In this case, company E_1 is the client and company E_2 is the provider for the contract C_1 . Company E_2 is the client and company E_3 is the provider for the contract C_2 . On the other hand, contract C_1 and contract C_2 are the same type of contract: Fixed Price Contracts. In this type of contract, the payment amount does not depend on resources used or time spent. The type of commitment concepts comes from the specialization of the concept “Production Management Consulting Services” included in the CPA taxonomy (appendix 1).

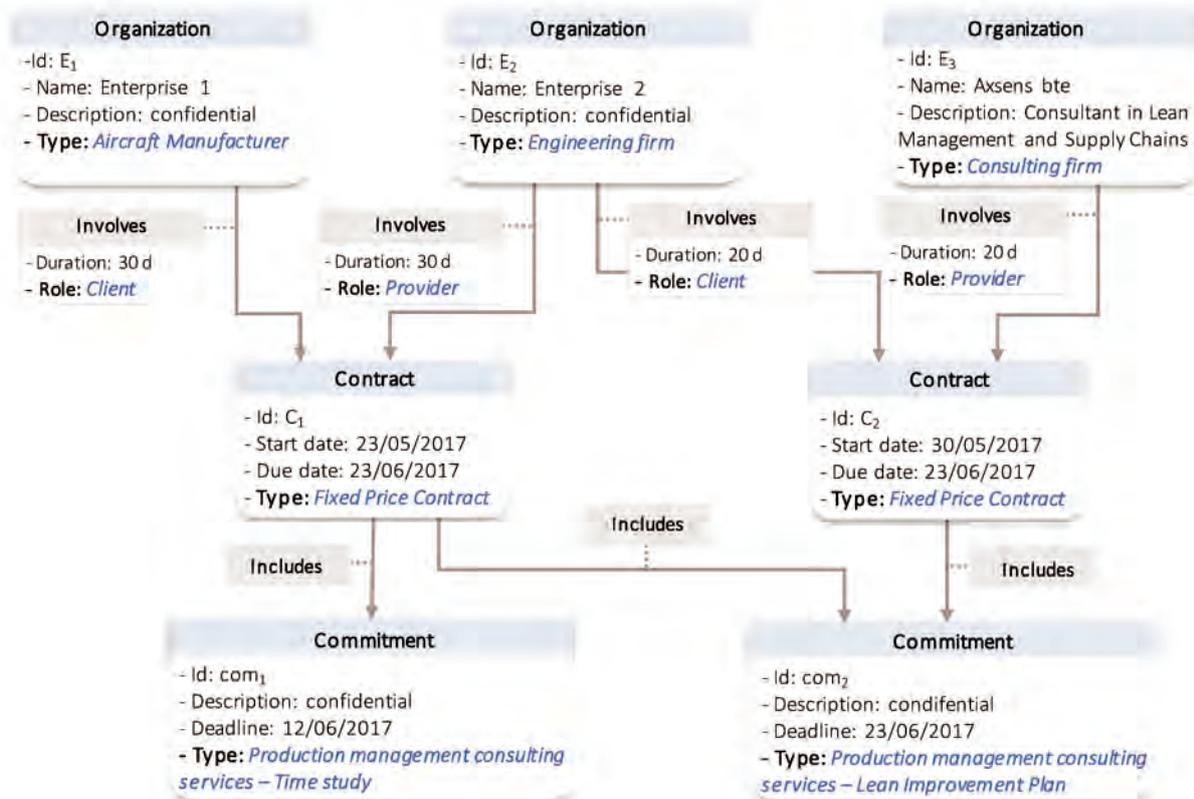


Figure 36. Part of the collaboration experience - organizations, contracts and commitments

In the case of commitments, it is necessary to define their associated requirements. The requirements specifications of commitment **com₁** are: requirement 1.1 (**req_{1.1}**) and requirement 1.2 (**req_{1.2}**). The type of requirement is identified in the taxonomy. In this particular case, both requirements are non-functional. Requirement **req_{1.1}** is the presentation, as spreadsheet graphs, of the data collected from the study of production times, this is an interface constraint (a subtype of non-functional requirements). Requirement **req_{1.2}** refers to the maximum duration for the commitment execution, which is one week, and it is a performance constraint (a subtype of non-functional requirements).

In order to meet the aforementioned commitments **com₁** and **com₂**, the activities of the process, as well as the required actors are defined, as shown in [Figure 37](#). The activities are: Project setting and safety training (**Act₁**), Preparation (**Act₂**), Execution of time study (**Act₃**), Analysis of historical data of the workshop data (**Act₄**), Process mapping (**Act₅**), Industrial maturity assessment (**Act₆**) and Definition of action plan (**Act₇**). [Figure 37](#) illustrates the characteristics of each activity. For example, the total cost of **Act₁** is 2160€, this cost includes both the human resource cost and the material cost used to carry out the activity. The duration is the estimated amount of time that is necessary to perform the activity **Act₁**. The total effort of the activity **Act₁** is the sum of the effort of each actor participating in the activity. In this case, it is the sum of the efforts by **a₂**, **a₄** and **a₇**. The type of activity is defined through the taxonomy illustrated in appendix 1.

In this process, the following actors are involved:

- Actor **a₁** with the role of project manager of company **E₁**
- Actor **a₂** as project manager of company **E₂**
- Actor **a₃** as project manager of company **E₃**
- Actor **a₄** as consultant specialized in time study of company **E₂**
- Actor **a₅** as lean consultant senior of company **E₃**
- Actor **a₆** as lean consultant junior of company **E₃**
- Actor **a₇** as technician of time data collection of company **E₂**

As illustrated in [Figure 37](#), the actors participated as follows:

- Actors **a₂**, **a₄**, **a₇** participated in activity **Act₁**
- Actors **a₁**, **a₂**, **a₄**, **a₇** participated in activity **Act₂**
- Actors **a₂**, **a₄**, **a₇** participated in activity **Act₃**
- Actors **a₁**, **a₂**, **a₃**, **a₄**, **a₅**, **a₆** participated in activity **Act₄**
- Actors **a₃**, **a₅**, **a₆** participated in activity **Act₅**
- Actors **a₅**, **a₆** participated in activity **Act₆**
- Actors **a₁**, **a₂**, **a₃**, **a₅** participated in activity **Act₇**

For each association of an actor to an activity, the effort level (in hours), the cost per hour, and the role taken by the actor have to be defined as shown in [Figure 37](#).

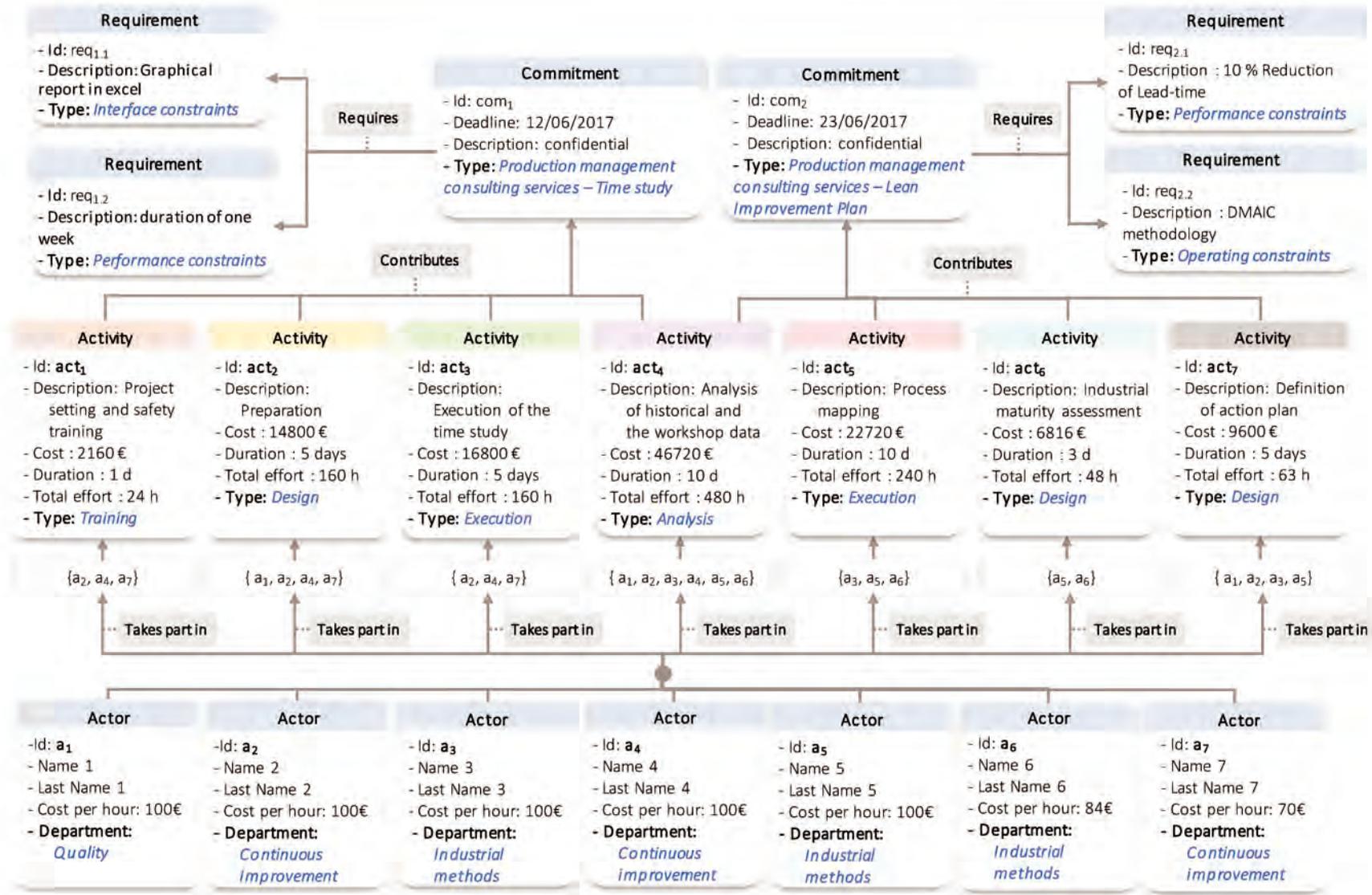


Figure 37. Part of collaboration experience: commitments, requirements, activities and actors

Figure 38 illustrates the participation and the interactions between the actors of Act₁. The role of each actor for the activity Act₁ is identified through the taxonomy of appendix 1: actor a₇ plays the role of trainee, actor a₄ the role of trainer and actor a₂ the role of manager. With regard to the interactions between the actors who participate in the activity Act₁, the duration and type of each interaction are defined.

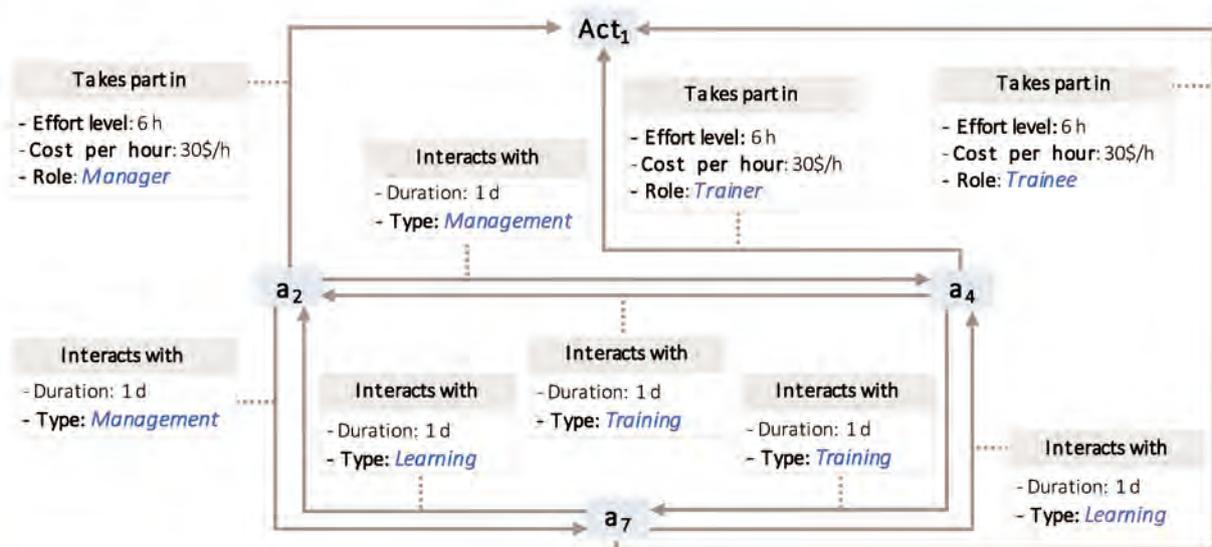


Figure 38. Part of collaboration experience model with the actors a₂, a₄ and a₇ and the activity Act₁.

3.0.2 Actual collaboration experience elaboration

Once the process execution is finished, the second part of the collaboration experience has to be defined. Therefore, the actual collaboration experience is elaborated on the basis of the planned one. All the changes that occurred during the execution of the activities are included into the actual model.

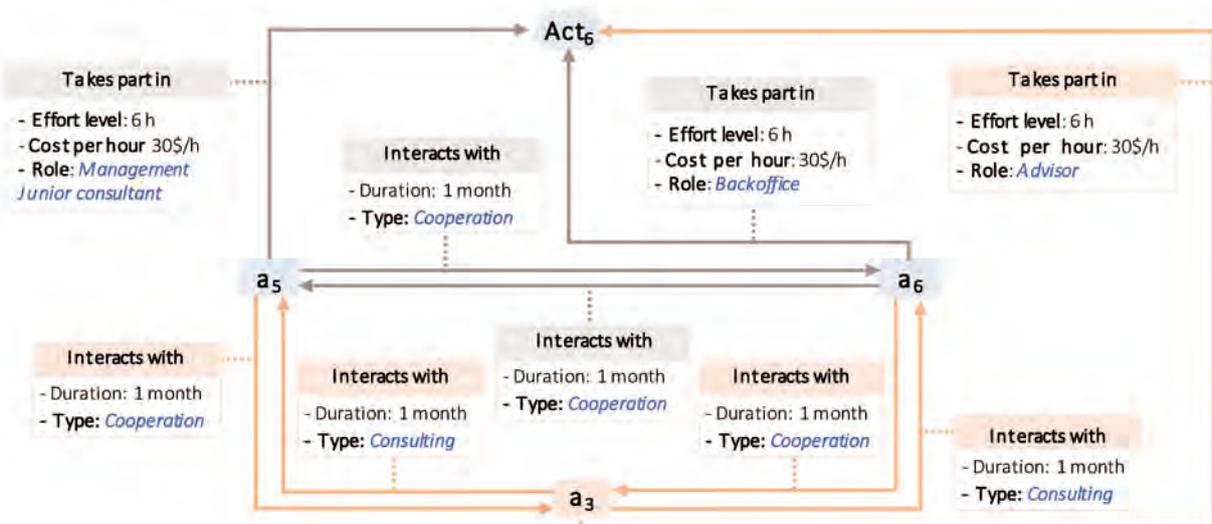


Figure 39. Graph of actual experience between the nodes "actors" and node "Act₆".

Figure 39 is a representation of the changes in the execution of the planned collaboration experience, which mainly concerns the activity Act₆; the other elements have not been

represented in the illustration because they are identical to the planned experience. However, they are copied without changes into the actual model. Within the relations “Interact with”, “Takes part in” and “Involves” the attributes values have to be updated following the actual available information. In each relation “Involves” and “Interacts with”, the real duration has to be given. In each relation “Takes part in”, the actual effort level and cost per hour values have to be given.

In the illustration of [Figure 39](#), the actor a_3 has been added in the actual collaboration experience. This actor interacted with the actors a_5 and a_6 with a “consulting” type of interaction, he/she helped the actors a_5 and a_6 to perform their activity Act_6 . The actors a_5 and a_6 interact with a_3 with a “cooperation” type of interaction. The actual duration of all the interactions are given. Therefore, by comparing planned and actual collaboration experience models, it is possible to compute performance indicators of time and cost deviation. However, these indicators do not measure the quality of collaboration or the satisfaction of commitments by each organization that participated in the industrial process. However, these two aspects are key to understanding the collaboration in industrial processes. In this regard, collaboration and performance indicators that allow to measure the quality of collaboration and the satisfaction of commitments between the organizations which participate in an industrial process are proposed in the next chapter.

3.7 Conclusion

In this section, a collaboration experience model has been defined. The main elements of this model, their interactions and their characteristics were introduced. This chapter is focused on the formalization and understanding of the main elements of a collaboration experience in an industrial process. The model allows characterizing the collaboration experience in two parts: the planned part and the actual part. This allows to compute performance indicators of time and cost deviation by comparing what is planned to what is really done.

A collaboration experience allows organizations to capitalize the information about the collaboration which has been realized during an industrial process. Therefore, it is possible to use the different experiences which are stored in the EB in order to assess:

- How actors collaborated,
- How organizations collaborated,
- Performance indicators of time and cost deviation. Therefore, some indicators are required to evaluate the quality of collaboration and the process performance based on the satisfaction of commitments. These indicators will be described in the next chapter.

The collaboration experience will permit to capitalize actors' collaborations for activities, organizations' collaborations for activities or processes realizations and to reuse them for future collaborations. Every experience is evaluated with regard to collaboration but also with regard to the process performance. This information will be very helpful for decision making.

The definition of this collaboration experience model facilitates the reuse of experiences. This generic model is stored in a knowledge base and every collaboration experience will be an instance of this model. Also, a taxonomy of concepts was presented in order to standardize the characteristics of the model's elements. Once an experience has been properly defined from the available knowledge, it is stored into the EB. The association between taxonomies and experiences provides a support for reusing past experiences. This requires both a methodology for evaluating the experience (subject of chapter 4) and a methodology with ad-hoc algorithms for the reuse of past experiences (subject of chapter 5).

Finally, an illustration of a consulting process based on a mission of the company Axsens-bte was presented with the aim of illustrating and explaining clearly the concepts and the methodology to build the information model for collaboration.

4. COLLABORATION AND PERFORMANCE EXPERIENCE INDICATORS

4.1 Introduction

In this chapter, the calculation of collaboration and performance indicators between organizations that participate in an industrial process is developed. First of all, the information used to evaluate: (i) the performance in terms of the acceptance of commitments, and (ii) the collaboration in terms of communication, cooperation, and coordination is presented. Second, the methodology to calculate the experience assessment between organizations which participate to the industrial process is developed. Afterwards, an illustration based on the collaboration experience illustration of chapter 3 is proposed in order to exemplify the introduced methodology. Finally, the conclusion of this section is presented.

4.2 Evaluation of a collaboration experience

In this subsection, the inputs to evaluate the collaboration and the performance of an experience are presented. As stated in chapter 3, the main objective of industrial processes is to carry out commitments that are defined and contracted by organizations. According to the information model presented in chapter 3, a commitment must meet at least one requirement. On one hand, collaboration is evaluated by the actors who interact in order to carry out the process and to realize the commitments. On the other hand, performance is evaluated through the requirements satisfaction and this evaluation is done by organizations that participate to the process.

4.2.1 Inputs for the calculation of the collaboration indicator

As stated in chapter 2, (Fuks et al., 2008) propose a framework for classifying collaborative systems. This framework supports collaboration analysis, and is based on the inter- and intra-relationships between organizations following three dimensions: communication, coordination, and cooperation.

According to (Salas et al., 2008), communication represents the efforts needed to maintain accurate and precise information exchange among team members throughout the team. Coordination, the second dimension, represents the strategies and the organization of elements needed to carry out the process. The last dimension (cooperation) represents the social component that allows holding the team together and inspires its members to achieve the proposed commitments. These three dimensions are fundamental requirements of teamwork and a constant interaction between them is a key to building an effective team. These elements operate interdependently: coordination organizes activities for cooperation, which demands effective communication to ensure the implementation of the defined strategies and commitments through coordination (Fuks et al., 2008).

In the literature, the aforementioned collaboration dimensions are measured in many different ways. Thus, to gain insight into the different dimensions of collaboration, a literature review has been conducted. This literature review specifically focused on existing measurement tools that evaluate at least one collaboration dimension. In this regard, ten case studies which measure collaboration mainly in academic, design, and health teams were analyzed. These analysis allow the definition of sub-dimensions for each collaboration dimension, as shown in [Figure 40](#).



Figure 40. Collaboration dimensions of experience

1) Coordination dimension

Regarding the *Coordination* dimension, two sub-dimensions are identified: “*planning*” and “*organization*”, as shown in Figure 41.

The planning sub-dimension is the management function that involves setting goals and deciding the best way to achieve them. Planning implies a preventive approach, and sets anticipated timelines. In this regard, a set of criteria that allows to evaluate the planning sub-dimension are: “*commitments*”, “*schedule*”, “*resources*” and “*control*”.

The criterion “*commitments*” involves the objective or objectives that the team members must reach by working together. The criterion “*schedule*” concerns the process of allocating activities to human and non-human resources and the times at which each one should happen or be done in a way that would maximize the resources efficiency. The criterion “*resources*” involves all the assets a company controls and can use to achieve its goals. These resources may be human, material, financial and intangible resources. The criterion “*control*” regards a framework of activities aimed at reducing the risk of error or fraud in a process.

The organization sub-dimension is the process of arranging tasks or resources so that you can perform or use them optimally. It facilitates an efficient work environment and increases the chance that individuals achieve their goals at work. The criteria that allow to evaluate the organization sub-dimension are: “*role*”, “*responsibility*” and “*Competences*”.

The criterion “*role*” concerns the position that an actor has in a process and the specific functions that members are expected to perform in each activity of a process. The criterion “*responsibility*” regards the set of tasks, activities or actions an actor is expected to perform, or allowed to do, according to the role. The criterion “*competences*” refers to a set of related abilities, knowledge, and skills that enable the team members to act effectively in process activities.

