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Characterisation of collaborative decision making processes

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This paper deals with the collaborative decision making induced or facilitated by Information and Communication Technologies (ICTs) and their impact on decisional systems. After presenting the problematic, we analyse the collaborative decision making and define the concepts related to the conditions and forms of collaborative work.

Then, we explain the mechanisms of collaborative decision making with the specifications and general conditions of collaboration using the modelling formalism of the GRAI method. Each specification associated to the reorganisation of the decisional system caused by the collaboration is set to the notion of decision-making centre.

Finally, we apply this approach to the e-maintenance field, strongly penetrated by the ICTs, where collaborations are usual. We show that the identified specifications allow improving the definition and the management of collaboration in e-maintenance.

Keywords: collaborative decision making, ICTs (Information and Communication Technologies), maintenance, e-maintenance.

1. Introduction

This paper outlines the collaborative decision making supported by Information and Communication Technologies (ICTs). We study the decision making mechanisms when collaboration between actors is needed in order to define collaboration modes and their creation conditions.

In the current economic context where companies must continuously improve their performance, while having less and less time to react and make choices, decisions:

- become increasingly complex,
- concern all decisional levels at the organisation,
- require more and more high volume of information and knowledge.

The use of ICTs tools such as personal computers, PDAs (Personal Digital Assistant), Internet and Intranet access..., that allow to access and exchange of all type of information is one solution implemented to answer to these companies' requirements. Thanks to an easy access to more information and many communication channels and forums, the actors can collaborate, share and increase their knowledge and so, improve their decision making.

ICTs have strongly modified the companies functioning introducing new concepts such as e-service, collaborative work, sharing of knowledge... and involving many changes in the organisation and the functioning of the underlying decisional systems.

The introduction of ICTs within an organisation offers the possibility for the actors to collaborate and communicate and it can produce redeployments of missions or powers, changes of the current balances..., leading positive or negative effects.

In this context, we discuss new results on the mechanisms of creation and functioning of collaborative decision making with ICTs tools. New characteristics about the creation, the functioning and the performance of collaboration in organisations are proposed in this paper in order to guarantee the progress of collaboration in an existing organisation.

Collaborative decision making mechanisms can occur in various contexts: design in concurrent engineering (*Pol et al*, 2007), management of supply chains, collaborative manufacturing (*Wang*, 2009), maintenance organisations... In maintenance – in most cases – the interventions occur in an emergency context (failure, accident, production breakdown) involving rough constraints for the creation and the execution of collaboration. A sharing of knowledge from different areas is often required to carry out maintenance interventions (computer and mechanic, for example). This pooling of knowledge often leads to collaboration. We have chosen this maintenance area and the e-maintenance field to illustrate our developments although the corresponding results are generic and transposable to other situations like new product development that require the collaboration of several skills.

The paper is divided in four main sections.

Section 2 contains a short presentation of the studied mechanisms of collaborative decision making. A literature review of existing works compared to our approach is also proposed. In section 3, an analysis is carried out by an identification of the main characteristics of these collaboration mechanisms. The purpose of this analysis is to help the progress of collaboration and to contribute to the idea that collaborations are beneficial to the organisation. Then, in section 4, an application of our analysis of a collaborative situation is proposed in the e-maintenance field. Finally, some conclusions and prospects of this work are expressed.

2. Collaborative decision making and ICTs

In an organisation, ICTs can affect all organisational levels and change the environment of decision makers and actors by:

- an enrichment and improvement of information, skills and expertise,
- an expansion of action zones,
- the feasibility of remote work.

ICTs can help decision making by allowing actors an easier access to remote and relevant information and knowledge. The creation of ad hoc collaboration is made possible by ICTs, in order to improve decision making and to act remotely on properly instrumented processes.

These changes can affect:

- the amount of information to consult and / or to treat,
- the volume of communications and exchanges,
- the relations between actors,
- the frequency of solicitations.

Before analysing in depth the impacts of ICTs, we are going to define the mechanisms of collaborative decision making.

2.1 Definition of decision

In the literature, there are several definitions of the term “decision”.

For (*Rey-Debove & Rey, 2004; Office of Quebec, 2008*), decision is "the action to decide, to judge, to adopt a final conclusion on a dispute point or to choose a solution in response to a problem". Kast proposes a more precise definition of the term, synonymous with "choice between several existing options, each with different consequences, the choice being made according to specific criteria of selection" (*Kast, 1993*).

The decision is often a complex activity for which ICTs may have different effects. If we consider, for example, the decision making process defined by Simon (*Simon, 1960*), ICTs can help:

- to search information on the problem to be solved,
- to design possible solutions,
- to evaluate different solutions and to choose among them,
- to control the implemented decision.

2.2 Collaborative work and collaborative decision making

Collaborative work can be considered as "an activity of a group of actors working together, with a common goal, sharing resources and communicating". Several forms of collective works exist (*Winer & Ray, 1994; Lubich, 1995; Kvan, 2000*):

- cooperation: a simple juxtaposition of individual and sporadic activities, without sharing an objective,
- collaboration: shared production and shared objectives, where each actor performs a part of the work with resources, benefits or risks sharing,
- codecision: a joint decision following the involvement of several actors with sharing resources and goals, and where each actor is involved in the decision making.

In our work, we consider the collaborative decision making as "the realization of a set of activities by a group of actors working together and sharing a common objective and resources, an activity leading to a decision" (*Seguy, 2008*).

