Multi-Agents Model Oriented Safety in Maintenance (MAM-SM)

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ABSTRACT

This paper proposes an agent-based simulation framework for the development of a decision support system for occupational risks management in a maintenance task. The proposed model is defined as a Multi-Agent system oriented Safety in Maintenance (MAM-SM). This model aggregates many agents, where architecture includes agents Supervisor, Resource, Machine, Environment, Reasoning, Task, Control and Agent Capitalization. Based on a multi-agent simulator, the objective of the proposed approach is to account for the complexity of the maintenance task for better analysis and understanding of risks. It allows orienting the actors to the best decisions in order to minimize risks that may arise. The method is applied to two case studies. The results show that this model can express the behavior of each agent and also the performance of the whole system. In particular, the results demonstrate that the maintenance tasks can be controlled to avoid an accident.

Keywords - Multi-agents system, safety, complexity, risks management, decision support.

1. INTRODUCTION

Maintenance has become an essential function and a primordial necessity in industrial activities. Generally, the objective of maintenance is to ensure the availability and the reliability of production equipments and all its related assets. As explained by [1], the primary purpose of maintenance is to prevent significant failure in plant functioning, which can threaten not only production, but also safety and to return to full functioning after breakdown or disturbance.

In the specialized literature, there are several studies related to the improvement of reliability and availability of equipment ([2], [3], [4], [5]-[6]). Other authors propose optimization of maintenance strategies based on the risk analysis approach. The introduction of risk in maintenance planning is known as risk based maintenance RBM [7]. Risk-based Maintenance (RBM) methodology provides a tool for maintenance planning and decision-making to reduce the probability of failure of equipment and the consequences of this failure. The resulting maintenance program maximizes the reliability of the equipment and minimizes the total cost of maintenance. There are different approaches to risk-based maintenance reported in the literature ([8], [9], [10], [11], [12]-[13]).

The concept of risk in RBM is related to the risk of failure and its impact on the availability of equipment. The approaches to RBM are not dealing with risk as a product of the criticality of maintenance tasks. This criticality can expose operators to serious occupational hazards. Indeed, although the essential nature of the maintenance work is now more widely recognized, maintenance activities are identified as critical situations for the safety of operators ([14], [15], [16]-[17]). In these situations, the risk can take two forms: occupational accident (which is a sudden event) or occupational disease (which results in a more prolonged exposure to dangerous phenomenon). The criticality of maintenance activities arises not only from the nature of maintenance task, but also from the organizational and environmental context in which they operate and the interactions between maintenance and operations.

Organizational context for safety in maintenance refers to conditions that influence the opportunities of a socio-technical system, an organization, or an individual to control the hazards related to work environment and hazards of potential accidents [18]. These conditions are important for organizational safety and working environment. This environment is composed of human, technical and organizational elements, that are organized together to achieve a specific intervention. The importance of these environmental conditions (related to safety) has been demonstrated in several accident investigations ([19], [20], [21], [22], [23], [24], [25]-[26]).

These conditions make maintenance not only a critical situation, but also a complex one. This complex character of maintenance activities is connected with a significant proportion of the serious accidents occurring in the plants. During maintenance tasks (such as inspection and repair), work needs to be done in complex conditions that involve several interactions between operators and organization of maintenance activities ([27], [28]). These are the main reasons why accidents happen during maintenance ([14], [29]-[30]). Moreover and according to the European Agency for Safety and Health at Work is estimated that 15 to 20% (depending on the country) of all accidents and 10 to 15% of all fatal accidents are related to maintenance [31]. Studies by the Occupational Safety and Health Administration (OSHA) of the accidents occurred in 1989 in the United States, showed that 122 fatalities were linked to maintenance activities ([32], [15]). A study by Hale on

294 accidents occurred in the chemical plants found out that 40% have their origins in the maintenance phase [1]. Another study by Pichot revealed that maintenance workers were more vulnerable to occupational diseases than other workers [33].

Consequently, safety related to maintenance must be one of the major challenges of any industrial activity. This is an opportunity to initiate a process of risk management in order to protect health and safety of operators. The implementation of safety in maintenance involves exploring the complexity of a maintenance task in order to avoid risks that could lead to incidents and/or serious injury.

A complex situation is perceived as a difficult understanding, anticipation and control of an observer [34]. According to [35], "complexity is the combination of a whole whose elements are combined in a way which is not immediately clear in the analysis". It can be characterized by the presence of a large number of independent elements in dynamic interaction". This dynamics is characterized by the interactions between the system components [36]. A similar view comes from organizational theory, where company is considered complex since its components (human, technical, social, etc.) and their interactions are multiple, and also because of the diversity of its dynamic behavior [37]. The dynamic behavior of the system can be perceived firstly by considering the system as a complex and open one with many interactions and secondly by considering its unpredictability because of interactions between its components ([38], [39]).

The objective of this work is to propose a modeling approach that can be considered as a decision support system for safety and occupational risks management in maintenance activities. This approach involves the complex character of maintenance situation and the interactions between its components.

After a brief presentation of the problem that raises the question of research, the remainder of the paper is organized as follows: Section 2 explains the adopted working methodology. Section 3 presents the model corresponding to the Multi-Agent Model oriented Safety in Maintenance (MAM-SM). Some application results are discussed in Section 4 using two case studies applied in chemical industry. Finally, the conclusive remarks and future work are given in Section 5.

2. WORKING METHODOLOGY

This paper aims to provide a safety model for complex systems maintenance. It consists of a decision support process for occupational risks analysis that takes into account the complexity in maintenance activity. This complexity is due to several interacting elements. The ultimate purpose is to simulate the interactions between these different elements and then help decision makers to make the best decisions to minimize risks. The method that allows understanding this complexity and which has been adopted in this work is based on the systemic modeling.

The systemic paradigm is directly related to the concept of system. In [35], author presented the systemic paradigm as a complex system of three components in close interaction: structure, activity and evolution. The systemic is an interdisciplinary approach used to understand the complexity and to describe the dynamics of a system. It consists of studying the interactions and causal interdependencies within a system. The systemic has become an approach to ensure the modeling of complex systems by reconciling different viewpoints [40]. It is a methodology for collecting and organizing knowledge in order to ensure effective action.

