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Collaboration evaluation methodology for experience capitalization in industrial processes

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Abstract: Collaboration is a key factor that encourages an efficient running of industrial processes. The measurement of the collaboration performance is necessary to allow experience capitalization and reuse in order to support decision making about efficient collaborations in future processes. This article describes a proposition of collaboration and performance evaluation methodology in industrial processes for experience capitalization. For this purpose, a collaboration model is introduced in order to develop an evaluation methodology. Finally, a case study applied to the aeronautical domain is presented to illustrate the methodology and validate the proposals.

Keywords: Collaboration, Performance Assessment, Experience Feedback Processes, Knowledge Management.

1. INTRODUCTION

Collaboration is the cooperative effort between two or more entities striving towards a common goal, as stated in Durugbo et al. (2011). The rise of outsourcing is a strong characteristic of current industry and collaboration plays a key role in the achievement of industrial processes. Moreover, industrial processes are composed of different activities and each participant has specific characteristics to contribute to these activities. For this purpose, participants 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).

In order to ensure performance in industrial processes, the use of past experiences and knowledge capitalization is a key aspect, Bergmann (2002). Consequently, experience and knowledge management applied in collaboration process creates value in inter-organizational activities, To and Ko (2016). However, there is a lack of methods and tools which permit to formalize experiences of collaboration for future reuse and to properly evaluate them with a collaboration and performance point of view.

Therefore, the aim of this paper is to propose a method that permits to build and capitalize experiences of collaboration relating to industrial processes realization. Each experience is evaluated with regard to the process performances as well as the collaboration performances with a reuse perspective. In order to be able to reuse past experiences, it is necessary to characterize every experience by means of indicators which reflect: i) the quality of the collaboration between the actors

who perform the activities, ii) the quality of the collaboration between the different companies involved into the process realization, iii) the performances of the process considering the requirements satisfaction.

The remainder of the paper is organized as follows: section 2 provides a panel of works about the evaluation of collaboration in industry and the knowledge management in collaborative processes. Section 3 presents the elements and the structure of a collaboration experience. Section 4 introduces the concepts that can be used to evaluate the collaboration and the performance corresponding to the execution of a process. Section 5 develops an illustrative application in order to validate the proposed model. Finally, the conclusion and the perspectives of this work are presented in the last section.

2. RELATED WORKS

In this section, two general approaches that contribute to our proposal are presented. On the one hand, the collaboration framework in collaborative systems is presented. On the other hand, experience management main formalisms for representing knowledge that can be used in our work are presented.

2.1 Collaboration framework in collaborative systems

Fuks et al. (2005) propose a framework for classifying collaborative systems (Fig. 1). This model supports collaboration analysis and it is based on the inter and intra-relationships between three dimensions: coordination, cooperation and communication.

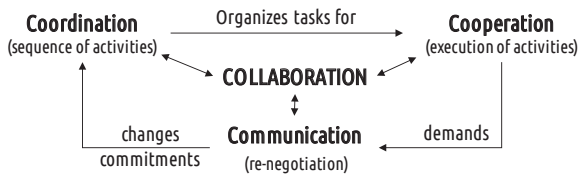


Fig. 1. 3Cs adapted from Fuks et al. (2005)

Durugbo et al. (2011) propose a mathematical model that allows to analyze how individuals in organizations work together. They propose three quantitative indicators (*team-work scale, decision-making scale and coordination scale*) based on the process network structure. These indicators characterize collaboration from the perspective of information structure in organizations. However, this model focuses solely on information flow and it does not consider the quality of collaboration during teamwork nor the performance of the process. On the other hand, Egghe (1991) propose two collaborative measures based on variables that allow characterizing the participation of authors to one or several articles. Just like in the aforementioned article, the quality of collaboration and process performance are not taken into account in these measures.

