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Towards a Simulation Model to Ensure the Availability of Machines in Maintenance Activities

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Abstract**—**The aim of this paper is to present a model based on multi-agent systems in order to manage the maintenance activities and to ensure the reliability and availability of machines just with the required resources (operators, tools). The interest of the simulation is to solve the complexity of the system and to find results without cost or wasting time. An implementation of the model is carried out on the AnyLogic platform to display the defined performance indicators.

Keywords**—**Maintenance, complexity, simulation, multi-agent systems, AnyLogic platform.

I. Introduction

MAINTENANCE has recognized a set of changes in recent years. It has become an essential function, and has been considered as a source of productivity. Generally, the main purpose of maintenance is to ensure the availability, the reliability of production equipments, and all its related assets in order to maintain a satisfactory level of the production service that necessarily requires a judgment for a time given to intervene.

Maintenance is now considered as an essential function in industry activities. It continues to evolve and change over time. However, it is not a simple task performed by an operator, but it is now treated as a system, and has become currently a complex task that involves several interacting components [1]. Indeed, to study the complexity and the different interactions between multiple entities and to simulate them, multi-agent systems are the appropriate tools for solving various problems in reality and suitable for modeling complex systems.

Agent-based modeling is a computational methodology that enables one to model complex systems. Agent-based models are composed of agents which are computational entities that have properties, or state variables and values (e.g., position, velocity, age, wealth, etc.). An agent can represent any element of a system. The goal of agent-based modeling is to create agents and rules that will generate a target behavior. They can be used to understand a phenomenon through experimentation with rules and properties.

The research using multi-agent systems in the maintenance field addresses specifically the scheduling problems of resources and production planning [2]-[5]. They do not take into account the availability and reliability of the resources required to perform a maintenance task.

The aim of this paper is to manage the complexity of maintenance activities in order to ensure the availability and reliability of the machines with just required resources (operators and tools) to perform a maintenance task by simulating various scenarios of these assigned resources.

The present work is organized as follows: section II presents the problem position. In section III, agent-based modeling is presented. Section IV presents the performance indicators that can be obtained from the multi-agent simulation. Sections V and VI are dedicated to the implementation and experimentation of the model on AnyLogic simulation platform. Finally, concluding remarks are provided.

II. Problem Position

The maintenance task is not a simple task performed by an operator, but it is a complex one for many reasons:

- The interactions between operators, equipment, organization, and working environment are denoted by the intervention of several actors in the system;
- The integration of various elements constitutes the maintenance function to achieve a common objective.

The co-evolution is manifested in:

- The depletion and the diversity of states of a system (normal state, degraded state, failed state);
- The duration of maintenance tasks that can be varied and unplanned;
- The urgent nature of certain maintenance tasks;
- The uncertainty and the learning related to the human factor;
- The availability or otherwise of resources, and disturbances that managers have to overcome.

To understand a complex system, modeling is necessary. In many cases, it is difficult to afford the experiment with real objects to find the right solutions: building, destroying, and making changes may be too expensive, dangerous, or just impossible. Therefore, it is agreed to build a model that uses a language to represent the real system and to find the way from the problem to its solution through a risk-free world where it is allowed to make mistakes, go back in time, and start over again [6]-[8]. In this regard, multi-agent systems are proven to

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be the right tool to manage maintenance activities, to ensure the availability and reliability of the resources required, and to perform a maintenance task.

In this paper, we present a maintenance model based on multi-agent systems to facilitate the simulation of the system and to manage the interactions between its different elements. The modeling of maintenance activities is a critical and necessary step for the optimization of resources to ensure their reliability and availability and finally to perform a maintenance task in the best conditions.

A simulator is developed with AnyLogic platform, and preliminary results which showed the performance of the park machine with minimal resources using the model are presented.

III. Agent Based Modeling

The presented multi-agent system is composed of one actor who is "Maintenance User" and four agents who are: Planner Agent (PA), Machine Agent (MA), Operator Agent (AOp), and Tools Agent (TA) as depicted in Fig. 1.

