

SIMULATION AS A DECISION SUPPORT TOOL IN MAINTENANCE FLOAT SYSTEMS – The Automatic Generation of Simulation Programs

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ABSTRACT

This paper is concerned with the use of simulation as a decision support tool in maintenance systems, specifically in MFS (*Maintenance Float Systems*). For this purpose and due to its high complexity, in this paper the authors propose a flexible way to develop typical MFS models, for any number of machines in the workstation, spare machines and maintenance crews. Arena® simulation language is used to understand a specific MFS, create the corresponding MFS model and analyze most common performance measures.

INTRODUCTION

According to (Pegden et al. 1990), simulation can be understood as the process of construction of a real system representative model, as well as an experimental process aiming to a better understanding of their behavior and to assess the impact of alternative operations strategies. Thus, simulation may also be considered as a decision support tool that allows to predict and to analyze the performance of complex systems and processes as they are in many real systems. In addition, with the use of simulation we acquired a capacity to forecast and to achieve quickly the importance of taking some decisions about the system under analysis. In some real systems like production areas, services such as transport companies, health service systems and factories, the main goal is to achieve high levels of competitiveness and operational availability. In this environment the need for equipment to work continuously is very likely in order to maintain high levels of productivity. This is why MFS has an important role on equipment breakdown and production stoppage has a high and direct impact on production process efficiency and, as a consequence, on their operational results. Therefore, maintenance control and optimization of equipment utilization become not only an important aspect for the mentioned reasons, but also for personnel security matters and to prevent negative environmental impact.

In general, preventive maintenance implementation increases equipment control and avoids unexpected stoppages. However, these maintenance actions could

make maintenance costs too high for a required availability.

In production systems involving identical equipments such as *Float Systems* it is an advantage to integrate maintenance management with materials and human resources. The existence of spare equipment to replace machines that fail or need overhaul is an example of this type of situation. Then, direct and indirect costs due to equipment stoppage are minimized and the level of production or service requirements fulfilled. Although the existence of spare equipment is important to maintain the production process working keeping the number of spare equipment at an optimum level is recommended.

Mainly due to the non-existence of a specific simulator for the maintenance field, we had a great difficulty in choosing an appropriate simulation tool. However, (Dias et al. 2005) had a definite contribution as far as the simulation tool decision is concerned.

In fact, the choice of Arena® as a simulation language was based on the fact that its hierarchical structure offers different levels of flexibility, thus allowing the construction of extremely complex models, allied to a strong visual component (Kelton 2004; Pidd 1989; Dias 2006 and Pidd 1993).

Having referred the importance of studying MFS, the next section of this paper will focus on the literature review on analytical models, but also on some type of simulation metamodels for this type of maintenance systems.

The following section describes new developments on a previous simulation model towards flexibility. In fact, the model presented in (Peito et al. 2011) will gain the capacity to automatically generate a specific simulation program for each specific MFS desired. The program will then be adapted for specific situations with no need of further coding effort. In fact the new proposed tool is intended exclusively to give a response to a type-standard configuration of MFS. Nevertheless, within this type-standard configuration, the user could easily evaluate different strategies under different number of resources available (active machines, maintenance crews and spare machines). This way, the resulting MFS model aims to fill a gap in terms of computer solutions currently existing for this specific type of maintenance systems. Conclusions and Future Developments are the closing sections for this paper.

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To conclude this introduction, once more, we must refer that the proposed tool is intended exclusively to give a response to a type-standard configuration of MFS. Nevertheless, within this type-standard configuration, the user could easily evaluate different strategies under different values for the number of active machines, the number of maintenance crews and the number of spare machines. This way, the resulting MFS model aims to fill a gap in terms of computer solutions currently existing for this specific type of maintenance systems.