2.2 Experience management

Experience Management (EM) consists of collecting, modeling, storing, evaluating and updating the experience for future reuse, Bergmann (2002). EM allows making better use of experiences during an industrial process. Organizational knowledge and its management are critical for organizational success and competitive advantage. Therefore, experience can be seen as a specialization of knowledge, Sun and Finnie (2005). A previous experience, which has been captured and learned in a way that it can be reused for the solving of future problems, is referred to a past case, Jedlitschka et al. (2002). Experience management considers collaboration as a driver in an industrial process. Nevertheless, it is necessary that enterprises recognize people as the centerpiece for new knowledge exploration in management, To and Ko (2016).

Existing collaboration models do not propose an inter-organizational process evaluation method based on the contributions of the actors who participated throughout the process. In addition, the capitalization of experiences of collaboration for future reuse is not proposed in these models. Thus, the aim of this article is to propose a model of an experience of collaboration in order to capitalize experiences for future reuse. The proposed experience model has to represent the performance of the process conjointly with the performance of the collaboration itself. Furthermore, the experience must characterize the collaboration performance at the enterprise level as well as at the actor's level.

3. COLLABORATION MODEL FOR EM

In order to obtain an accurate evaluation of collaboration, an evaluation model must be established. We proposed in Meléndez et al. (2018) a collaboration model that allows standardizing the experience capitalization. This model

facilitates the calculation of indicators in terms of collaboration and performance process from the perspective of the client's acceptance.

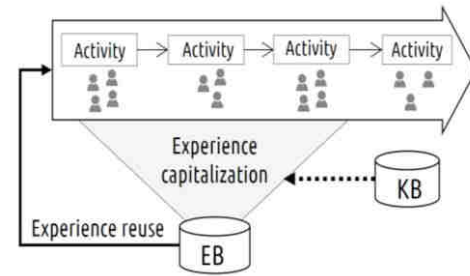


Fig. 2 Experience feedback process, Meléndez et al. (2018)

Fig. 2 shows the overall experience feedback process. It allows to capitalize experiences of collaboration during industrial processes realizations and to reuse them to define future collaborations. Fig.3 shows the experience model first proposed in Meléndez et al. (2018). It is a UML model composed of six types of entities (*Enterprise, Contract, Commitment, Requirement, Activity and Actor*) and seven types of relations between them (*involves, includes, requires, contributes to, takes part in, interacts with and employs*).

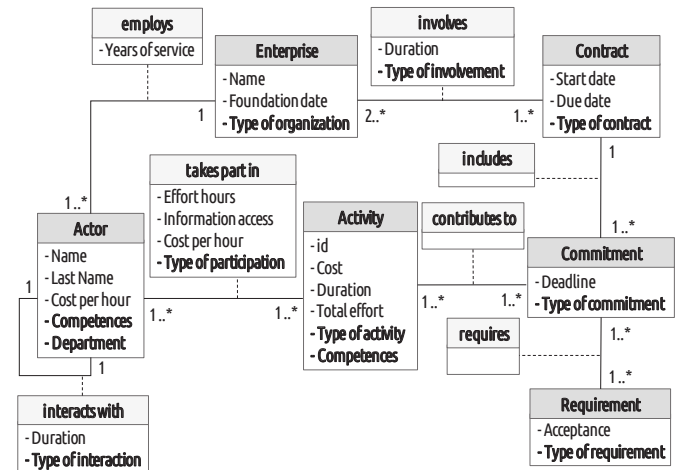


Fig. 3 Collaboration Model, Meléndez et al. (2018)

The collaboration experience building is based on this generic model. Every time an industrial process is realized, an instance of this collaboration model is created. It constitutes an experience which is stored into an experience base. Some attributes values are selected in a taxonomy. That permits: to standardize experiences and to facilitates the future retrieval of collaboration experiences from the experience base. The structure of the collaboration experience allows modeling the interactions of the actors in order to ask them their perception of collaboration throughout the activities of the process. On the other hand, the companies have to evaluate their satisfaction with respect to the satisfaction of the requirements which are gathered in the commitments. In the next section, the methodology which permits to evaluate the different performance indicators of an experience is described. In the rest of the paper, experiences are named "collaboration experiences".