Collaboration modes can be differentiated according to space criteria (local or remote collaboration) and time criteria (synchronous or asynchronous collaboration) (*Schmidt, 1990; Rodden, 1991*).

In this article, we focused on the synchronous and remote collaboration, which could evolve to an asynchronous and remote collaboration in case of temporary unavailability of one of the actors.

2.3 Decision's modes

Collaborative work can lead to different decision making situations according to the geographical situation of the actors and to the collaborative conditions. These situations depend on the actor's decision power, the actor's knowledge and the activity's degree of complexity.

Three collaborative decision cases can be distinguished:

- local decision: the local actor keeps his decision making power. After consulting remote actors or databases, he is the only one to decide,
- external decision: the local actor transfers the decision making power to a remote actor; the decision is not made by the local actor but by another remote actor, distant from the action site,
- multiactor decision: several actors (local and remote) work together and share their knowledge to make a joint decision.

The distinction between local decision and external decision is related to the fact that in the first case, the e-service contributions are just a way to strengthen the local actor decision, while in the second case, it is a true decision transfer to another actor with another decision frame.

These situations are detailed in section 3, with particular attention to the last situation "multiactor decision" which requires special conditions for a correct implementation of the collaboration.

Before presenting the detailed multiactor decision, a short bibliographic part is presented to compare and position our approach in relation to existing works.

2.4 Literature review

In this paper, we propose an analysis of collaborative works and we specify the criteria for collaborative work. The activities of collaborative decision making are complex, like presented in the last part. This is the reason why, we think it is important to specify in detail the realization conditions of collaborations in order to help collaborative processes and to guarantee the performance of the processes.

Before the presentation of our work, we have analysed the literature to compare existing works to our approach and to show the specificity and the contributions of our work. We can notice here that concerning this matter, few works can be compared to ours. However, some research fields and some works can still be presented here.

An important field of collective works is led in design, with the design of new products, the management of designer's teams, the project management... (*Girard & Robin, 2006; Zha & Du, 2006; Chen & al, 2008; Keeney, 2009; Movahed-Khah & al, 2010*). In this field, some works are at the intersection with the knowledge management field and deal with the formalization and the reuse of knowledge developed for a design project (*Robin & al, 2007*). In this article, the authors present a modelling of collaborative knowledge in order to help the management of design project. In this purpose, a modelling of collaborative process is proposed; the process is decomposed in several steps and also there is a description of the collaborative exchanges and their context. The aim of this work is to specify all the elements characterizing a collaborative process, knowledge included, in order to more specify and more manage the design activities.

Other field where collective works are studied and where there are management solutions of collective works is the supply chain management and the virtual enterprise (*Galasso & Thierry, 2009; Mo & al, 2003; Camarinha & Afsarmanesh, 2007*). In (*Camarinha & Afsarmanesh, 2007*), the authors propose a modelling framework of a collaborative organisational network. This model is positioned at a too macroscopic level, so that it is not operational for the success of collaborative work within organisations.

In the literature, there are some works on models of networks or of collaborative organisations, but no proposition about conditions to be met in order for collaboration to be conducted properly and be beneficial to the organisation.

The aim of collaboration is to help the organisation to improve its performance. To this end, it seems necessary to propose an analysis of collaborative processes in order to define some characteristics ensuring that collaboration goes smoothly. In our work, we have similar objectives to the ones of Robin 07, related to the characteristics and specifications of collaborative processes. The analysis proposed aims at formalizing the different stages of development, progress and ending of a collaborative process in order to supervise and to improve the occurrences of collaboration within an organisation. These characteristics can be used for reorganisation or daily management of each collaboration. We place this work at an operational level of a decisional organisation.

3. Collaborative decision making analysis

The mechanisms of collaborative decision making can be analysed from general terms to conditions of collaboration. For this purpose, we take the modelling of the decisional system and the decision centre as physical support of the decision making in an organisation.

3.1 Basic representation: decision centre

The concept of a decision centre (DC) was defined in the GRAI method (*Doumeingts & al.* 1998; *Roboam & Pun*, 1989) to model the decisional system of an organisation (*Chen & al.*, 1997). We expose then this DC concept and some modifications that we brought there.

A DC is a "set of activities with the same horizon and same period, having to be executed following the same set of objectives given by a single decision frame" (*Doumeingts & al.*, 1978).

A DC can be associated to a time management in terms of (*Roboam*, 1993):

- horizon: time interval considered to construct the decision,
- period: validity duration of the decision.

A DC is composed of a decision frame defined by a higher hierarchical DC, the objectives to achieve and the constraints to respect (*Doumeingts & al.*, 1978).

Then, a DC receives information of follow-up and coordination of follow-up from upstream and downstream DCs. A DC can also receive information of synchronization from a DC belonging to the same decisional level.

These definitions are completed by Marcotte (*Doumeingts & al.*, 1995) with the integration of decision variables and selection criteria available for the DC.

Using GRAI formalism, we have extended the modelling principles of a decision centre (DC) (*Seguy & al.*, 2009) in order to lead to the formalism proposed in Figure 1. Some new labels are adopted:

- a mission frame: all the characteristics defining the DC mission,
- a decision frame: all the resources associated to the DC.

