Sociotechnical System Digital Twin as an Organizational-enhancer Applied to Helicopter Engines Maintenance

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Abstract - **This research work aims at improving collective decision-making and learning through a digital twin of the organization in the context of a complex industrial activity such as helicopter engine maintenance. Field and bibliographic studies allowed to determine that the digital twin should be based on a multi-agent system model for reasons of flexibility and modularity necessary in this constantly changing environment. The digital twin is intended to adapt to the organization but also to enhance it by including missing information flows. This paper presents the agent model chosen and inspired from reinforcement learning and how it allowed to identify these missing flows. The importance of interfaces in the digital twin and what they should contain to integrate agents is shown, as well as the psychosocial aspects to be considered for humans to handle their design.**

Keywords - **Collaborative decision-making, multi-agent system, helicopter engines maintenance, learning organization**

I. INTRODUCTION

Today's industrial activity is increasingly complex and changing. This study was carried out in a helicopter engine maintenance company which is concerned by this evolving context. Each stakeholder has only part of the knowledge and know-how as well as incomplete situational awareness [1]. However, these knowledge and situational awareness are necessary to carry out the activity in question. Improved situational awareness should lead to improved quality of decisions [2] which is of strategic importance [3].

A field study based on twenty-one semi-structured interviews with 15 employees in nine departments of the company was conducted, all involved in repair and maintenance processes. It was found that the complexity of the situation that is difficult to comprehend does not only originate from the product itself, the helicopter engine, but also to a large extent from the entire Socio-Technical System (STS). This STS is involved in the engine maintenance activity, and engines are part of it as objects. For this, a Digital Twin (DT) of this STS can allow each stakeholder to obtain a dynamic representation to understand the state of the STS, its evolution and better act accordingly [4]. The components of the STS to be modeled, in our case humans and machines, imply heterogeneous and evolving characteristics. In addition, a degree of autonomy is essential for its component because it allows them to practice and develop their skills. The modularity and flexibility of a multi-agent system (MAS) [5] allow to model such a system of systems as the enterprise [6].The systemic approach to the enterprise as a whole, from which the term STS derives, is not new [7]. The notions of shared decision-making [8] as well as the learning organization have been explored, emphasizing the importance of participant autonomy and responsibility through self-reflection [9].

Recent literature in organizational psychology confirms the necessity of the reflexivity of the stakeholders of a company in their autonomy in the construction of problems, especially in engineering [10]. It is therefore consistent to see the DT, notably based on a multi-agent model, as a tool for reflexivity that digitally reproduces the real multi-agent organization and the links within it [11].

However, this will for an accurate representation of the existing system implies that we consider this system to be complete. Indeed, one can wonder about the usefulness of creating a digital entity exactly identical to the existing one [12]. This limitation may be challenged. The DT should not just agglomerate existing features and components of the organization, but should complement them by adding new ones, for example a new agent or information flow in the network.

This study brings a new approach by exposing how a DT of the organization based on a MAS model should allow to enhance it by integrating the missing inter-agent data and information flows.

To enable each agent to become part of the system, the aim is to connect agents, including human agents, via interfaces that have emerged in recent years as a dimension in the definition of a DT [13]. Therefore, this paper is about modeling these agents and determining what are the issues concerning interfaces.

The model proposal section is divided into two subsections. We have chosen a MAS model to represent the STS and his DT. So, the first subsection explains the bibliographical studies conducted to define an adequate agent model and to outline the important parameters to be considered in the future implementation. The second subsection shows the field studies and how the model facilitated the discovery of missing information exchanges between agents that could enhance collaboration and learning within the organization.

The conclusion summarizes this work and provide the needs and perspectives for further work.

II. MODEL PROPOSAL

We have chosen a multi-agent model to apprehend the STS and to design a DT to enhance it. MAS flexibility allows to accurately describe the STS of our study. MAS modularity allows it to adapt to changes and to respect the autonomy of its components. The following work is about formalizing the agents composing this MAS and the interactions that put them in relation. This relationship must give them access to the information necessary for their good collaboration and their collective learning. Both bibliographic and field research were conducted to formalize a model. The resulting modeling choices are presented in the following section.