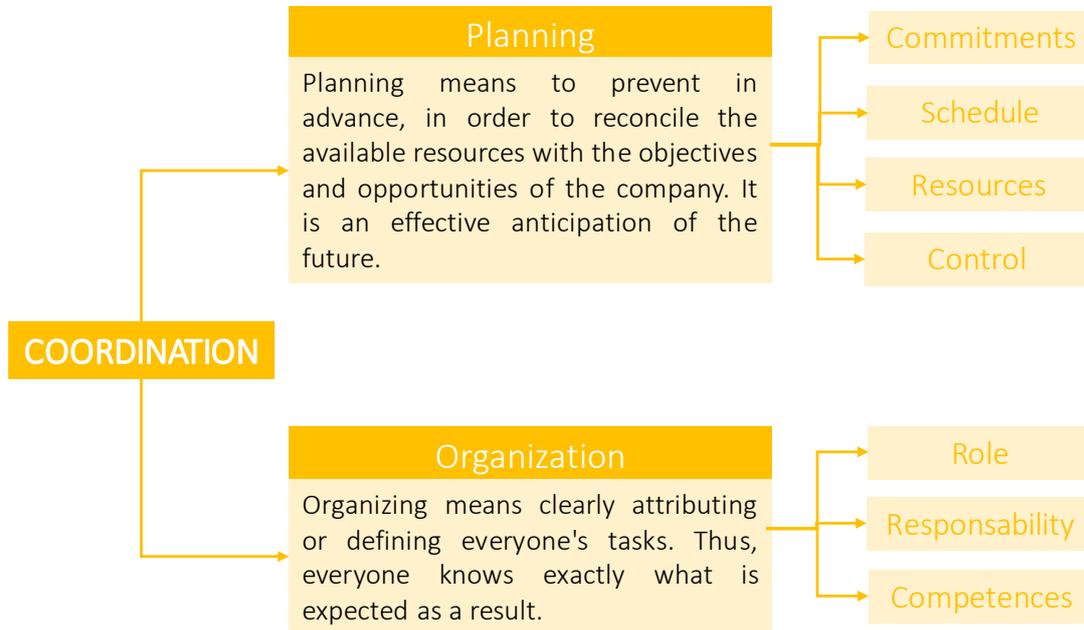


Figure 41. Sub-dimensions of coordination

In order to allow actors of processes to assess the coordination, some questions have been defined in order to define a survey. They are “agree/disagree questions” based on the case studies of existing collaboration measurement tools. These questions allow measuring the quality of the experience’s coordination and they are presented in Table 3. They are evaluated with the following agreement scale: strongly agree, agree, disagree or strongly disagree.

| PLANNING | |
|--------------|---|
| → | Commitments |
| - | A contract or agreement is in place and it is satisfactory to both parties |
| - | The team's activities are guided by a clear Mission Statement/Charter |
| - | The team keeps commitments and completes assignments on time |
| → | Schedule |
| - | There was a team planning |
| - | Team members have the means to see the progress toward important objectives |
| - | The team met important deadlines on time |
| → | Resources |
| - | There was someone in the team who coordinated the tasks |
| - | The team managed time effectively |
| - | There was a Knowledge transfer |
| - | The labor's division was fair, and team members presented the completed work |
| → | Control |
| - | We try to have set procedures or protocols to ensure that things are orderly and run smoothly (e.g., minimize interruptions; everyone gets the opportunity to have their say) |
| - | Team plans and schedules were effective |
| ORGANIZATION | |
| → | Roles |
| - | The team roles were distinct without ambiguity |
| - | The team members did their part of the work |
| → | Responsibility |
| - | The team responsibilities were distinct without ambiguity |
| - | Each team member had at least one backup who was able to perform their role if necessary |
| → | Competences |
| - | The team has the right members in order to be successful |
| - | Tasks are assigned to those best qualified to undertake them, whether internal or external |

Table 3. Coordination questions survey

2) Cooperation dimension

Concerning the *Cooperation* dimension, two sub-dimensions are identified: “*team*” and “*environment*”, as shown in Figure 42. The team sub-dimension concerns the group of individuals working together to achieve their goal. The criteria that allow to evaluate the team sub-dimension are: “*commitment*” and “*team spirit*”. The criterion “*commitment*” refers to the willingness of a team to work in order to achieve a goal. The criterion “*team spirit*” concerns the feeling of “*belonging together*” that the team members have towards other members of the team. The environment sub-dimension involves the conditions by which team members are surrounded. The criteria that allow to evaluate the environment sub-dimension are: “*training*”, “*trust*” and “*leadership*”. The criterion “*training*” refers the short educational process by which knowledge and technical skills in regard to teamwork are acquired to achieve the team’s goals. The criterion “*trust*” concerns the confidence in the certainty of the successful execution of the team's future activities. The criterion “*leadership*” regards the ability to commission, manage, take initiative, convene, promote, motivate and incentivize the teamwork.



Figure 42. Sub-dimensions of cooperation

For the survey, the questions that allow measuring the experience coordination quality are presented in Table 4. They are evaluated by the following agreement scale: strongly agree, agree, disagree or strongly disagree.

| TEAM | |
|-------------|---|
| → | Commitment |
| | <ul style="list-style-type: none"> - When the situation changed, the whole team adapted quickly to new circumstances. - Team members were willing to perform other team members work tasks necessary for this - The team was willing to make changes to the work approach along the process - Each member has the ability to make compromises - Everyone on the team participates at an acceptable level - There were not missed deadlines, work unprepared or absent for team meetings |
| → | Team spirit |
| | <ul style="list-style-type: none"> - There was a 'We are together' attitude - Team members were willing to adjust strategies because someone else needed assistance - The team members positively tuned to teamwork along the way in the work process - Team members support each other - When a team member needed help, variable team members helped. - This team works well together |
| ENVIRONMENT | |
| → | Training |
| | <ul style="list-style-type: none"> - Each member of the team correctly assumes their role and responsibilities - There were real attempts to share information - The team have a common understanding of its goals - This team works well with other teams or departments in the organization |
| → | Trust |
| | <ul style="list-style-type: none"> - Fosters a climate of trust - The actions that affect teammates were taken without their input - Team members fully trust the other team members and don't closely monitor others - Our team feels that we are all in it together and shares responsibilities |
| → | Leadership |
| | <ul style="list-style-type: none"> - The leader promoted teamwork |

Table 4. Cooperation questions survey

3) Communication dimension

Concerning the *Cooperation* dimension, two sub-dimensions are identified: “*context*” and “*message*” as shown in Figure 43. The context sub-dimension is the setting in which communication takes place and the guidelines for communication. The criteria that allow to evaluate the context sub-dimension are: “*channel*” and “*message*”. The criterion “*channel*” involves the way in which the information flows within the organization. The criterion “*guidelines*” refers to all the rules designed to facilitate effective communication.

The message sub-dimension is the content of the communication process which is successfully delivered, received and understood. The criteria that allow to evaluate the message sub-dimension are: “*synergy*”, “*clearness*” and “*channel*”. The criteria that allow to evaluate the context sub-dimension are: “*synergy*”, “*clearness*” and “*channel*”. The criterion “*synergy*” involves the factors that facilitate proactive communication between the team members and the generation of new ideas. The criterion “*clearness*” concerns several aspects of communication as completeness, clarity, conciseness, concreteness, and courtesy. The criterion “*correctness*” refers to the veracity of the message. For the survey, the questions which allow measuring the experience coordination quality are presented in Table 5. They are evaluated by the following agreement scale: strongly agree, agree, disagree or strongly disagree.

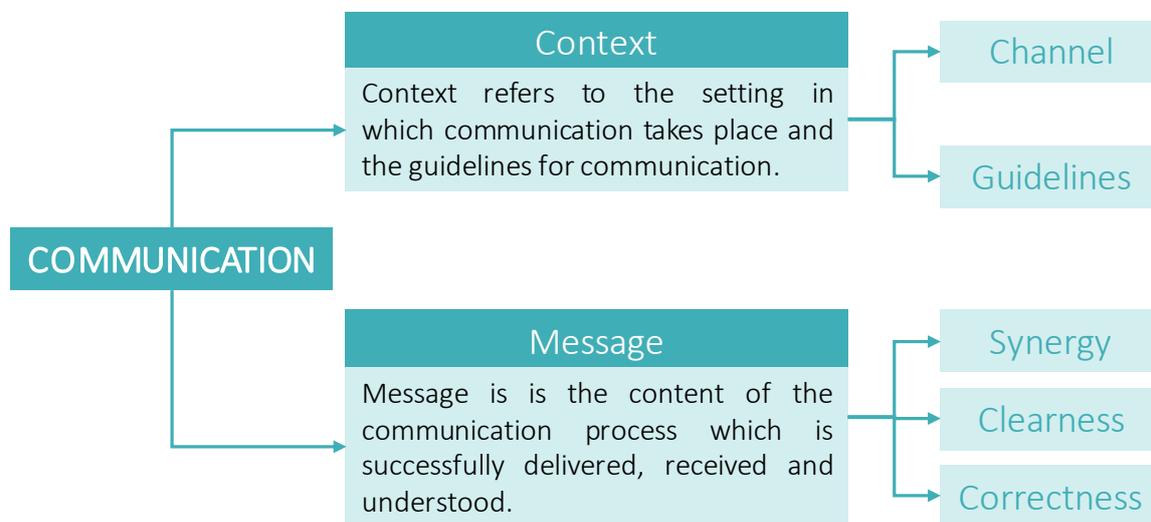


Figure 43. Sub-dimensions of communication

| CONTEXT | |
|---------|---|
| → | Channel |
| | <ul style="list-style-type: none"> - There were top-management communication channels - The communication channels facilitate a prompt communication of changes to team members |
| → | Guidelines |
| | <ul style="list-style-type: none"> - The plan was communicated to all team members - Team members are encouraged to express different points of view - There was a common language - The team leader has a process for sharing information with all team members |
| MESSAGE | |
| → | Synergy |
| | <ul style="list-style-type: none"> - The team members shared all the information necessary to execute the activities successfully. - People keep each other informed - Team members were afraid or did not like to ask others for help - There was effective communication between team members - There was an environment for open dialogue |
| → | Clearness |
| | <ul style="list-style-type: none"> - The team leader always reassured that his/her instructions were understood - When team members talk, we understand each other - There was a clear communication route between the partners (open and frequent) |
| → | Correctness |
| | <ul style="list-style-type: none"> - The team leader's instructions were always explicit and directed - Team members express disagreements constructively - Information passed between team members is accurate |

Table 5. Communication questions survey

The surveys presented in [Table 3](#), [Table 4](#) and [Table 5](#) facilitate a standardized evaluation of collaboration dimensions. This evaluation is carried out by the actors who participate in the industrial process when it is executed. The evaluation result is a number between 0 and 1, with 1 indicating a high level of perceived collaboration and 0 indicating a low level of perceived collaboration. Each actor evaluates the other actors who have interacted with him following the three dimensions of collaboration. The evaluation or grade is obtained by dividing the total number of points obtained by the maximum total number of points that can be obtained.

For each question, some points are given according to the following scheme: strongly agree = 3 points, agree = 2 point, disagree = 1 point and strongly disagree = 0 point. Finally, a matrix is created for each dimension, with the dimension evaluation carried out by the actors. The first column of the matrix indicates the evaluation given by the actor a_1 to the other actors who have interacted with her/him in the process, as shown in [Figure 44](#).

The number of actors to be evaluated can be large in an industrial context. In this regard, if an actor believes that the quality of interactions with other actors was homogeneous, we suggest that the actor carries out a general collaboration evaluation of the process. This implies attributing the same value to interactions with other actors, this value being the general collaboration evaluation value.

Figure 44 illustrates an example of collaboration evaluation. The actor a_1 gives a general evaluation to the actors who interacted with her/him: 0.7 for cooperation, 0.7 for coordination, and 0.5 for communication. However, it is possible to carry out a specific evaluation for one or several actors, e.g. with respect to cooperation a_n gives 0.7 to a_1 and 0.6 to a_2 . If an actor does not interact with another actor, no evaluation is given to her/him.

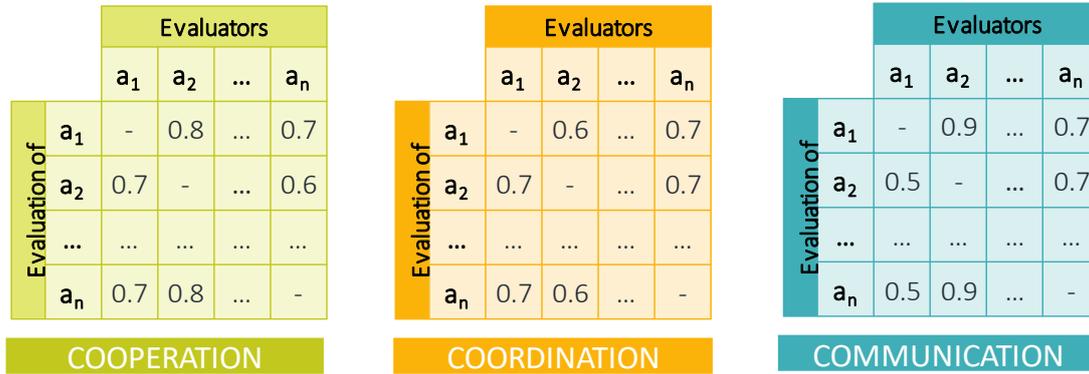


Figure 44. Example of collaboration evaluation experience

4.2.2 Inputs for the calculation of the performance indicator

According to (Raja et al. 2018), the success of an industrial process or project is determined by how well the output satisfies the needs and expectations of customers and stakeholders. These needs and expectations are generally expressed in terms of functional requirements on the product's behavior and performance.

As stated in subsection 3.3, there are two main types of requirements: functional requirements and non-functional requirements. For both types of requirements, we propose a satisfaction evaluation grade that ranges between 0 and 1. A value of 1 means that the organization gives the best rating for the requirement (fully satisfied), while a value of 0 means that the requirement was rated with the lowest possible evaluation (not satisfied).

Figure 45 illustrates the evaluation of a quantitative requirement (r_1) and the evaluation of a qualitative requirement (r_2) by two organizations O_1 and O_2 .

| | | O_1 | O_2 |
|-------|-----|-------|-------|
| r_1 | 1 | 1 | |
| r_2 | 0.9 | 0.8 | |

Figure 45. Example of requirements evaluation

4.3 Calculation Methodology

As stated in section 2.1.3, an industrial process can be modeled as a network between two or more organizations which have an internal network of actors who work for them. These networks are represented by graphs where nodes are entities (e.g. people, organizations, activities ...) and arcs represent the interactions between these entities (Meléndez et al., 2019). According to (Ghoniem et al., 2004), a graph can be represented as a connectivity matrix. This matrix is a matrix of booleans values whose rows and columns represent the vertices of the graph. When two vertices are connected, the intersection cell of the corresponding line and column contains the value 1. Otherwise, it contains the value 0. The proposed methodology is based on the representation of graphs as matrices (M).

As stated in subsection 4.1, the evaluation of a collaboration experience is based on two parts: collaboration and performance evaluation. In subsection 4.2, two types of input matrices that allow the experience evaluation in terms of collaboration and performance were presented. The first matrix type is the collaboration dimension evaluation matrix between the different actors that participated in the process (I_{a-a}) and the second matrix is the requirements acceptance matrix of a commitment com_i by organizations ($I_{O-Req}^{Com_i}$).

The evaluation of collaboration is assessed at the level of actors. The objective of the method proposed in this subsection is to aggregate this evaluation at the level of organizations. Therefore, the connectivity matrices of the graph will be used to calculate the evaluation between organizations.

The collaboration is evaluated at the actors' level (blue elements of Figure 46), and performance evaluation at the requirement level (purple elements of Figure 46). The objective of the methodology proposed in this subsection is to expose both evaluations at organizations' level. Therefore, the matrices of connection (M) of the graph will be used to calculate the evaluation between organizations, as shown in Figure 46.

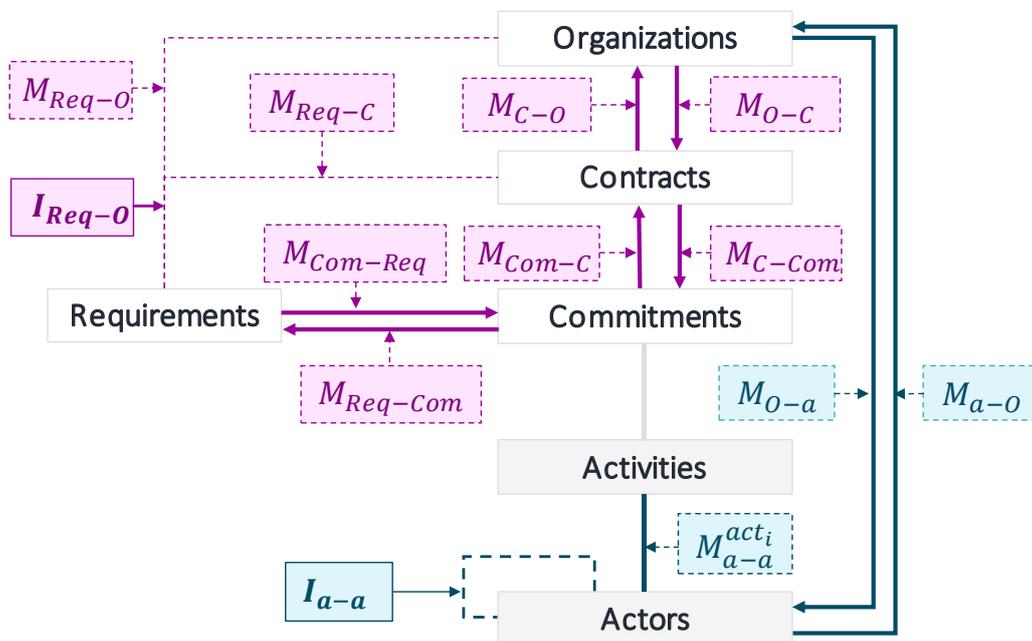


Figure 46. Connectivity matrices of a collaboration experience

Finally, the matrices resulting from the multiplication between the input matrices obtained from the surveys (I) and connection matrices (M) will be called *assessment matrices* (A) and the final result *total performance between organizations* ($Perf$) and *total collaboration between organizations* ($Coll$). The calculation between the aforementioned matrices will be developed in detail in subsection 4.3.1 and subsection 4.3.2.

4.3.1 Evaluation of collaboration

Collaboration is evaluated thanks to three dimensions of the 3C model proposed by (Fuks et al., 2008): Communication, Coordination, and Cooperation. The first step is the construction of three matrices where the actors evaluate each collaboration dimension of the global process (I_{a-a}) through the surveys presented in subsection 4.2.2.

The value of each consolidated collaboration dimension rating varies between 0 and 1. In this regard, the matrix by activity for each criterion is obtained from the Hadamard product between the connectivity matrix of an activity Act_i and the actors who participated to Act_i ($M_{a-a}^{Act_i}$) and the collaboration dimension evaluation matrix of the industrial process (I_{a-a}) as follows:

$$A_{a-a}^{Act_i} = I_{a-a} \circ M_{a-a}^{Act_i} \quad (1)$$

The matrix $A_{a-a}^{Act_i}$ shows (for a given collaboration dimension) the assessment given by the actors who actually collaborated for the activity Act_i . These values have been calculated for each collaboration dimension (coordination, cooperation and communication). Then, the evaluation of an actor a_j (for each collaboration dimension) received by each organization O_m that participated in the activity Act_i must be calculated (the assessment done by each organization is based on the assessments done by actors who work for them). This evaluation is obtained through the individual evaluations that the actors who work for organization O_m give to the others actors. This is obtained by the multiplication between the matrix $A_{a-a}^{Act_i}$ and the connection matrix between actors and organizations M_{a-o} , with the latter indicating who are the actors employed by the organizations (value 1 if the actor a_j is employed by the organization O_m ; 0 otherwise) as follows:

$$A_{a-o}^{Act_i} = A_{a-a}^{Act_i} \times M_{a-o} \quad (2)$$

Then, the assessment matrix $A_{a-o}^{Act_i}$ shows the evaluation for a given collaboration dimension that all the actors of each organization gave to each actor who participated in the activity Act_i . In order to obtain the evaluation for one collaboration dimension between organizations (matrix $A_{o-o}^{Act_i}$), the connection matrix M_{o-a} is multiplied by the assessment matrix $A_{a-o}^{Act_i}$ as follows:

$$A_{o-o}^{Act_i} = M_{o-a} \times A_{a-o}^{Act_i} \quad (3)$$

The matrix $A_{o-o}^{Act_i}$ shows the collaboration evaluation (for one collaboration dimension) between organizations, e.g., if O_1 and O_2 are organizations that participated in the execution of the activity Act_i , $A_{o-o}^{Act_i}$ allows to show the evaluation that O_1 's actors give to O_2 's actors and vice versa. Finally, the overall collaboration evaluation matrix for a specific dimension j ($Coll_j$)

is obtained by adding all the collaboration evaluation matrices for all the m activities of the process as follows:

$$Coll_j = \sum_{i=1}^m A_{O-O}^{Act_i} \quad (4)$$

An illustration of these calculations is given in the section 4.4. Once the collaboration dimension assessment ($Coll$) matrices between organizations (coordination, cooperation and communication) have been calculated, the next step is to show this evaluation as relative values (denoted $Coll_j^{\%}$) with regard to the best possible values. This allows feeding a dashboard containing the main indicators of the experience. This dashboard is explained in detail in subsection 4.3.3.