The model and the modeling are the basic concepts of system concept. According to [41], the model is a representation of a real system whether it is mental, physical, expressed in verbal form, graphical or mathematical. This representation can be derived from a material or immaterial reality [42]. Reference [42] presented a model that allows describing a reality using some concepts representing the observed reality.

The systemic modeling is a process representing the real system, which when combined with the simulation provides a decision support tool that takes into account the dynamic behavior of the system and its components, and formalizes the structure, the organization and the characteristics of the real system. The simulation aims to analyze the properties of theoretical models of the real world in order to explain and to predict the natural phenomena.

The multi-agents system is one of the approaches that is based on the systemic paradigms. It brings a solution by offering the opportunity to represent the individuals, their behaviors and their interactions. The model proposed in this work is founded on a multi-agents systems oriented safety in maintenance.

3. MULTI AGENT MODEL ORIENTED SAFETY IN MAINTENANCE (MAM-SM)

In this section, we show the interests of multi-agent approach used in this work, and then the proposed model is presented.

3.1 Multi-Agents Systems (MAS) interests

MAS are defined as a network of coupled problem solvers that interact to solve problems beyond individual capabilities [43]. These problem solvers are often called "agents". They are autonomous and can be heterogeneous in nature [44]. MAS are entities that interact to produce a collective behavior. One of the interesting features is the ability to reproduce the behavior to solve a problem. The goal of MAS is to distribute the complexity of multiple agents in the form of a multi-agents system to solve problems. Agents are entities that interact to produce a collective behavior [44]. The principle of multi-agent systems (MAS) is to bring together the knowledge and thinking skills held by the agents. Each agent can be specialized in a sub-domain of the global field and the unification of their skills can solve the entire problem [43].

The multi-agents approach has been used in a wide variety of industrial problems such as manufacturing management ([45], [46], [47], [48], [49], [50]), supply chain modeling ([51], [52], [53], [54], [55], [56], [52]), crisis management ([57], [58]), risk management in supply chain [59].

The proposed model is a Multi-Agents Model oriented Safety in Maintenance (MAM-SM), that aims to provide a decision support system for occupational risks management, through developing a methodology to promote action to improve and control safety in maintenance.

The adoption of multi-agents to build our modeling solution sounds relevant and obvious approach. Indeed, the characteristics of multi-agents systems seem to be particularly suitable for the representation and the simulation of our SSM (Safety System in Maintenance). We find a set of analogies between SSM and MAS (Table 1), where both systems are considered as a network of entities that interact to achieve a common goal.

Consequently, the use of multi-agent approach in this work is justified by its various interests such as: adaptation to reality, complex problem solving, decision making, modularity, efficiency, representation of dynamics.

In order to better understand the relationship between maintenance and concepts related to the process of damage occurrence (risk, danger, dangerous situation, accident, etc.), we have developed a metamodel which formalizes the interaction between maintenance and risk.

Table 1 Analogy between Safety System in Maintenance (SSM) and Multi-Agent Systems (MAS)

Criteria of comparison	**Safety System in Maintenance SSM**	**Multi-Agents System MAS**
Multiplicity of intervening elements	Several elements in different roles to achieve common tasks	Several elements in different roles to achieve common tasks
Characteristics of the elements	SSM's actors have goals, methods and skills needed to perform tasks, and they follow a set of instructions to risk management	The agents have goals, skills, roles and reasoning abilities, that they implement according to various complex decision-making ways
Capabilities of the decision-making	Learning and reasoning are necessary for decision making in SSM	Reasoning skills, acquisition or modification of knowledge through interaction with the environment
Cooperation between elements	Coordination of SSM's actors by sharing material flow, informational or decision	Coordination of agents activities by interacting with other agents
System dynamics	SSM is dynamic	Agents can join the system and others may be destroyed

3.2 Metamodel Risk/Maintenance

The proposed metamodel is based on the UML notation. It is the subject of a class diagram that models the structure of a maintenance situation that is dangerous. In this structure, we develop the various interactions between a maintenance task (Block M) and concepts of risk (Block R) for representing a metamodel Risk/Maintenance (Figure 1).

This diagram highlights the link between a maintenance situation (with all its components) and the process of the appearance of damage in which normal situation becomes dangerous. The maintenance situation (which could be either corrective or preventive) becomes dangerous when the maintenance operator is in a contact with a danger. This danger can be a source of energy at the machine (mechanical energy, vibration energy, electrical energy, etc.), or in the work environment, such as: the temperature, the light, the noise, etc.

The exposure to danger produces a risk that, with the presence of a triggering event, leads to damage. For example, in the case of maintenance of energized equipment (risk), the electrician is in a dangerous situation when his hands are just a few millimeters from electrical equipment. This situation can lead to electric shock (damage) when the person comes in contact with this equipment (triggering event).