A. Bibliographical studies

The proposed model is based on the concept of Reinforcement Learning (RL) [15]. This artificial intelligence field results from studies on collective intelligence and on the principles of stigmergy like in insect colonies [14] or for learning and task allocation in human brain [15]. To consider acceptability, user adherence and trust in the proposed model, the fields of social psychology [16] and human-computer interface engineering [17] have been explored.

1) *The agent model:* RL, which is a subfield of Deep Learning, has provided an agent model that matches the goals of learning and collaboration while maintaining the autonomy of the organization's experts within it.

Indeed, as represented on Fig. 1, an agent requires three types of communication channels with its environment: actions, rewards, and observations. The actions allow the agent to act according to an evaluation of the environment allowed by the observation. The agent must be rewarded with positive or negative reward according to MAS objectives. This will allow learning from experience.

2) *The MAS model:* An important aspect of the flexibility of a MAS model is its multi-level dimension. In our model inspired by cognitive science, agents that perform a function together can be called an agency [18]. This agency is an agent itself. Fig. 2 shows that two agents can

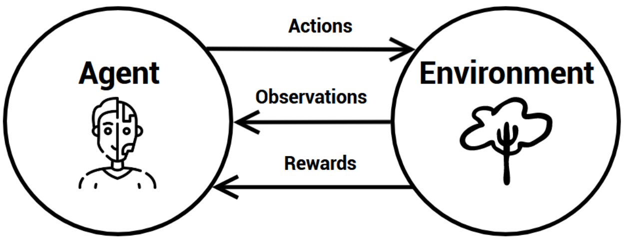

Fig. 1. Agent and its communication channels with its environment.

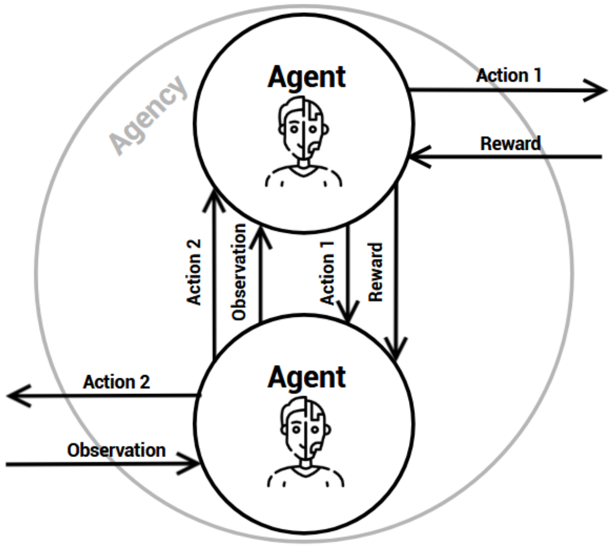

Fig. 2. An agency and its internal and external communication flows.

complement each other by transferring the necessary information flows to each other. For example, a human agent can be complemented by its digital counterpart (i.e., its DT). Thus, each one has at least one flow of each type (action, observation, and reward) to respect the characteristics of the definition of an agent. The three flows are necessary for the good performance of an agent, i.e., to be able to learn and improve decisions quality.

3) *Influences of conduct in groups:* the present research focuses on a collaborative framework. The successful integration of individuals, especially from a third group, into a collaborative activity is conditioned by access to information about them. This allows to see them as individuals, disregarding prejudices linked to their group or transpositions of hierarchical distinctions that are not adapted to this context to promote collaboration [18]. Yet, this information must be managed with caution. During tasks performed in groups, the presence of others plays a role on everyone's motivation [16].

Demotivation, or *social laziness*, is induced in participants when they cannot identify their individual contribution [19] and believe that it is not assessable [20]. Possible factors are members' perceptions of each other's contributions to the group's work such as:

- It may seem unnecessary [23].
- Suspicion that others are taking advantage of it to provide less effort [21].
- The group "braking norm" to avoid abusive management [22].

All these findings should be taken into consideration to determine which data should be visible or not between the different stakeholders to avoid counterproductive effects.

This social laziness can be overcome. A system that allows to evaluate individual contributions to the collective effort is sufficient to eliminate the effect of social laziness.