Finally, a global collaboration indicator for all organizations that participated in the industrial process ($Coll_{O_i}$) is proposed. It is based on the three collaboration dimensions assessment. In this regard, the assessment (for a collaboration dimension) of an organization O_i can be calculated by adding the assessments that O_i received from all organizations (included its self-evaluation). This global collaboration indicator for organizations is calculated in order to facilitate the experience reuse approach that is presented in chapter 5. The global collaboration experience indicator ($Coll_{O_i}$) of an organization O_i in an experience E_n is the aggregation of the three collaboration dimensions ($Coll(O_i)_1$, $Coll(O_i)_2$ and $Coll(O_i)_3$) using a GOWA operator (Yager, 2004) described in the equation 5. The parameter λ permits to tune the operator from minimum to maximum. If $\lambda \rightarrow +\infty$, the GOWA operator functions as a maximum operator. If $\lambda \rightarrow -\infty$, it functions as a minimum operator.

$$Coll_{O_i} = \left(\sum_{j=1}^3 \frac{1}{3} Coll(O_i)_j^\lambda \right)^{1/\lambda} \quad (5)$$

4.3.2 Evaluation of performance

The process performance is calculated through the acceptance level for each of the commitments required by the customer. As stated in subsection 4.2.1, the requirements are evaluated on a scale from 0.0 to 1.0 (low level to high level of acceptance). This evaluation is registered in matrix I_{Req-O} . For that, it is necessary to identify which organization must evaluate each requirement for each commitment (Com_j). Considering that the main objective is to calculate the total performance of each organization based on the requirement acceptance of each organization, it is necessary to build the connection matrix between requirements Req and organizations O for each commitment $M_{Req-O}^{Com_i}$. First of all, the connection matrix $M_{Req-C}^{Com_i}$ between requirements Req and contracts C for a commitment Com_i must be calculated by multiplying the connection matrix $M_{Req-Com_i}$ between requirements Req and a commitment Com_i by the connection matrix M_{Com_i-C} between a commitment Com_i and contracts C . This connection matrix is calculated as follows:

$$M_{Req-C}^{Com_i} = M_{Req-Com_i} \times M_{Com_i-C} \quad (6)$$

Then, the connection matrix $M_{Req-C}^{Com_i}$ is multiplied by the connection matrix $M_{C-O}^{Com_i}$ between contracts C and organizations O for a commitment Com_i in order to obtain the connection matrix $M_{Req-O}^{Com_i}$ between requirements and organizations. This connection matrix is calculated in the following manner:

$$M_{Req-O}^{Com_i} = M_{Req-C}^{Com_i} \times M_{C-O}^{Com_i} \quad (7)$$

The matrix $M_{Req-O}^{Com_i}$ allows to identify which organization must evaluate each requirement for each commitment Com_i . Therefore, the Hadamard product between $M_{Req-O}^{Com_i}$ and the evaluation matrix of each requirement by organizations I_{Req-O} ensures that the evaluations are only given by the organizations participating in the contract, for each commitment Com_i . The assessment matrix $A_{Req-O}^{Com_i}$ contains the evaluations of commitments by organizations. It is calculated as follows (the operator \circ is the Hadamard product):

$$A_{Req-O}^{Com_i} = M_{Req-O}^{Com_i} \circ I_{Req-O} \quad (8)$$

Thus, the next step is to calculate the process performance between each organization O for every commitment Com_i (matrix $A_O^{Com_i}$) by multiplying the connection matrix M_{Com_i-Req} between a commitment Com_i and requirements Req by the assessment matrix $A_{Req-O}^{Com_i}$ as follows:

$$A_O^{Com_i} = M_{Com_i-Req} \times A_{Req-O}^{Com_i} \quad (9)$$

Then, the assessment matrix $A_O^{Com_i}$ is multiplied by the connection matrix $M_C^{Com_i}$ between a commitment Com_i and contracts C in order to obtain the assessment matrix ($A_{C-O}^{Com_i}$) between contracts C and organizations O for a commitment Com_i . This assessment matrix is calculated as follows:

$$A_{C-O}^{Com_i} = M_C^{Com_i} \times A_O^{Com_i} \quad (10)$$

Then, the connection matrix $M_{O-C}^{Com_i}$ between organizations O and contracts C is multiplied by the assessment matrix $A_{C-O}^{Com_i}$ in order to obtain the assessment between organizations for a commitment Com_i (matrix $A_{O-O}^{Com_i}$), as follows:

$$A_{O-O}^{Com_i} = M_{O-C}^{Com_i} \times A_{C-O}^{Com_i} \quad (11)$$

Finally, the overall performance matrix ($Perf$) is obtained by adding all the evaluation matrices $A_{O-O}^{Com_i}$ for the n commitments as follows:

$$Perf = \sum_{i=1}^n A_{O-O}^{Com_i} \quad (12)$$

An illustration of these calculations is given in the section 4.4. Once the performance ($Perf$) matrix between organizations has been calculated, the next step is to show this evaluation as relative values (denoted $Perf\%$) with regard to the best possible values. This allows the feeding of a dashboard containing the main indicators of the experience. This dashboard is explained in detail in the next subsection.

4.3.3 Experience Dashboard

According to (Eckerson, 2010), experience dashboard is a performance management tool used to display critical data proposed to the actors of the process to support decision making. In this regard, the purpose of the dashboard is to help decision making by providing collaboration and performance indicators based on the process execution.

Once the collaboration dimensions ($\{Coll_j\}$) and performance ($Perf$) matrices between organizations have been calculated, the next step is to show the indicators as relative values with regard to the best possible values. The indicators are calculated by dividing the final matrices of the process execution $Coll_j$ and $Perf$ (Figure 47 – Actual results) by the final matrices of the best possible results ($Coll_j^{max}$ and $Perf^{max}$) (Figure 47 – Best possible results) for each collaboration dimension j . The best possible results are obtained when all the evaluations given by actors (for collaboration dimension evaluation - I_{a-a}) and organizations (for performance evaluation - $I_{O-Req}^{Com_i}$) take their maximum values.

| | | COLLABORATION | | | | | | | | | PERFORMANCE | | | | | |
|-----------------------|---------------|---------------------------------------|--------------|----------------|---------------------------------------|---------------|----------------|---------------------------------------|--------------------|----------------|---------------------------|----------------|----------------|----------------|-----|----------------|
| ACTUAL RESULTS | Evaluation of | Coll₁ | | | Coll₂ | | | Coll₃ | | | Perf | | | | | |
| | | Evaluators | | | Evaluators | | | Evaluators | | | Evaluators | | | | | |
| | | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m |
| | | 25 | ... | 21 | 18 | ... | 25 | 29 | ... | 28 | 1.9 | ... | 1.8 | ... | ... | ... |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| O _m | 28 | ... | 22 | O _n | 15 | ... | 25 | O _m | 29 | ... | 32 | O _m | 1.7 | ... | 1.8 | |
| COOPERATION | | | COORDINATION | | | COMMUNICATION | | | SATISFACTION LEVEL | | | | | | | |
| BEST POSSIBLE RESULTS | Evaluation of | Coll₁^{max} | | | Coll₂^{max} | | | Coll₃^{max} | | | Perf^{max} | | | | | |
| | | Evaluators | | | Evaluators | | | Evaluators | | | Evaluators | | | | | |
| | | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m | O ₁ | ... | O _m |
| | | 30 | ... | 29 | 30 | ... | 29 | 30 | ... | 29 | 2 | ... | 2 | ... | ... | ... |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | | |
| O _m | 32 | ... | 34 | O _m | 32 | ... | 34 | O _m | 32 | ... | 34 | O _m | 2 | ... | 2 | |
| COOPERATION | | | COORDINATION | | | COMMUNICATION | | | SATISFACTION LEVEL | | | | | | | |

Figure 47 Collaboration and performance dashboard

Finally, Figure 48 shows an example of the relative dashboard for an experience of collaboration. The experience dashboard shows the evaluation of cooperation, coordination, and communication given by the actors of an organization to the actors of the other organizations with whom they interacted in the different process activities. Also, the evaluation is given for the actors of the same company (intersections O₁/O₁, O₂/O₂, and O₃/O₃).

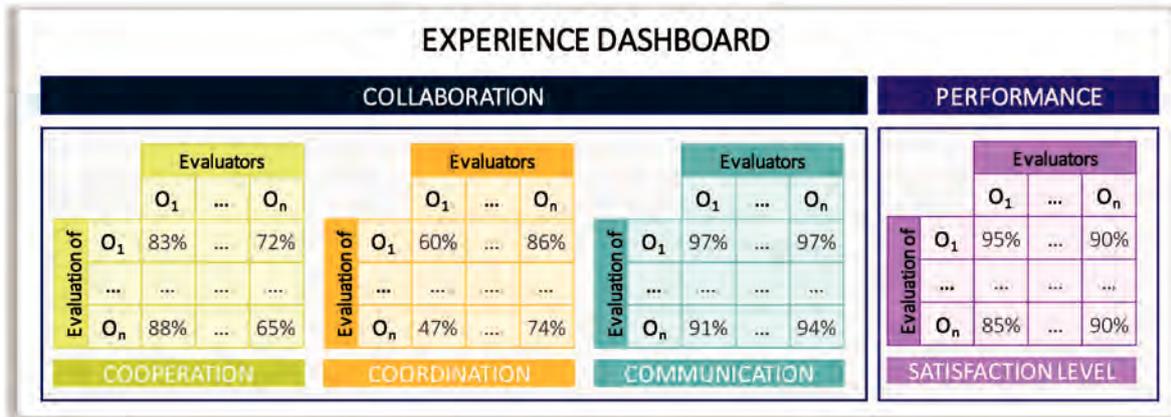


Figure 48. Experience dashboard with relative values

4.4 Illustrative example

In order to illustrate the aforementioned methodology, the illustration of collaboration and performance evaluations of chapter 3 is developed in this subsection. First, the inputs of collaboration and performance evaluation in the industrial case illustration are presented. Then, the calculation process of collaboration and performance dimensions indicators are developed. Finally, the experience dashboard for the illustration case results is presented. The process is composed of seven activities *Act*₁ to *Act*₇.

4.4.1 Experience inputs

For this industrial illustration, the process must reach two commitments: a time study of aircraft activity painting (*com*₁) and a lean improvement plan for aircraft activity painting (*com*₂), according to the experience graph presented in subsection 3.3. Requirements *r*_{1,1} and *r*_{1,2} concern *com*₁ and requirements *r*_{2,1} and *r*_{2,2} concern *com*₂. *O*₁ evaluated *com*₁ and *com*₂; the evaluation was 0.8 for *r*_{1,1} and *r*_{1,2} and 1.0 for *r*_{2,1} and *r*_{2,2}. *O*₂ evaluated *com*₁ and *com*₂; the evaluation was 1.0 for *r*_{1,1}, *r*_{1,2}, *r*_{2,1} and *r*_{2,2}. Finally, *O*₃ evaluated the requirements *r*_{2,1} and *r*_{2,2} of *com*₂, and their evaluation was 1.0 for both requirements. These inputs allows to build the matrix *I*_{Req-O} (Figure 49).

| | O ₁ | O ₂ | O ₃ |
|------------------|----------------|----------------|----------------|
| r _{1,1} | 0.8 | 1.0 | 0.0 |
| r _{1,2} | 0.8 | 1.0 | 0.0 |
| r _{2,1} | 1.0 | 1.0 | 1.0 |
| r _{2,2} | 1.0 | 1.0 | 1.0 |

$$I_{Req-O}$$

Figure 49. Evaluation of the requirements of *com*₁ (*r*_{1,1} and *r*_{1,2}) and *com*₂ (*r*_{2,1} and *r*_{2,2})

The actors who participated in this illustrative case evaluated the three collaboration dimensions (cooperation, coordination, and communication). *O*₁ and *O*₂ gave an overall evaluation for the global process. Meanwhile, actors of *O*₃ proposed a separate evaluation of the actors of *O*₂ and *O*₃. Figure 50 illustrates the proposed evaluations given by the actors for cooperation, coordination, and communication dimensions.

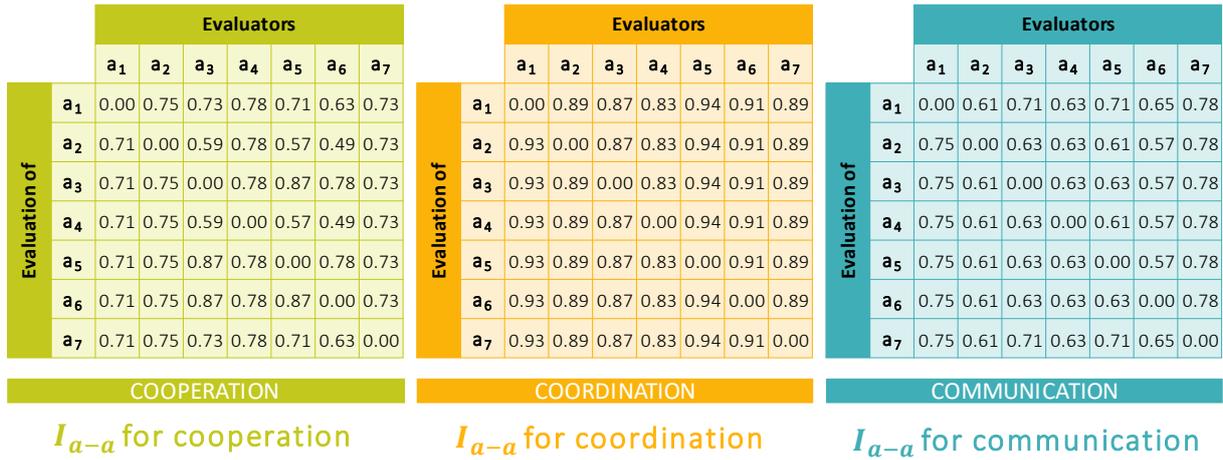


Figure 50. Evaluation experience of collaboration criteria

4.4.2 Collaboration indicators calculation

Following the approach outlined in subsection 4.2.1, the collaboration quality indicators of this illustrative case are calculated. First, the evaluation matrix of each activity between actors is calculated for each collaboration dimension ($A_{a-a}^{Act_i}$). This matrix is obtained by calculating the Hadamard product between the collaboration evaluation matrix for a specific collaboration dimension (I_{a-a}) of Figure 50 and the connectivity matrix between actors who participated in Act_1 . Figure 51 illustrates the calculation of the cooperation dimension for the activity Act_1 . This calculation is also done for the remaining six activities and for coordination and communication dimensions. However, the calculations are not represented.

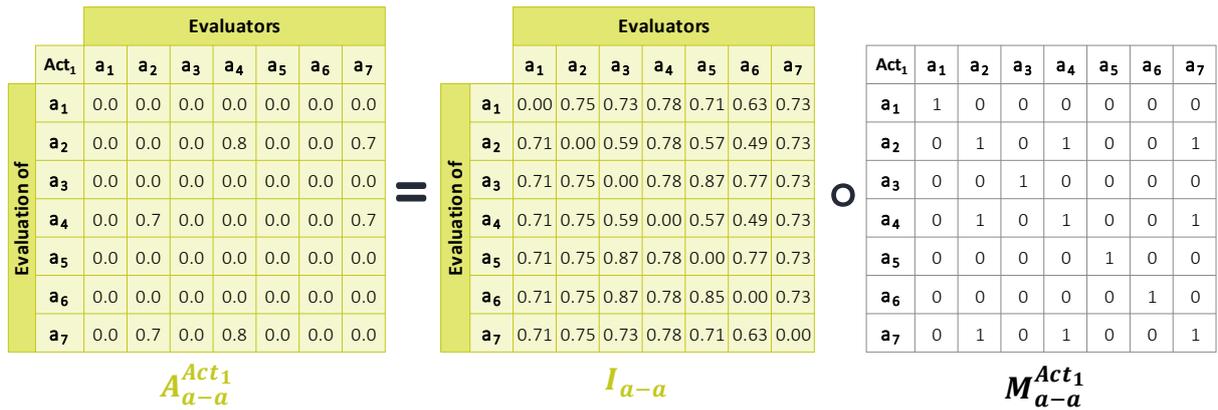


Figure 51. Cooperation calculation between actors for activity Act_1 ($A_{a-a}^{Act_1}$)

In order to show the collaboration dimension evaluation between organizations, the evaluation matrix between actors for the activity Act_1 ($A_{a-a}^{Act_1}$) is multiplied by the connection matrix between actors and organizations (M_{a-o}). The product corresponds to the collaboration evaluation matrix that the actors received from each organization for the activity Act_1 . Figure 52 illustrates the cooperation evaluation that actors received from O_1 , O_2 and O_3 for the activity Act_1 .

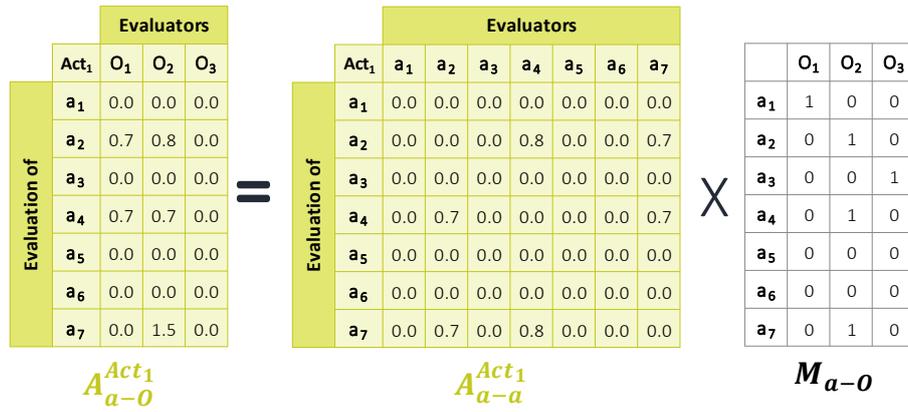


Figure 52. Cooperation calculation between organizations and actors for activity Act₁

Then, the collaboration dimension evaluation (A_{o-o}^{Act1}) between organizations for the activity Act₁ is obtained by multiplying the connection matrix between organizations and actors (M_{o-a}) by the evaluation matrix between actors and organizations (A_{a-o}^{Act1}). Figure 53 illustrates the cooperation evaluation between organizations for the activity Act₁. This is done for the remaining six activities and for coordination and communication dimensions.

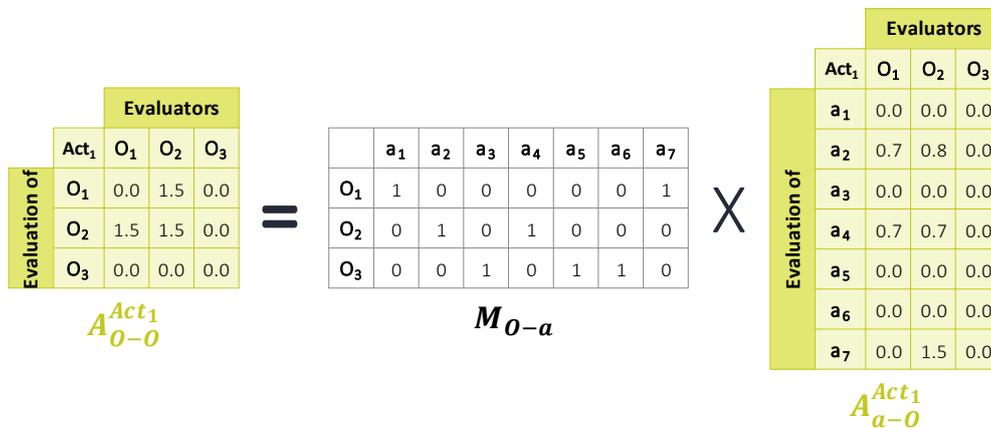


Figure 53. Cooperation calculation between organizations for the activity Act₁

Then, the cooperation calculation between organizations must be calculated for all the activities of the process. Figure 54 illustrates the cooperation results for the seven activities.

