# Scheduling of production and maintenance activities using multi-agents systems


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***Abstract*—Manufacturing systems are usually confronted to conflicting situations between production and maintenance services since their activities are considered as source of disturbance to each other. In order to reduce these conflicts, a multi-agents system SCEMP (Supervisor, Customer, Environment, Maintainer and Producer) is proposed in this paper, making sure that these two entities collaborate in order to achieve a common goal. It consists of scheduling the production activities according to the health states of the machines. The main idea is to use the prediction of the durations of use and remaining useful lifetimes of the machines devices, which can be obtained using prognostic techniques. This enables simultaneous scheduling of production and maintenance activities.**



***Index Terms*—Scheduling, production, maintenance, prediction, multi-agents systems**


## I. Introduction

As firms evolving in competitive markets cannot afford to fall behind, they seek continuous improvement and innovation in order to increase and maintain their productivity. The processing of customer requests is made at the upstream of the production line. Thus, when an article is unavailable in the stock, a new fabrication order $OF(R_i, D_i)$ is sent to the manufacturing systems, where $R_i$ and $D_i$ are its release and due date. The objective of the manufacturing systems is to plan the execution sequence of these orders on the machines according to their corresponding bill of materials and to deliver them before their due dates. The scheduling problem is therefore among the most significant activities in the industry, which explains the variety of studies dealing with scheduling problem. The scheduling problem encompasses, in its abstraction, a large number of special cases. Besides, there may exist several constraints to be respected in the planning so that each special case may be the subject of a new study compared to the existing literature. This is the case for this study. However theoretical scheduling methods are seldom applied to real-world industry mostly because the studied problems are often oversimplified due to many assumptions [30], and their complexities are always repellent for workshops managers [20]. The objective of this paper is to propose a generic method with a more realistic model.

Among the existing scheduling problems we consider the job-shop problem, which is a well-known NP-hard problem [19]. Nevertheless, in our case some tasks can be manufactured on only some machines and so the notion of eligibility appears. The processing time of each operation depends on the resource on which it is planned. Also machines can be unavailable at some moments because of maintenance activities. However, the scheduling of maintenance activities is an other field of research by itself. Many studies have been dedicated to maintain the technical resources in good working states. Over the years, many maintenance strategies have been introduced in order to reduce the maintenance cost. Some of these researches focus on studying the evolution of health states of the machines where the evolutions of degradations of their devices are supervised by diagnostic techniques and by predictions of their future health states using prognostic techniques. These techniques are encouraged by Prognostic and Health Management (PHM). A comprehensive survey of these methods and bibliography can be found in [13]. However, most of these works do not consider the production demands.

The management of the production and maintenance activities is therefore a very challenging problem since these two sectors depend on one another and since they are very often in conflict. This brings us back to the objective of this work which consists of proposing a generic method allowing to plan the production and maintenance activities simultaneously according to the health states of the machines using prognostic results. Also, the production and maintenance services can be in different centers, thus time, distance and traveling costs should be considered.

Considering the complexity of the problem, the use of exact methods to solve it within a reasonable time is almost impossible. That is why we propose in this paper an heuristic based on multi-agents system composed of autonomous agents of different natures. Multi-agents systems offer a convenient framework for modelling the different services of a manufacturing system [11]. The use of these systems allows to solve complicated problems by cooperation between the agents and to solve conflict situation using negotiation techniques. In this paper, we extend the multi-agents system discussed in [1] and [11] to solve the joint scheduling problem of production and maintenance activities according to health state of machines.

In the following section, we briefly review some related works. Then in section III the description of the considered problem is formulated and modelled by an UML class diagram. In section IV the multi-agent system model used to solve the problem is presented. First we introduce the different agents, then the communication protocol of these agents is described. In section V an illustrative example is given in which the advantages and disadvantages of the method are shown. Finally, some directions for further research are listed in the conclusion.