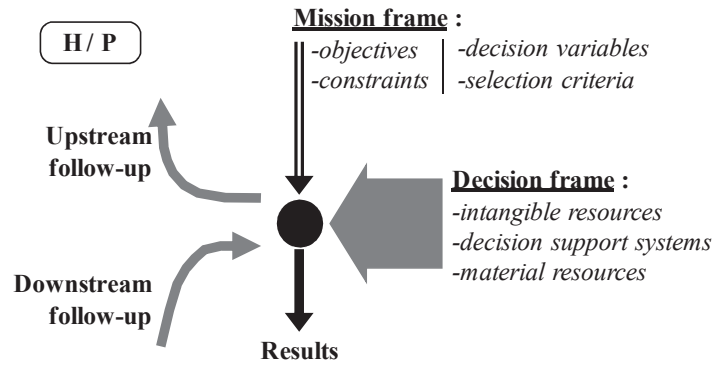


Figure 1. Modelling of a decision centre

In this way, a DC is made up of:

- a mission frame for bringing together the items that the DC receives from the upstream DC in terms of objectives, constraints, decision variables and selection criteria,
- a decision frame composed of all tangible and intangible resources (informational and human) whose decision centre has to achieve its mission,
- results that represent the production of the decision centre to the downstream decision centre(s),
- a downstream follow-up which is the information from the downstream decision centre(s),
- an upstream follow-up which is the feedback given to the upstream decision centre(s),
- the time management with the horizon and period (H / P) which depends on the decisional level associated to the DC.

The instrumentation of a DC with ICTs tools can lead changes in its characteristics:

- reinforcement of the decision frame: contributions of remote information, knowledge..., increase of processing capacity...,
- improvement of upstream and downstream follow-up and communication,
- modifications, often not scheduled, of the mission frame with changes of relationships with surrounding DC (upstream, downstream or even of the same decisional level).

3.2 Reorganisation principle

An analysis of the collaborative decision making is proposed using this representation of a DC. We consider that the collaboration of DC leads to bring together the DCs and so, to create a collaborative decision centre (CDC) according to the principle presented in Figure 2.

In Figure 2, the reorganisation principle of DCs is presented when there is DCs collaboration via ICTs tools, in case of a multiactor decision (see section 2.3). The grouping of DCs (DC_1 and DC_2) involved in the collaboration led to the creation of a collaborative decision centre (CDC) which decisional characteristics (mission frame, decision frame,...) are deduced from those of two grouped DCs and mission dedicated to the collaboration established by the original DC (DC_0). This

reorganisation induces some changes in the initial decisional system, which can be more or less important.

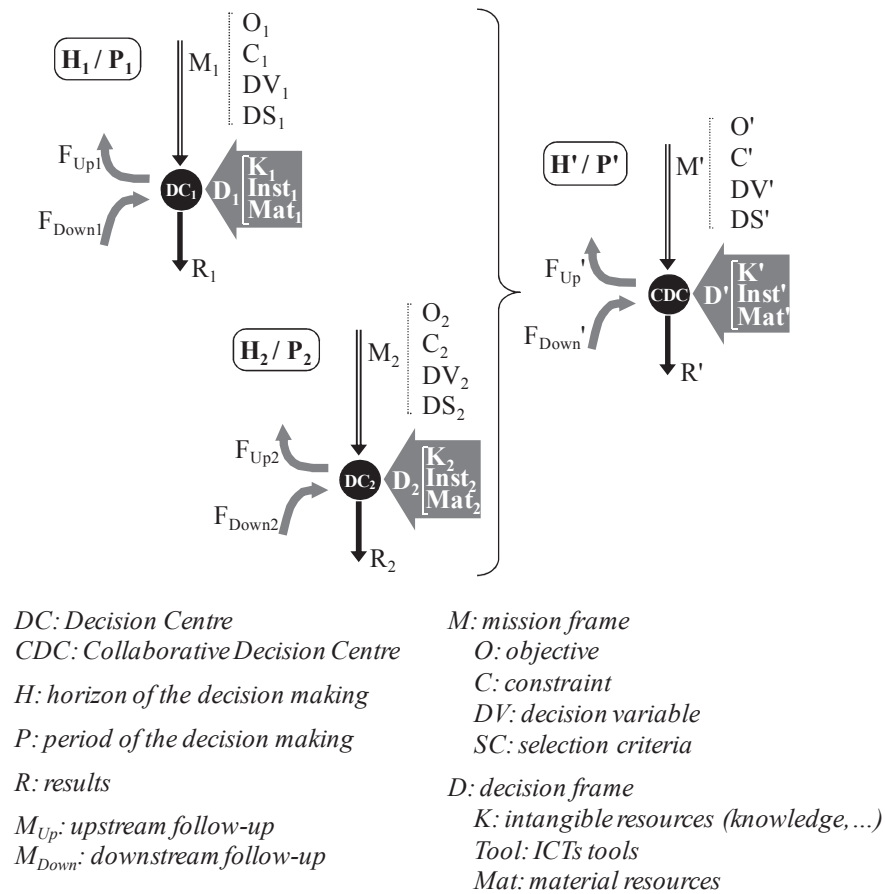


Figure 2. Reorganisation principles

Before the collaboration, each DC (DC₁ and DC₂) has its own decisional characteristics (mission frame, decision frame). The mission frame has often a common part with a higher hierarchical DC.

After the grouping, the created CDC has its own characteristics and decision rules which must reflect the mission to achieve, the consistency of the CDC working and its integration into the initial decisional system.

The connexion of DCs corresponds to a set of relationships relating the characteristics of the initial DCs (DC₁ and DC₂) and the mission dedicated to the collaboration (M₀) to the characteristics of CDC resulting from the collaboration.