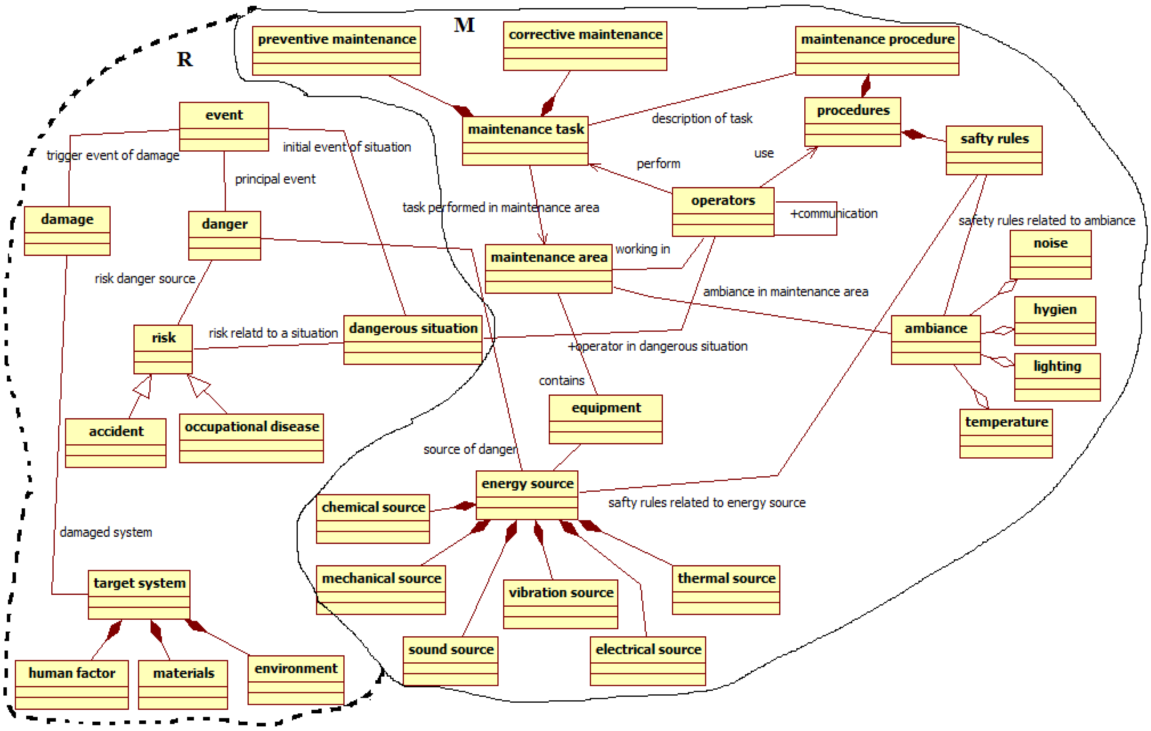

Figure 1 Risk/Maintenance Metamodel.

3.3 Architecture of MAM-SM

A safety model based on multi-agent architecture has to minimize and avoid situations that may affect the physical integrity of operators. It is an approach that helps decision makers to make better choices using agents as managers of risk situations. To solve this problem, we propose a model that depends on the interaction of the following agents: Supervisor Agent (SA), Resource Agent (RA), Machine Agent (MA), Environment Agent (EA), Reasoning Agent (ReA), Task Agent (TA), Control Agent (CA) and Capitalization Agent (CaA). Figure 2 shows the architecture of MAM-SM (Multi-Agents Model of Safety in Maintenance) developed in this work.

The interactions between these agents are represented in form of sending messages that we present by a sequence diagram formalizing the overall behavior of MAM-SM (Figure 3).