## II. Related works

Although the models made for either production or maintenance scheduling are designed to achieve the common goal of boosting the productivity. Unfortunately, they generally ignore or consider the activities of the other as a constraint. The approaches dealing with scheduling problems with unavailability periods can be classified into two categories: deterministic and stochastic approaches [15]. The problem of integrating the maintenance activities into the production scheduling has been proven to be an NP-hard problem in the strong sense in [24] even when the availabilities of the machines are previously known. Moreover, the joint scheduling becomes a complex task given the various uncertainties related to the random demand and failures. In this context [34], [33], [32] were interested by the variation rate of demands. They assume, in their works, that failures depend on the duration of use and on the production rate. Also, the duration of the maintenance activities can be variable. According to [18] the durations of maintenance activities depend on their start times but in reality they can also depend on the maintainer processing it repairement. The health state of the machine can also affect the duration of execution of the operations. These variations are usually modelled by a deterioration effect initially introduced by Brown in 1990 [7]. In all these works, the maintenance activities are considered as a single task that should be executed by one resource which is not always the case. In fact, a maintenance task can require a certain kind of treatments. In this context, the authors of [29] have proposed a genetic algorithm to solve the multiple resources scheduling problem. Some researchs use flow networks to solve scheduling problems with availability constraints like [26] and [5] who have extended the flow network procedure proposed by Horn in 1974 [16]. The flow network procedure has first been introduced by Brateley in 1971 [6]. The idea is to built a bipartite graph that has an arc of capacity one between each pair of eligible nodes, and to find a feasible flow in this network. Three years later Horn has proposed a similar flow network procedure to determine a feasible scheduling of a set of preemptive jobs with release and due dates first on a single machine then on a set of identical machines within a polynomial time.

We note that the foregoing works did not consider the eligibility constraints. This problem has been studied by Centeno and Armacost in 1997 [8] and 2004 [9]. In 1997, the authors have proposed an heuristic based on LFJ rule (Least Flexible Job first), which selects the job that could be executed on the lowest number of machines first. The LFJ rule is optimal when there is no release date of jobs, all jobs have equal processing times and machines eligibility sets are nested ($M_j \neq M_k$, $M_j \not\subset M_k$ and $M_j \cap M_k \neq \emptyset$, with $M_j$ and $M_k$ set of machines that can process job $j$ and $k$). In 2004, they have shown that LPT rule (Longest Processing Time) gives better result than LFJ in presence of release dates. Studies of the eligibility constraint in a hybrid workshops environment have also been made (see [28], [25] and [19]). A comprehensive survey of works dealing with eligibility is given in [22]. Liao and Sheen [21] have considered the problem of both machines availability and machine eligibility constraints. Their method is based on network flow, an extension of Horns' network flows proposed by [16], [26] and [5].

An other class of researchs uses the concept of multi-agents systems (MAS) to solve scheduling problems. MAS deals with behavior management in collections of several independent entities, or agents. A comprehencive survey and bibliography of the MAS is given in [27]. Such approaches are attractive because the autonomous, distributed, and dynamic nature of the agents fit the requirement for the construction of complex, flexible, robust, and dynamic manufacturing systems [30]. In this work, a multi-agents system Supervisor, Customer, Environment, Maintenance and Production (SCEMP) is proposed. This multi-agents system is drifted from the SCEP (Supervisor, Customer, Environment and Production) model first introduced in [1]. In 2000 a distributed aspect has been introduced in the SCEP model in [10] enabling multiples sites of different natures to connect in order to plan their activities in the same environment. The SCEP model is a flexible multi-agents system that has been developed to test various scheduling strategies in a multi-agents context. It can now be found in several scheduling works with different applications such as: [31], [23], [17]. In all of theses works, several local scheduling processes are made by each agent and then are communicated through a main environment, which enables them to reach an agreement that satisfies all. Considering the problem of conflict between the production and maintenance services, a method called R@MSES has been proposed in [2] where a systematic maintenance has been integrated in the SCEP model, while in [11] a Conditional Based Maintenance (CBM), such as soiling, was considered. However, the maintenance activities are either considered as known or launched automatically when a certain condition is verified. In this work, the demands for maintenance activities are launched by the producer when he notices that the health state of a certain device is critical. A new maintenance agent is integrated into the SCEP model, in order to make the producer agents and the maintenance agents cooperate indirectly. A detailed description of the considered problem is given in the next section.

## III. System description and problem formulation

In this work, a set of $N$ manufacturing orders $MO = \{MO_1, MO_2, ..., MO_N\}$ is considered, where $MO_i$ is characterized by a sequence of $n_i$ tasks $S_i = \{TF_{(i,1)}, TF_{(i,2)}, ..., TF_{(i,n_i)}\}$. The tasks -each of which has a fictive operating duration $p_{(i,j)}$ and requires a list of activities $L_{(i,j)}$- are successively executed on the machines. The real execution time $p'_{(i,j)}$ of the $TF_{(i,j)}$ depends on the machine on which it is executed.