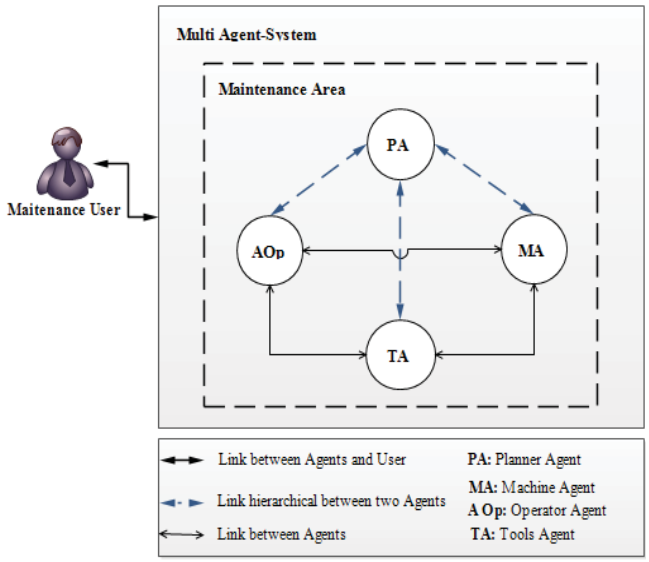

Fig. 1 General architecture of a multi-agent system to ensure the availability and the reliability of resources

A. Maintenance User

His/her role is to enter the parameters and data needed to run the simulation. Then, he/she runs the simulation to get general information about maintenance task.

B. Machine Agent (MA)

The MA identifies the behavior and state of the machine and its operation mode (Normal Function, Function degraded, requiring preventive maintenance or failure). It defines the nature of the machine (Electrical, Mechanical, Pneumatic, and Hydraulic). Moreover, the reliability, the availability, and the number of failure of each machine are calculated.

The agent machine allows us to have the following performance indicators:

- The Reliability characterized by MTBF;
- The Maintainability characterized by MTTR;
- The Availability.

C. Planner Agent (PA)

The PA allows organizing the process of a maintenance task according to an order of intervention for the corrective maintenance or a schedule for the preventive maintenance. This agent can perform the following tasks:

- The definition of the number of resources needed to perform the maintenance task;
- The definition for the duration of the intervention for maintenance;
- The scheduling priority of a task, or a maintenance operation with respect to another task in the event of the unavailability of some resources.

D. Operator Agent (AOp)

The AOp describes the behavior; which moves to a machine requiring a task. This task can be an intervention order or a schedule. Later, after repairing or executing the maintenance task it returns to the shop.

The AOp can see the availability of operators, the number needed for the fulfillment of a task, and the right skills. It simulates the choice and interest of competency based on the nature of the maintenance task. For example, maintenance of an electrical machine requires the intervention of an operator with expertise in the electrical field.

The AOp allows calculating the following performance indicators:

- Rate of availability;
- Utilization Rate;
- Occupancy Rate;
- Mean Time of Moving to the machine that we called (MDT).

E. Tools Agent (TA)

TA contains the necessary tools to perform a maintenance task. This agent determines:

- Technical resources utilization rate;
- Occupancy rate per technical resource.

To formalize coordination in the behaviour of different agents, we adopted the UML activity diagram. This diagram represents the sequences of operations macroscopically and microscopically, and describes the internal behaviour (algorithm) of each agent as shown in Fig. 2. Each of these agents that composes the presented system defines their specific performance indicators related to maintenance.

IV. Maintenance Performance Indicators

Maintenance performance indicators that the presented multi-agent system will display as a dashboard are as follows:

A. MTBF

It is an indicator to measure the functioning time. It characterizes the reliability of an entity.

$$\text{MTBF} = \frac{\sum \text{Up Time}}{\text{Nbr Failures}}$$

B. MTTR (Mean Time to Repair)

It is an indicator to measure the level of difficulty and repair work on a defective device. It characterizes the maintainability of an entity.

$$\text{MTTR} = \frac{\sum \text{Repair Time}}{\text{Nbr Failures}}$$

C. Availability

Availability is the ability of an entity to perform required function under given conditions at a given time. It is expressed as a percentage calculated by dividing the period during the equipment or system is operational by the time theoretical total.

$$\text{Availability} = \frac{\text{UpTime}}{\text{UpTime+Down Time}}$$

D. Utilization Rate

This indicator is defined as the total amount of work allocated to each resource. It is used to control the planning and to ensure the availability of resources.

$$\text{Utilization Rate} = \frac{\text{Operational time}}{\text{Opening time}}$$

E. Occupancy Rate

It is a ratio between the rented units and the total units. It presents the percentage of all rental units that are occupied at a given time.

$$\text{Occupancy Rate} = \frac{\text{Units Rented Out}}{\text{Total Units}}$$

These indicators are obtained as results of the specified agents that are simulated and implemented on the AnyLogic platform.