4. COLLABORATION EXPERIENCE EVALUATION

In this section, the evaluation of experiences by means of collaboration and performance indicators is presented.

4.1 Evaluation of a collaboration experience

The evaluation of a collaboration experience is based on two parts: collaboration and overall performance. In order to evaluate them, a graph model is used (Fig. 4). It permits to represent the interactions between all the entities within the experience. For instance, in Fig. 4, three actors (a_1, a_2, a_3) are collaborating for the execution of two activities (A_1, A_2). They contribute to satisfying a commitment Com_1 (two requirements: r_1, r_2) recorded in a contract C_1 . The contract C_1 provides that E_1 and E_2 have to collaborate to reach Com_1 . The actors a_1 and a_2 are employed by the enterprise E_1 and a_3 is employed by E_2 .

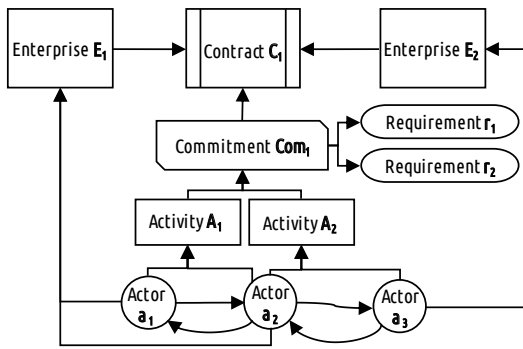


Fig. 4 Graph model of a collaboration experience

The experience evaluation is performed through the matrix representations of this graph (Fig. 4). Regarding the evaluation of collaboration, the elements to take into account are actors, activities and enterprises. On the other hand, the elements necessary to calculate the performance are the requirements, the commitments, the contracts and the enterprises.

4.2 Evaluation of collaboration

The collaboration is evaluated following three criteria: *communication, coordination* and *cooperation*, Fuks et al. (2005). The first step is the construction of matrices where the actors evaluate the performances of the other actors when they are collaborating with regard to each criterion. A matrix As_i is built for each activity A_i and for each criterion. In order to simplify, each actor can give a global note (between 0 and 1) for each criterion (communication, coordination and cooperation) for the whole set of activities. The value 1 means that the actor gives the best rating for the criterion. This rating is affected by the whole set of activities that constitute the industrial process. However, if an actor considers that some activities require a specific rating, she/he can evaluate them independently. The value 0 means that the rating is the lowest possible (negative evaluation) or that the actors have not collaborated with the actor. In the rest of the paper, the examples of matrices are given only for one

collaboration criterion. Then, an adjacency matrix between actors for each activity A_i has to be defined (matrix B_i). A matrix B_i identifies which actor collaborated with the other actors for the activity A_i . The Hadamard product ($As_i \bullet B_i$) permits to obtain the matrix C_i for each activity A_i (and for each criterion). The matrix C_i shows (for a criterion) the evaluation given by the actors who actually collaborated for each activity A_i (Fig. 5). It must be calculated for each criterion.

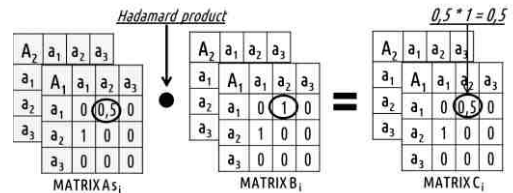


Fig. 5 Evaluations given by actors to other actors for activities A_1 and A_2 (for a collaboration criterion)

The next step is to calculate the overall evaluation considering that actors participated only to certain activities. The matrix C_i is multiplied by the participation matrix of each activity (matrix D_i : value 1 if an actor participates to the activity; 0 otherwise). The matrix D_i shows which actors participated in the activity A_i . The result is the matrix E_i that shows the overall group score given by each actor (for one collaboration criterion) for the activity A_i . Finally, the matrix F is built by joining the matrices of each activity (Fig. 6). It represents the evaluations given by the group of actors to the whole process (for one collaboration criterion).