Given the release date $R_i$ and the due date $D_i$ of each $MO_i$, the release $r_{(i,j)}$ and due dates $d_{(i,j)}$ of each task $TF_{(i,j)}$ can be calculated as follow :

$$r_{(i,j)} = r_{(i,j-1)} + p_{(j-1)} \qquad \forall j = 2,, n_i \tag{1}$$

$$d_{(i,j)} = d_{(i,j+1)} - p_{(j-1)} \qquad \forall j = n_i - 1,, 1 \tag{2}$$

Recalling that for $j = 1$, $r_{(i,j)} = R_i$ and $j = n_i$, $d_{(i,j)} = D_i$. A task can be assigned to one machine if and only if the machine has all the competencies needed to achieve it. Therefore, for each task $TF_{(i,j)}$ there is a set $M_{(i,j)}$ of machines that can achieve the task.

The manufacturing system considered is composed of a set $M = \{M_1, M_2, ..., M_m\}$ of $m$ machines each of which has a list of competencies, knowing that each competency is associated to one activity. Each competence $k$ is managed by a group of devices of the machine $j$ and can perform the associated activity within a given capability $Cap_{(k,j)}$. If task $j$ of the $MO_i$ is executed on machine $k$, the duration $p'_{(i,j)}$ is calculated by the equation 3.

$$p'_{(i,j)} = p_{(i,j)} \times max_k\{Cap_{(k,m)} \ \forall \ k \in L_{(i,j)}\} \tag{3}$$

The machine can perform an activity during a period of time, if its devices will not fail during this interval. In section III-A, the estimation of Remaining Useful Life (RUL) of a competency is calculated using $RUL$s of its devices. We assume that the devices are degraded by use and their probability density functions of $RUL_{jk}$ are known. In this work, only progressive failures are considered. Thus, preventive maintenance tasks ($TM$) are planned whenever the probability of failure of a certain device exceeds an agreed threshold in order to increase the machines availability. The $TM$ are performed by the maintainers who, in turn, have a list of skills allowing them to repair certain types of devices within a certain speed and price. Just like $TF$s, each maintenance task $TM_{(i,j)}$ has a set $M_{(i,j)}$ of maintainers that can perform it. However, one maintainer can for many reasons be unavailable at some periods, as for example if he is being called for a maintenance activity in another center at this time. Thus the planning of the maintenance tasks is also made according to the availability of maintainers. The modelling of the knowledge is represented by an UML (Unified Modeling Language) class diagram shown in figure 1.

### A. *Estimation of failure*

The importance of PHM is justified by the fact that it permits to reduce the number of systematic maintenance actions as some may not be necessary. Indeed, it allows to follow the degradation evolution of the machines health state through the techniques of detection and diagnosis and to predict the $RUL$s of their devices using prognostics. This makes the estimation of the machines failures times possible and therefore it enables to schedule the maintenance of the critical components before their failures. The existing approaches used to estimate the $RUL$s of the devices can be classified into three main categories: experience-based, model based and data driven approach [12]. The probability of failure of a device can be calculated at any time using the equation 4, where $f$ is the density function of a device prediction of $RUL$ provided from prognosis.

$$P\left[x \leq t_k\right] = \int_0^{t_k} f(t)\mathrm{d}t \tag{4}$$

As said in the previous section, a machine is composed of a list of devices. The devices bring into operation functions and functions bring into operation higher level functions till functions called ”competencies”. Two types of functions can be distinguished:

- Simple functions are composed of a set of devices and/or sub-functions. It fails when one of its devices or sub-functions fails.
- Redundant functions are carried out by at least two devices or sub-functions, so that, when one fails, the service produced is still operative. Thus, the function fails only when there is no device or subfunction left able to produce the service.

Following the same approach as [12], we can obtain the future availability of machines competencies and critical devices using $RUL$s and mean time before failure ($MTBF$) of their devices. Using this information, preventive maintenance can be planned in advance. Therefore, conflicts can be managed between the maintenance and production services. For this aim, a method based on multi-agents system called SCEMP is proposed in the next section.

### B. *Necessary conditions*

As it is considered in [2], for each task $TF_{(i,j)}$, the set of machines that could perform the task cannot be empty ($M_{(i,j)} \neq \emptyset$) meaning that one machine, at least, has all the required competencies among its set of competencies. It is also a necessary condition for each $TM$ and maintainers skills.

The nominal state of all devices should be able to perform at least the heaviest task (ie the task which has the longest operating duration).