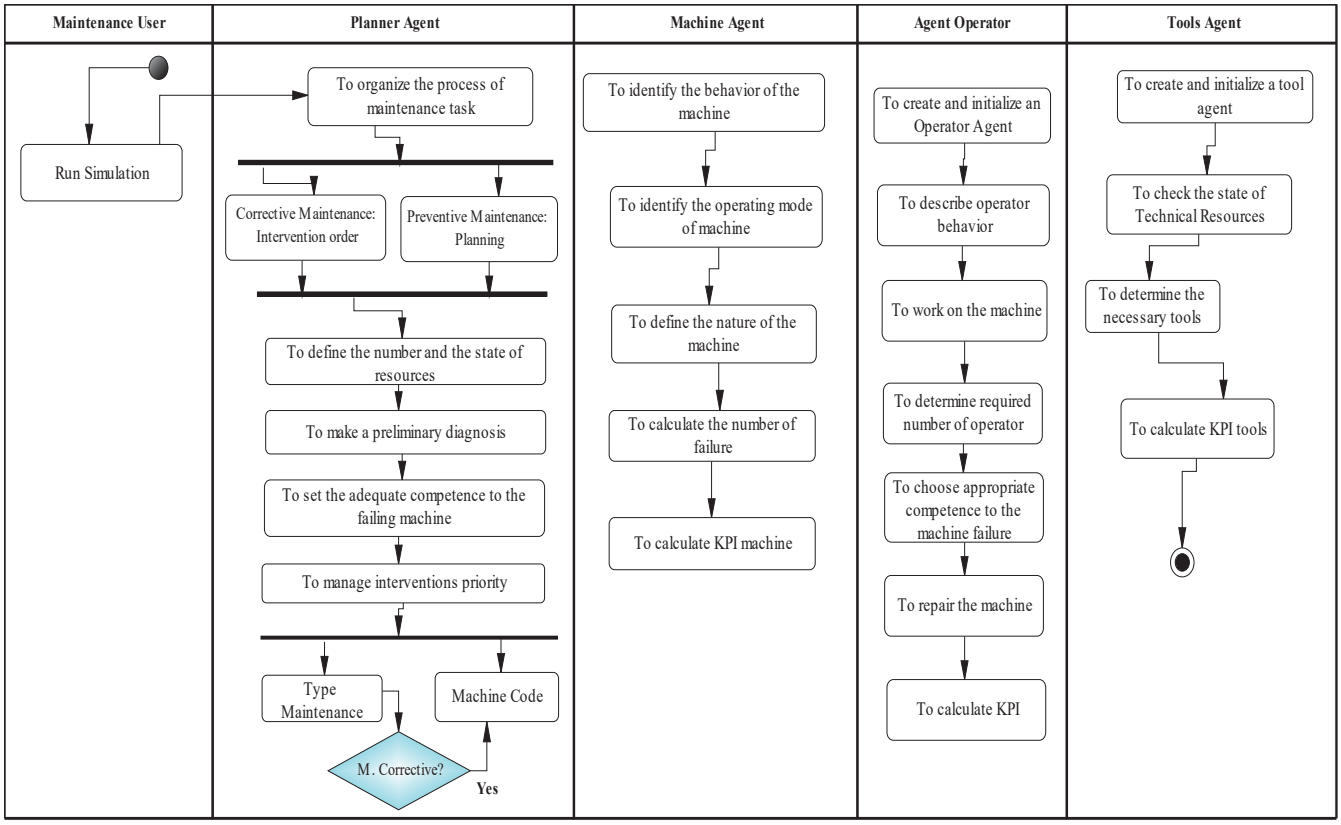

Fig. 2 Activity diagram of Agents

V. AnyLogic Simulation

A simulation is a scientific approach that consists of achieving an artificial reproduction, called model, of a real phenomenon that would be studied. It is to observe the behavior of this reproduction, when certain parameters vary experimentally, and to induce what would happen in reality under the influence of similar variations.

A simulation model is an executable model, when it runs; it builds a trajectory of the changes of system's state. It is a set of rules that tell users how to move from a system's current state to a future state. The rules can take many forms, including differential equations, statecharts, process flowcharts, and schedules. The model's outputs are produced and observed as the model runs [8].

There are several platforms for multi-agent simulation. Our choice fells on the platform AnyLogic because it is able to model industrial problems, and the probability distributions (Weibull, Exponential, triangular distribution…) are well defined.