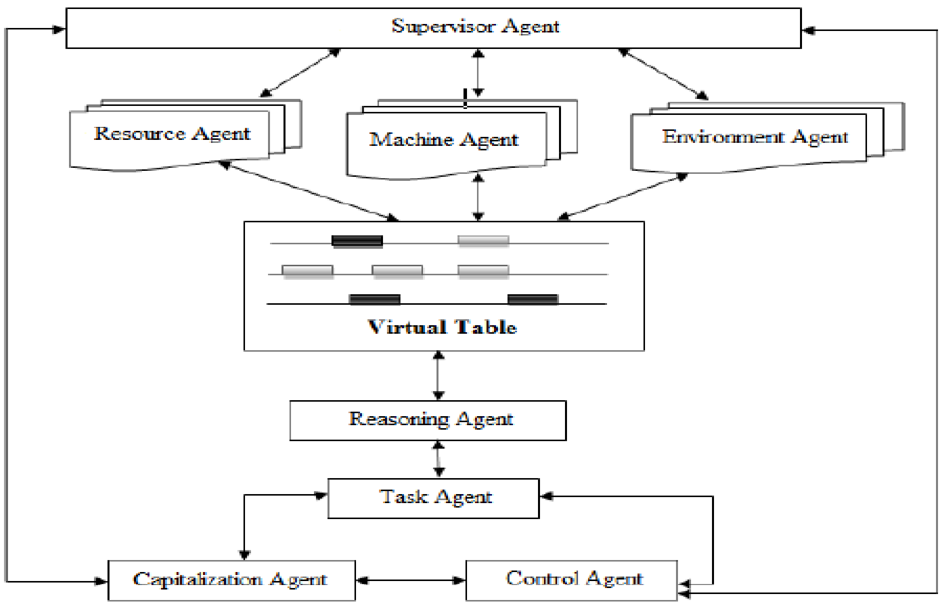

Figure 2 Architecture of MAM-SM

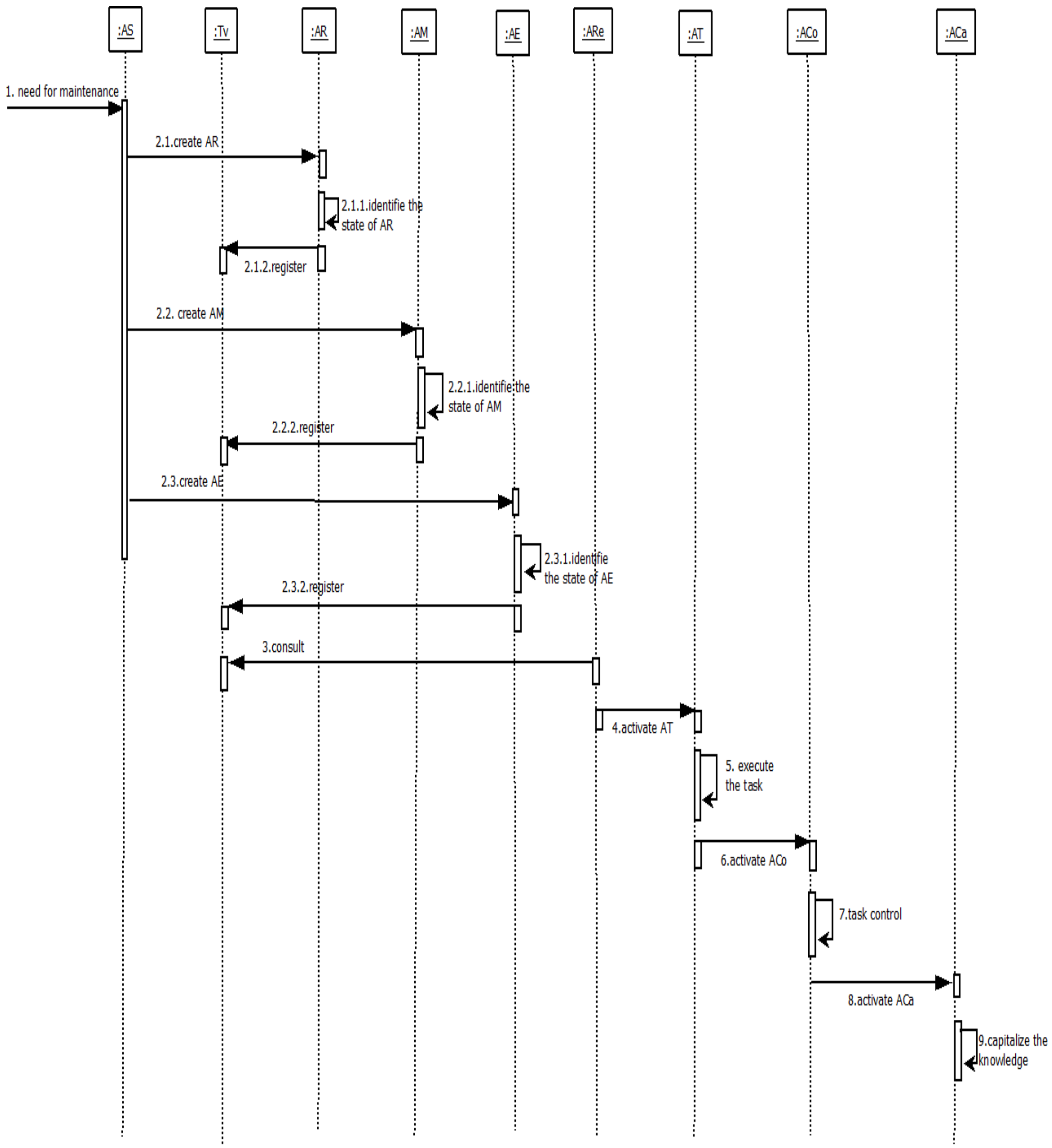

Figure 3 MAM-SM during a signal for a maintenance activity

When there's a signal for a maintenance task, the Supervisor Agent (SA) creates and initializes the Resource Agent (RA), the Machine Agent (MA) and the Environment Agent (EA). Each of these three agents identifies and saves its state in a Virtual Table (VT). Thereafter, the Reasoning Agent consults this table and if no defects were detected, it activates the Task Agent (TA) to execute the maintenance task. Once the maintenance task is completed, the Task Agent activates Control Agent (CA) that is responsible to ensure that the machine can be reused safely.

When control is complete, Control Agent activates Capitalization Agent (CaA) which allows to accumulate and capitalize knowledge related to safety in performed maintenance task.

3.4 Description and presentation of agents' behaviour in the system MAM-SM

The behaviors of the different agents of MAM-SM are described as follows.

3.4.1 Supervisor Agent (SA)

The role of SA is to manage and control the operation of the system. It describes the overall objectives of the system in terms of maintenance activity to perform safely. It creates and initializes the Resource Agent, the Machine

Agent and the Environment Agent. The definition of these agents does not follow a particular order. In this work, the machine can also correspond to equipment or a set of equipments.

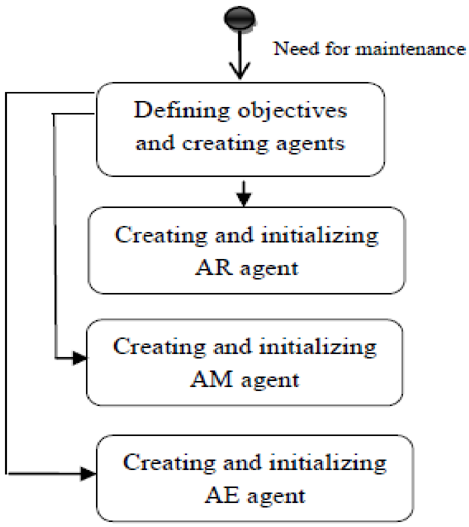

Figure 4 Behavior of Supervisor Agent (SA)

3.4.2 Resource Agent (RA)

This agent corresponds to each important resource to execute maintenance task. It may be human (operators), technical (spare parts, tools box, materials) or organizational (procedures, instructions, safety rules). RA is the main responsible for the analysis of risks related to each resource. The results of this analysis are recorded in a VT.

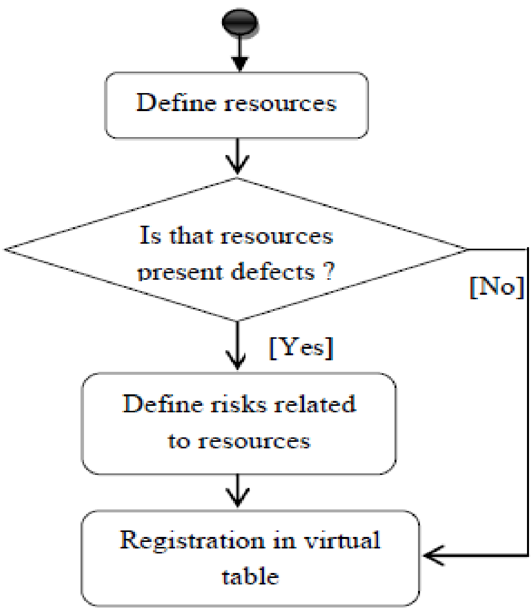

Figure 5 Behavior of Resource Agent (RA)

3.4.3 Machine Agent (MA)

This agent defines the forms of energy used by the machine (or equipment) object of the intervention: hydraulic power, electric, chemical, mechanical, radiation, etc. These energy sources can act as potential source of risks. Machine Agent is responsible for risk analysis related to different energy sources. The results of this analysis are recorded in the VT.