## IV. SCEMP MODEL

Multi-agent systems (MAS) have shown their effectiveness in solving scheduling problems having several objectives. Their aim is to solve complex problems, usually in conflict situation, by making several autonomous agents cooperate. An agent can be considered as an entity with goals, actions, and domain knowledge [27]. Communication between agents is indirectly arranged between them through a blackboard. In this work, a new MAS model SCEMP is proposed. This new model is drifted from the SCEP model first introduced in [1]. SCEMP introduces an indirect cooperation between tree communities: customer agent, producer agent and maintainer agent. The description of the different agents is given in the

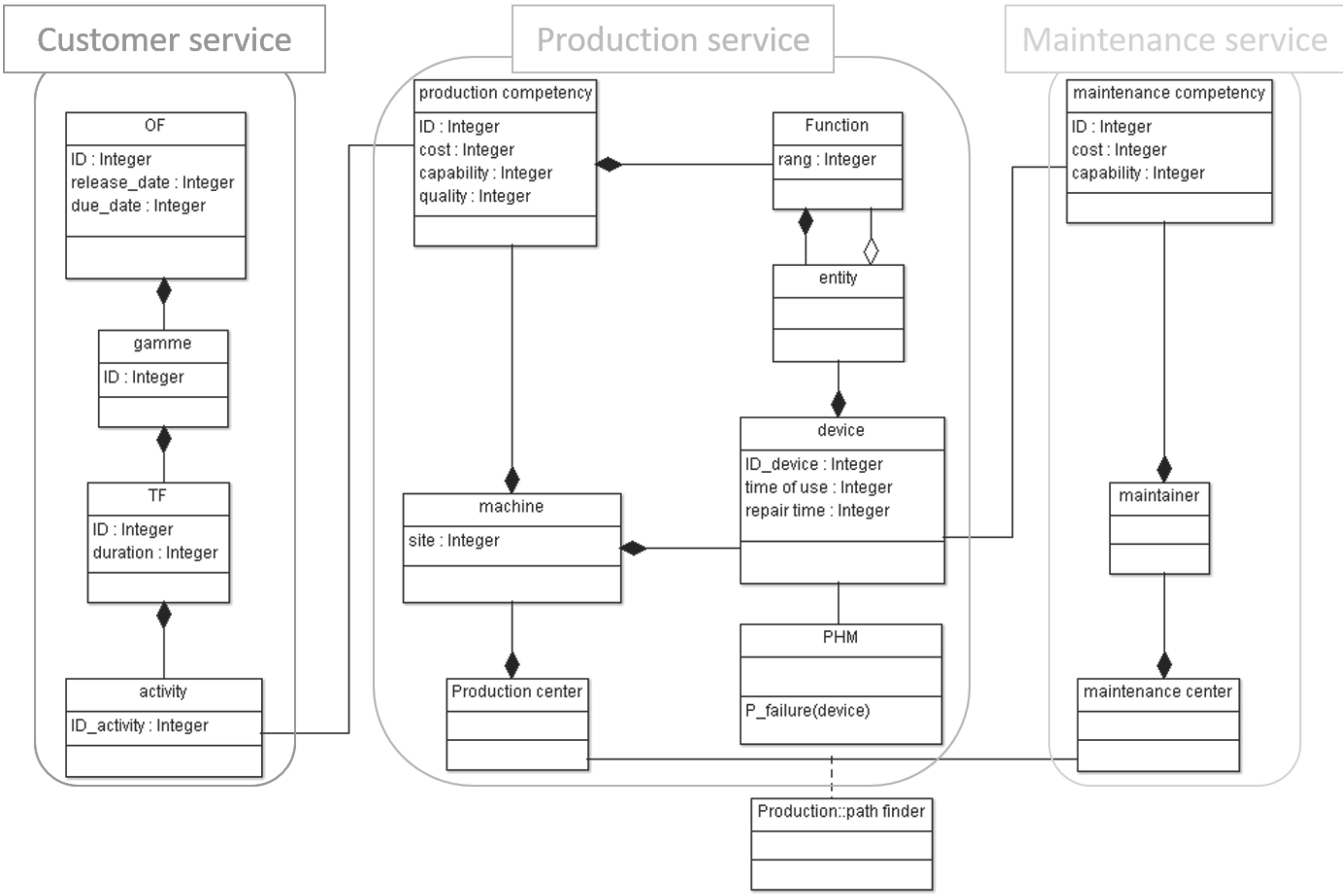


Fig. 1. Functional UML diagram modelling

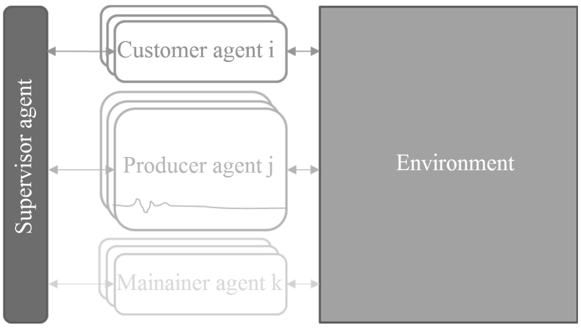


Fig. 2. SCEMP Model

next section. The cooperation protocol between the different agents is described by a diagram sequence shown in figure 3.