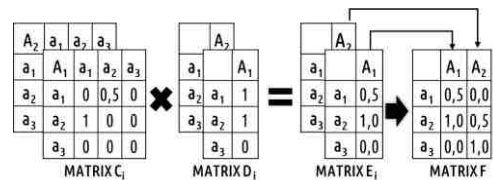


Fig. 6 Evaluation by the actors of the process

In order to obtain H , the evaluation matrix with the point of view of the enterprises, the matrix F is multiplied by G , the adjacency matrix enterprises/actors (matrix G : value 1 if an actor is employed by an enterprise; 0 otherwise). The matrix H (Fig. 7) shows the evaluation of collaboration (for one criterion) given by the actors employed by the enterprises for each activity of the industrial process. For example, for one collaboration criterion, the rating given by the actors of E_1 for collaboration in A_1 is 1.5.

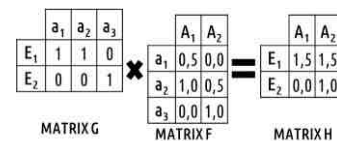


Fig. 7 Evaluation of collaboration by enterprises and activities (for one collaboration criterion)

Then, the adjacency matrix J (Fig. 8) between enterprises and activities (activity A_1 is performed by two actors of E_1 and A_2

by one actor of E_1 and one of E_2) is defined, it is obtained from the multiplication of the adjacent matrix between $A_i - a_i$ (matrix I) and the transpose of Matrix G. This allows obtaining the global collaboration evaluation between enterprises (Fig. 9) by multiplying H and J (matrix K).

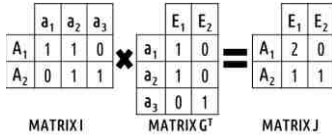


Fig. 8 Adjacency matrix between enterprises and activities

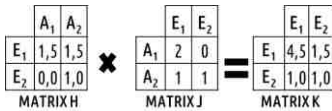


Fig. 9 Evaluation of collaboration between enterprises

In this example, the value 4.5 of cell K_{11} is the overall collaboration evaluation given by the actors of E_1 to the other actors of E_1 for one criterion. The value 1.5 of cell K_{12} is the overall collaboration evaluation given by the actors of E_1 to the actors of E_2 for one criterion.

4.3 Evaluation of performance

The process performance is calculated with the requirement's client acceptance level for each commitment. The requirements are evaluated on a scale from zero to one (low level to high level of acceptance). The matrix N_i represents the relationships between the requirements and the enterprises. For each commitment, it is obtained by multiplying the adjacency matrix contracts/commitments (matrix L_i) by the adjacency matrix commitments/requirements (matrix M_i) (Fig. 10).

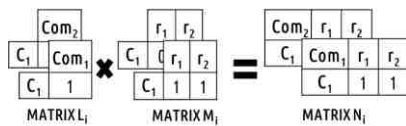


Fig. 10 Matrix contracts/requirements for each commitment

It allows calculating the matrix P_i which is obtained by multiplying the adjacency matrix enterprises/commitments O_i and the matrix N_i (Fig. 11).

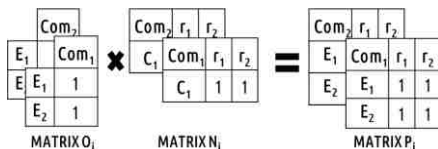


Fig. 11 Matrix enterprises/requirements for each commitment

The matrix P_i allows to identify which enterprise must evaluate which requirement for each commitment Com_i . The matrix Q_i is built with the evaluations given by enterprises (Fig. 12). The Hadamard product ($(P_i \bullet Q_i)$) ensures that the evaluations are only given by the enterprises participating in

the contract, for each commitment Com_i . For instance, in Fig. 12, E_1 has given a medium evaluation (0.5) to the satisfaction of r_1 in the commitment Com_i . The next step is to calculate the process performance between enterprises for each commitment (matrix W_i). In Fig. 13, the transposed matrix M_i is multiplied by the matrix R_i in order to obtain the evaluation performance matrix enterprise/ commitment (matrix S_i). The matrix S_i is multiplied by the adjacency matrix commitment/contract (matrix T_i) in order to obtain the matrix enterprise/contract (matrix U_i). The matrix U_i is multiplied by the adjacency matrix contract/enterprise (V_i) in order to obtain the evaluation performance matrix enterprise/enterprise for each commitment Com_i (matrix W_i).