The CDC characteristics can be formalized with the following mathematical relationships:

- the mission frame $M' = f(M_0, M_1, M_2)$ divided into:

$$O' = f_1(O_0, O_1, O_2)$$

$$C' = f_2(C_0, C_1, C_2)$$

$$DV' = f_3(DV_0, DV_1, DV_2)$$

$$SC' = f_4(SC_0, SC_1, SC_2)$$

- the decision frame $D'=g(D_1,D_2)$ divided into:
 - $K'=g_1(K_1,K_2)$
 - $Tool'=g_2(Tool_1,Tool_2)$
 - $Mat'=g_3(Mat_1,Mat_2)$
- the results: $R'=h(R_0,R_1,R_2)$
- the follow-up:
 - upstream follow-up: $F_{up}'=j(F_{Up0},F_{Up1},F_{Up2})$
 - downstream follow-up: $F_{Down}'=k(F_{Down0},F_{Down1},F_{Down2})$
- time management with the horizon / period:
 - horizon: $H'=f(H_0,H_1,H_2)$
 - period: $P'=f(P_0,P_1,P_2)$

These decisional characteristics have been defined independently as proposed in the GRAI method, the basis of our approach. These characteristics are nevertheless related and cannot be understood separately, like it is shown in the approach developed in the following paragraphs.

In the GRAI method, a DC is associated to a decisional level (same horizon and same period) and carries out activities having the same horizon and period. The CDC must also respect this GRAI rule and has a horizon and a period according to the mission of collaboration and to the DCs which collaborate.

3.3 Collaborative decision making specifications

To study thoroughly the formation of a CDC, different configurations of collaboration have been explored and we have identified the key characteristics of collaboration of DCs conditioning the creation and the life of a CDC.

3.3.1 Global frame

The prerequisite for any collaboration is the definition of the global frame of this collaboration.

The creation of a CDC must be authorized and approved by an upstream DC or a higher hierarchical DC. For every DC of the lower level, the higher hierarchical DC must define:

- the grouping methods: communication channel, protocols...
- the missions that can be processed by a CDC,
- the allowed freedom degrees to facilitate the decision making,
- the DCs with which it is possible to collaborate and their characteristics,
- the validity of the CDC duration: limited in response to a special need or sustainable in response to a durable need.

This authorization to collaborate may be:

- decided by a higher hierarchical DC to improve performance of lower DCs,

- induced by strategic decisions of the management to change the engagement and the management of human resources.

In addition, this authorization may concern:

- a one-time activity whose occurrence date can be expected or unexpected,
- a periodic activity requiring regular collaboration.

The creation of a CDC, while within the general frame, can be planned or unplanned and in this case unexpected.

This general frame of the mission is defined with the same characteristics as the mission frame, with objectives, constraints, selection criteria and decision variables.

3.3.2 *Decision rules*

Decision rules of the work and the consistency of DCs involved in the collaboration, from GRAI (*Roboam*, 1993), must be respected when defining the general frame.

Some of the GRAI rules to respect and having a high value in the creation of a CDC are presented here:

- any DC should receive only one mission frame; in case where there are several, it must verify that they have a common origin,
- two DCs can share a common objective, provided that they have a higher DC which coordinates them, i.e. which define the priorities on the objectives and which synchronizes the decisions concerned with these objectives,
- to be synchronized, two DCs which share common decision variables must receive of a higher hierarchical DC, a decision frame that defines possible areas of this decision variable for each two DCs.

It will be necessary to check that these rules are or will be respected by the mission frame of the upstream DC or when the general frame of collaboration is established by a higher hierarchical DC.

3.3.3 *Initial need*

The both origin of the collaboration and the CDC creation is a "trigger element"; this is the key element of the collaboration that will define the mission frame dedicated to the collaboration in terms of objectives, constraints...

This need can have several origins:

- an upstream origin: the upstream DC expects from the concerned DC to collaborate with other DC for a specific mission,
- a downstream origin: the concerned DC asks to its upstream DC the authorization to collaborate with another DC for a mission that it cannot achieve alone because this mission is out of its decision frame or of its mission frame (need for knowledge or decision resources from other decision frames...).

Following the need occurrence, a CDC is created according to the general frame, which is sufficient to realize the current mission with the mission frame and the decision frame.

The mission frame dedicated to the collaboration is defined to specify the collaborative mission with the objectives, constraints, decision variables and selection criteria based on the need to collaborate.

In the case of an upstream origin, the DCs must consider the decisional characteristic like defined by the upstream DC. In the case of a downstream origin the characteristics to consider are those defined by the downstream DC having required the need to collaborate. The DCs who collaborate should also consider the characteristic defined in their global mission frame and their authorization to work together.

Generally, in the case of an upstream origin, the DCs constituting the CDC are from lower hierarchical levels. In the case of a downstream origin, they belong to a higher hierarchical level or to two different levels.

3.3.4 Typology of DCs groupings

The last CDC characteristic is the type of grouping having led to the creation of a CDC.

The CDC depends on the positioning of the DCs which collaborate in the initial decisional system and on the interrelationships between DCs (belonging to a same decisional system, decisional level and the hierarchical link between collaborating DCs).

We have analyzed various possible situations of collaboration between DCs of an organisation (Figure 3). To do this, we have considered an organisation composed of several decisional structures as, for example, the maintenance function (decisional system A) and production or an external customer (decisional system B).

In this generic context, we identified four grouping types R_i , presented in Figure 3:

- grouping R_1 : two DCs owned different decisional systems, without a direct link and without (necessarily) belonging to the same decisional level,
- grouping R_2 (similar to R_1): two DCs with no direct link but belonging to the same decisional system,
- grouping R_3 : collaboration of two consecutive DCs of the same decisional system; these two DCs are so-called in series,
- grouping R_4 : collaboration of two DCs belonging to the same decisional level and with the same upstream DC; these two DCs are so-called in parallel.