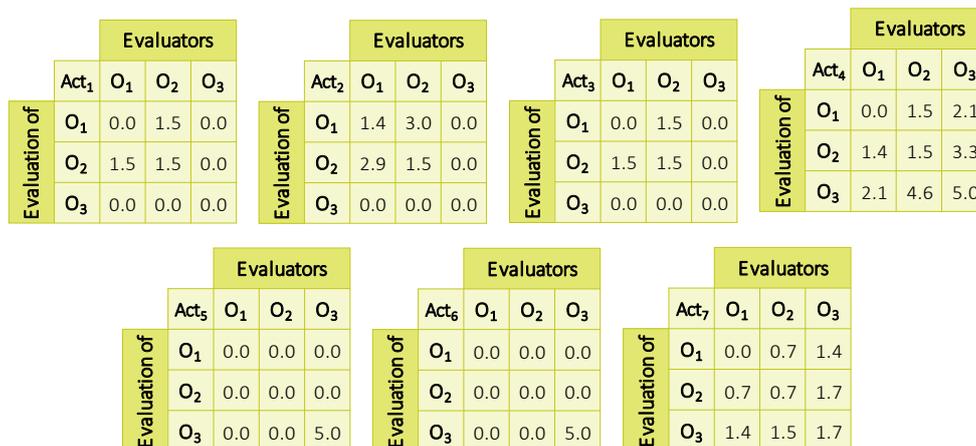


Figure 54. Cooperation calculation between organizations for the overall process

Finally, the cooperation assessment matrix between organizations of this illustration case (Figure 55) is obtained by adding the assessment matrices of the seven activities. Furthermore, the assessment matrices of coordination ($Coll_2$) and communication ($Coll_3$) dimensions between organization must be calculated. Figure 55 illustrates the collaboration assessment matrices of the illustration case of chapter 3.

| $Coll_1$ | | Evaluators | | |
|---------------|----------------|----------------|----------------|----------------|
| | | O ₁ | O ₂ | O ₃ |
| Evaluation of | O ₁ | 1.4 | 8.4 | 3.5 |
| | O ₂ | 7.9 | 6.9 | 5.1 |
| | O ₃ | 3.6 | 6.1 | 16.9 |
| COOPERATION | | | | |

| $Coll_2$ | | Evaluators | | |
|---------------|----------------|----------------|----------------|----------------|
| | | O ₁ | O ₂ | O ₃ |
| Evaluation of | O ₁ | 1.8 | 9.5 | 4.5 |
| | O ₂ | 10.0 | 7.8 | 8.1 |
| | O ₃ | 4.7 | 6.9 | 18.1 |
| COORDINATION | | | | |

| $Coll_3$ | | Evaluators | | |
|---------------|----------------|----------------|----------------|----------------|
| | | O ₁ | O ₂ | O ₃ |
| Evaluation of | O ₁ | 1.5 | 7.0 | 3.5 |
| | O ₂ | 8.4 | 5.7 | 5.4 |
| | O ₃ | 3.7 | 5.2 | 14.1 |
| COMMUNICATION | | | | |

Figure 55. Collaboration assessment matrices of the illustration case of chapter 3

4.4.3 Performance indicators calculation

Following the approach outlined in subsection 4.2.2, the performance indicator of this illustrative case is calculated. First of all, the connection matrix between requirements and organizations for each commitment must be calculated from the experience graph presented in subsection 3.3. For that, the connection matrix between requirements of com_1 is multiplied by the connection matrix between com_1 and contracts in order to obtain the connection matrix between requirements of com_1 and contracts, as shown in Figure 56.

$$\begin{matrix} \text{Com}_1 & C_1 & C_2 \\ \hline r_{1.1} & 1 & 0 \\ r_{1.2} & 1 & 0 \\ r_{2.1} & 0 & 0 \\ r_{2.2} & 0 & 0 \end{matrix} = \begin{matrix} & \text{Com}_1 \\ \hline r_{1.1} & 1 \\ r_{1.2} & 1 \\ r_{2.1} & 0 \\ r_{2.2} & 0 \end{matrix} \times \begin{matrix} & C_1 & C_2 \\ \hline \text{Com}_1 & 1 & 0 \end{matrix}$$

$M_{Req-C}^{Com_1} \qquad M_{Req-Com_1} \qquad M_{Com_1-C}$

Figure 56. Connection matrix between requirements of com_1 and contracts calculation

Then, the connection matrix between requirements of com_1 and contracts is multiplied by the connection matrix between contracts and organizations with the purpose of calculating the connection matrix between requirements and organizations as shown in Figure 57.

$$\begin{matrix} \text{Com}_1 & O_1 & O_2 & O_3 \\ \hline r_{1.1} & 1 & 1 & 0 \\ r_{1.2} & 1 & 1 & 0 \\ r_{2.1} & 0 & 0 & 0 \\ r_{2.2} & 0 & 0 & 0 \end{matrix} = \begin{matrix} \text{Com}_1 & C_1 & C_2 \\ \hline r_{1.1} & 1 & 0 \\ r_{1.2} & 1 & 0 \\ r_{2.1} & 0 & 0 \\ r_{2.2} & 0 & 0 \end{matrix} \times \begin{matrix} & O_1 & O_2 & O_3 \\ \hline C_1 & 1 & 1 & 0 \\ C_2 & 0 & 1 & 1 \end{matrix}$$

$M_{Req-O}^{Com_1} \qquad M_{Req-C}^{Com_1} \qquad M_{C-O}^{Com_1}$

Figure 57. Connection matrix between requirements of com_1 and organizations calculation

In order to calculate the performance evaluation given to the requirements by organizations, the Hadamard product between the connection matrix between requirements of com_1 and organizations and the input performance evaluation matrix is calculated as shown in Figure 58.

$$\begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline r_{1.1} & 0.8 & 1.0 & 0.0 \\ \hline r_{1.2} & 0.8 & 1.0 & 0.0 \\ \hline r_{2.1} & 0.0 & 0.0 & 0.0 \\ \hline r_{2.2} & 0.0 & 0.0 & 0.0 \\ \hline \end{array} = \begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline r_{1.1} & 1 & 1 & 0 \\ \hline r_{1.2} & 1 & 1 & 0 \\ \hline r_{2.1} & 0 & 0 & 0 \\ \hline r_{2.2} & 0 & 0 & 0 \\ \hline \end{array} \circ \begin{array}{|c|c|c|c|} \hline & O_1 & O_2 & O_3 \\ \hline r_{1.1} & 0.8 & 1.0 & 0.0 \\ \hline r_{1.2} & 0.8 & 1.0 & 0.0 \\ \hline r_{2.1} & 1.0 & 1.0 & 1.0 \\ \hline r_{2.2} & 1.0 & 1.0 & 1.0 \\ \hline \end{array}$$

$A_{Req-O}^{Com_1}$ $M_{Req-O}^{Com_1}$ I_{Req-O}

Figure 58. Performance matrix between requirements of com_1 and organizations calculation

The next step is to multiply the connection matrix between com_1 and requirements, by the input performance matrix given by organizations evaluation of requirements, in order to calculate the overall evaluation that each organization gives to com_1 , as shown in Figure 59.

$$\begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline Com_1 & 1.6 & 2.0 & 0 \\ \hline \end{array} = \begin{array}{|c|c|c|c|c|} \hline & r_{1.1} & r_{1.2} & r_{2.1} & r_{2.2} \\ \hline Com_1 & 1.0 & 1.0 & 0.0 & 0.0 \\ \hline \end{array} \times \begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline r_{1.1} & 0.8 & 1.0 & 0.0 \\ \hline r_{1.2} & 0.8 & 1.0 & 0.0 \\ \hline r_{2.1} & 0.0 & 0.0 & 0.0 \\ \hline r_{2.2} & 0.0 & 0.0 & 0.0 \\ \hline \end{array}$$

$A_O^{Com_1}$ M_{Com_1-Req} $A_{Req-O}^{Com_1}$

Figure 59. Performance matrix between com_1 and organizations calculation

Then, the connection matrix between contracts and com_1 is multiplied by the performance assessment matrix com_1 of organizations to obtain the performance assessment matrix of contracts concerning the com_1 , as shown in Figure 60.

$$\begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline C_1 & 1.6 & 2.0 & 0.0 \\ \hline C_2 & 0.0 & 0.0 & 0.0 \\ \hline \end{array} = \begin{array}{|c|c|} \hline & Com_1 \\ \hline C_1 & 1 \\ \hline C_2 & 0 \\ \hline \end{array} \times \begin{array}{|c|c|c|c|} \hline Com_1 & O_1 & O_2 & O_3 \\ \hline Com_1 & 1.6 & 2.0 & 0 \\ \hline \end{array}$$

$A_{C-O}^{Com_1}$ $M_C^{Com_1}$ $A_O^{Com_1}$

Figure 60. Performance matrix between contracts and organizations calculation for com_1

Finally, the performance assessment matrix for com_1 is obtained by multiplying the connection matrix between organizations and contracts by the performance assessment matrix between contracts and organization of com_1 as shown in Figure 61.

$$\begin{array}{|c|c|c|c|} \hline \text{Com}_1 & \text{O}_1 & \text{O}_2 & \text{O}_3 \\ \hline \text{O}_1 & 1.6 & 2.0 & 0.0 \\ \hline \text{O}_2 & 1.6 & 2.0 & 0.0 \\ \hline \text{O}_3 & 0.0 & 0.0 & 0.0 \\ \hline \end{array} = \begin{array}{|c|c|c|} \hline \text{Com}_1 & \text{C}_1 & \text{C}_2 \\ \hline \text{O}_1 & 1 & 0 \\ \hline \text{O}_2 & 1 & 1 \\ \hline \text{O}_3 & 0 & 1 \\ \hline \end{array} \times \begin{array}{|c|c|c|c|} \hline \text{Com}_1 & \text{O}_1 & \text{O}_2 & \text{O}_3 \\ \hline \text{C}_1 & 1.6 & 2.0 & 0.0 \\ \hline \text{C}_2 & 0.0 & 0.0 & 0.0 \\ \hline \end{array}$$

$A_{O-O}^{Com_1}$ $M_{O-C}^{Com_1}$ $A_{C-O}^{Com_1}$

Figure 61. Performance matrix between organizations calculation for com₁

The calculations aforementioned are also done for com₂ but they are not represented. It leads to the matrix of $A_{O-O}^{Com_2}$ of Figure 62 which illustrates the performance assessment matrix between organizations for com₂.

| Com ₂ | O ₁ | O ₂ | O ₃ |
|------------------|----------------|----------------|----------------|
| O ₁ | 2.0 | 3.6 | 2 |
| O ₂ | 4.0 | 7.2 | 4 |
| O ₃ | 2 | 3.6 | 2 |

$A_{O-O}^{Com_2}$

Figure 62. Performance matrix between organizations for com₁

Finally, the performance assessment matrix between organizations of this illustration case (Figure 63) is obtained by adding the assessment matrices of the two commitments com₁ and com₂.

$Perf =$

| <i>Perf</i> | | Evaluators | | |
|---------------|----------------|----------------|----------------|----------------|
| | | O ₁ | O ₂ | O ₃ |
| Evaluation of | O ₁ | 3.6 | 5.6 | 2.0 |
| | O ₂ | 5.6 | 9.2 | 4.0 |
| | O ₃ | 2.0 | 3.6 | 2.0 |

Figure 63. Performance assessment matrix between organizations of the illustration case of chapter 3

4.4.4 Experience evaluation

Following the approach outlined in subsection 0, the calculation of the experience dashboard is carried out. Figure 64 illustrates the actual results of the experience. The best possible results are obtained when all the evaluations given by actors and enterprises take their maximum possible value (1.0). The actual result and the best possible result are the experience dashboard inputs. The indicators are calculated by dividing the final matrices of the process execution ($\{Coll_j\}$ and $Perf$) by the final matrices of the best possible results ($\{Coll_j^{max}\}$ and $Perf^{max}$) for each collaboration dimension and performance.

employed by O_3 are 84% about themselves, 70% with regards to the actors of O_1 and 56% with regards to the actors of O_2 . The experience dashboard shows that the appreciations of the O_1 and O_2 actors related to cooperation are relatively homogeneous, ranging from 71% to 76%. However, O_3 actors' perceptions of O_2 actors were 14% lower (56%) than O_3 actors' perceptions of O_2 actors (70%). This implies that the O_3 actors felt that the cooperation was better with the O_1 actors than with the O_2 actors. The interpretation is the same for coordination and communication results. Therefore, it can be concluded that communication was the weakest dimension in the present illustrative case. In this regard, this allows us to identify the weak points in order to define possible action plans for continuous improvement in future executions of the process.

The performance of the process in this industrial case was calculated through the enterprises' satisfaction for each requirement. This evaluation is measured on a scale from 0% to 100% of requirements, with a score of 100% representing total customer satisfaction, as stated in section 4.2.2. In this experience, the performance evaluation that O_1 gave itself is 90%, giving O_2 an score of 93% and a score of 100% to O_3 . The performance evaluation that O_2 gave itself is 92%, evaluating O_1 with 93% and O_3 with 90%. The performance evaluation that O_3 gave itself is 100%, giving an evaluation of 100% to O_1 and also giving a 100% score to O_3 .

Finally, the planned experience, the actual experience, collaboration and performance indicators between organizations are stored in the Experience Base for its future reuse. Moreover, the analysis of many experiences allows to observe the variations of the indicators values over time. It is also important in order to evaluate the stability and the maturity of the different organizations (see chapter 6).

4.5 Conclusion

In this chapter, a collaboration evaluation methodology for experience capitalization has been defined in order to analyze the collaboration and the performance throughout an industrial process. The main inputs of the evaluation of collaboration and performance were introduced (Figure 66). The collaboration evaluation is done by the actors who participated in the industrial process. In this regard, the formalization of a survey that allows measuring the main characteristics of each collaboration dimension (communication, cooperation, and communication) in an industrial process has been performed. These three questionnaires enable actors to express their feelings about collaboration using clear and unambiguous questions. The performance evaluation is done by the organizations that are involved in the industrial process. It includes the evaluation of requirements in order to calculate the process performance. Afterwards, a methodology to calculate the collaboration and performance indicators between organizations has been developed.

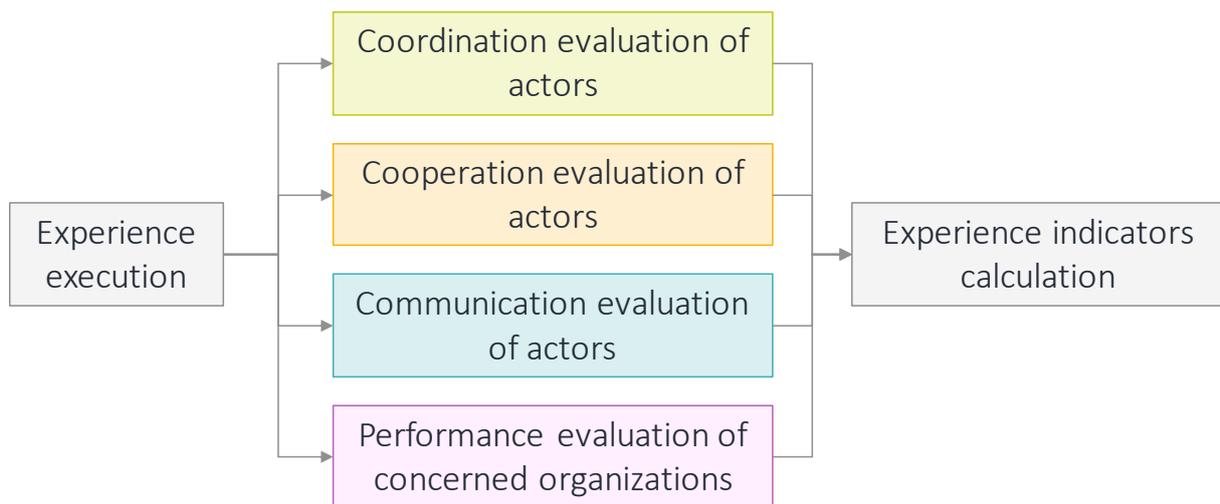


Figure 66. Process of experience indicators calculation

Finally, an experience dashboard is proposed in order to formalize the experience results. The dashboard indicators are capitalized in the Experience Base for later reuse. Nevertheless, it is necessary to define the methods that will allow to exploit the past experiences. These methods will be developed in chapter 5. Finally, an illustration of a consulting process based on a mission performed by the company Axsens-bte was presented to illustrate and explain the concepts and the methodology to build the information model for collaboration. This illustration was previously characterized in section 3.3.

5. EXPERIENCE MANAGEMENT APPROACH FOR COLLABORATION EXPERIENCE

5.1 Introduction

The structure of a collaboration experience described in chapters 3 and 4 is based on four elements of representation: the planned process, the actual process, the collaboration indicators and the performance indicators. Every collaboration experience is built by using these elements and stored as an experience in the Experience Base.

Figure 66 illustrates the overall approach to capitalize collaboration experiences relating to a process execution. The elements of the collaboration model and the taxonomy stored in the knowledge base allow to build a planned experience model of the industrial process. Then, additional elements can be gradually added as the process progresses in order to build the actual experience. The experience is updated during the different activities of the process and the calculation of the collaboration and performance indicators is done and stored in the Experience Base when the process ends.

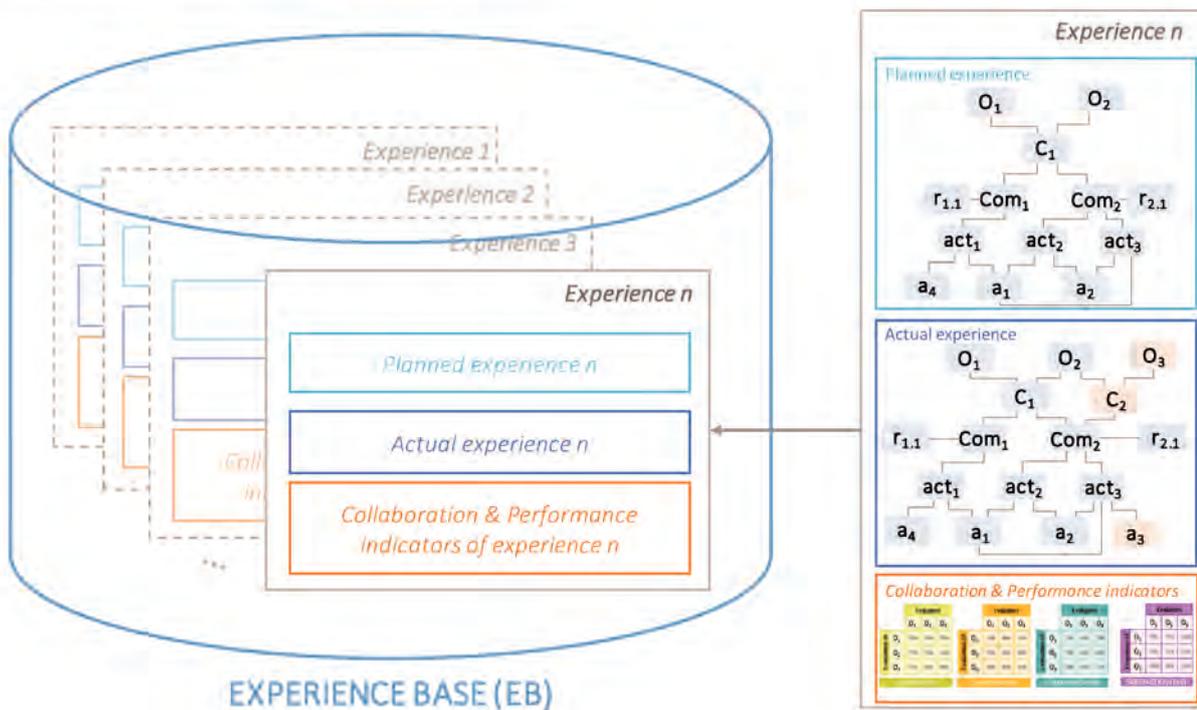


Figure 67. Global approach of experiences capitalization

The objective of the experience base is to provide relevant information in order to support the decision making in new similar processes.

In this section, we present an experience feedback approach which allows to reuse past experiences of industrial processes realizations. The main objective of this approach is to support the identification and the selection of potential organizations and/or actors for a new process to perform. It is inspired by the case-based reasoning (CBR) cycle (Aamodt and Plaza, 1994; Kolodner, 1993). Figure 68 represents the experience feedback process developed to support our approach.

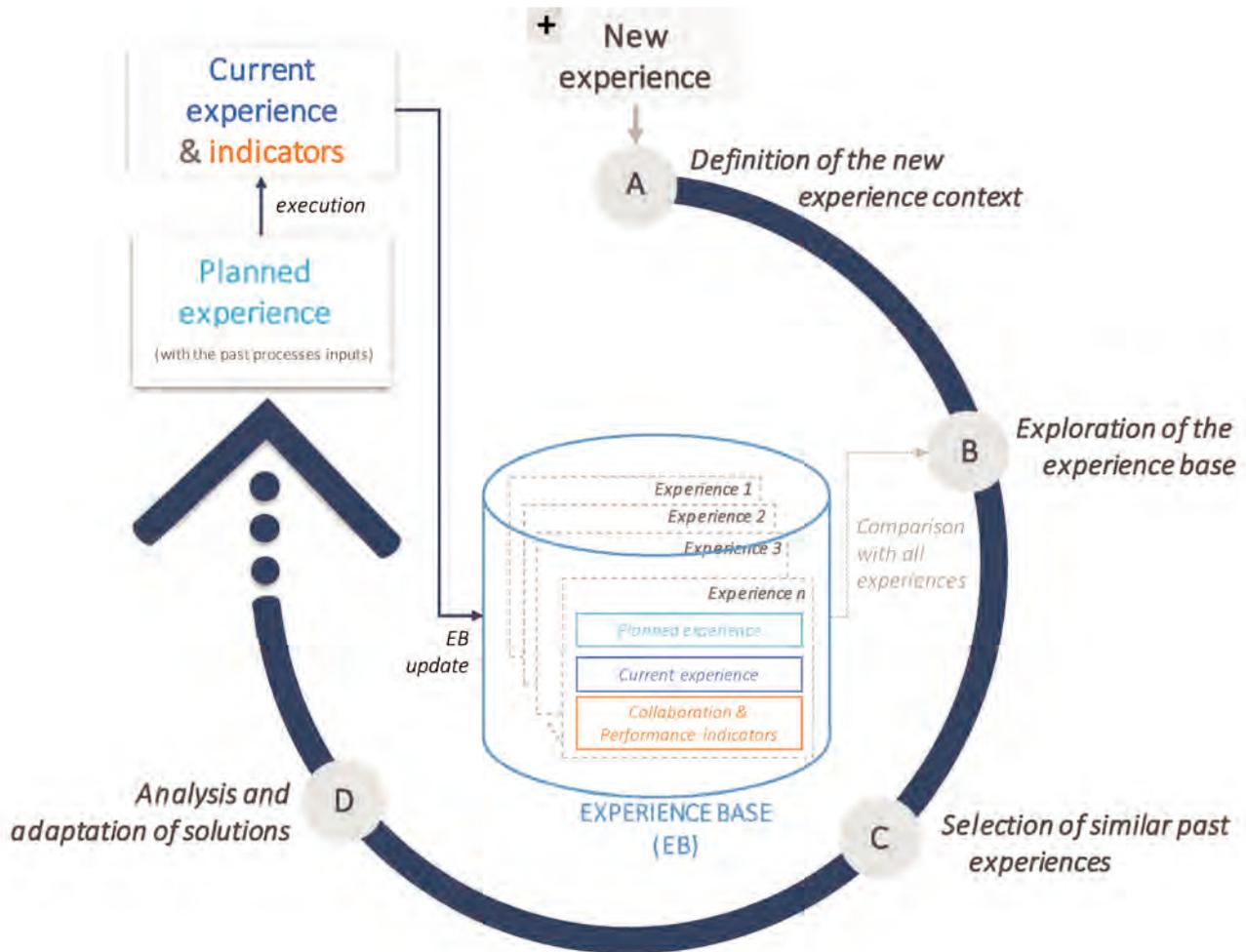


Figure 68. Global approach for the experience reuse

The four main steps of the proposed experience feedback approach are as follows:

- A. **Definition of the new experience context:** in this step, the context of the new process is defined using the formalization proposed in chapter 3.
- B. **Exploration of the experience base:** in this step, collaboration experiences which are similar to the new process are identified. A dedicated search algorithm is proposed for the exploration of the experience base.
- C. **Selection of similar past experiences:** in this step, the selection of experiences is done. This selection is based on three criteria: (i) the similarity measure between the new process and the past experience, (ii) the collaboration indicators and (iii) the performance indicators.
- D. **Analysis and adaptation of solutions:** this step allows to analyze and adapt the selected experiences in order to build a solution for the new process.