AnyLogic is a simulation platform for discrete, continuous, and hybrid type systems as well as for the development of deterministic, stochastic, or agent-based systems models [9]. AnyLogic is the first dynamic simulation tool that gathers and combines these three different approaches to modeling-simulation: System Dynamics, Discrete Event, and Multi-Agent Systems (MAS). It is a tool based on the object-oriented approach. All its elements of simulation and animation (3D) are developed in Java programming language.

VI. Case Study: Results and Discussions

We consider the case of a fish canning company. This company has four types of machines: cookers, washing machines, Steriflow, seamers. The most critical machine for the production is the cooker. The hourly load for operators is 8h/day. The company performs the preventive maintenance according to a schedule predefined by the maintenance responsible while giving priority to the corrective maintenance if it comes. This company is enrolled in an improvement process of maintenance management. Its purpose is to bring improvements to the maintenance service and maintain equipment. It seeks to get a better machine availability with the optimal resources (operators and tools).

The company wants to know the necessary number of operators to ensure better availability of these machines in order to guarantee production under favorable conditions. In this aspect, the developed simulator in AnyLogic allows seeing the behavior of machines, operators, and the execution of the maintenance task. It also allows testing several scenarios by changing the number of resources and compares the performance indicators over a long period of time.

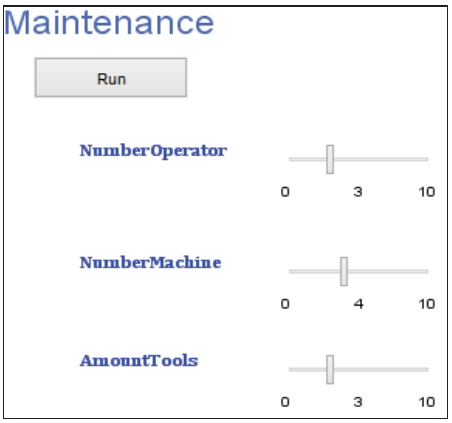

Fig. 3 Anylogic Runtime Interface

In a first step, we fix the number of machines, operators, and the amount of tools as shown in Fig. 3. Then, we are looking at the behavior of the agents of our system with the instant calculation of pre-defined performance indicators as presented in Fig. 4.

We set: number of machine = 4; number of operators= 3; amount of tools = 3 and we obtain the following performance indicators at time = 32.56 UT (Unit Time).