The four groupings can be achieved at different decisional levels from the operational level to the strategic level.

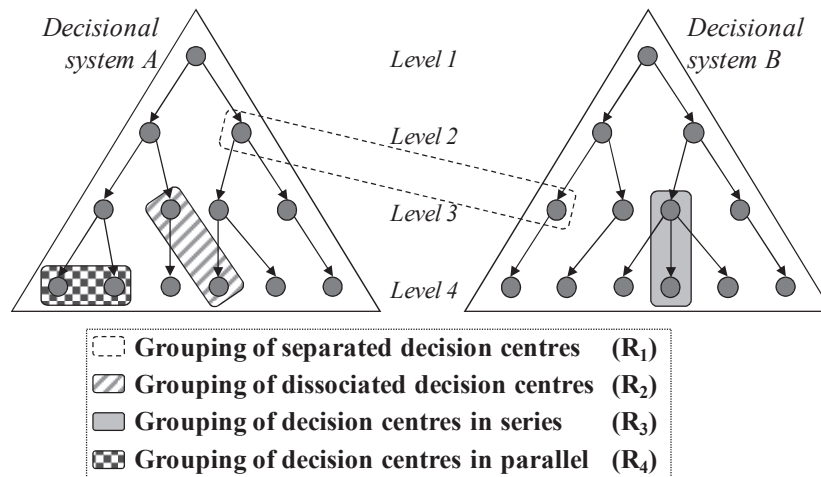


Figure 3. Typology of collaborations

Let us consider two services of a manufacturing company to illustrate these forms of groupings:

- a maintenance service made up of a head of department (MH), supervisors (MS) and maintainers (M_j) (cf. Figure 4-a)
- a purchase service made up of a purchase responsible (PR) and purchasers P_k (cf. Figure 4-b).

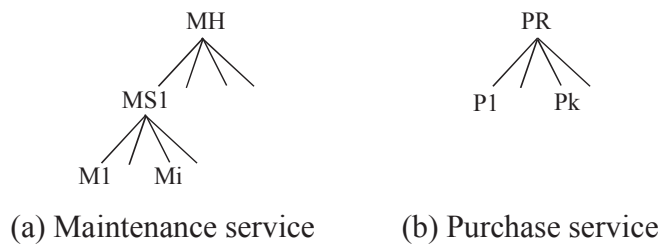


Figure 4. Example of collaborations (a. Maintenance service - b. purchase service)

Both services have many reasons to collaborate. We propose in Table 1 an example of collaboration for each form of regrouping based on this maintenance and purchase services context.

Type	Trigger	Actors	Collaboration grounds
R_1	Development of the estimated budget for the purchase of spare parts	Head of department maintenance (MH) and purchase responsible (PR)	Development of a total order to reduce: the costs (economy of scale) out-of-stock conditions but possibility of increasing the delivery periods because of synchronization of orders
R_2	Near to the R_2 grouping: the principal distinction is related to the choice of the level of abstraction leading or not to a common root		
R_3	Development of the requirements in spare parts for the next period	Supervisor (MS) and maintainer (M_j)	Development of the requirements while integrating: <ul style="list-style-type: none"> - forecasts of consumption compared to the state of the equipment, - the current state of stocks, - the needs for the other maintainers

			under the responsibility of the supervisor.
R ₄	Development of an order relating to a electromechanical complex subset	Specialized mechanical maintainer (M ₁) and specialized electrical maintainer (M ₂)	Specification of the design features of the complex subset and the expected level standard

Table 1. Example of grouping types R_i

3.3.5 Persistence of the initial mission frames

After creating a CDC, DCs mission frame may suffer more or less important changes. The achievement of the overall mission of the CDC may become the single mission of a DC or be only a part of it. Thus, the collaborative DCs can keep or lose their previous missions.

The items (objectives, constraints, decision variables and selection criteria), composing the mission frame of CDC, depend directly on the work to carry out and therefore depend on the collaboration origin:

- in the case of an upstream origin, the DCs must consider the elements as defined by the upstream DC,
- in the case of a downstream origin, the items to consider are those defined by the downstream DC which has stated the need to collaborate. However, in this case, the integrated DC must also consider the elements set out in the overall mission frame, which allow or do not allow to collaborate.

We can note that these items may go out of the overall mission frame of the DC included in the CDC, which may affect the quality of the results.

The keeping or the disappearance of initial mission frames also depends on the duration of the collaboration:

- punctual collaboration: the DCs keep their initial mission frame and the collaborative mission is just added to it. The achievement of this mission leads to the disappearance of CDC temporarily created,
- durable collaboration: it is necessary to redefine the mission frame of the DC with the initial and collaborative missions. This change may lead to the disappearance of one of the DCs of the decisional system.

3.3.6 Horizon and period of the CDC

The time management of the CDC (horizon and period of the decision making) depends on the general frame of collaboration and the initial need of collaboration.

The horizon, corresponding to the duration of the decision construction, is associated with the CDC and may be defined:

- by the upstream DC, which is the origin of the collaboration (to the DC of its decisional level or of one of the collaborating DCs) and may correspond to the largest horizon of the collaborating DCs,

- by the downstream DC, which is the origin of the collaboration and can force other DCs involved in the collaboration (which can be of a higher decisional level) to respect its own horizon.