These four the steps are presented in the following sections.

5.2 Definition of the new experience context

The objective of the first step is to describe and to characterize the new process which has to be carried out. This characterization aims to define the elements of the new experience context that are known a priori. These characterized elements will be used to perform the experience filtering (section 4.3). This step is performed by the expert who is in charge of the new process. In this regard, the collaboration model and the taxonomy described in chapter 3 are used in order to create a new instance of the collaboration model as shown in Figure 69. This instance will be the base of the new planned experience. We propose that the expert defines the description of the commitments as initial input elements that the process must reach. This is a scenario we have considered, however, other scenarios with other elements of the collaboration model can be considered.

The expert must define the greatest number of elements required from the context of the new experience as well as its characteristics. The elements that can be defined are organizations, contracts, commitments, requirements, activities and actors as well as their interactions. Furthermore, their attributes must be characterized and some of these attributes are derived from the taxonomy (type of organization, type of activity, type of interaction, type of contract, type of commitment, department and role).

Figure 69 illustrates an example of an instance in which the expert defines one fixed price contract and two commitments: a software maintenance and an accounting program. If the expert had more information, he could complete the instance with the requirements of each commitment and the activities of the process.

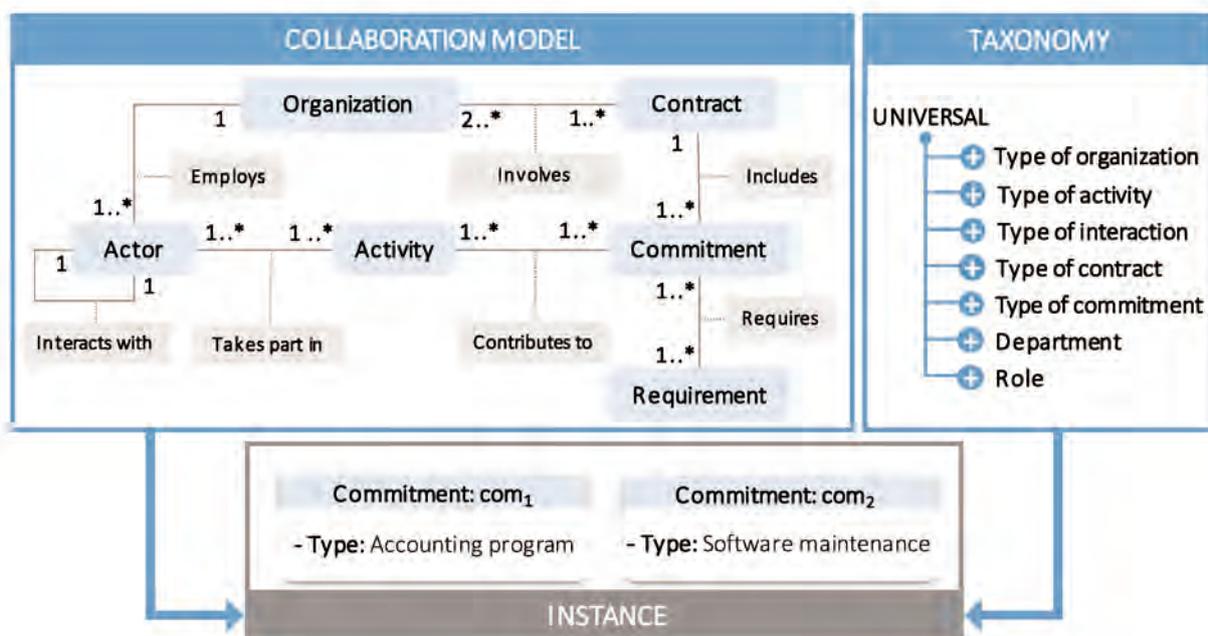


Figure 69. Instance example

5.3 Exploration of the Experience Base

The objective of this step is to search past experiences which are similar to the new one. For that, the similarity of the new experience with each experience stored in the EB is calculated. In this regard, the similarity measure between two concepts is first presented. Then, an algorithm is proposed in order to calculate the similarity between two experiences.

5.3.1 Similarity measure between two concepts

The identification of relevant past experiences in the Experience Base is based on a similarity measurement approach between the new experience and past experiences. A similarity measure is used to assess the degree of similarity between two objects in the same domain (Bergmann, 2002).

As stated in chapter 2, the collaboration between organizations aims to achieve one or more commitments. For this reason, the element of the collaboration model that will be used to carry out the similarity measurement approach between experiences is the element "commitment". In this regard, the similarity between the set of commitments of the new experience and the set of commitments of each experience stored in the EB needs to be evaluated. The commitments are tagged by means of concepts which come from the taxonomy. Therefore, this section describes the calculation of the similarity measure between two concepts which later will allow us to calculate a global similarity between the concepts of two experiences (see section 5.3.2).

According to (Jabrouni et al., 2011), the semantic similarity measure between two concepts can be done if the two concepts belong to the same taxonomy. For the purpose of this research, a method inspired by the Wu and Palmer proposal (Wu and Palmer, 1994) is used due to its simplicity and performance. This adaptation of the Wu and Palmer similarity measure is based on the concepts depth and it is calculated as:

$$sim_{wp}(c_1, c_2) = \frac{2 * depth(c_{ca})}{depth(c_1) + depth(c_2)} \quad (12)$$

The following notions are used: $depth(c_i)$ is the number of arcs on the path from the root concept of the taxonomy to c_i and c_{ca} is the first common ancestor of c_1 and c_2 in the taxonomy. The lower the distance between two concepts, the higher their similarity is as shown in [Figure 70](#).

We used a method inspired by the Wu and Palmer proposal because we count arcs (not nodes) which allows to have zero similarity when two concepts do not belong to the same first level class (otherwise, with a classic Wu and Palmer measure, the similarity is never zero). This method seems equivalent to give zero as similarity if the two concepts are from two different first level classes and to apply a Wu and Palmer similarity computation from the common first level class (which would serve as the root) if both concepts belong to the same first level class.

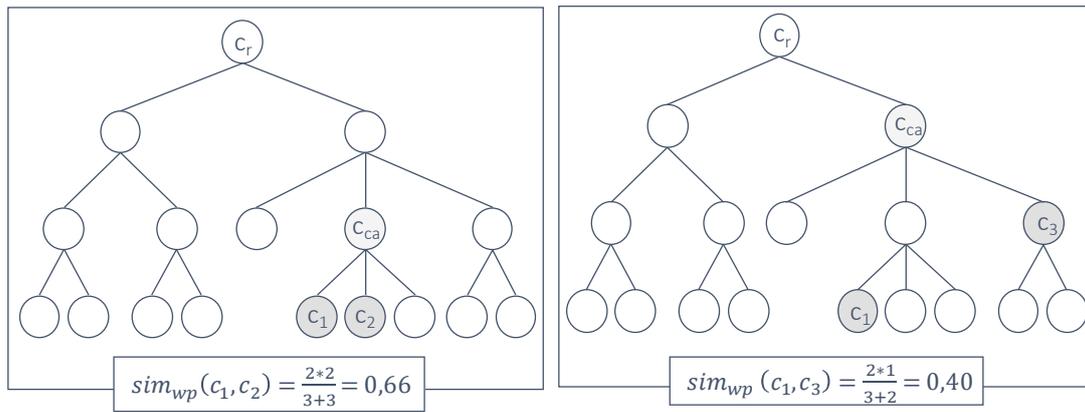


Figure 70. Similarity measure calculation of two different pairs of concepts

An algorithm is developed in the next section in order to calculate the similarity between two experiences (the new experience and a past one). First, a function which allows the calculation of the similarity measure inspired by the Wu and Palmer similarity measure (Figure 71) between two concepts is developed as follows:

```
# Compute adapted Wu & Palmer similarity between two nodes
def sim_wu_palmer(root,node1,node2):
    # Find first common ancestor of nodes node1 and node2
    common_anc=commonancestor(node1,node2)
    # Compute distance between the 1st common ancestor and the root node
    n=length(common_anc,root)
    # Compute distance between node1 and the root node
    n1=length(node1,root)
    # Compute distance between node2 and the root node
    n2=length(node2,root)
    # Return the value of the adapted Wu & Palmer similarity
    return 2*n/(n1+n2)
```

Figure 71. Similarity measure function between two concepts

Once the similarity function between two concepts is defined, the next step is to calculate the similarity measure between the new experience and past experiences stored in the EB according to the number of commitments of each one.

5.3.2 Similarity measure between the new experience and past experiences stored in the EB

At this step, the definition of the commitments of the new experience and their type (i.e. the associated concepts) are done. For the case where the new experience and the past experiences stored in the Experience Base have more than one commitment, a combinatorial problem arises. In the example of Figure 72, the new experience has two commitments (com₁ and com₂) and the past experience three commitments (com₁, com₂ et com₃). Then, six similarity calculations must be done and the maximum of the six similarity measures obtained will be considered as the result (best match).



Figure 72. Calculation example of the similarity level between two experiences

Based on the different comparisons between two commitments, the calculation of the similarity between both experiences (Similarity (NE–E_n)) has to be done. The different combinations of commitments have to be taken into account. For instance, in Figure 73 when the similarity of the couple (com'1, com1) has been calculated, two other couples of commitments have to be taken into account: (com'2, com2) and (com'2, com3). Taking into account a second couple (com'1, com2), the two couples (com'2, com1) and (com'2, com3) has to be evaluated. Third, starting from the couple (com'1, com3) the couples (com'2, com1) and (com'2, com2) have to be evaluated.

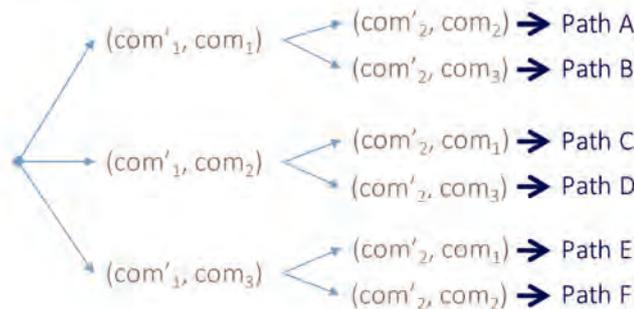


Figure 73. Combinations of commitments to calculate the similarity between NE and E_n

Each path of the graph of the Figure 73 has to be evaluated in order to compute the similarity. The similarity of one path is obtained by the aggregation of the similarity measure of the couples of the path divided by the number of couples of the path (i.e. the path A similarity measure is obtained by the aggregation of similarity measures of (com'1, com1) and (com'2, com2) divided by two). The six path are the followings:

| PATH | COUPLES OF COMMITMENTS | AVERAGE |
|--|-------------------------------|---------|
| A | (com'1, com1) → (com'2, com2) | 0,85 |
| B | (com'1, com1) → (com'2, com3) | 0,75 |
| C | (com'1, com2) → (com'2, com1) | 0,75 |
| D | (com'1, com2) → (com'2, com3) | 0,85 |
| E | (com'1, com3) → (com'2, com1) | 0,95 |
| F | (com'1, com3) → (com'2, com2) | 0,75 |
| Similarity (NE–E _n)= Max {A, B, C, D,E, F} | | 0,95 |

Table 6. Similarity between experience E_n and new experience

Finally, the similarity between both experiences is obtained by applying the maximum operator to the similarities obtained by combining the different commitments as shown in Table 6. In this regard, an algorithm which allows the calculation of the similarity measure between two experiences is developed as follows (Figure 74):

```
# Recursive similarity computation
# t1 : list of commitments of new experience
# t2 : list of commitments of an experience stored in EB
# s : current similarity;
#     s is equal to 0 initially
#     s is equal to the final similarity when the recursivity stop condition is reached
# l : current list of pairs of compared commitments;
#     l is equal to [] (empty list) initially
#     l is equal to the list of pairs corresponding to the final similarity
#     when the recursivity stop condition is reached
# nb : number of commitments in the new experience; used to compute average value of similarity
#     when the recursivity stop condition is reached
def simrec(t1,t2,s,l, nb) :
    # recursive stop condition: if one of the lists t1 or t2 is empty
    if (not t1 or not t2) and len(l)==nb:
        # Add the result to the list L of all results
        L.append((l,s/nb))
    else:
        # Select an element in t1 (a) and an element in t2 (b)
        for a in t1:
            for b in t2:
                # Consider only elements after value a in the list t1 (to avoid useless computing)
                tp1=remove_before(a,t1)
                # Consider all the elements of the list t2 except b
                tp2=remove(b,t2)
                # Add couple (a,b) to the list of visited pairs of commitments
                lp=l+[(a,b)]
                # Add similarity between a and b to the current global similarity
                sp=s+simwp(univ,a,b)
                # Recursive call
                simrec(tp1,tp2,sp, lp ,nb)
```

Figure 74. Algorithm 1 to calculate similarity between two experiences

The main principle of the algorithm 1 (Figure 74) is to compute the similarities of the different couples of commitments and avoiding to calculate many times a same similarity.

Once all the similarity measures have been calculated for all the possible combinations between the commitments of the new experience and a past experience of the EB, the similarity measure between the new experience and the experience n is the maximum similarity measure of the possible combinations. The algorithm 2 (Figure 75) allows to calculate the similarity measures between all the experiences stored in the EB and the new experience.

```

# Computation of the similarity between new experience and the experiences of the EB
# newExp is the list of new experience commitments
# Lsexp is a dictionary linking experience id and its similarity with current experience
Lsexp={}
# For all the couples (exp,lexp) of the experience base
# exp=name of experience, lexp=list of commitments of experience exp
for (exp,lexp) in EB:
    # The global list of results in empty at first
    L=[]
    # minlen is the smallest length between list newExp and list lexp
    minlen= min(len(newExp),len(lexp))
    # Call the recursive similarity computation
    simrec(newExp,lexp,0,[], minlen)
    # Compute the maximum similarity of all tested pairings
    # The maximum is 0 by default
    maxi=0
    # For all couples (pairing, associated similarity)
    for (pairing,sime) in L:
        # If current similarity is higher than current maximum
        if sime>maxi:
            # then it becomes the new maximum
            maxi=sime
        # Store the result in the dictionary
        Lsexp[exp]=maxi
print("Similarities before filtering",Lsexp)

```

Figure 75. Algorithm 2 to calculate similarity between new experience and every past experiences

Figure 76 illustrates an example of algorithm 2 outputs

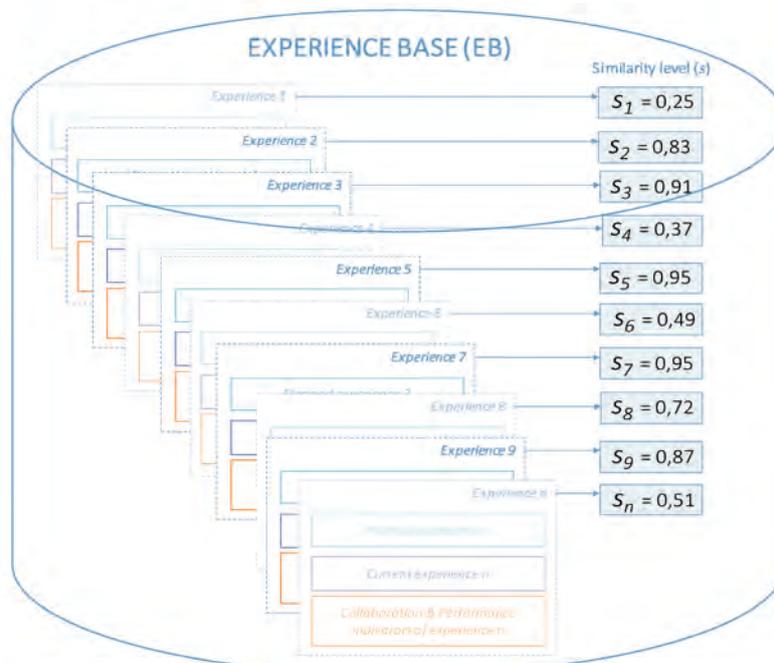


Figure 76. Illustration of similarity measures between a new experience and the experiences stored in the EB

5.4 Selection of similar past experiences

At this stage, it is necessary to define a threshold of similarity (α) in order to filter all past experiences that are sufficiently similar to the new experience based on the similarity measures between commitments. In Figure 77, the past experiences with a similarity measure greater than 0.8 (α) are assessed as sufficiently similar to the new process. The similarities of experiences E_1 , E_4 , E_6 , E_8 , E_4 and E_{10} do not satisfy the threshold of 0.8 therefore, they are discarded.

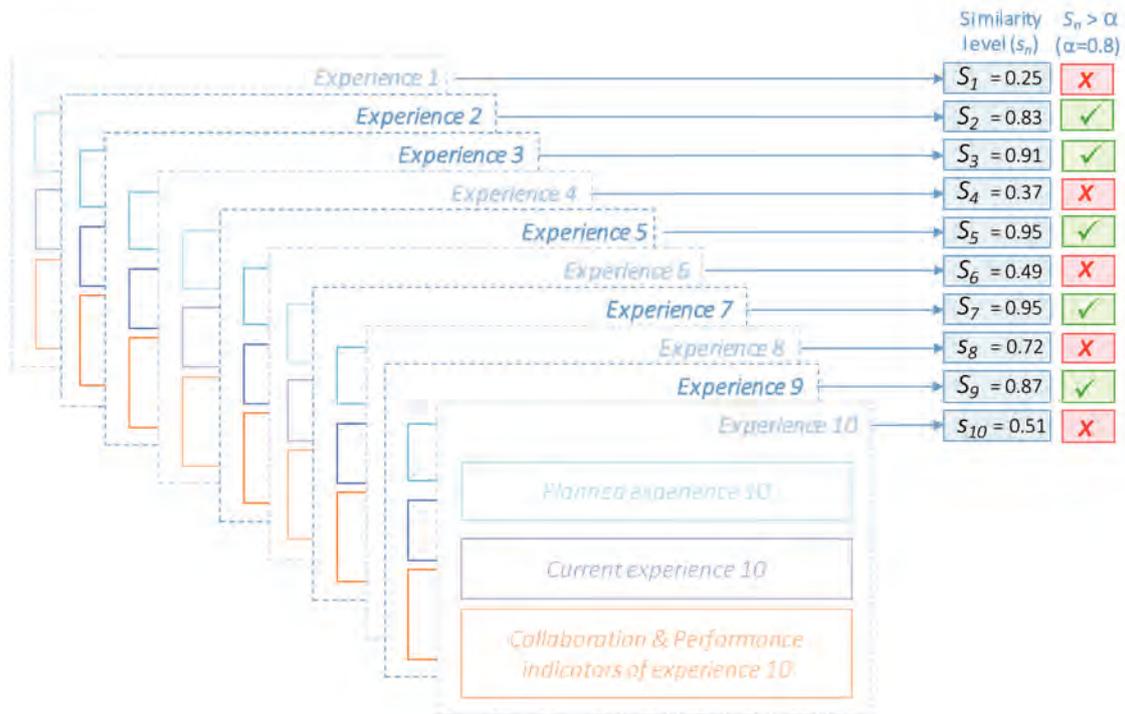


Figure 77. Illustration of similar projects selection from a degree of similarity α

An algorithm which allows to filter the past experiences with a level of similarity greater than α is developed as follows (Figure 78):

```
# Filtering of the experiences based on the similarity
Lsexp2={}
# For all experiences
for (e,c) in EB:
    # If the maximum of similarity for all pairings is more than the threshold alpha
    if Lsexp[e] >= alpha:
        Lsexp2[e]= Lsexp[e]
print("Similarities after filtering",Lsexp2)
```

Figure 78. Algorithm 3 to filter the past experiences according to a threshold of similarity (α)

Once the past experiences are selected, the expert can use them for three purposes: (i) the reuse or adaptation of past experiences for the new experience (ii) the identification of key actors and (iii) the identification of organizations which participated in the similar past experiences.