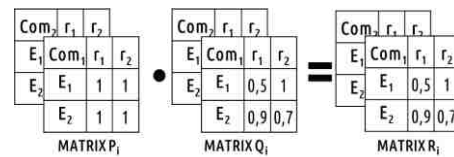


Fig. 12 Evaluation of requirements by enterprises for each commitment Com_i

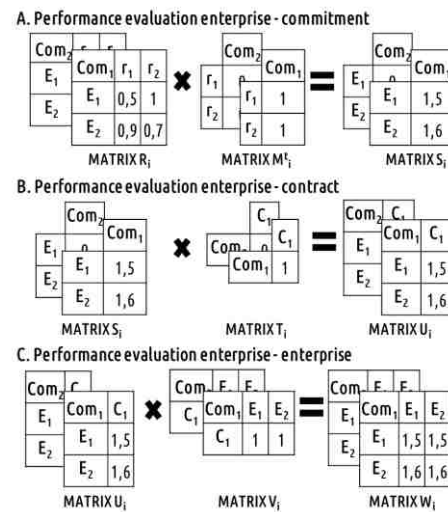


Fig. 13 Performance evaluation by the enterprises for each commitment Com_i (Matrix W_i)

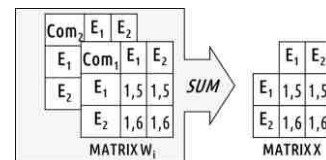


Fig. 14 Calculation of global performance

The overall performance matrix is obtained by adding all the evaluation matrices for all the commitments (Fig. 14). Once the collaboration and performance matrix 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 (Fig. 15 - Part B) by the final matrices of the best possible results (Fig. 15 - Part A) for each collaboration criterion. The best possible results

are obtained when all the evaluations given by actors and enterprises take their maximum value (see the dashboard of Fig. 15). Fig. 16 shows an example of the relative dashboard for an experience of collaboration.

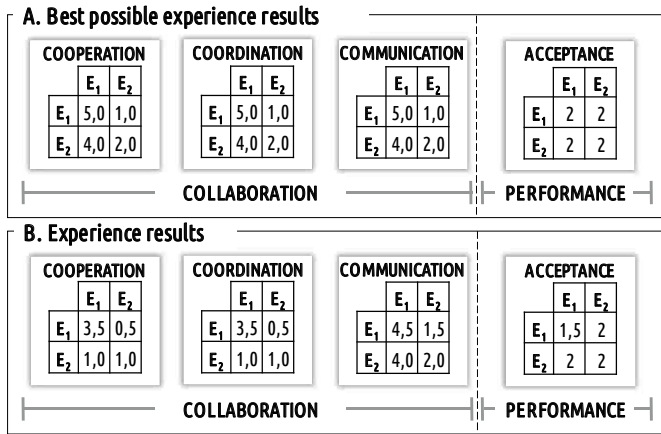


Fig. 15 Collaboration and performance dashboard

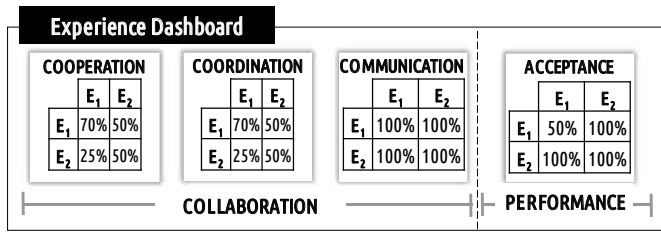


Fig. 16 Experience dashboard

5. ILLUSTRATIVE APPLICATION

In this section, an illustrative application inspired by a real industrial consulting process is presented in order to illustrate the concepts presented above.