The period corresponds to the validity duration of decisions taken by the CDC. Similarly to the horizon, the period depends on the collaboration origin and can be defined:

- by the upstream DC in the case of an upstream origin,
- by the downstream DC in the case of a downstream origin and may correspond to the shortest period of the collaborating DCs.

Moreover, depending on the missions and on the DCs involved, the horizon and the period may correspond either to operational (close to real time) or strategic (long term) decision levels.

3.4 Specifications of the decisional characteristics of the CDC

Now, we can consider all the cases of DCs groupings for the CDC creation in a decisional system, with the elementary types of grouping (R_i) and the general characteristics of a CDC.

To illustrate our analysis, we consider the collaboration of several DCs and define the characteristics of the DCs involved in the collaboration (initial DCs and CDC). The using notation is the following:

- X' : characteristic X related to the CDC (global),
- X_{O-Up} : characteristic X related to the upstream DC, origin of the collaboration,
- X_{O-Down} : characteristic X related to the downstream DC, origin of the collaboration,
- X_1 or X_2 : characteristic X related to the collaborating DCs with the original DC,
- X_{High} : characteristic X related to the higher hierarchical DC.

A need to collaborate implies the collaboration of two DCs, responding to the request of the original DC and leading to the creation of a CDC. In Figure 5, we distinguished the two types of initial need of collaboration defined in section 3.3.3: upstream origin (Figure 5-a) or downstream origin (Figure 5-b).

Some details of the main decisional characteristics of DCs involved in collaboration and of the CDC for the two cases of initial origin (see Figure 5) are presented in Table 2.

The mission frame is defined by the global frame of collaboration and depends on the collaboration origin. For a downstream origin, the authorization to collaborate is established by a higher hierarchical DC with the higher mission M_{High} .

Whatever the collaboration origin, the initial DCs (DC_1 and DC_2) have pooled and share their own decisional characteristics. These characteristics are complemented with those dedicated to the collaboration of the mission frame defined by the original DC and authorized by a higher hierarchical DC.

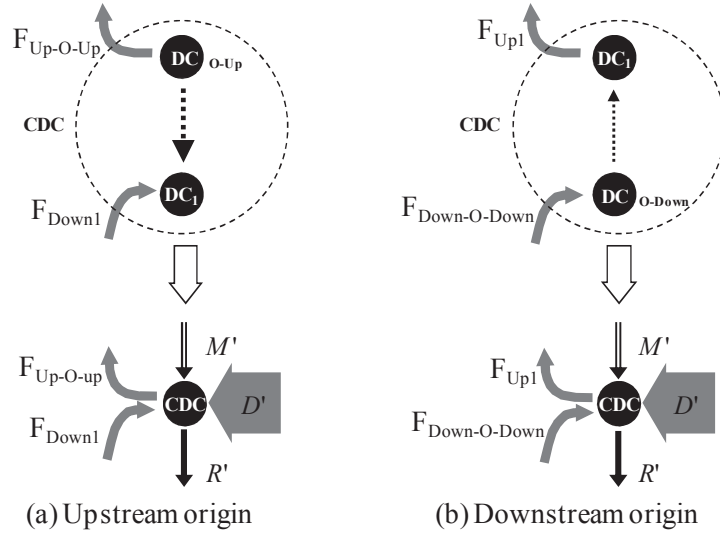


Figure 5. Two types of initial origin of the collaboration (a. Upstream origin - b. Downstream origin).

	<i>Upstream origin</i>	<i>Downstream origin</i>
Mission frame	$M' = M_{O-Up}$	$M' = M_{O-Down} \cap M_{High}$
Horizon / period	$H' = \max(H_1, H_2) \text{ ou } H_{O-Up}$ $P' = \min(P_1, P_2) \text{ ou } P_{O-Up}$	$H' = H_{O-Down}$ $P' = P_{O-Down}$
Decision frame	$D' = D_1 \cup D_2 \cup D_{O-Up}$	$D' = D_1 \cup D_2 \cup D_{O-Down}$
Results	$R' = R_1 \cap R_2 \cap R_{O-Up}$	$R' = R_1 \cap R_2 \cap R_{O-Down}$
Upstream follow-up	$F_{Up}' = F_{Up-O-Up}$	$F_{Up}' = F_{Up1} \cup F_{Up2}$
Downstream follow-up	$F_{Down}' = F_{Down1} \cup F_{Down2}$	$F_{Down}' = F_{Down-O-Down}$

Table 2. Description of the collaboration characteristics

The mission frame of a DC can also be broken down according to objectives, constraints, decision variables and selection criteria. We present in Table 3 the details of the characteristics of the mission frame depending on the collaboration origin.

	<i>Upstream origin</i>	<i>Downstream origin</i>
Objective	$O' = O_{O-Up}$	$O' = O_{O-Up} \cap O_{High}$
Constraint	$C' = C_{O-Up} \cup [(C_1 \cup C_2) \cap C_{O-up}]$	$C' = C_{O-Down} \cup [(C_1 \cup C_2) \cap C_{High}]$
Decision variable	$DV' = [(DV_1 \cup DV_2) \cap DV_{O-Up}] \cup DV_{O-Up}$	$DV' = [(DV_1 \cup DV_2) \cap DV_{High}] \cup DV_{O-Down}$
Selection criteria	$SC' = [(SC_1 \cup SC_2) \cap SC_{O-Up}] \cup SC_{O-Up}$	$SC' = [(SC_1 \cup SC_2) \cap SC_{High}] \cup SC_{O-Down}$

Table 3. Description of the mission frame

Each DC involved in the collaboration contributes to the constitution of the CDC with its own items, while respecting the collaboration origin (upstream or downstream DC) and the general frame defined by a higher hierarchical DC.