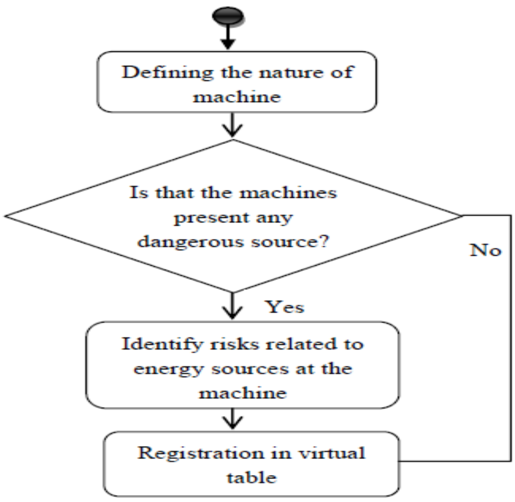

Figure 6 Behavior of Machine Agent (MA)

3.4.4 Environment Agent (EA)

This agent defines the types of ambience in the intervention area (noise, light, thermal ambience), and also the organization of work (work posture, nature of soil, etc.). This environment can present potential source of risks. EA is also responsible for risk analysis in the maintenance environment and the results of this analysis are recorded in the VT.

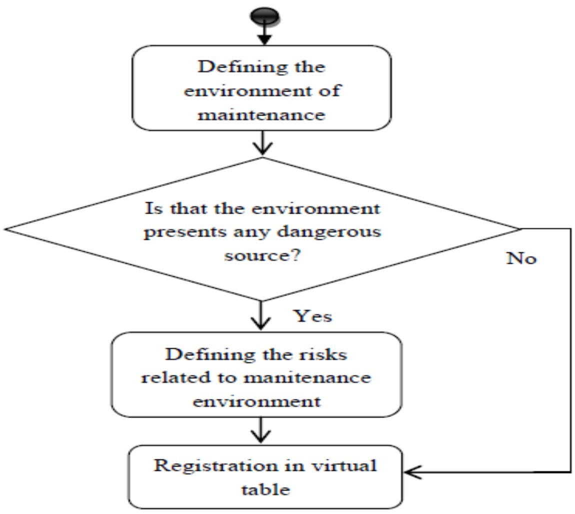

Figure 7 Behavior of Environment Agent (EA)

3.4.5 Reasoning Agent (ReA)

ReA takes decisions and formalizes the agent's goals. This agent receives information from VT. The latter presents the nature of the risks defined by Resource Agent (RA), Machine Agent (MA) and Environment Agent (EA). On the basis of this information, the system takes safety measures through reasoning agent (ReA) that is responsible for defining the necessary safety measures to be implemented. It also verifies the consistency and ensures the harmonization of these measures in order to produce goals based on relevant information to the Task Agent (TA). When the safety measures are implemented, ReA authorizes TA to initiate and follow maintenance task.

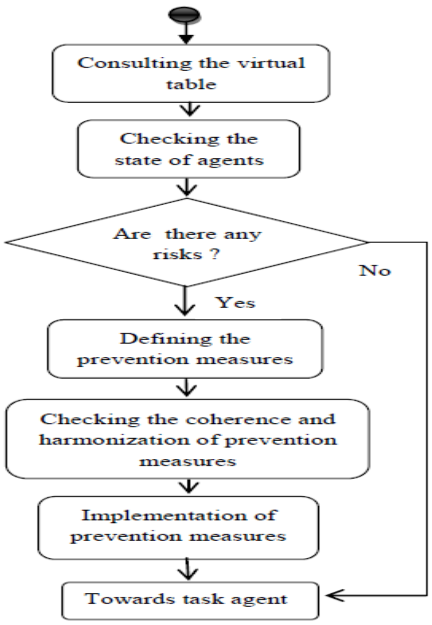

Figure 8 Behavior of Reasoning Agent (ReA)

3.4.6 Task Agent (TA)

This agent allows initiating and following step by step the tasks of maintenance.

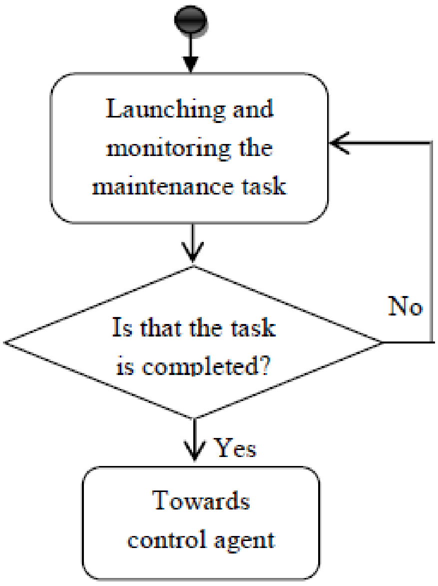

Figure 9 Behaviour of Task Agent (TA)

3.4.7 Control Agent (CoA)

This agent is activated once the maintenance task is completed. It ensures that, all insulating elements have been removed, all tools are stored and the machine can be safely used.

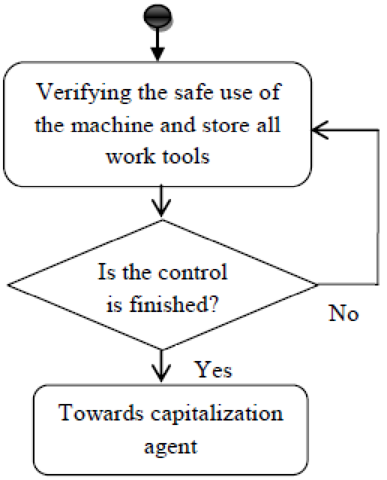

Figure 10 Behaviour of Control Agent (CoA)

3.4.8 Capitalization Agent (CaA)

This agent allows the capitalization of knowledge related to safety in maintenance. The basic principle of this agent is that both risk analysis and management are performed in order to prevent risks by improving the various factors in maintenance task. This agent collects knowledge from the VT, ReA and CoA. The achieved progress should be capitalized and disseminated through training and information.