### A. Agents description

The cooperation between the agents is ensured by a blackboard called environment. The environment is a shared space which is designed for the registration of demands and proposals for the different agents. It is composed of a list of objects each of wish is characterized by an ID and 4 positions: wish, potential, effective and final position. The definition of theses position is implicitly given in the next section. Each position has the format $([t_1, t2], n)$, where $[t_1, t_2]$ is a continuous temporal interval and $n$ is the ID of the resource executing it. However, if two agents of different natures are both making changes in environment at the same time, conflicts and loss of information can happen. Thus, agents of different natures should not have access to the this space at the same time. This accessibility problem is managed by an other agent called the supervisor.

- Customer agent: Each customer agent manages a MO, which is composed of a set of TF. The customer agent makes sure that tasks execution sequencing is well respected during the planning. Meaning that no task in the MO sequence can start before the completion of the task which precedes it.
- Producer agent: Each producer agent manages a machine. One producer can only schedule the TFs which its machines it able to perform (has all the competencies required). Since each producer has its own objective (minimize the total tardiness of jobs, minimize the total cost, ...) each producer schedules the TFs according to a specific rule (FIFO, SPT, LPT, ...). Definitions and

other existing rules are listed in [4]. The producer agent schedules the $TF$s according to health status it assesses and makes the $TM$ requests for all devices that need to be repaired.
- Maintainer: Each maintainer has for aim to schedule the list of $TM$ he can repair (has the competencies needed). The maintainer schedules the $TM$s according to $FIFO$ rule.

### B. communication

At the beginning of the process the supervisor agent initialize the agents. First the customers agents are activated while the other are invited to wait. A customer agent associate to each $TF$ of its sequence an object in the environment. The customer agent calculates the wish date for each task. The wish date of each $TF$ is calculated by the corresponding customer using equations 1 and 2. Once all $TF$s are displayed on the environment, the supervisor gives producers the access to environment in order to retrieve and schedule the $TF$s which their machines are illegible to. First each producer sorts its $TF$ list according to its rule then calculates the effective and potential position for each $TF$ according to health state of its machine. The effective position (EF) is the position of the $TF$ taking into account all the $TF$ on its list, while the potential (PP) position is considering only the considered task. EF/PP refers respectively to a situation in which all the $TF$ of the resource list would be fixed/rejected. In other words, they refer to the worst and the best position a task can get by an agent. While the producers are calculating the $PP$ and $EF$ for each task, if one finds out that its machine is unable to perform a task (because a required competency will not be able to achieve it under an acceptable probability), new $TM$s are announced on the blackboard. The $TM$s sent by producer concern all devices leading to the failure of the competency. The producer associates to each $TM$ an object in the environment with its wish position and pursue the scheduling of $TF$s which do not require the failed devices. If at a certain point all the unscheduled tasks require at least one critical device, the scheduling processes for this producer is suspended until it gets feedback from maintainers. Once the supervisor gets the information that scheduling process of all producers is stopped it gives access to the maintainer agents in order to schedule the $TM$s launched by producers. Several maintainers treat the maintenance activities launched by the producers and propose an effective and potential position for each $TM$ it can perform. Then each producer accepts the best of this proposals.

The producers continue the scheduling of their remaining production tasks. By the end of this phase, producers send their proposals to the environment for each $TF$. The supervisor orders the customers by then to access the environment so they can validate some of the proposals. A proposal is validated by a customer if the potential position equals the effective one. In case a $TF$ gets several proposals for which satisfy this condition, the associated customer agent selects the best one. Therefore, a $TF$ is planned on a machine only if it has been validated by the customer, which ensures that each $TF$ is executed on only one machine. By the end of each cycle, the customer agents update their wishes for the remaining $TF$.

Finally, the supervisor gives access to producers in order to get the validated tasks and add them into their schedules. Naturally, if no $TF$ has been validated on a machine, it is then useless to carry out the $TM$ launched by its producer agent. An accepted maintenance task launched by a producer is therefore validated if at least one $TF$ is validated on the machine.

### C. convergence of the model

The purpose of this section is to prove that at each cycle, the final position of at least one $TF$ is validated in the SCEMP model. Let us consider that this assumption is not true. Meaning that there is at least one cycle $k$ in which no $TF$ has been validated.