The elements proposed in this section aim at characterizing the collaboration of DCs and the creation of CDC. Now, we will apply these generic results to the case of e-maintenance activities in order to show their interests.

4. Maintenance application

We have chosen the maintenance function as the application context of our study for the following reasons:

- the maintenance has a basic place in companies with a crucial contribution to their performance achievements,
- the maintenance is a domain widely penetrated by ICTs with, for example, concepts of telemaintenance, e-maintenance and remote work. ICTs have changed the way of working of maintainers by making collaboration easier with exchanges, as well as the working conditions, the decision making, ... and they have also had an impact on the hierarchical relationships,
- maintenance activities are varied and concern both technical works involving more or less sophisticated resources, and complex decisions requiring intellectual and intangible resources (knowledge, skills, information,...).

4.1 Presentation of the application

In this case study, we associate to the maintenance interventions several categories of actors as shown Figure 4-a (§3.3.4) who execute these interventions through collective work.

The CDCs are created to carry out preventive or corrective interventions. In the case of preventive interventions, collaborative work can be scheduled. For the corrective maintenance, the occurrence of failures is not scheduled and the collaboration, which is necessary to quickly repair the faulty equipment, is unplanned. However, whatever the type of maintenance considered, collaboration must be previously authorized by a higher hierarchical DC.

NOTE. We consider that the equipment is available to maintain. The scheduling of maintenance interventions and the sharing of the equipment with the production activities are not considered in this article but there are many references related to this point of view like (*Archimede and Coudert, 2001*).

This case study relates to the maintenance of numerically controlled machine tools (NCM) that is comparable to electromechanical equipment.

Further to the detection of a failure which leads to the setting in safety, the machine tool must be the object of a corrective maintenance action. The maintenance service responsible of this intervention is centralized and structured according to the hierarchical organisation illustrated in the diagram of the Figure 5-a (§4.3.4).

Each actor can be considered to a DC (decisional centre) belonging to the decisional system of the production or maintenance service and linked to other DCs by hierarchical relationships.

To structure the example, we consider the maintenance workflow of the Figure 6 (*Pérès and Noyes, 2006*).

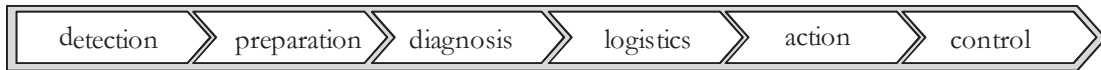


Figure 6. Maintenance workflow frame

We will consider in the next paragraph the proposed modeling elements for each of these six stages.

4.2 Implementation of collaboration in maintenance activities

Detection

The considered machine tool or the operator responsible of the NCM emits a signal of alarm at the t_0 date (Figure 7). This signal follows a failure of the numerical control in accordance with the appearance of a particular trigger event like an overpressure or electronic device breakdown....

The machine tool turns in safety and, so, cannot produce any more.

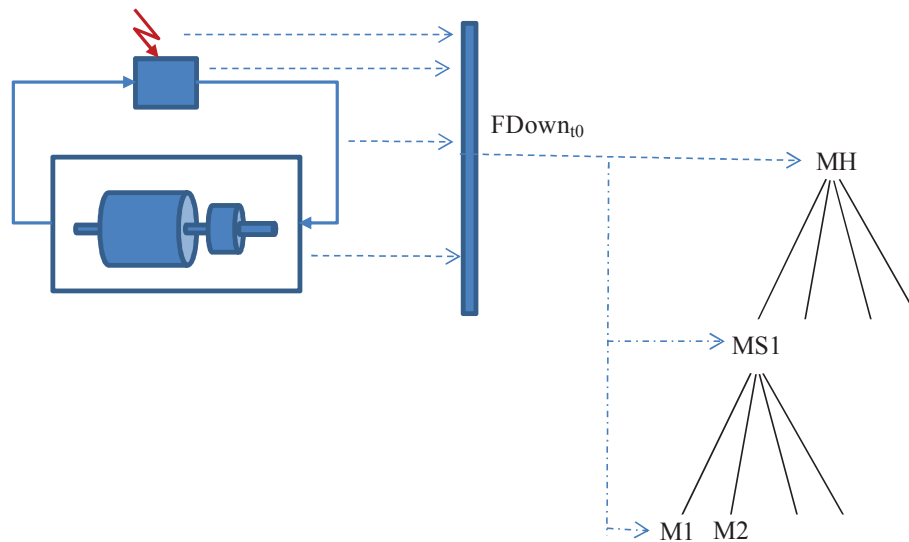


Figure 7. Situation of the studied case

Preparation

The responsible (MH) of the maintenance service receives this request via the local area network (LAN) and transmits it with the corresponding $F_{Down\ t_0}$ vector of state to the supervisor (MS_1).

The prediagnosis of the supervisor MS_1 using the vector of state characteristics, the discussions with the operator and his expertise gives: “deprogramming of a numerical PID of CN with a risk of propagation of the failure on the equipment of the operative part (breaking of tool, loss of indexing...)”.

The treatment of this failure requires electrical and mechanical competences and the supervisor MS_1 must create an operating team made up of two maintainers: a M_1 electrician and a mechanic M_2 so that they intervene jointly to solve the problem.