If the expert wants to identify the best organizations which participated in the similar past experiences, a new filter based on the collaboration and performance indicators of organizations is proposed. Figure 79 illustrates the calculation of indicator “Coll” using the operator GOWA described in section 4.3.1 for the three collaboration dimension indicators (coordination, cooperation and communication) and for $\lambda=1$ (Average).

| E_j | S_i | O_i | Coordination | Cooperation | Communication | GOWA Coll ($\lambda = 1$) | Perf |
|-------|-------|----------|--------------|-------------|---------------|--------------------------------|------|
| E_2 | 0.8 | O_1 | 1.00 | 1.00 | 0.99 | 1.00 | 0.90 |
| | | O_3 | 0.50 | 0.95 | 0.98 | 0.81 | 0.97 |
| | | O_4 | 0.85 | 0.75 | 0.43 | 0.68 | 0.29 |
| | | O_6 | 0.12 | 0.02 | 0.15 | 0.10 | 0.45 |
| E_3 | 0.9 | O_2 | 0.17 | 0.16 | 0.15 | 0.16 | 0.93 |
| | | O_5 | 0.00 | 0.11 | 0.05 | 0.05 | 0.07 |
| | | O_8 | 0.35 | 0.44 | 0.50 | 0.43 | 0.30 |
| | | O_6 | 0.49 | 0.12 | 0.60 | 0.40 | 0.49 |
| E_5 | 1 | O_7 | 0.68 | 0.40 | 0.62 | 0.57 | 0.98 |
| | | O_9 | 0.95 | 0.83 | 0.70 | 0.83 | 0.84 |
| | | O_2 | 0.17 | 0.14 | 0.20 | 0.17 | 0.90 |
| | | O_3 | 0.70 | 0.98 | 0.99 | 0.89 | 0.98 |
| E_7 | 1 | O_{10} | 0.38 | 0.29 | 0.30 | 0.32 | 0.63 |
| | | O_1 | 0.95 | 0.89 | 0.91 | 0.92 | 0.80 |
| | | O_4 | 0.86 | 0.80 | 0.16 | 0.61 | 0.10 |
| | | O_5 | 0.16 | 0.09 | 0.10 | 0.12 | 0.04 |
| | | O_6 | 0.55 | 0.12 | 0.17 | 0.28 | 0.30 |
| E_9 | 1 | O_7 | 0.63 | 0.74 | 0.41 | 0.59 | 0.94 |
| | | O_8 | 0.72 | 0.86 | 0.71 | 0.76 | 0.65 |
| | | O_9 | 0.83 | 0.90 | 0.79 | 0.84 | 0.90 |
| | | O_{10} | 0.50 | 0.15 | 0.82 | 0.49 | 0.79 |
| | | O_3 | 0.90 | 0.90 | 0.89 | 0.90 | 0.97 |

Figure 79. Illustration of indicators (collaboration and performance) of each organization for each experience

Once the “Coll” indicator has been calculated for the organizations that participated in each one of the similar past experiences, global Collaboration and Performance indicators have to be calculated for these organizations. The global indicator for an organization is the average of its Collaboration indicators in similar past experiences weighted by the similarity measure of the similar past experiences that have been selected. For example, for organization O_2 the global Collaboration indicator ($Coll_{O_2} = 0.17$) and the global Performance indicator ($Perf_{O_2} = 0.91$) are calculated as follows (equation 14):

$$Coll_{O_2} = ((0.16 \times 0.9) + (0.17 \times 1.0)) / 1.9 = 0.17$$

14

$$Perf_{O_2} = ((0.93 \times 0.9) + (0.90 \times 1.0)) / 1.9 = 0.91$$

An algorithm that allows the calculation of “Coll” and “Perf” indicators has been developed in the following manner (Figure 80):

```

# Compute the list Lorg of all organizations present in the list of experiences
Lorg=[] # Lorg is empty at first
seen = set()

for (exp, orga, perf, comm) in Lperf: # For all
    if exp in Lsexp.keys() and orga not in seen:
        seen.add(orga)
        Lorg.append(orga)
# Compute the performance and collaboration indicators for the whole set of experience, weighted
by similarity
# Lorg is a list of organizations involved in experiences of the EB
print("Results")
for org in Lorg:
    # For all organization present in the experience base
    sim,perfo,collab=0,0,0
    cpt=0
    for (exp, orga, perf, coll) in Lperf:
        # For all experiences where the organization is present
        if exp in Lsexp2.keys() and org==orga:
            # Compute the total number of relevant experiences (to normalize the results)
            cpt=cpt+1
            # Compute the total performance value
            perfo=perfo+perf*Lsexp2[exp]
            # Compute the total collaboration value
            collab=collab+coll*Lsexp2[exp]
    if cpt != 0:
        # Print the normalized results
print(org,"performance:", '{:.2f}'.format(perfo/cpt), "collaboration:", '{:.2f}'.format(collab/cpt))

```

Figure 80. Algorithm 4 to calculate the global indicators

Table 7 illustrates an example of algorithm 4 outputs.

| O _i | Coll | Perf |
|-----------------|------|------|
| O ₁ | 0.95 | 0.85 |
| O ₂ | 0.17 | 0.91 |
| O ₃ | 0.87 | 0.97 |
| O ₄ | 0.64 | 0.19 |
| O ₅ | 0.09 | 0.05 |
| O ₆ | 0.27 | 0.41 |
| O ₇ | 0.58 | 0.96 |
| O ₈ | 0.60 | 0.48 |
| O ₉ | 0.83 | 0.87 |
| O ₁₀ | 0.41 | 0.71 |

Table 7. Illustrates an example of Algorithm 4 outputs

Once the calculation of the global indicators for each organization is done, the next step is to analyze this information in order to help the decision-making process. The aim is to help to choose the organizations which will participate to the new collaboration experience using the

experience feedback. The two global indicators “Coll” and “Perf” obtained by each organization are used to identify the best ones. The next section describes the method developed to help the decision making.

5.5 Analysis and adaptation of solutions

In order to facilitate the decision-making process, a dashboard with the indicators of each organization identified in section 5.4 is proposed as shown in Figure 81. The horizontal axis of the dashboard is the value of 1 minus the global collaboration value of organizations (1-Coll). The vertical axis of the dashboard is the value of 1 minus the global performance value of organizations (1-Perf).

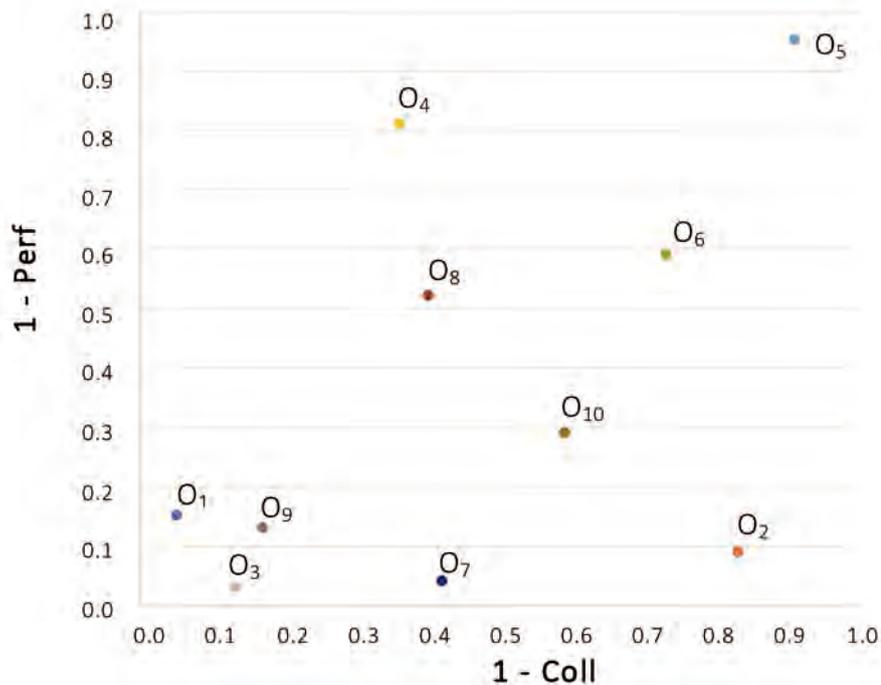


Figure 81. Dashboard with the organizations

In order to choose the best organizations, the Pareto dominance principle is applied: an organization is dominated by another one if the two indicators (1-Coll) and (1-Perf) are better or equal. O_i dominates O_j if $(1-Coll_{O_i}) \leq (1-Coll_{O_j})$ AND $(1-Perf_{O_i}) \leq (1-Perf_{O_j})$ and if there is at least one indicator which is strictly better. This principle is given by the equation 14:

$$\begin{aligned}
 & (1 - Coll_i) < (1 - Coll_j) \text{ AND } (1 - Perf_i) < (1 - Perf_j) \\
 \text{OR } & (1 - Coll_i) = (1 - Coll_j) \text{ AND } (1 - Perf_i) < (1 - Perf_j) \\
 \text{OR } & (1 - Coll_i) < (1 - Coll_j) \text{ AND } (1 - Perf_i) = (1 - Perf_j)
 \end{aligned} \tag{15}$$

In the example of Figure 81, only the organizations O_1 and O_3 are non-dominated. The organization O_5 is the worst with regard to the indicators. This method can be helpful for decision makers to select a panel of organizations which are interesting.

For the organizations which are interesting, we propose to consult all past processes in which these organizations participated in order to visualize and to analyze the two indicators over

time. This information will help to decide whether or not the identified organizations will be considered for the new experience. Then, the use of the history of collaboration and performance indicators are proposed as shown in Table 8.

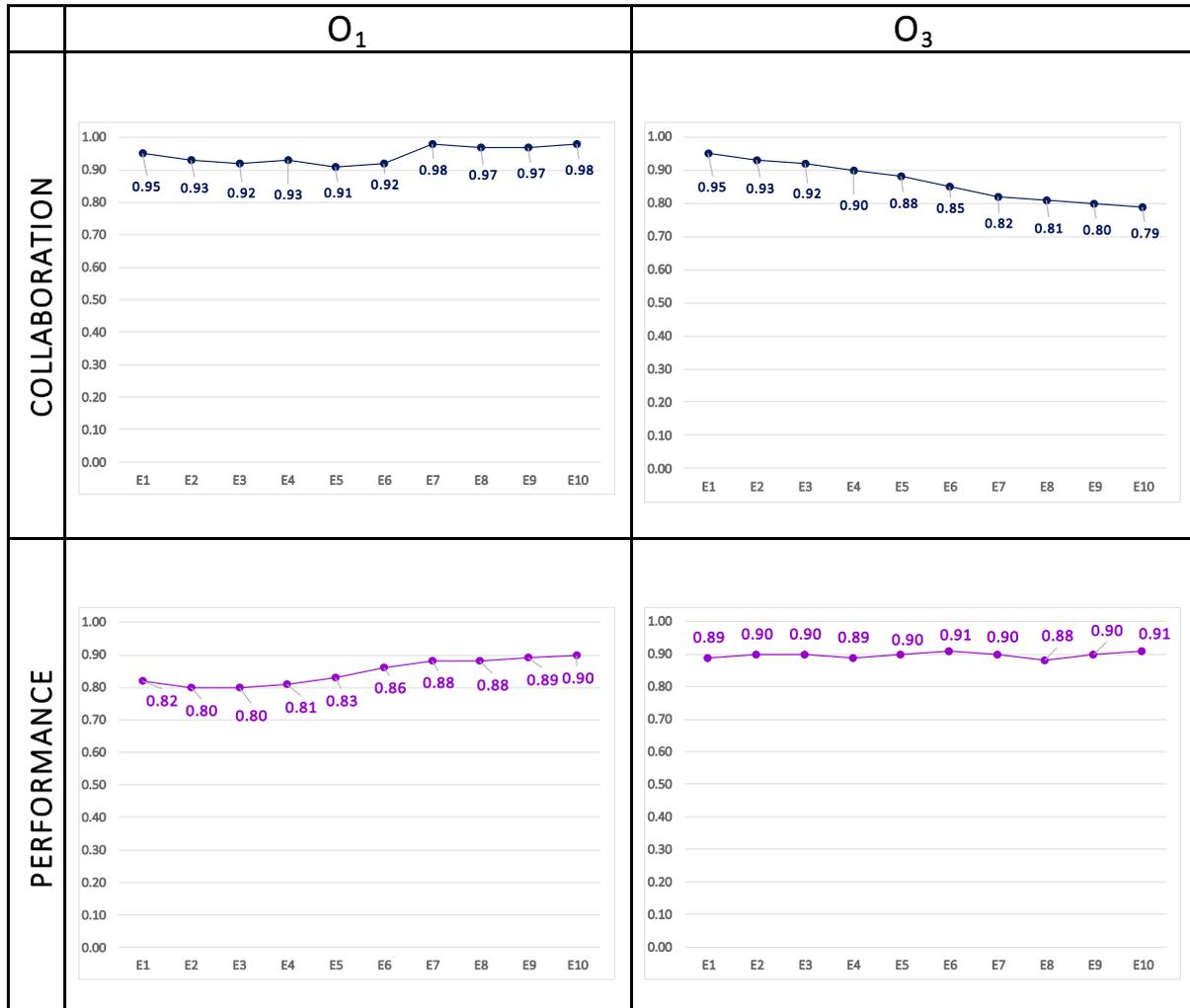


Table 8. Historical collaboration and performance indicators graphs of organizations O₁ and O₃

Finally, this process is the same to analyze the participation of possible actors for the new experience. Also, the information of similar past experiences can be used as input for the structure of the new process i.e., the team structure for a specific type of activity, the identification of specific roles for the execution of one or several activities among others.

The stability of an indicator of an organization over time is a good way to evaluate the indicators of this organization and decide to integrate it or not in a new process. For example, the organization O₃ has a collaboration indicator that is decreasing over time, experience after experience. A deeper analysis of this organization could be done in order to decide if it can be selected or not. The organization O₁ is more stable and the decision maker can be more interested in it. Furthermore, the similar experiences can be reused and/or adapted by the expert in order to define the new planned experience.

5.6 Conclusion

In this chapter, we have presented the method which allows the reusing of collaboration experiences capitalized in the experience base and it is based on CBR principles. The importance of experience capitalization and reuse principles for characterizing and measuring collaboration experience in industrial processes have been outlined.

The proposed approach for identifying similar processes is based on the similarity measures between two concepts that belong to a taxonomy. This similarity measurement is calculated mainly for the type of commitments because organizations collaborate in order to achieve one or more commitments. First, the commitments for the new experience needs to be characterized. For this purpose, a set of concepts is defined from the taxonomy. This set of concepts allows to filter the experience base in order to retrieve past experiences with similar characteristics with regard to the new experience.

Once all past experiences had been assessed in terms of similarity, it is possible to reuse them with three main objectives:

1. The identification of possible experience structures based on similar processes found in the experience base. The similar past experiences serves as a guideline for the new experience execution.
2. The identification of key actors.
3. The identification of the best organizations.

For the last objective, a complementary approach was proposed. This step aims to select a set of similar experiences which reach a given threshold of collaboration and performance indicators levels. It combines similarity, collaboration indicators and performance indicator. The underlying general idea is to choose the best organizations according to their global collaboration ($Coll_{O_i}$) and performance ($Perf_{O_i}$) indicators. These indicators are obtained from the weighted average of organizations' indicators (collaboration and performance) and similarity measures of selected past experiences.

6. ILLUSTRATION OF EXPERIENCE REUSE

6.1 Introduction

In the previous chapters, the characterization of a collaboration model for industrial process and projects has been detailed. Additionally, indicators regarding collaboration and performance have been established. In order to illustrate the practical use of this collaboration model, its application to a real case corresponding to an industrial process in a consulting company is described in this chapter.

The work conducted in the Axsens-bte company consisted mainly in two steps: (i) the participation in consulting and training projects in order to interact directly with the actors of the processes and (ii) the interviewing of company experts in order to evaluate the collaboration and performance indicators of the projects which form the Experience Base of this illustration. These steps were considered in order to build a knowledge and experience base for the company and to validate the survey, which allows to measure the collaboration of an industrial process or project. In order to describe the case study, knowledge and experience bases are presented in section 6.2. Second, the main characteristics of the new project are detailed. Then the experience reuse approach is carried out from section 6.4 to section 6.6.

6.2 Knowledge and Experience Base

The organizational structure of Axsens-bte is composed by the following business units (see [Figure 82](#)): (i) *Supply Chain & Logistics*, (ii) *Industrial Methods & Lean Six Sigma*, (iii) *Aerospace Supplier Development* and (iv) *Research & Methods*. This thesis is performed in the Research & Methods Business Unit, which relies on the other three departments to identify research topics relevant to the current needs of the industry. For the purpose of this research, the experience and knowledge bases of this illustration were built from projects of Industrial Methods & Lean Six Sigma Business Unit and Research & Methods Business Units (see [Figure 82](#)).

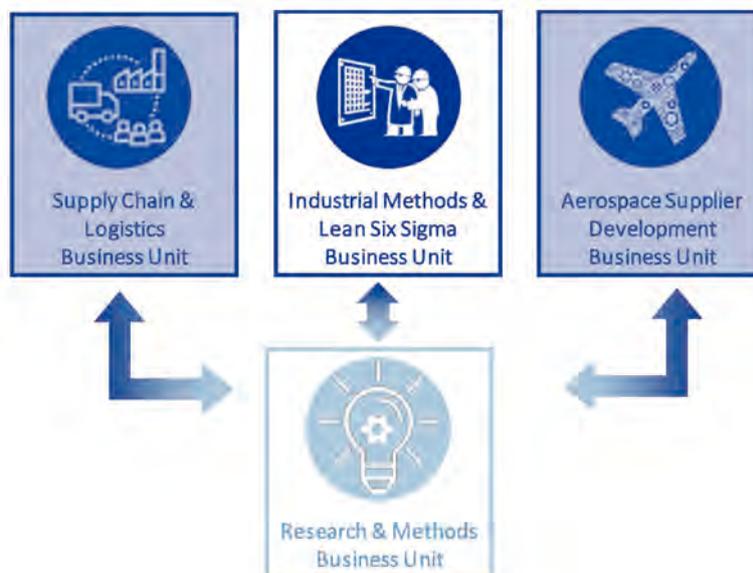


Figure 82. Context of the Experiences Base projects

The Experience Base was built with 20 experiences which were identified during the three years of this doctoral project. The experiences in the Experience Base were characterized using the collaboration model presented in chapter 3. The description of the projects stored in the Experience Base are listed below:

1. **Project PhD Thesis I:** it is a research project that describes a conceptual framework, process, and methodology for the collaborative resolution of problems within supply chains (Romero Bejarano, 2013).
2. **Project IPSM 2015:** Industrial Problem-Solving Methods is an annual workshop-conference organized to bring together industrial and academic partners who work together around quality management and the improvement of company performance in 2015.
3. **Project IPSM 2016:** idem IPSM 2016.
4. **Project IPSM 2017:** idem IPSM 2017.
5. **Project PhD Thesis II:** it is a research project which describes a proposition of an agile problem-solving process driven by the reuse of experiences and knowledge (Llamas, 2017).
6. **Project PhD Thesis III:** it is a research project which describes the formalization of collaboration experiences and collaboration and performance indicators in industrial processes in order to reuse past experiences to improve current situations (this research project).
7. **OPERA project:** it is an applied research project that aims to formalize the bidding process and support it with decision support tools that enable bidding companies to quickly propose fairer and more accurate bids in which there is greater confidence.
8. **EASYNNOV project:** it is an applied research project in order to define a methodology and a tool for solving problems in the industry 4.0
9. **ALIES project:** it is an applied research project in order to develop a problem-solving course and a prototype of Knowledge Management for a consulting group.
10. **LSS n°2017-053 project:** it is a Lean Six-Sigma Project which aims to optimize the aircraft painting activity.
11. **LSS n°2018-028 project:** it is a Lean Six Sigma Project which aims to optimize the aircraft molding activity.
12. **PSP n°2017-08 project:** it is a project which aims to structure the process of problem-solving in a manufacturing company of aerospace finished components.
13. **PSP n°2018-04 project:** it is a project which aims to structure the process of problem-solving in a surface treatment company specialized in the aeronautical sector.
14. **PSP n°2018-05 project:** it is a project which aims to structure the process of problem-solving in a manufacturing company specialized in precision mechanical assemblies, machining of complex parts for the aeronautic sector, especially engine parts.
15. **Training AL n°2016-02:** excel training for logistics optimization in the transport sector.
16. **Training AL n°2017-01:** excel training for logistics optimization in the transport sector.
17. **LSS n°2018-15 project:** it is a Lean Six-Sigma Project which aims to optimize an aircraft assembly activity.
18. **QA n°2018-12 project:** it is a project which carries out the quality control of a Procurement Management System.

19. LSS n°2018-028 project: it is a Lean Six Sigma Project which aims to optimize the preparation and loading of products in a producer company of Powder Metallurgy Steels and High-Speed Steels.

20. LSS n°2017-033 project: it is a Lean Six Sigma Project which aims to optimize the manufacturing process of prefabricated bathrooms.

Furthermore, the taxonomy stored in the Knowledge Base was specialized according to the consulting company context, as shown in Figure 83. This taxonomy is based on the specialization of the sixth level of the CPA taxonomy provided by the European Union. This specialization covers the knowledge of the three company areas (Supply Chain Operational Excellence, Industrial Methods and Research & Methods expertise). The numbers in brackets of some concepts of Figure 83 mean the number of sub-concepts (e.g. for the concept Management system QSE there are five sub-concepts). The taxonomy is provided in appendix 1.