5.1 Graph definition

The industrial process is a standard process of consulting in the domain of lean management. Fig. 17 shows the experience graph of the process. Three companies E_1 , E_2 and E_3 participated contractually (C_1) in the execution of the process with two objectives. The first one was to carry out an action plan to reduce the lead-time of the industrial operation by at least 10% (Com_1). The second one was to provide a time and motion study of the industrial process (Com_2). For Com_1 , two requirements were identified: calculation of ROI (r_1) and reduction of at least 10% of lead-time (r_2). For the commitment Com_2 , one requirement was identified: to analyze the percentage of the Total Cycle Time that is a function of Non-Value-Added operations (r_3).

In order to accomplish the commitments, four activities were defined: analysis of historical process data and organization (A_1), process mapping (A_2), definition of the Action Plan (A_3) and time and motion study (A_4). Fig. 18 shows the interactions between actors for each activity of the industrial process. In this process, five actors participated as follows:

$\{a_1; a_2; a_3; a_5\}$ participate to A_1 ; $\{a_1; a_2; a_3\}$ participate to A_2 ; $\{a_1; a_3; a_4; a_5\}$ participate to A_3 and $\{a_2; a_3\}$ to A_4 .

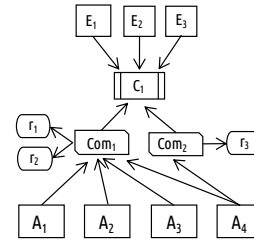


Fig. 17 Graph experience between the nodes "enterprises" down to the nodes "activities"

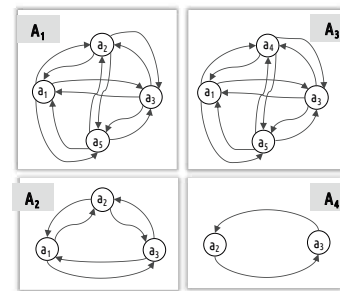


Fig. 18 Actor interactions in process activities

Finally, Fig. 19 shows the relations between actors and enterprises. In this experience, actors a_1 and a_2 are employed by E_1 , actors a_3 and a_4 are employed by E_2 and actor a_5 is employed by E_3 .

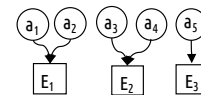


Fig. 19 Connexion between actors and enterprises

5.2 Collaboration and performance evaluation

The experience graph allows to define the evaluation matrices corresponding to this experience of collaboration in terms of collaboration and performance. The three criteria communication, cooperation, coordination are used.

	a_1	a_2	a_3	a_4	a_5
a_1	0,0	1,0	0,6	0,5	0,7
a_2	1,0	0,0	0,7	0,7	0,7
a_3	0,4	0,8	0,0	1,0	1,0
a_4	0,4	0,8	1,0	0,0	1,0
a_5	1,0	1,0	1,0	1,0	0,0

COMMUNICATION

	a_1	a_2	a_3	a_4	a_5
a_1	0,0	1,0	0,6	0,5	0,7
a_2	1,0	0,0	0,8	0,7	1,0
a_3	0,6	0,8	0,0	1,0	1,0
a_4	0,4	0,7	1,0	0,0	1,0
a_5	1,0	1,0	1,0	1,0	0,0

COOPERATION

	a_1	a_2	a_3	a_4	a_5
a_1	0,0	1,0	0,6	1,0	0,7
a_2	0,5	0,0	0,7	0,7	0,2
a_3	1,0	0,8	0,0	1,0	0,3
a_4	1,0	0,4	1,0	0,0	0,4
a_5	1,0	1,0	1,0	1,0	0,0

COORDINATION

Fig. 20 Experience evaluation inputs of communication, cooperation and coordination

The actors were asked about their perception of three collaboration criteria (cooperation, coordination and communication) throughout the process (Fig. 20). They evaluated all the other actors.