The decision to make these two maintainers M_1 (DC_1) and M_2 (DC_2) collaborated induces a temporary CDC, by regrouping DC_1 and DC_2 . The need of collaboration is punctual and concerns only the achievement of this intervention.

This situation corresponds to the type of regrouping R_4 (§3.3.4 and Figure 3) with an event downward release.

To be able to create this temporary CDC, the supervisor must define:

- the mission M' characterized by the objectives (O'), the constraints (C'), the variables of decision (DV') and the criteria of selection (SC'),
- temporal aspects characterized by the horizon (H') and the period (P')
- a framework of decision D' corresponding to the provision of a sufficient level of knowledge (K'), tools (T') and material resources (Mat'),
- the downward information with the definition of the new mission for the maintainers on the one hand and, on the other hand, the information of the beginning of the intervention for the operator responsible of the NCM (F_{Up}).

We present in Table 4 the elements characterizing the framework of the CDC's mission (Me).

The objective $O1$ contains the synthesis of information of the request for control and the orders of intervention of the maintainer M_1 and the maintainer M_2 .

The characteristic elements of the temporal aspects of the CDC are presented on Table 5 (row 1 and 2).

The demands correspond to an operational level of the decisional system. Thus, the horizon is associated to the real-time and the notion of period is not applicable to the operational level.

Characteristics	Designation / Value
Objectives	O_1 : Repair of the machine tool
Constraints	C_{1-Up} : financial constraints (at lower cost) C_{2-Up} : time constraints (quickly) C_{11} : availability constraints of the maintainer M_1 C_{12} : mechanical enabling to intervene on this type of machine C_{21} : availability constraints of the maintainer M_2 C_{22} : electrical enabling to intervene on this type of machine
Decision variables	DV_{1-Up} : qualified maintainers currently available DV_{2-Up} : material resources currently available DV_{3-Up} : intervention period margin DV_{4-Up} : financial margin DV_{5-Up} : subcontracting company
Selection criteria	SC_{1-Up} : cost of the intervention SC_{2-Up} : intervention period SC_{3-Up} : MTTF VC_{4-Up} : MTBF

Table 4. Main characteristics of the CDC (1)

Once the order of intervention is produced, the maintainers begin the intervention. The corresponding $F_{UP-O-up}(t1)$ information is done on row 2 of Table 5.

Horizon	H': real time
Period	P': not planned curative action. Concept of period non applicable in this case
$F_{UP-O-up}$	$F_{UP-O-up}(t1)$: information on the assumption of responsibility of the failed machine tool $F_{UP-O-up}(t2)$: synthesis of the intervention (history) gravity of the failure cost of the repair

Table 5. Main characteristics of the CDC (2)

Diagnosis

Initially, the maintainers look into the origin of the failure and identify the consequences. They deduce from this analysis the parts to be changed, the actions to be carried out and on the whole, the gravity of the failure. Then, the supervisor responsible for the intervention is informed of the established diagnosis.

Logistics

By using ICTs, the maintainers check the availability of the spare parts and make a request for exit of store.

Action

Once the spare parts available, the maintainers repair the equipment and turn it on again.

Control

Following the repairing realization, the maintainers check the performance of the machine tool and, if it corresponds to the nominal performance, they write down a report.

The results of this temporary CDC are transmitted to the supervisor following the ascending hierarchical way (see $F_{UP-O-up}(t2)$ on Table 5).

The supervisor closes the temporary CDC when receiving this information.

To conclude this case study, several advantages result from this formalization of the CDC following the principles that we developed.

These advantages appear on three levels.

- First of all, the fast constitution of the CDC thanks to an easy definition of the principal elements that characterize it: mission, decision frame and results; it is precisely this easy definition of the CDC elements what allows a better reaction when implementing an intervention.
- Then, the guarantee of a coherent definition of the CDC. As the CDC is defined according to its mission, there is an easy way to check the adequacy between

mission, objectives and constraints. This coherence makes the CDC reliable and improves its robustness. Moreover, the definition of both the horizon and the period of decision gives, in many cases useful information on the collaborative mechanisms to be set up on the one hand and on the other hand allows a correct dimensioning of the resources to be engaged.

- Finally, the stability of the CDC performance; indeed, the engagement of collaborative CD's is guided by the formalization of the CDC and the results will be little influenced by the variability of the regroupings in the case of choice among several CD.

5. Conclusion

In this article, we have analysed the problem of collaborative decision making caused or facilitated by the Information and Communication Technologies (ICTs) and we have considered the imbalances caused within an organisation. To do this, we have identified the key characteristics of DC collaboration in a decisional system through ICTs. We have highlighted the following characteristics:

- the general frame of collaboration establishing collaboration authorisations and potential collaboration (DCs that can collaborate),
- the origin and nature of the collaboration needs (upstream or downstream),
- the conditions of collaboration: duration and frequency of collaboration, horizon / period,...
- the benefits of collaboration concerning the mission frame (increasing of freedom degrees and reducing of constraints) and the decision frame (contribution of another intangible resources like skills, information...).

To illustrate this work, we considered the case of e-maintenance and applied our approach to a collaboration example. The characteristics described in section 3 and illustrated in section 4 allow to obtain a better organisation of the decisional system and, in our example of maintenance, an improvement of the collaboration implementation that is more and more frequent, particularly with the common use of ICTs.

We intend to extend the previous approach to the development of a methodology to implement collaborative decision centres. This methodology will be based on the definition of collaboration characteristics in order to facilitate the creation of collaboration while preserving the balance of the decisional system involved in the collaboration.

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