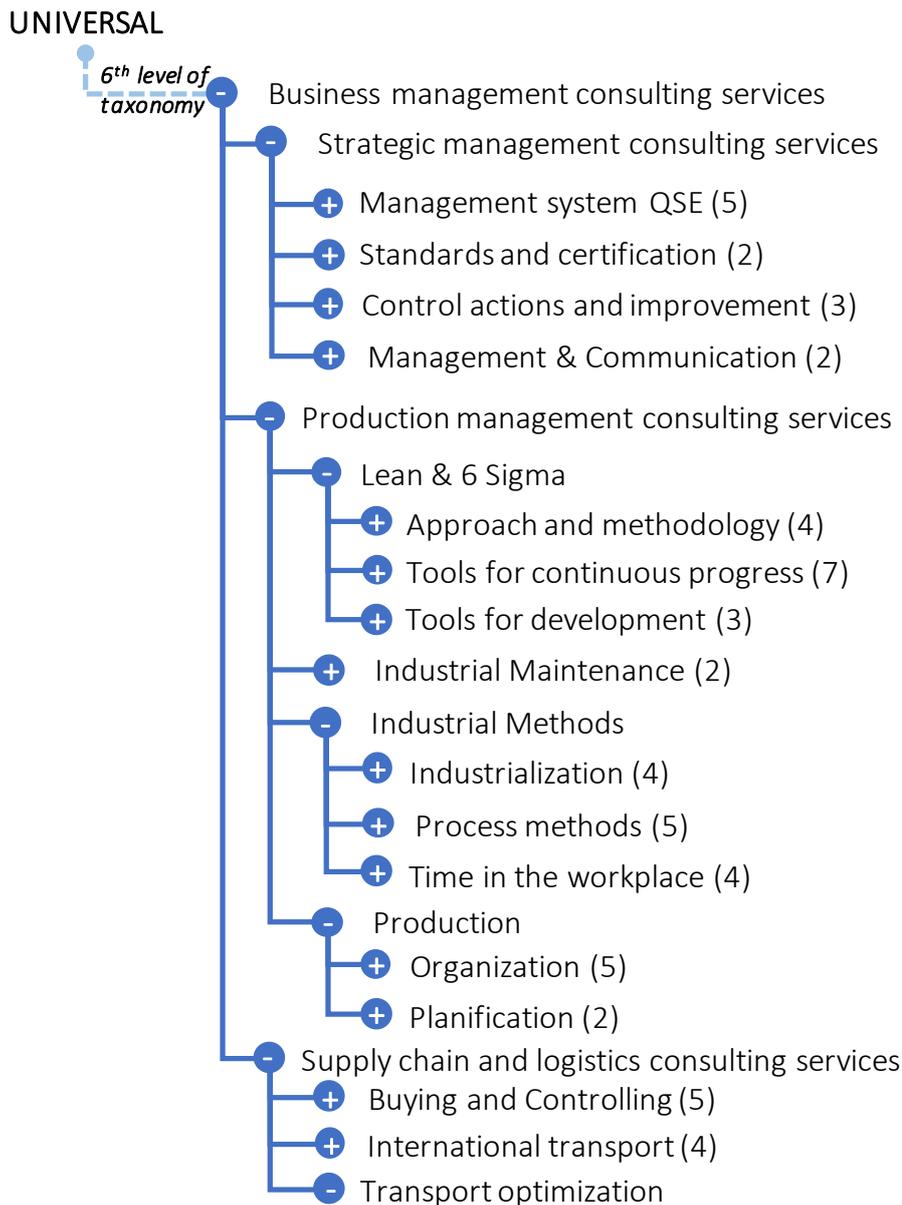


Figure 83. Extract of the specialized taxonomy for consulting service

Axsens-bte has a portfolio with three types of services: consulting services, training services and applied research in industry. In this regard, a taxonomy was developed for each type of service, and afterwards, each taxonomy was included in the CPA taxonomy. Figure 83 shows an extract of the specialized taxonomy (see appendix 1) for consulting services. The taxonomy of the training service is the same as the taxonomy of consulting service with a difference in the CPA taxonomy inclusion, since the training service is a type of “other education services” in CPA taxonomy as shown in Figure 84.

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Figure 84. Extract of the specialized taxonomy for training and research services.

6.3 Illustration of the new research project

First, the expert must define the main characteristics of the new experience. For this purpose, the type of each commitment of the new experience must be defined as shown in Figure 85.

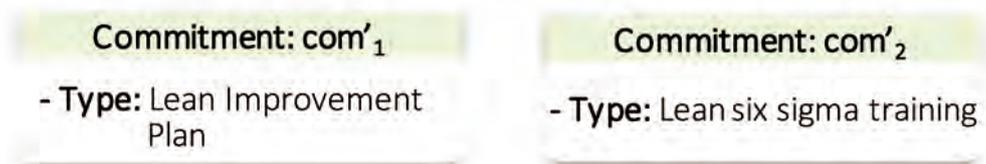


Figure 85. Type of commitments of the new experience

Once the definition of each commitment type is done, the exploration of the Experience Base described in the next section is performed.

6.4 Exploring the Experience Base

In this section, the results of the algorithm that calculates the similarity level between the new experience and past experiences (see algorithm 1, section 5.3.2, pp. 101) are presented. A description of past experiences commitments is provided in the appendix 2. Table 9 presents the similarities of past experiences stored in the Experience Base. The similarity measure was adapted of the Wu and Palmer similarity (see function 1, section 5.3.2, pp. 99).

| N° | PROJECT | Similarity |
|----|------------------------|------------|
| 1 | Project PhD Thesis I | 0.18 |
| 2 | Project IPSM 2015 | 0.19 |
| 3 | Project IPSM 2016 | 0.19 |
| 4 | Project IPSM 2017 | 0.19 |
| 5 | Project PhD Thesis II | 0.18 |
| 6 | Project PhD Thesis III | 0.18 |
| 7 | Project OPERA | 0.07 |
| 8 | Project EASYNOV | 0.08 |
| 9 | Project ALIES | 0.08 |
| 10 | Project LSS n°2017-053 | 0.78 |
| 11 | Project LSS n°2018-028 | 0.78 |
| 12 | Project PSP n°2017-08 | 0.15 |
| 13 | Project PSP n°2018-04 | 0.15 |
| 14 | Project PSP n°2018-05 | 0.15 |
| 15 | Training AL n°2016-02 | 0.50 |
| 16 | Training AL n°2017-01 | 0.50 |
| 17 | Project LSS n°2018-15 | 1.00 |
| 18 | Project QA n°2018-12 | 0.63 |
| 19 | Project LSS n°2018-041 | 1.00 |
| 20 | Project LSS n°2017-033 | 1.00 |

Table 9. Similarity of past experiences stored in the Experience Base.

Once the similarity level for each experience is calculated, the selection of similar past experiences must be done. This selection process is developed in the next section.

6.5 Selection of past projects based on collaboration and performance indicators

At this stage, all the past projects stored in the Experience Base that are similar enough to the new experience are identified. The accepted degree of similarity (α) has to be defined. For the purpose of this case study, α is set at 0.7. With this threshold, the selected projects are:

- Project LSS n°2017-053 with $\alpha = 0.79$
- Project LSS n°2018-028 with $\alpha = 0.79$
- Project LSS n°2018-15 with $\alpha = 1.00$
- Project LSS n°2018-041 with $\alpha = 1.00$
- Project LSS n°2017-033 with $\alpha = 1.00$

Once the selection of past projects with a similarity level higher than 0.7 is carried out, a second selection must be done taking into consideration the collaboration and performance indicators of the selected past projects. The experts can then retrieve experiences capitalized

for each similar project to obtain information about similar past experiences in order to reuse them and to facilitate the decision-making of the new experience structure and organization. In this regard, the identification of the organizations that participated in similar past experiences, must be done as shown in Table 10. The participation of an organization is represented with a 1, or 0 in case it did not participate. For confidentiality reasons, the organizations are denoted O_i ($i \in \{1, \dots, 9\}$).

| PROJECT | O_1 | O_4 | O_5 | O_6 | O_7 | O_9 |
|------------------------|-------|-------|-------|-------|-------|-------|
| Project LSS n°2017-053 | 1 | 1 | 0 | 0 | 1 | 0 |
| Project LSS n°2018-028 | 1 | 0 | 1 | 0 | 1 | 0 |
| Project LSS n°2018-15 | 1 | 1 | 1 | 0 | 1 | 0 |
| Project LSS n°2018-041 | 1 | 0 | 0 | 1 | 0 | 0 |
| Project LSS n°2017-033 | 1 | 1 | 0 | 1 | 1 | 0 |

Table 10. Participation of organizations in similar past experiences

Then, the analysis of organizations is based on the collaboration and performance indicators in order to analyze the best organizations information. First, a global collaboration indicator must be calculated for each organization of each similar past experience. As stated in chapter 5, it is obtained using the GOWA operator among the evaluation of each dimension of collaboration (coordination, cooperation and communication). For the purpose of this case study, the value for the λ constant is 0.5. Then, the performance evaluation is obtained from the Experience Base for each similar past experience. Table 11 shows the coordination, cooperation and communication indicators, the global collaboration indicator and the performance indicator for the organizations (O_i) which participates in selected similar projects in section 6.4.

| Project | O_j | sim_i | Coordination | Cooperation | Communication | Collaboration | Performance |
|----------------|-------|---------|--------------|-------------|---------------|---------------|-------------|
| LSS n°2017-053 | O_1 | 1.00 | 0.84 | 0.89 | 1.00 | 0.91 | 1.00 |
| LSS n°2017-053 | O_4 | | 0.84 | 0.90 | 1.00 | 0.91 | 1.00 |
| LSS n°2017-053 | O_7 | | 0.78 | 0.82 | 0.92 | 0.84 | 0.82 |
| LSS n°2018-028 | O_1 | 1.00 | 1.00 | 0.95 | 1.00 | 0.98 | 1.00 |
| LSS n°2018-028 | O_5 | | 0.94 | 0.89 | 0.94 | 0.92 | 0.66 |
| LSS n°2018-028 | O_7 | | 0.92 | 0.87 | 0.92 | 0.90 | 0.74 |
| LSS n°2018-15 | O_1 | 1.00 | 0.84 | 1.00 | 1.00 | 0.94 | 0.71 |
| LSS n°2018-15 | O_4 | | 0.85 | 1.00 | 1.00 | 0.95 | 0.64 |
| LSS n°2018-15 | O_5 | | 0.79 | 0.95 | 0.97 | 0.90 | 0.50 |
| LSS n°2018-15 | O_7 | | 0.78 | 0.93 | 0.95 | 0.88 | 0.54 |
| LSS n°2018-041 | O_1 | 0.71 | 0.70 | 0.45 | 0.72 | 0.62 | 1.00 |
| LSS n°2018-041 | O_6 | | 0.60 | 0.40 | 0.61 | 0.53 | 1.00 |
| LSS n°2017-033 | O_1 | 1.00 | 0.78 | 0.84 | 0.81 | 0.81 | 0.97 |
| LSS n°2017-033 | O_6 | | 0.67 | 0.72 | 0.70 | 0.70 | 0.88 |
| LSS n°2017-033 | O_7 | | 0.73 | 0.78 | 0.76 | 0.76 | 0.68 |

Table 11. Report of similar past projects for the case study with collaboration and performance indicators

For the purpose of this research, the objective is to analyze the best organizations among the ones that participated in similar past experiences, for carrying out the new project. Once the indicators of similar experiences organizations are calculated, a global collaboration and performance indicator of each organization must be calculated using the algorithm 5 presented in section 5.4, as shown in Table 12.

| Organization | Collaboration | Performance |
|----------------|---------------|-------------|
| O ₁ | 0.77 | 0.83 |
| O ₄ | 0.83 | 0.71 |
| O ₅ | 0.81 | 0.51 |
| O ₆ | 0.61 | 0.94 |
| O ₇ | 0.75 | 0.61 |

Table 12: Report on the overall collaboration and performance indicators of organizations which participated in similar past experiences

This classification does not show all the information of past experiences. Nevertheless, the access to the elements of the expert's interest (in this case, the organizations) can be provided in more detail for further analysis. This is described in the next section.

6.6 Analysis and adaptation of solutions

From the synthesis obtained in section 6.5, the expert can preserve, modify or reject the knowledge acquired from past experiences. All the organizations identified in similar past projects will be the starting point for the construction of the new experience. The expert will be able to identify the organizations that may be part of the new experience. In this regard, a mapping associated to the table of similar past projects report is proposed in order to facilitate the visualization of the global level of collaboration and performance indicators (see Figure 86). As stated in section 5.5, the horizontal axis of the dashboard is the value of 1 minus the global collaboration value of organizations. The vertical axis of the dashboard is the value of 1 minus the global performance value of organizations. The optimal coordinate for an organization corresponds to the point (0,0).

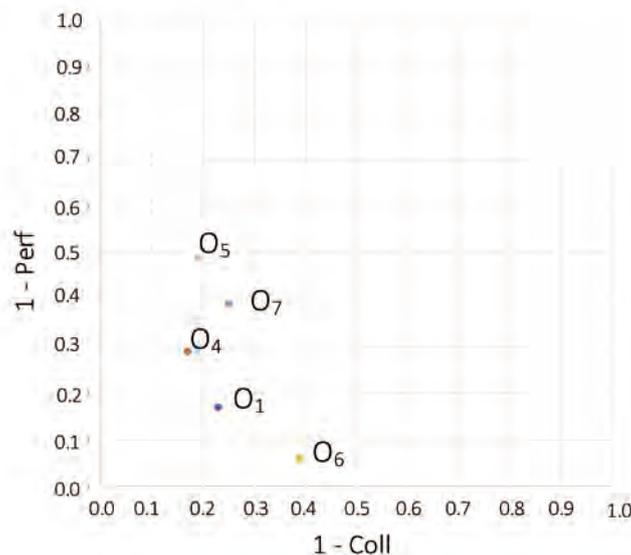


Figure 86: Mapping associated with the table of similar past projects report (Table 12)

In the dashboard of Figure 86, the five organizations are represented. As proposed in the section 5.5, it is necessary to define the Pareto front (i.e. the set of organizations which are not dominated). The organization O_5 is dominated by the organization O_4 (the two indicators are better). It must not be selected. Similarly the organization O_7 is also dominated by O_4 and must not be selected. It can be observed that the organizations O_4 , O_1 and O_6 are on the Pareto front because they are not dominated by the other organizations with regards to the performance and collaboration indicators. However, the organization O_6 has not obtained a good value for the collaboration indicator. The decision maker can choose to eliminate it and to analyze only the organizations O_1 and O_4 . For these two organizations, we propose to consult all the past processes in which they participated in order to analyze the evolution of collaboration and performance indicators over time. This investigation will help to decide whether the identified organizations will be considered for the new experience or not. The evolutions of collaboration and performance indicators overtime are presented in Table 13 for the organizations O_1 and O_4 .

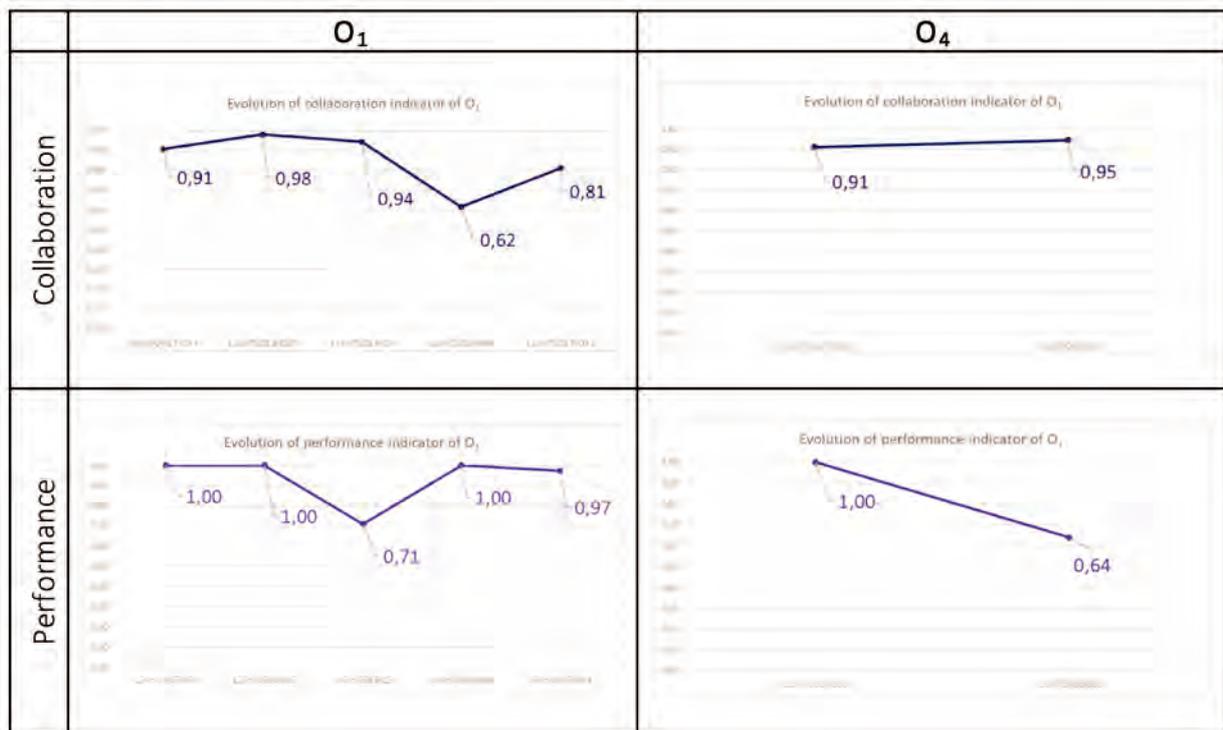


Table 13. Historical collaboration and performance indicators graphs of organizations O_1 and O_4

From the synthesis obtained, the expert can decide which is the best organization, based on stable (or improving) behavior of indicators over time. Furthermore, taking into account the experience reuse approach, the adaptation and implementation of similar past experiences will serve as a baseline for the expert to preserve, modify or reject the knowledge acquired from them, therefore, to structure the new experience based on all the available information extracted of similarly successful past experiences in relation to collaboration and performance evaluation. O_1 it is the best organization because it has participated in more projects than organization O_4 and the collaboration and performance indicators, four out of five experiences are above 80% and 97% respectively.

In addition, the new experience can be completed by the expert based on the structure of the selected similar past experiences i.e. one or several actors can be allocated to the activities of

the new experience. Figure 87 illustrates a partial instantiation of the new experience. The cost of the activities has not been reported because not all partners in the process have yet been identified.

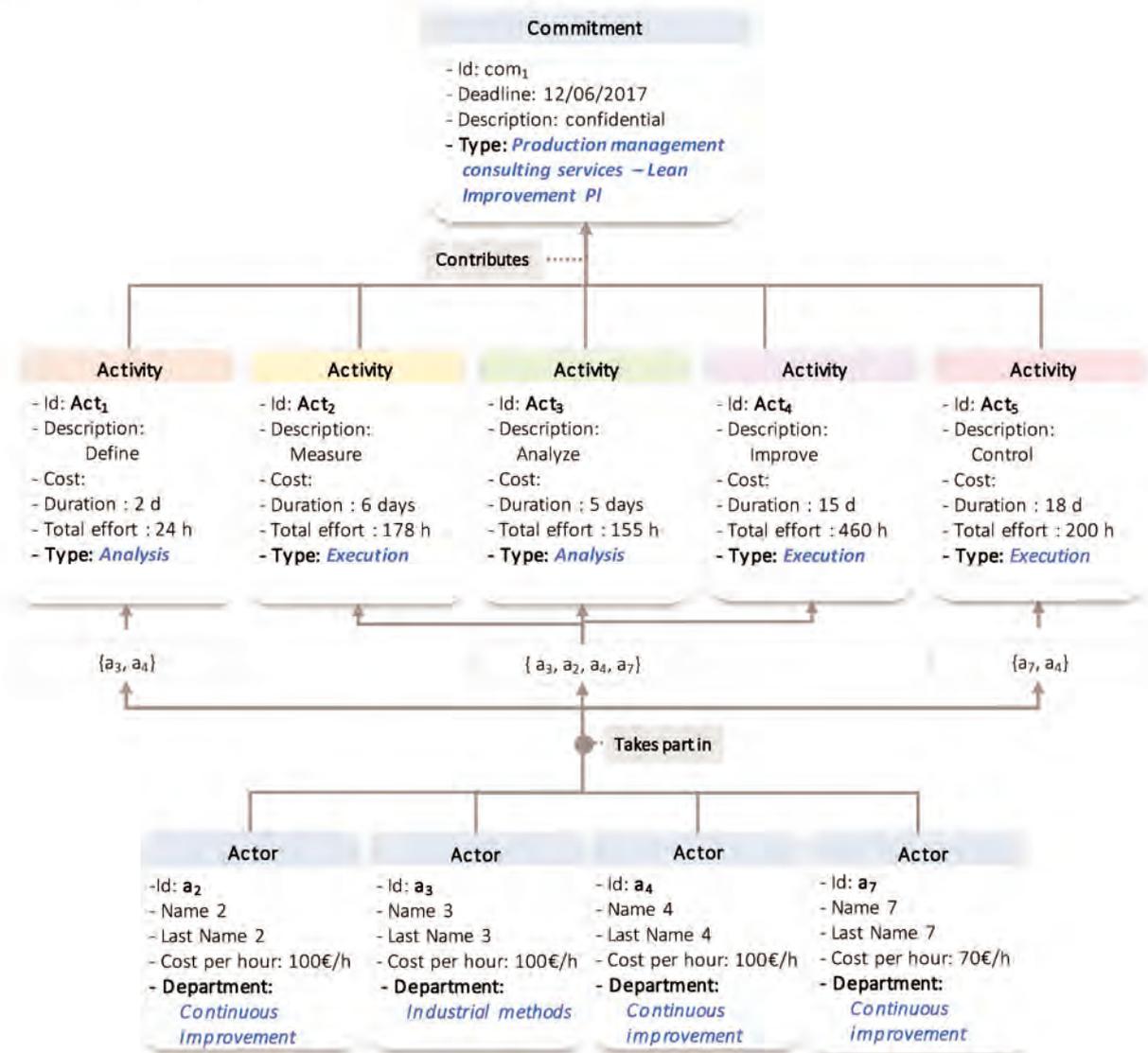


Figure 87. Partial Instance of new experience

6.7 Conclusion

A real case conducted in the Axsens-bte consulting company was studied in this chapter and it is used to illustrate the approach of the capitalization and reuse of experiences. The projects chosen to validate a prototype of knowledge and experience base were projects of short duration and with a maximum of 10 actors to decrease the level of complexity of the collaboration characterization. The participation in these projects allows to collect the main information through interviews and existing information in documents in order to create the knowledge and experience base of the company. In this regard, experiences were modelled according to the collaboration model presented in chapter 3. Furthermore, a specialization of the taxonomy of products and services provided by the European Union - CPA - was extended from the types of services offered by the consulting company in order to have a type of commitment according to the study case context.