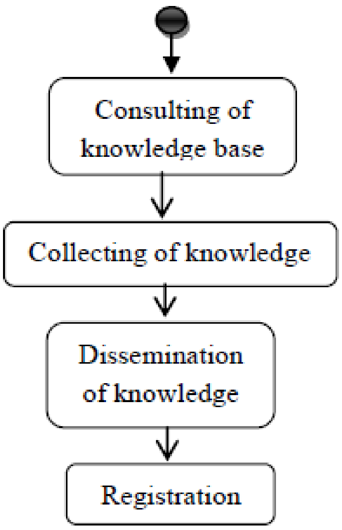

Figure 11 Behaviour of Capitalization Agent (CaA)

4. CASE STUDIES

In this section, experimental results of the proposed multi-agents system are presented. The experimental validation of the proposed model is performed on two case studies in maintenance tasks in an oil industry.

4.1 Case Study 1

The first case study corresponds to maintenance task of the boiler. The human resources involve a mechanic while the technical resources comprise a toolbox. These two resources do not present any default and the working environment do not presents any hazard. The sources of hazard can occur at the boiler (otherwise in the machine), and which could lead to potential risks. In this example, the proposed model seeks to secure the maintenance task of the boiler before performing its execution. The safety measures are defined to prevent existing risks at the Machine Agent (MA). Table 2 shows the sources of hazards, the associated risks and the necessary safety measures:

Table 2 Risks in the maintenance tasks of the boiler

Sources of hazards		**Risks**	**Safety measures**
MA	- Sulfur smoke, high temperature - Flammable Products (Sulphur) - Dust	- Asphyxia -Fire -Skin irritations -Eye-damage	- Provision and use of personal protective equipments - Eliminate sources of ignition - Smoke detector - Regular Cleaning

The behavior of agents for this example is formalized using the diagram displayed in Figure 12.

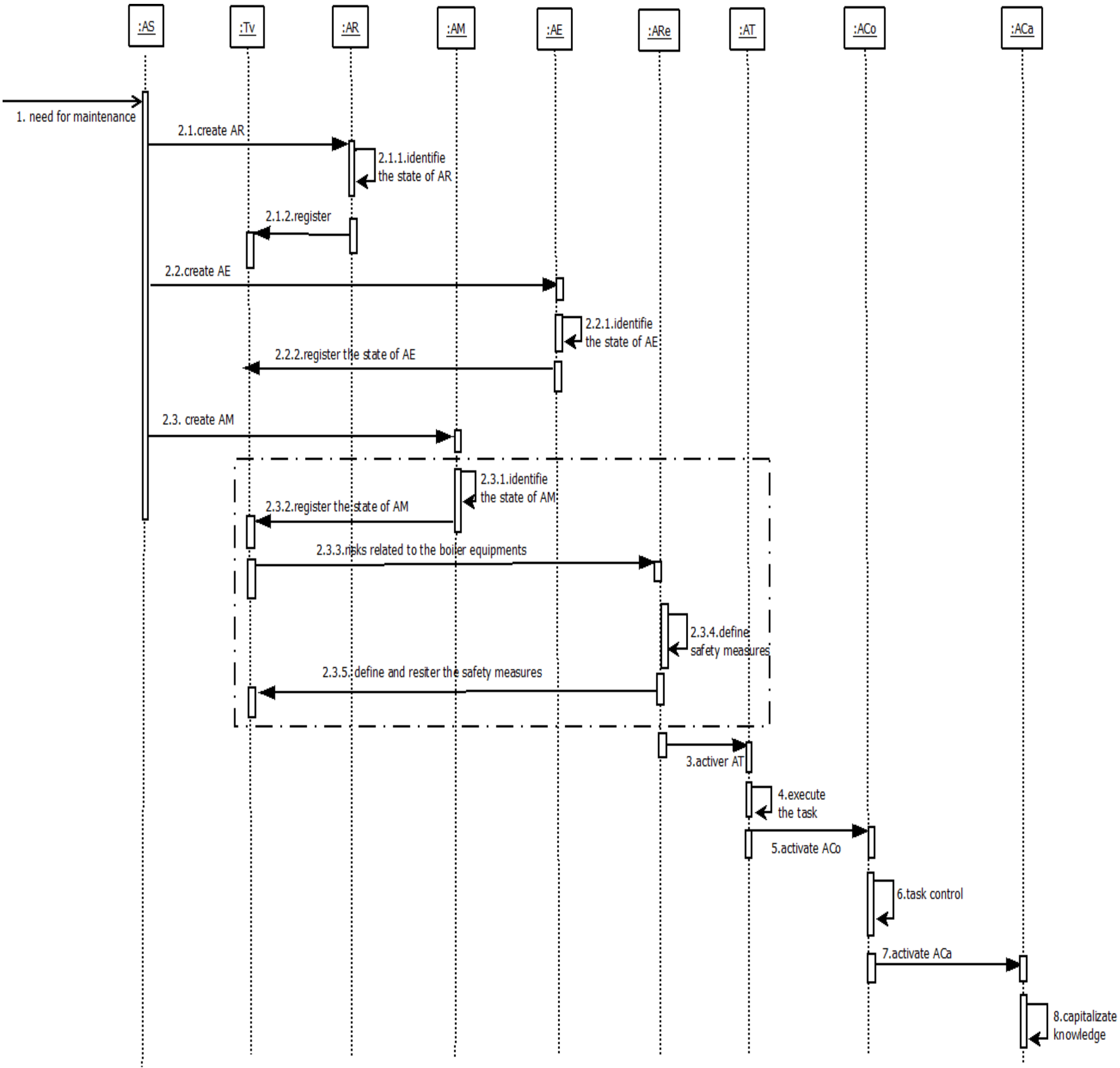

Figure 12 Application of the MAM-SM to maintenance task of boiler: case of the risks in the boiler equipments

In this example, the Machine Agent (MA) identifies the possible risks present at the boiler equipments and records these risks in the VT. The Reasoning Agent (ReA) receives the information recorded in this table and defines the safety measures to avoid the identified risks. Thereafter, ReA authorizes Task Agent (TA) to initiate and follow maintenance of boiler equipments. The figure 13 presents clearly the scenario presented in Figure 12.