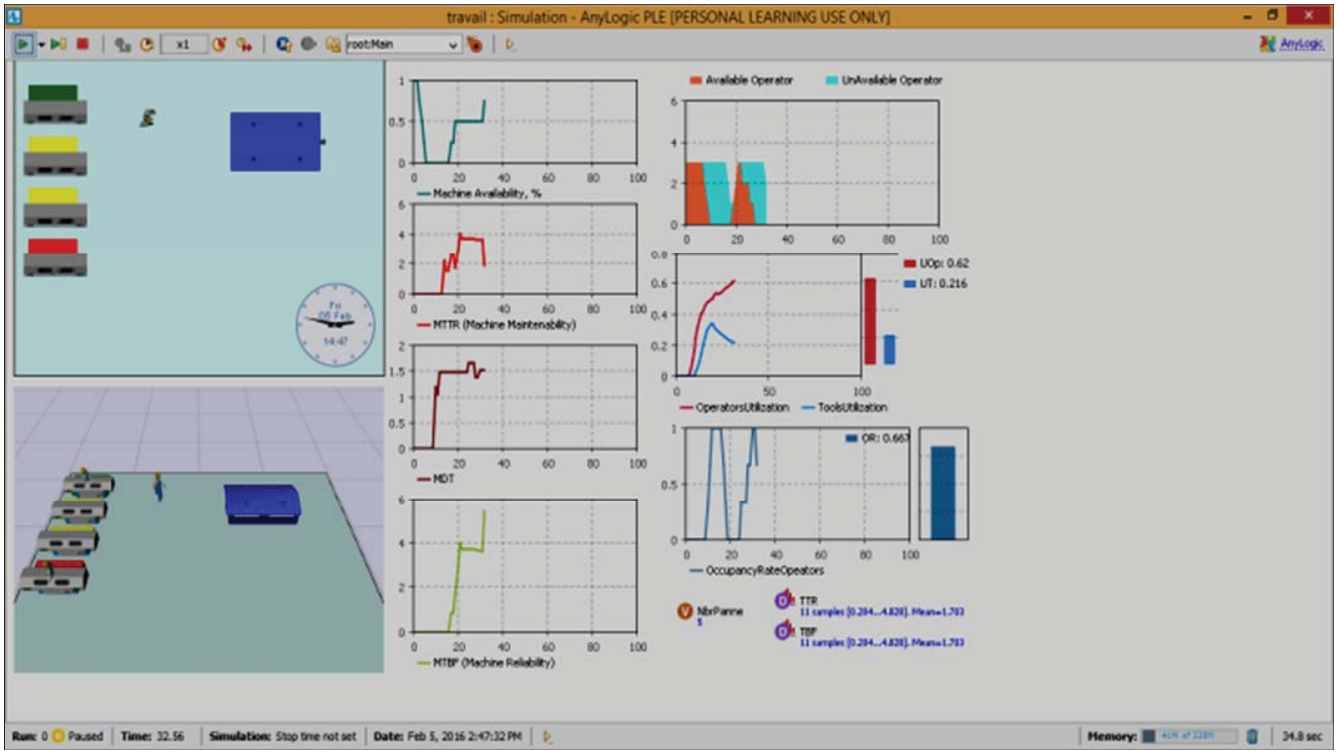

Fig. 4 Simulator representation on the AnyLogic platform

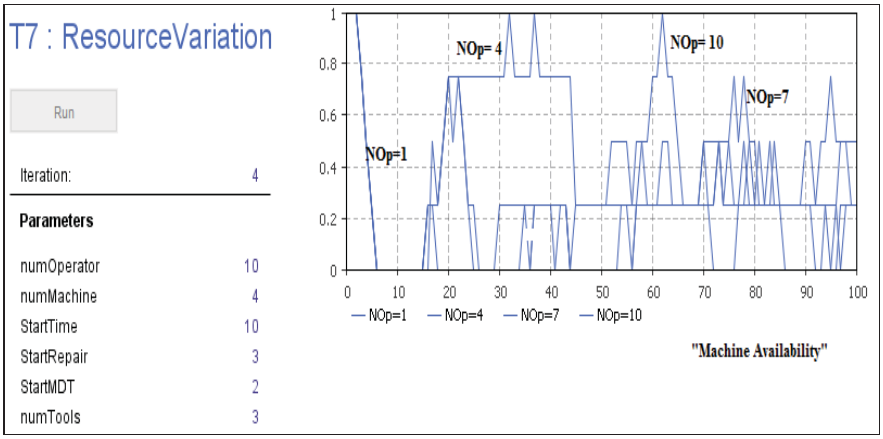

Fig. 5 Representation of the machine availability according to the variation of operator's number

TABLE I
PERFORMANCE INDICATORS CALCULATED BY THE SIMULATION

Agent	Machine Agent	Operator Agent	Tools Agent
Performance Indicators	Availability= 70% MTTR = 2UT MTBF = 5.5 UT	Available Op = 0 Unavailable Op = 3 Utilization Rate= 62% Occupancy Rate = 66.7% MDT= 1.5 UT	Utilization Rate= 21%

This simulator provides the optimum number of operators to ensure better machine availability, by simulating different scenarios, selecting operators' number, and setting the number of machine and tools. We vary the number of operators (NOp) to see its influence on machine availability (Fig. 5). By setting the input parameters and varying the number of operator, we observe the behavior of these operators on the machine availability. We see that we can achieve a 100% uptime with four or ten operators. It is concluded that for the increased availability of four machines, we can perform the maintenance task with just the necessary resources.

VII. CONCLUSION

This paper presents an agent-based model to manage the maintenance activities. It addresses the problem of the availability and reliability of the machines just with required resources (operators and tools) to perform a maintenance task. The aim is to compare different scenarios to monitor the behavior of the agents constituting the presented system at each instant by integrating the constraints of priorities with the goal to optimize these resources (operators and tools).

Initially, we presented the architecture of the multi-agent system. Then, we gave the performance indicators defined for each agent. Subsequently, we developed a simulator where we implemented our model. AnyLogic platform was used for the development of this simulator. We discussed at the end the results through a case study. They showed that for higher availability of the machine, we did not need a lot of resources.

Several other improvements can be made to the model and simulator such as ensuring the safety of maintenance by providing a decision support system, for occupational hazard analysis in maintenance tasks, which will allow orienting the actors to the best decisions in order to minimize hazards that may arise. It is a model for risk management for assessing and simulating risk scenarios related to the maintenance activities. A database will be integrated into this multi-agent system to record various information, and the results obtained by these agents that will serve as an example.

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