Com ₁	r ₁	r ₂	r ₃	Com ₂	r ₁	r ₂	r ₃
E ₁	1,0	0,9	0,0	E ₁	0,0	0,0	0,7
E ₂	0,9	0,8	0,0	E ₂	0,0	0,0	1,0
E ₃	1,0	1,0	0,0	E ₃	0,0	0,0	1,0

Fig. 21 Evaluation of requirements acceptance for each commitment by the three enterprises

Furthermore, the acceptance given by each company for each commitment was registered (Fig. 21). Taking into consideration the experience graph and the evaluations of acceptance and collaboration criteria, the experience dashboard is calculated (Fig. 22).

COOPERATION				COORDINATION			
	E ₁	E ₂	E ₃		E ₁	E ₂	E ₃
E ₁	77%	74%	73%	E ₁	82%	79%	80%
E ₂	75%	77%	79%	E ₂	77%	80%	81%
E ₃	100%	100%	100%	E ₃	100%	100%	100%

COMMUNICATION				ACCEPTANCE			
	E ₁	E ₂	E ₃		E ₁	E ₂	E ₃
E ₁	64%	63%	62%	E ₁	87%	87%	87%
E ₂	76%	78%	75%	E ₂	90%	90%	90%
E ₃	100%	100%	100%	E ₃	97%	97%	97%

Fig. 22 Dashboard of industrial case in aeronautical industry

The experience dashboard shows the evaluation of cooperation, coordination and communication given by the actors of an enterprise to the actors of the other companies with whom they interacted in the different activities. In addition, the evaluation is also given for the actors of the same company (intersections E₁/E₁, E₂/E₂ and E₃/E₃).

As shown in Fig. 22, the first row of the cooperation matrix is the evaluation given by the actors of E₁ among themselves and to the actors of E₂ and E₃. This evaluation is measured on a scale from 0% to 100%, with 100% indicating a high level of perceived cooperation and 0% indicating a low level of perceived cooperation. In the experience dashboard, the results concerning the perceived cooperation by actors employed by E₁ are 77% about themselves, 74% with regard to the actors of E₂ and 73% with regard to the actors of E₃. The interpretation is the same for coordination and communication results. As for the process performance, it was calculated by evaluating each commitment's requirements provided by each company as shown in Fig. 21. This evaluation is afterward measured on a scale from 0% to 100%, with a score of 100% representing total customer satisfaction. In this case, E₁ to E₂ and E₃ evaluate the same requirements, this is due to the graph structure with a single contract. Evaluations between enterprises may be different if the process involves two or more contracts. Finally, the results in Fig. 22 can be used as a basis for recommending or not a future collaboration, e.g., if the score is less than 50%, a future collaboration with similar characteristics is not recommended.

6. CONCLUSION

Previous work has proposed a collaboration model based on the execution of process activities where actors collaborate in order to reach the process commitments, Meléndez et al. (2018). In this article, a collaboration evaluation methodology for experience capitalization has been proposed to analyze the collaboration and the performance throughout an industrial process. This methodology evaluates the experience collaboration in three dimensions: communication, cooperation and coordination. Furthermore, the methodology includes the evaluation of acceptance requirements in order to calculate the process performance. Finally, an experience dashboard is proposed in order to formalize the experience results and capitalize them for later reuse. An industrial case study involving the collaboration evaluation methodology for a consulting process in aeronautical sector was used to demonstrate how this methodology can be used to evaluate the collaboration and performance of enterprises that participated in the process execution. This work describes a framework for the development of a collaboration evaluation methodology for experience capitalization in industrial process. Nevertheless, more work needs to be done on the experience feedback process. From a set of collaboration experiences stored in the experience base, it is necessary to define methods which will permit to exploit them. Our goal is to propose tools that will allow to define best collaborations between enterprises and actors with regard to a set of new commitments to reach.

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