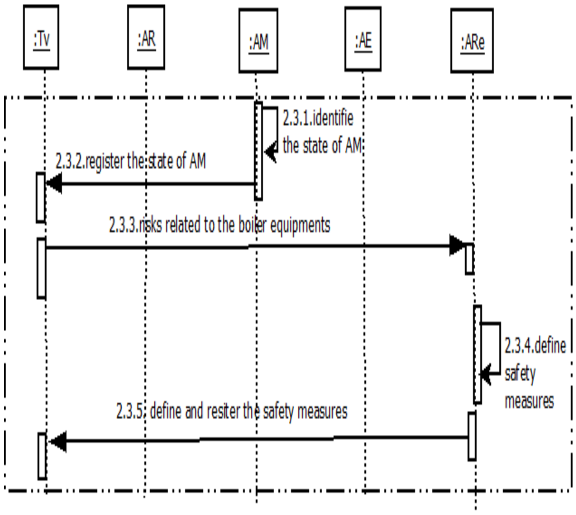

Figure 13 Intervention of Reasoning Agent (ReA) to address risks at the boiler

4.1 Case Study 1

The second case study shows the experimentation of the MAM-SM on the maintenance of rotating machines (pumps, turbines and compressors). The maintenance tasks involve the following: a general review, an alignment and a removal of leakage. These maintenance tasks require the intervention of a fitter mechanic (human resource) with the use of a toolbox and a laser alignment device (technical resources). Several sources of hazard occur at the machines (MA), work environment (EA) and at the technical resources (RA). In this example, the proposed model attempt to secure the maintenance of rotating machines before achieving their execution. Safety measures are defined to prevent existing risks in RA, MA and EA. Table 3 shows the sources of hazards with associated risks and safety measures to implement:

Table 3 Risks in the maintenance tasks of rotating machines

Sources of hazards		**Risks**	**Safety measures**
MA	-Noise emitted by machinery -Contact with hot equipment -Presence of product leakage and energy source -Leaking and projection of product - Direct contact with the product or equipment which contains the product	-Noise Nuisance- -Burns -Fire -Eye-damage -Skin Irritation	Giving and use of personal protective equipments (safety helmet, goggles, coveralls non floating fire, leather gloves, safety shoes).
EA	-Passage cluttered by storage objects; -Slippery soil -Repetitive movements at high speed	-Fall Walk -Fall Walk -Injuries	-Regular cleaning of workstations and storage -Control the storage of objects -Reducing the pace of work
RA	-Use of sharp tools	- Injuries	-Use of more consistent tools -Control the compliance of tools

The behavior of agents for this example is formalized by the diagram displayed in Figure 14.

In this case study, the risks present in resources, environment and machines are identified respectively by the corresponding agents: RA, EA and MA. The Reasoning Agent (ReA) occurs at each of these three agents in order to define safety measures to address the identified risks. Then, ReA authorizes Task Agent to initiate and perform maintenance tasks of rotating machines.

Figures 15, 16 and 17 show respectively the intervention of Reasoning Agent (ReA) at the level of states recorded by RA, EA and MA in order to secure the maintenance tasks.

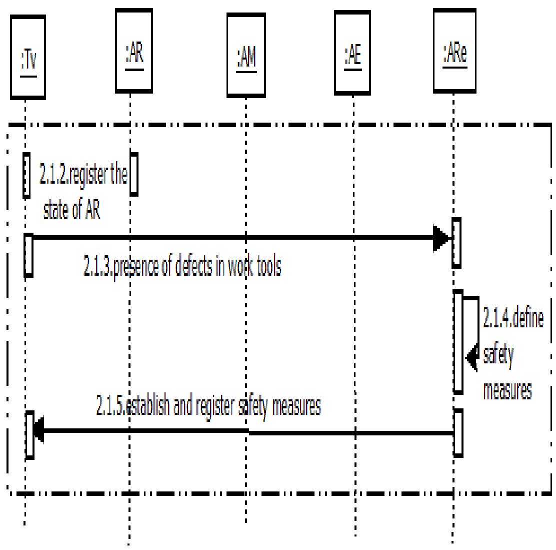

Figure 15 Intervention of Reasoning Agent (ReA) to address risks in the level of resources