However, it appears that the individual identification of industrial actors by others, with respect to their returns, can pose an organizational problem. Because of the risk that the information given by the individual will be used for other reasons by third parties, such as the evaluation of his work, he may censor himself. Anonymity could therefore contribute to more realistic information [23].

In general, the factors responsible for social laziness are generated during group work. So even if the above-mentioned device is sufficient to eliminate social laziness, solutions have also been studied regarding motivation in group work. Efforts must be profitable, i.e., lead to a positive evaluation, whether it is a self-evaluation or an evaluation by others.

- The desire not to be identified as the least productive in the group motivates one to excel (Köhler effect), provided that the comparison between one's own performance and that of others does not seem to show too great a difference [24].

- The task must represent an interesting challenge that enhances the self-image. In this case, the braking norm, or effort matching seen earlier, can be replaced by a social compensation process in which those who feel better provide more effort to compensate for the shortcomings of the lesser performers and ensure good group results [25].

- Intergroup competition can motivate one's group to win when the game is to beat other groups compared to groups working alone. Belonging to a valued group is part of an individual's positive social identity [26]. This motivation generated by belonging to a group has been demonstrated in experiments involving groups in competition. Groups with the same color T-shirts were the most successful [27].

The design of the DT as a multi-agent, multi-level system (agencies) allows these parameters to be modulated via the interfaces according to the context. Indeed, the visibility of the agents' contributions seems to ensure a correct participation in the activities of the agency to which they belong. However, the connections of this agency with other agencies or with the higher level to which it belongs will not necessarily be of the same nature. They may be of a higher level of granularity, for example (agglomerated and therefore anonymized). This flexibility makes it possible to guard against perverse effects such as self-censorship and surveillance, which would generate each other and undermine both well-being and collective performance and improvement.

B. Field studies

1) *Real cases studies:* the exploration of reports associated with 9 interviews of experts within three departments often in relation for the resolution of maintenance cases allowed to determine a framework. This framework is consolidated by studying past cases treated and by confronting them to the model. Fig. 3 is a simplified but typical representation of a problem-solving case. This is represented as a diagram of sequential information exchanges between different agents in a network. This network involves four agents: a machine agent "HM" for Health Monitoring, a human agent "SE" for Service Engineer, a human agent "FR" for Field Representative, the person in direct contact with the company's customer, and a human agent "Customer" outside the company, for whom the maintenance service is provided. The satisfaction of this customer is at the heart of the activity.

In this diagram, the arrows represent the information exchanges, and each associated number represents the order in which they took place in this sequence.

The exchanges that took place correspond to: (1) The SE consults the internal HM portal; (2) The internal portal shows him an alert about a helicopter engine; (3) The SE notifies the FR responsible for the concerned customer of the abnormal measurement and the suspected engine problem; (4) The FR assesses the situation and chooses to inform the customer and asks him to perform an inspection; (5) The customer confirms the reality of the problem and requests the engine change as recommended in the documentation; (6) The FR reports it to the SE to consult its expert opinion; (7) The SE confirms that an engine change is advisable; (8) The FR approves the engine change to the customer; (9) The customer congratulates the FR for the company's preventive action. In Fig. 3, black arrows represent reward from the receiver point of view.

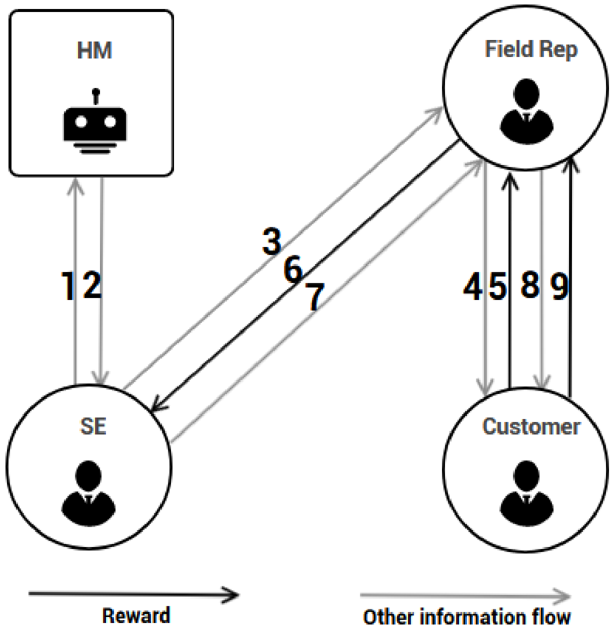

Fig. 3. Real field case involving a MAS.