Considering the cycle $k$, with ($k > 1$), 3 cases are possible for each producer:

- maintenance activity is launched at the beginning of the scheduling,
- maintenance activity is launched between two $TF$s,
- no maintenance activity is launched.

In the first case, all positions are shifted to the end of the maintenance activity, including potential positions. In this case the maintenance task can be considered as a fixed task. Therefore, all the $TF$ scheduled can be validated according to SCEP conditions. However, it is shown in [2] that at each cycle of SCEP, the final position of at least one task is fixed, which contradicts the assumption.

In the second case, there is at least one $TF$ that is scheduled before the $TM$. The validation of the set of tasks planned before $TM$ is made according to SCEP conditions. Thus, there is at least one task that has an effective position which is equal to its potential position. This also contradicts the assumption.

For the third case, no maintenance activity is launched, meaning that only $TF$s are planned. In this case, a SCEP model is proceeded and, so, the assumption is not true.

This means that for each cycle, a final position of at least one task is fixed, and so the set of tasks to schedule at the next cycle decreases by at least one task.

For better understanding of the $SCEMP$ functioning, a simple illustrative example is given in the next section.

## V. Illustrative example

In order to evaluate the method, it has been implemented in C++ programming language. At first, we consider 3 $OF$. Each $OF$ has a release date and a due date and has to be scheduled according to its sequence (table I and II).

The considered shop is made of three machines that can achieve several activities like milling, turning and drilling. The machine 1 has the competency to do the activity of milling with a capability of 1, the machine 2 can perform the activity of turning with a capability of 1 and the machine 3 can do turning and drilling with a capability of 1.5 and 1. The machines structures is given in figure 4.