Once the knowledge and experience base were built, the commitments of a new case were identified in order to calculate the similarity between the new experience and the past experiences stored in the Experience Base. The results obtained using the algorithm for measuring the similarity between projects were presented. Then, the threshold of the similarity level, the collaboration and performance indicators were defined. Once the similar projects are found in the Experience Base, it is possible to identify the organizations and actors that could participate in the current project. For that, the evolution of collaboration and performance indicators overtime for each organization is presented in order to support the decision-making process for the expert. In addition, information from similar projects with good performance can be an input for experts to transpose it into the structure of the new experience.

7. CONCLUSION AND PERSPECTIVES

In this chapter, the main contributions of this research and the outlook of future work are presented. Facing intensified global competition, organizations strive for greater collaboration in order to gain competitive advantage in the current market. This involves the use of resources and knowledge throughout their business processes because organizations that build long-term relationships, work closely to the plans and execute common activities toward common goals, achieve more benefits than those working independently. Accordingly, organizations are involved in industrial networks to preserve and improve their business efficiency. As stated by (Goossen, 2014), an organization can be represented as a network of individuals. In this regard, collaboration between organizations that participate in an industrial network can be characterized and evaluated from collaboration between individuals who work for these organizations.

This thesis works on how organizations can improve collaboration in their industrial processes using an experience feedback approach. It deals with the lack of methods which allow to define and improve collaboration in industrial processes. Hence, to address this problem a collaboration model is proposed. Mechanisms for capitalization and reuse of past experiences is proposed and applied to a company real case.

The conceptual framework has been established from a study combining a literature review and the know-how of industrial experts, specifically, consultants within the Axsens-bte company. In this regard, the core idea of this thesis is that the configuration of industrial processes or projects can be assisted by using capitalization and reuse of similar past experiences taking into account the results of collaboration and performance evaluations.

In order to clearly state the objectives of the research, a literature review was conducted. The two main research pillars were introduced in chapter 2. First, the different approaches of collaboration characterization in industrial processes were presented. The main characteristics of collaboration at the organizational and individual level were presented. Collaboration involves a collaborative network which can be configured by several elements which are related to the definition of collaboration for its characterization. Moreover, the 3C model of (Ellis et al., 1991) was presented to understand collaboration through three pillars: Communication for exchanging information, Coordination for managing the activities, actors and resources, and Cooperation in order to achieve the commitments that have been established. Second, knowledge and experience capitalization, and reuse principles were introduced. In this regard, this chapter introduces and positions the general context and the scientific disciplines of this research. The two main research questions that were addressed in this thesis were:

1. *How to characterize and memorize collaboration during an industrial process taking into consideration organizations and actors who work for them?*
2. *How to define and improve future collaborations based on past experiences?*

The first question focuses on defining the characteristics of collaboration in a process. We answer this question by studying the notion of collaboration, including its definitions and characteristics. The theoretical bases of the collaboration model were introduced in chapter

3. Its main elements were described, as well as their interactions. The collaboration model has six elements: “*organizations*”, “*contracts*”, “*commitments*”, “*requirements*”, “*activities*” and “*actors*”. On one hand, the last two elements allow to characterize the collaboration at an individual level. It is due to the fact that the *actors* interact between them in order to accomplish one or several process “*activities*”. On the other hand, organizational level concerns the “*commitments*” or goals, the “*requirements*” or engagements of each “*commitment*” and relationships between “*organizations*” related through one or several “*contracts*” as well as the process “*activities*”. The collaboration model is stored in the knowledge base. In order to standardize some characteristics of the modeled elements, a taxonomy of concepts was proposed, this taxonomy is also stored in the knowledge base.

Once the collaboration model is described, indicators that allow to measure the collaboration quality and performance of an experience were presented in chapter 4. The proposed collaboration indicators are evaluated by actors throughout a survey that measures the three collaboration dimensions: communication, cooperation and coordination. In the literature, studies proposed different measures to evaluate collaboration during a teamwork. However, as far as we know, no research work converts the evaluation of collaboration in a team into a collaboration evaluation between the organizations. Henceforth, a methodology which allows to display the collaboration evaluation made by the actors from the point of view of the organizations is proposed. Due to the collaboration model aforementioned, it can be represented with a network. The proposed methodology is based on the matrix theory since networks can be modeled by matrices.

The second question concerns the definition and improvement of future collaborations by the analysis of past collaborations. The objective was to develop an approach for capitalization and reuse of experiences in order to facilitate the definition of a new process taking into account the performance and collaboration evaluation of past experiences. For this purpose, we proposed to work at a higher abstraction level to capture experiential knowledge that allows to characterize collaboration by basing it on the perspectives and experiences of organizations and actors who work for these organizations. Therefore, the objective is to reuse existing experiences about industrial processes to define and improve future collaborations. In chapter 5, the experience reuse approach for improving future collaborations, based on CBR principles, was presented. It has four steps that allow the definition of a new experience. The first step considers the definition of the new experience context. In step two, a dedicated search algorithm is proposed in order to explore the experience base and calculate the similarity between the new experience and the past experiences stored in the experience base. The third step regards the selection of the past processes which are similar to the new process. This selection is based on three parts: (i) the similarity measure between the new process and the past experiences, (ii) the collaboration indicators and (iii) the performance indicator. In the fourth and last step, the experts decide the way forward supported by the analysis and adaptation of solutions identified in this step in order to define the planned experience. Once the planned experience is executed, it is defined as a current experience with its indicators. Finally, the experience base is updated with the planned experience, the current experience and the collaboration and performance indicators.

Finally, a real application was described in chapter 6. This case study was conducted into the consulting company Axsens-bte. Data of twenty processes was collected through interviews

and participation in these processes in order to build the company knowledge and experience bases. Considering such information, a new experience was defined. The commitments of the new experience were characterized from the taxonomy. Then, the experience base exploration was performed in order to calculate the similarity level between the new experience and the past experience (twenty projects). This similarity level is based on the similarity measure of Wu and Palmer. Once the similarity levels were calculated for all past processes, a minimum degree of similarity (α) was defined in order to select the most similar past processes. The decision makers can retrieve the past experiences with the best collaboration and performance evaluation in order to reuse them. For the purpose of this case study, the objective was to identify the best organizations that could participate in the new process. Therefore, all past processes which these organizations participated were consulted in order to analyze the evolution of collaboration and performance indicators over time as an input to decision-making for experts. The Pareto optimality principles were applied taking into account performance indicator and collaboration indicator. Two non-dominated organizations were identified.

The proposed collaboration model contributes to the problem described in the first chapter of this work regarding the lack of methodologies which allows to define and improve future collaborations in an industrial context. Our model facilitates decision making through the characterization and measure of collaboration and performance of an industrial process. The defined experience reuse method allows users to retrieve past similar experiences in order to define and/or adapt their current experience according to information of the best experiences already performed within the consulting company. Once the process or the project is executed, the actors who perform the activities evaluate it in terms of collaboration and the sponsor of each organization evaluates the process performance. Then, the dashboard of the experience is displayed with the communication, cooperation, coordination and performance indicators. Moreover, the proposed experience reuse approach ensures that when the experience has been carried out it is properly stored in the Experience Base in order to ensure its future reuse.

The application of the collaboration model and the experience reuse methodology contributed to their improvement and to the definition of some limits of our work. In addition, some aspects have not been developed as part of this PhD thesis but deserve, however, further research in order to enrich the proposed model and to facilitate the development of capitalization and reuse of past experiences approach in an industrial context. These aspects, potentially broadening the scope of this research, are listed next according to an estimated horizon: medium and long-term.

Two perspectives were identified to be deployed in the medium-term:

1. The first perspective concerns the collaboration model presented in chapter 3. It allows to characterize and measure the main elements of collaboration during a process or a project. However, the collaboration characterization could be enhanced with the notion of team members' competences to carry out an activity. In this regard, the "activity" and "actor" entities could be labelled with more than one concept (the list of competences required or acquired). On one hand, an actor may have several competences according to his/her academic formation and his/her professional experience. On the other hand, the competences required to carry out an activity

must be identified. It entails the use of multiple labelling for competence concept. Multiple labelling naturally complicates the similarity calculation since the combinatorial structure is more complex. Then, more work could be done to develop suitable and efficient algorithms, which can deal with the aforementioned combinatorics.

2. In chapter 3, a formal tool that defines quantitative metrics to assess the three dimensions of collaboration (cooperation, coordination and communication) was proposed. In this regard, the historical collaboration and performance indicators for each organization can be retrieved and displayed as an input for decision-making. Nevertheless, it would be interesting to develop a structural specification of a maturity model in order to develop further generic guidelines and insights of collaboration in industrial processes. The main objectives of such a maturity model would be:
 - a. The definition of a conceptual framework based on the collaboration dimensions evaluation presented in chapter 4 in order to evaluate the maturity of collaboration in processes or projects over the time. This framework should be made up of different maturity levels, which respond to the measure of each collaboration dimension indicators.
 - b. The definition of a maturity collaboration indicator for a given organization based on the trends of indicators of all experiences in which this organization has participated over time.

Three long-term perspectives linked to this work are described next:

3. In this work, the collaboration evaluation was carried out when the process or project was finished in order to facilitate the calculations. Nevertheless, the proposed methodology allows to evaluate the collaboration for each activity when it is completed. However, it would be interesting to carry out the evaluation not only after the activity has been completed but also during its execution in case of problems related to collaboration. This would allow to have a feedback during the execution of each activity and it could facilitate the problem identification and hence, to suggest strategies or actions to improve collaboration in real time.
4. The collaboration and the performance are evaluated at the end of the process execution. Nevertheless, taking into account that an experience feedback approach allows to identify the similar past experiences, it would be interesting to calculate the expected collaboration and performance evaluations of the planned experience based on collaboration and performance indicators of the similar past experiences.
5. The last perspective concerns the effective implementation of the proposals in industry. Indeed, three proofs of concept have been developed in order to: (i) evaluate the collaboration dimensions and it is done by each actor, (ii) calculate the evaluation of collaboration dimensions at organizations level, it means displays the collaboration evaluation and performance that each organization receives from other organizations and vice versa, (iii) calculate and select the past experiences according to their similarity level, their collaboration and performance indicators. In this regard, a software could be developed in order to achieve the implementation of proofs of concept aforementioned in industry. It is necessary for this software to be consistent

with the proposed collaboration model, to perform the calculations, and to provide the relevant experiences in terms of similarity, collaboration and performance indicators. Furthermore, it will be essential to develop a friendly interface for model input and results display. Finally, it must be scalable, ergonomic and robust in order to handle experiences with numerous input elements.

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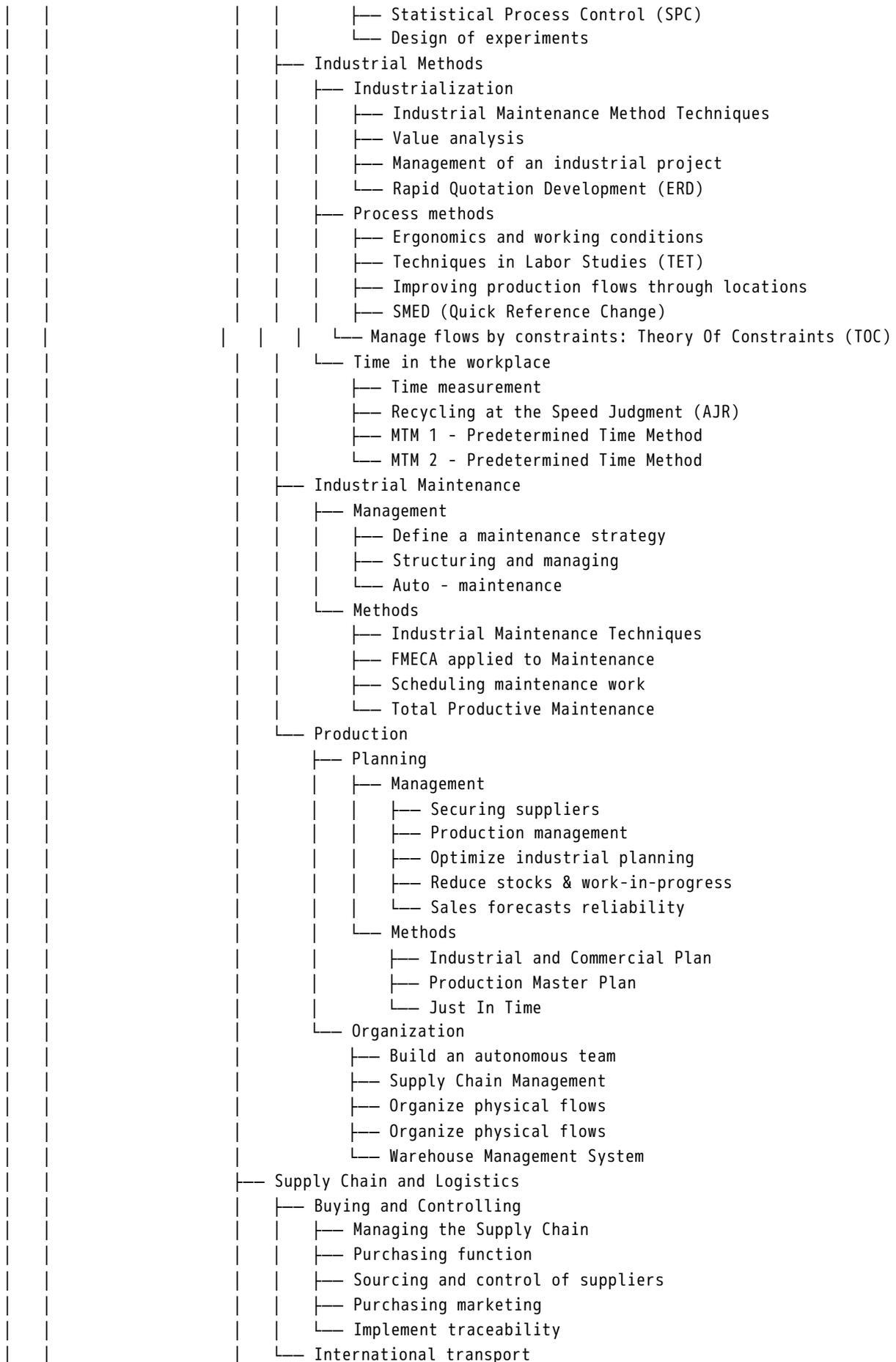
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APPENDIX



- └─ Education services
 - └─ Higher education services
 - └─ Other education services
 - └─ Production Management
 - └─ Lean & Six-Sigma
 - └─ Approach and methodology
 - └─ Lean Manufacturing 1
 - └─ Value Stream Mapping (VSM)
 - └─ 6 Sigma - Reduce process variability
 - └─ Lean Improvement Plan
 - └─ Tools for continuous progress
 - └─ Analysis and problem solving -[8D]
 - └─ 5S
 - └─ Detection and measurement of quality costs
 - └─ Customer satisfaction measurement
 - └─ Performance indicators and dashboard
 - └─ Participatory Management
 - └─ The Continuous Improvement Toolbox
 - └─ Tools for development
 - └─ Failure mode, effects & criticality analysis (FMECA)
 - └─ Statistical Process Control (SPC)
 - └─ Design of experiments
 - └─ Industrial Methods
 - └─ Industrialization
 - └─ Industrial Maintenance Method Techniques
 - └─ Value analysis
 - └─ Management of an industrial project
 - └─ Rapid Quotation Development (ERD)
 - └─ Process methods
 - └─ Ergonomics and working conditions
 - └─ Techniques in Labor Studies (TET)
 - └─ Improving production flows through locations
 - └─ SMED (Quick Reference Change)
 - └─ Manage flows by constraints: Theory Of Constraints (TOC)
 - └─ Time in the workplace
 - └─ Time measurement
 - └─ Recycling at the Speed Judgment (AJR)
 - └─ MTM 1 - Predetermined Time Method
 - └─ MTM 2 - Predetermined Time Method
 - └─ Industrial Maintenance
 - └─ Management
 - └─ Define a maintenance strategy
 - └─ Structuring and managing
 - └─ Auto - maintenance
 - └─ Methods
 - └─ Industrial Maintenance Techniques
 - └─ FMECA applied to Maintenance
 - └─ Scheduling maintenance work
 - └─ Total Productive Maintenance
 - └─ Production
 - └─ Planning
 - └─ Management
 - └─ Securing suppliers
 - └─ Production management
 - └─ Optimize industrial planning

- | |— Effective communication
- | |— Argue and convince
- | |— Public Speaking
- | |— Knowledge communication
- |— Management system QSE
 - |— Implementation of management systems
 - |— Awareness of workplace safety
 - |— Initiation to the Quality approach
 - |— The Quality Manager function
 - |— Management by quality

Appendix 2. Illustration case commitments description of past experiences

A description of the commitments of the projects (past experiences) stored in the Experience Base of the illustration case of chapter 6 is provided in the following table:

| PROJECT | Commitment 1 | Commitment 2 | Commitment 3 | Commitment 4 |
|------------------------|-------------------------------------|---|---|--|
| Project PhD Thesis I | Thesis report | Conference paper | Journal Paper | 60 hours of scientific training |
| Project IPSM 2015 | Conference | Conference proceedings | Stand | Catering service |
| Project IPSM 2016 | Conference | Conference proceedings | Stand | Catering service |
| Project IPSM 2017 | Conference | Conference proceedings | Stand | Catering service |
| Project PhD Thesis II | Thesis report | Conference paper | Journal Paper | 60 hours of scientific training |
| Project PhD Thesis III | Thesis report | Conference paper | Journal Paper | 60 hours of scientific training |
| OPERA project | Industriall case description | Progress Report | Progress Report | Progress Report |
| EASYNOV project | Problem Solving in Industry | Guidelines of Innovative Problem Solving Training | Guidelines of Innovative Problem Solving consulting service | Guidelines of a Community of Practice in Problem Solving |
| ALIES project | Innovative Problem Solving Training | Prototype of Knowledge Management System | | |
| LSS n°2017-053 project | Lean-Improvement-Plan | Time study | | |

| PROJECT | Commitment 1 | Commitment 2 | Commitment 3 | Commitment 4 |
|------------------------|--|--------------|--------------|--------------|
| LSS n°2018-028 project | Lean-Improvement-Plan | Time study | | |
| PSP n°2017-08 project | Problem Solving Process definition | | | |
| PSP n°2018-04 project | Problem Solving Process definition | | | |
| PSP n°2018-05 project | Problem Solving Process definition | | | |
| Training AL n°2016-02 | Training od excel application for logistics optimization | | | |
| Training AL n°2017-01 | Training od excel application for logistics optimization | | | |
| LSS n°2018-15 project | Lean-Improvement-Plan | | | |
| QA n°2018-12 project | Implementation of a Procurement Management System | | | |
| LSS n°2018-028 project | Lean-Improvement-Plan | | | |
| LSS n°2017-033 project | Lean-Improvement-Plan | | | |

ABSTRACT

In the current changing market-place, today's organizations must continuously evolve and improve. They are coerced to join industrial networks to maintain their business efficiency. Furthermore, each organization which participates in industrial networks is, at the same time, an organizational network of actors who work for it. In this regard, collaboration plays a central role to carry out activities in industrial processes and it has become one of the relevant areas of performance measurement. Then, a need arises to define a methodology for collaboration characterization and evaluation between organizations based on the interactions between actors. Also, the experience reuse principles are an interesting approach to define future collaborations based on past experiences.

This thesis work describes a proposition of an approach of capitalization and reuse of experiences in order to facilitate the definition of future collaborations taking into account the performance and collaboration dimensions of past experiences. For this purpose, a collaboration model is defined as well as a collaboration and performance evaluation of an experience in order to allow the experience capitalization and its future reuse. Then, we propose an experience reuse system that allows defining the best collaboration experiences between organizations and actors concerning partial information of the new experience. This work provides a novel approach which lies in the fact that we explicitly integrate an experience reuse approach in order to define future collaborations at an organizations level and actors level.

Keywords: Collaboration measure, Collaboration Model, Industrial Processes, Experience Management

RESUME

Dans le contexte actuel, les organisations d'aujourd'hui doivent constamment évoluer et s'améliorer. Dans ces conditions, elles sont amenées à rejoindre des réseaux industriels afin d'assurer une bonne compétitivité. Au sein d'un réseau industriel, chaque organisation constitue elle-même un réseau organisationnel d'acteurs qui doivent collaborer pour la réalisation d'activités. La collaboration reste donc un facteur clé. Nos travaux de recherche sont axés sur la définition d'une méthodologie de caractérisation de la collaboration entre organisations à partir des interactions entre leurs acteurs. L'approche développée dans cette thèse est basée sur le principe du retour d'expérience : chaque expérience de collaboration est capitalisée dans une base d'expériences à des fins de réutilisation ultérieure.

Cette thèse décrit donc la proposition d'une approche de capitalisation et de réutilisation des expériences passées afin de faciliter la définition des collaborations futures en tenant compte des performances du processus industriel mais également des performances de la collaboration. A cet égard, un modèle de collaboration est défini ainsi qu'une évaluation de la collaboration et de la performance d'une expérience afin de permettre la capitalisation de l'expérience et sa réutilisation future. Ensuite, nous proposons un système de réutilisation des expériences qui permet de définir les meilleures expériences de collaboration entre les organisations et les acteurs concernant les informations partielles de la nouvelle expérience. Ce travail fournit une approche novatrice qui réside dans le fait que nous intégrons explicitement la réutilisation de l'expérience afin de définir des collaborations futures au niveau des organisations et des acteurs.

Mots clés : Mesure de collaboration, Modèle de collaboration, Processus industriels, Retour d'expérience