2) *Service blueprints:* After having identified agents and information flows, service blueprints [28] were used to easily identify and categorize exchanges for each agent. Thus, the past cases told by the different experts have been represented with this formalism to break them

down into sub-steps composing the events that can be classified. The three categories of exchanges of an agent with its environment according to the chosen model are used to perform this classification: action, observation, and reward. Thus, it is then possible to analyze the current state of the organization and the possible points of improvement using the classified events. Fig. 4 shows the activity of the HM agent, which includes sequences corresponding to two types of information flows. The first can be denoted as observation. The second and third as actions. Thus, according to the agent model, this process lacks a reward-type information flow allowing it to learn.

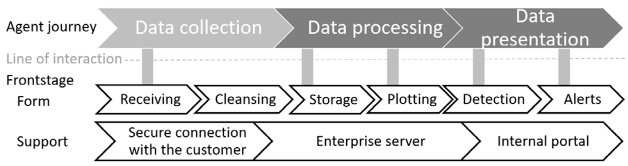

Fig. 4. Service blueprint from the Health Monitoring agent point of view.

During collective tasks, all agents do not communicate directly with each other but through other agents. This allowed us to highlight missing flows, in particular rewards that are mandatory for agents to get feedback on their participation in the collective task. It is found that there is typically a halving of the number of rewards transmitted as one moves away from a node in the agent network relative to the sending agent (i.e., the customer in our example, as represented in Table 1).

TABLE I
REWARD RECEIVED BY AGENTS

Distance from source (agents)	Agent	Number of rewards
1	Field representative	2
2	Service engineer	1
3	Health monitoring engineer	0

These results provide crucial information on the aspects to be considered and the necessary elements in the design of collaborative environment for facilitating agents' interactions that will allow the integration of agents.

The information gaps and possible sources to fill them are easily highlighted when observing the activity at different levels of granularity. In other words, it appears necessary to observe the activity not only at the individual agent level but also at the collective level, i.e., at the system of systems level [29]. Thus, if the problems of the augmented human have been addressed in the last decades [30], we must now face the extension of this problem to a collective level, i.e., the augmented organization, or augmented sociotechnical system. Indeed, just as a technology integrated to the human being can allow him to face situations that until now would have exceeded his physical or cognitive limits, it is a question of developing a DT integrated to the organization, to enhance it by completing it for tasks that were previously inaccessible.

III. CONCLUSION

An agent and MAS model based on the RL and social psychology bibliography has been proposed. It has been validated with cases treated to identify the critical points in an STS we want to enhance with a collaborative environment. This collaborative environment could improve information flows and decisions quality by promoting collaboration.

It is planned to design the interfaces in an iterative way with user tests. For this, in addition to use the classical principles of interface ergonomics [31], this research give us good indications on the elements to be tested.

Among these elements to be tested are sections corresponding to actions, with principles of shared decision making [8], observations, taking into account which information promotes motivation according to group psychology [16], and rewards, fed by an evaluation system, whether automatic, by peers or by oneself. At the end of each episode of collective task, simple and binary questions like "was the solicitation of your/their skills relevant in this case?" will generate rewards to feed the learning process by, for example, connecting the right experts in future similar cases. The integration of these elements in the interfaces to make tangible an improved DT of the organization will be studied in future work. The consequences in collaborative problem-solving will be studied and the testing of prototypes with different features will be conducted. The question of which features should be common to all agents, and which should be variable according to situations, roles, or agent types will be explored. The question of adding information flows but also additional agents in the DT that do not exist in the physical twin to fill missing functions will also be explored.

It is hoped to find a systemic approach to the problem of collaborative decision-making and knowledge integration that will result in a solution that is elegant in the mathematical sense [32], i.e., efficient and accurate in a wide variety of situations while being concise and easily understood.

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