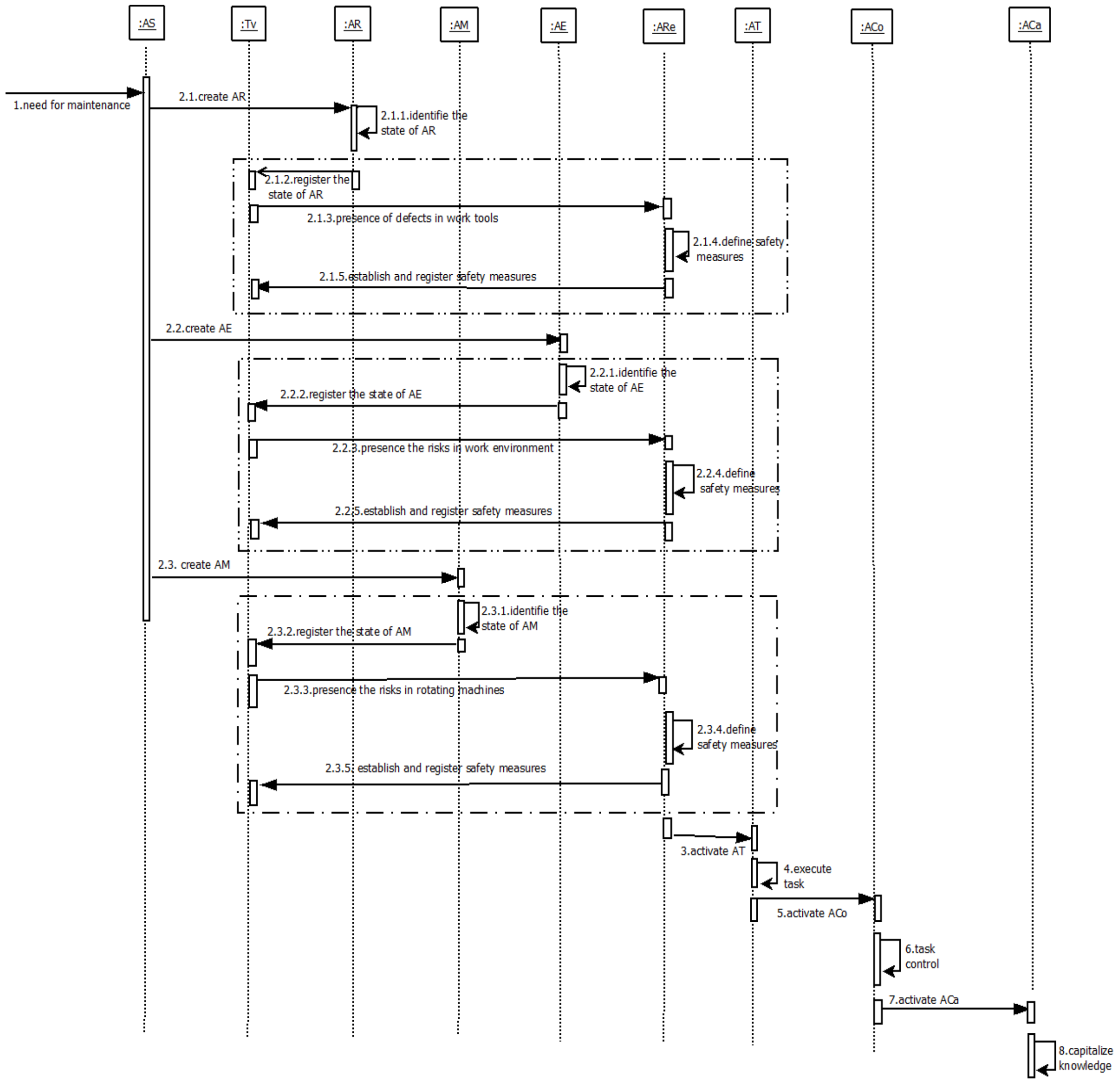

Figure 14 Application of the MAM-SM to maintenance activity of rotating machines: case of risks in the level of technical resources, environment and in the level of machines

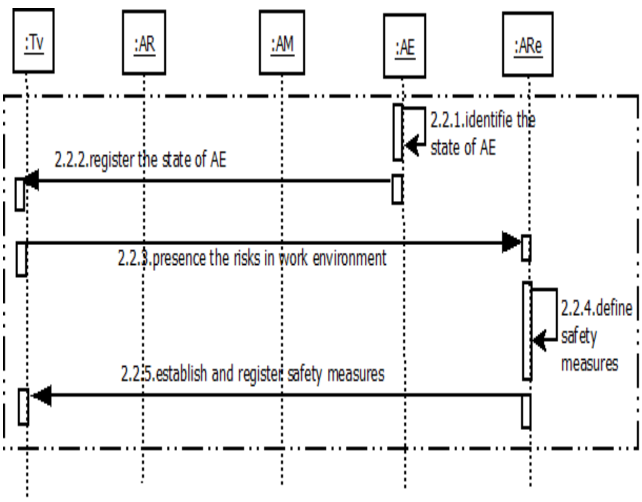

Figure 16 Intervention of Reasoning Agent (ReA) to address risks in the level of environment

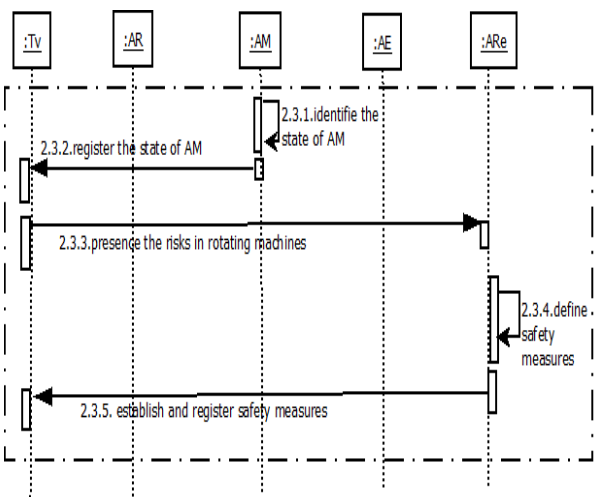

Figure 17 Intervention of Reasoning Agent (ReA) to address risks in the level of machines

In all these examples, the system takes safety measures through reasoning agent (ReA). This agent receives data from VT. In this table, we find the nature of the risks defined by RA, MA, and EA. On the basis of these data, Reasoning Agent (ReA) produces a safe goal according to the state of RA, MA and EA. It defines the necessary safety measures to implement. Task Agent can intervene later to perform the maintenance. The proposed model express the behavior of these agents and maintenance task can be controlled to avoid a potential accident.

5. CONCLUSIONS AND PERSPECTIVES

In this paper, we propose a decision support system for risk management in the maintenance activities based on multi-agent approach. This system is composed of agents to safe maintenance tasks. The proposed model (MAM-SM) is able to take into account the complexity of the maintenance activity to better understand and analyze the risks. The main contribution of this paper is the development of an approach to prevent risks in maintenance activities by improving their means of detection. Due to the presence of risks at all levels, this approach provides a decision support tool that can guide decision makers to perform the best choices.

The proposed model has several interests: from a theoretical perspective: it provides the necessary knowledge in the field of safety in the work and especially safety in maintenance tasks. From practical and operational perspectives, the current work may interest stakeholders in the field of prevention of occupational risks since it deals with risks associated with each component of a maintenance task (technical resource, organizational, human, and environmental). It can also significantly facilitate the definition of risks though providing substantial information for risk treatment.

Future work is currently directed to the performance of the proposed framework using an agent based simulation. Indeed, the resulting model is the subject of an implementation of a simulation platform to test the structure and behavior of the model. This framework will play a valuable role in the simulation field of occupational safety of operators.

ACKNOWLEDGEMENT

The authors express their gratitude to the industry that provide the data used in the experimentation of the model proposed in this work.

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