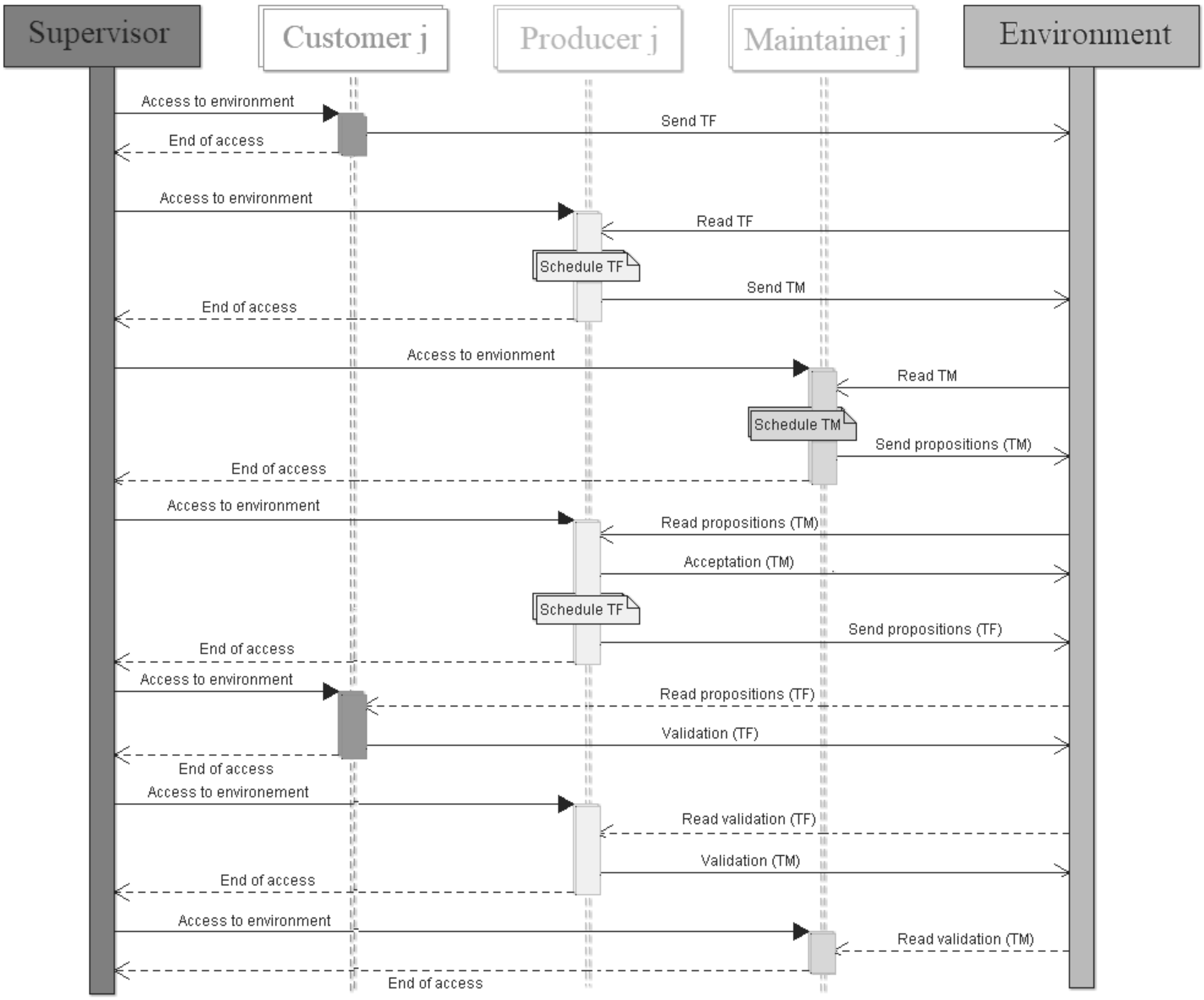


Fig. 3. Communication protocol

TABLE I
CHARACTERISTICS OF THE MOS

| MO | Quantity | Order date | Due date | Routing |
|---|---|---|---|---|
| 1 | 1 | 2 | 26 | 1 |
| 2 | 1 | 1 | 14 | 2 |
| 3 | 1 | 0 | 9 | 3 |

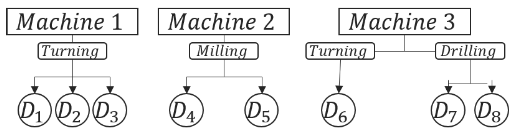


Fig. 4. Machines structure

In order to simplify the calculation, we consider two maintainers that have all skills allowing them to repair all the devices of the machines with an aptitude of 1. We consider also that production and maintenance scheduling policy is a FIFO rule.

TABLE II
CHARACTERISTICS OF THE ROUTINGS

| Routing | Operation | Activity | Duration |
|---|---|---|---|
| 1 | 1 | Milling | 6 |
| | 2 | Turning | 8 |
| | 3 | Drilling | 5 |
| 2 | 1 | Turning | 8 |
| | 2 | Drilling | 7 |
| 3 | 1 | Drilling | 8.5 |

We consider that the probability of failure of the respective devices $D_4$ of machine 2 and $D_6$ of machine 3, follow an exponential law with parameter $\lambda = 0.17$.

At the first cycle, the supervisor initialize the agents, and orders the customers to display their wishes in the environment. Table III shows the state of the environment at the beginning of the processes. Then the supervisor gives access to producers in order to schedule the displayed $TF$. The second and third producers discover that $D_4$ and $D_6$ will fail at time 9 and 20.5,

TABLE III
INITIAL ENVIRONMENT

| Object | Wish | Eff | Pot | position |
|---|---|---|---|---|
| $(1,1,M)$ | $[2,8]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $(1,2,T)$ | $[8,16]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $(1,3,D)$ | $[16,21]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $(2,1,T)$ | $[1,9]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $(1,2,D)$ | $[9,16]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $(3,1,D)$ | $[0,8.5]$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |

TABLE IV
PROPOSITIONS FOR THE MO

| Object | Wish | Eff | Pot |
|---|---|---|---|
| $(1,1,M)$ | $[2,8]$ | $([2,8],1)$ | $([2,8],1)$ |
| $(1,2,T)$ | $[8,16]$ | $([8,16],2)$<br>$([8,20],3)$ | $([19,27],2)$<br>$([30.5,42.5],3)$ |
| $(1,3,D)$ | $[16,21]$ | $([16,21],3)$ | $([49.5,54.5],1)$ |
| $(2,1,T)$ | $[1,9]$ | $([1,9],2)$<br>$([1,13],3)$ | $([1,9],2)$<br>$([8.5,20.5],3)$ |

so two $TM$ are launched in the environment. The maintainers short the $TMs$ according to their release dates, and so founds out that they can repair the device $D_4$ at time 9 which is equal to the producer wish. Same for the device $D_6$. Therefore, only one maintainer has been called for the two $TM$ launched. The two launched $TM$ had been validated thus the communication between the producers and the maintainers has ended. Then both producers pursue their production scheduling. The table IV represents the positions proposed by the producers for each $TF$. We can notice that for the first $TF$, the potential position is equal to the effective position which leads the customer 1 to validate the first $TF$ of it sequence. Since the first $TF$ has been validated, the same customer can still look for validation of the second $TF$, however all the proposals do not satisfy the validation condition. And so the validation process of the first customer ends.
Following the same process, we obtain the results shown in figure 5.

Adding a new device $D_9$ in the structure of machine 3,

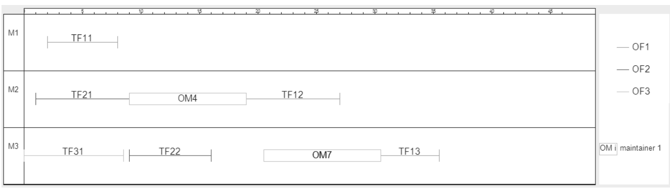


Fig. 5. Gantt chart diagram of production and maintenance activities

TABLE V
CHARACTERISTICS OF THE MOs

| MO | Quantity | Order date | Due date | Routing |
|---|---|---|---|---|
| 1 | 1 | 2 | 26 | 1 |
| 2 | 1 | 1 | 14 | 2 |
| 3 | 1 | 0 | 9 | 3 |
| 4 | 1 | 7 | 20 | 4 |
| 5 | 1 | 10 | 20 | 5 |
| 6 | 1 | 12 | 20 | 6 |

TABLE VI
CHARACTERISTICS OF THE ROUTINGS

| Routing | Operation | Activity | Duration |
|---|---|---|---|
| 1 | 1<br>2<br>3 | Milling<br>Turning<br>Drilling | 6<br>8<br>5 |
| 2 | 1<br>2 | Turning<br>Drilling | 8<br>7 |
| 3 | 1 | Drilling | 8.5 |
| 4 | 1<br>2 | Turning<br>Milling | 7<br>2 |
| 5 | 1 | Milling | 3 |
| 6 | 1 | Turning<br>Drilling | 2 |

such as it is used by the two competencies of the machine. And considering that the device $D_9$ has a probability function that follows an exponential law within parameter $\lambda = 0.17$. We have chosen the same parameter as the other devices so that two $TM$ will be launched nearly at the same moment. We obtain the results shown in figure 6. We notice that two maintainers are called, because one cannot do both at the same time, and the wait for him to finish the task so he can repair the second one will cause tardiness of the $MOs$.
Adding now 3 other $OF$ to the list where the characteristics are presented in table V and VI. Notice that operation 1 of $OF_6$ requires two activities: Turning and Drilling, which means that this operation could be executed one only the machine 3, because it is the only one who has the two corresponding competencies together. The results obtained in this case is shown in figure 7. In figure 7, we can notice that production and maintenance activities are well scheduled on the same Gantt chart diagram and there is no overlapping of the activities. However, since all $TM$ launched by producers at each cycles are validated, some of them would not be needed at the incoming cycles, like the case of the second maintenance activity of machine 2 made over the device 4. Which means that new maintenance validation policies should be made in order to reduce the unneeded maintenance activities.

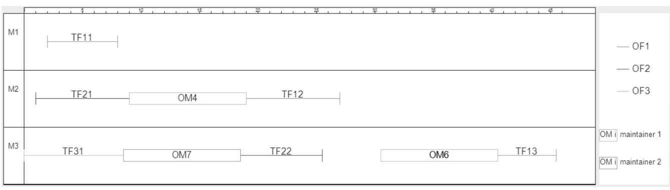


Fig. 6. Gantt chart diagram of production and maintenance activities

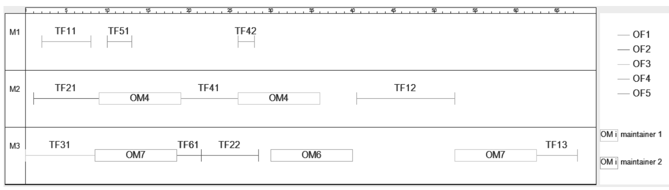


Fig. 7. Gantt chart diagram of production and maintenance activities

## VI. CONCLUSION

In this work, a new SCEMP model is proposed to solve scheduling of production and maintenance activities using data provided from prognostic allowing to predict the $RUL$ of devices and therefore the reliability of the machines to achieve a given set of tasks. This is just the first edition of this method, where all $TM$ launched are validated. In the given examples we have shown how this policy can increase the maintenance cost. However, in more complicated cases it can contribute to serious issues like the braking of the production process. In this context, further works are under investigation such as the test of several strategies and policies of $TM$ validation and the grouping of maintenance activities in order to reduce the maintenance cost. Other policies of scheduling the $TF$ based on meta-heuristics methods will be considered in future works. So that the scheduling made by each producer will be optimized and takes into account the health state of its corresponding machine.

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