RESEARCH BACKGROUND

As far as float systems maintenance models is concerned, (Lopes 2007) refers some studies where simulation has been used to produce results based on specified parameters. Due to the fact that these simulation models were only concerned with the input/output process, without dealing with what is happening during the simulation data process, some metamodels have emerged (Madu and Kuei 1992a; Madu and Kuei 1992b; Madu and Lyeu. 1994; Kuei and Madu 1994; Madu 1999; Alam et al. 2003). The metamodels express the input/output relationship through a regression equation. These metamodels can also be based on taguchi methods (Madu and Kuei 1992a; Kuei and Madu 1994) or neural networks (Chen and Tseng 2003). These maintenance system models were also recently treated on an analytical basis by (Gupta and Rao 1996; Gupta 1997; Zeng and Zhang 1997; Shankar and Sahani 2003; Lopes 2007). However, the model proposed by (Lopes 2007) is the only one that deals, simultaneously, with three variables: number of maintenance crews, number of spare equipments and time between overhauls, aiming the optimization of a system composed by M active and identical equipments. Although this proposed model already involves a certain amount of complexity it may become even more complex by adding new variables and factors such as: a) time spent on spare equipment transportation, b) time spent on spare equipment installation; c) the introduction of more or different ways of estimating efficient measures; d) allowing the system to work discontinuously; e) speed or efficiency of the repair and revision actions; f) taking into account restrictions on workers timetable to perform the repair and revision actions; g) taking into account the workers scheduling to perform the repair and revision actions; h) taking into account the possibility of spare equipment failure; etc. Anyway these mentioned approaches would aim at ending up with MFS models very close to real system configurations. In fact, the literature review showed that most of the works published, involving either analytical or simulation models, concentrate on a single maintenance crew, or on a single machine on the workstation or even considering an unlimited maintenance capacity – thus overcoming the real system complexity and therefore not quite responding to the real problem as it exists.

As far as the model presented by (Lopes et al. 2005; Lopes et al. 2006; Lopes 2007) is concerned it is assumed that systems work continuously, its availability is not calculated and the system optimization is only based on the total maintenance cost per time unit. Moreover, it

considers that the total system maintenance cost is the same without taking into account the number of machines unavailable, which in many real situations is not the best option. Finally the referred analytical model only allows that its failures occur under a *Homogeneous Poisson process* (HPP).

Another important aspect on the companies management strategic definition is to have their tasks correctly planned. To help this planning procedure it is important to know different indicators such as: machine availability, equipment performance and maintenance costs, among others. Therefore one should consider new factors that affect these float systems indicators: possibility of some machine failure, efficiency, repair time.

Moreover, when preventive maintenance policy is used, the time for individual replacement is smaller than time for group replacement. It means that the latter situation requires more machines on the process to be stopped, and also implies an increase on the number of maintenance crews for certain time periods.

In general, companies policy lies on using economic models to define their best strategies. Profits maximization or costs minimization are the most frequent goals used. However, strictly from the maintenance point of view, availability is frequently used as an efficient measure of the system performance, and sometimes more important than the cost based process.

DESCRIPTION OF THE MFS

Our model represents a typical *Maintenance Float System* and it is composed of a workstation, a maintenance centre with a set of maintenance crews to perform overhauls and repair actions and a set of spare machines (Fig.1). The workstation consists of a set of identical machines and the repair centre of a limited number of maintenance crews and a limited number of spare machines. However, the model we have adopted, being a typical MFS, presents certain specificities both as far as the philosophy of the maintenance waiting queues are concerned, and related to the management of the maintenance crews.

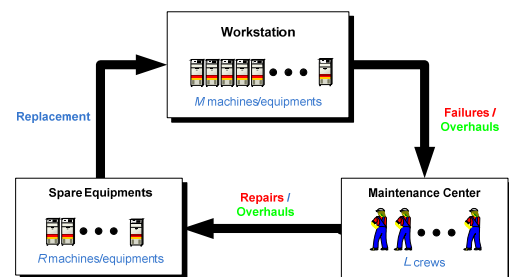


Fig. 1 –Typical Maintenance Float System

This model follows the one proposed and developed by (Lopes 2005; Lopes et al. 2006; Lopes et al. 2007), considering M active machines, R independent and identical spare machines and L maintenance crews. The active machines considered operate continuously. Machines that fail are taken from the workstation and sent

to the maintenance park waiting queue, where they will be assisted according to arrival time. Machines that reach their optimal overhaul time are kept in service until the end of a period T without failures. However they will be also kept on a virtual queue to overhaul. If the number of failed machines plus the number of machines requiring overhaul is lower than the number of maintenance crews available, machines are replaced and repaired according to FIFO (*First In First Out*) rule. Otherwise if it exceeds the number of maintenance crews, the machines will either be replaced (while there are spare machines available) or will be sent to the maintenance queue. The machines that complete a duration period T or time between overhauls in operation without failures are maintained active in the workstation, where they wait to be assisted, and they are replaced when they are removed from the workstation, to be submitted to a preventive action. Its replacement is assured by the machine that leaves the maintenance centre in the immediately previous instant. If an active machine happens to fail it awaits for the accomplishment of an overhaul, then it will be immediately replaced, if a spare machine is available or as soon it is available.

In this version of our model it is assumed that the M active machines of the workstation have a constant failure rate while the model runs.

Time between failures are assumed as independent and identically distributed following an *Exponential Distribution* for all machines (failures occur under a *Homogeneous Poisson Process*). However, during a simulation run, this value could be adjusted based on time between overhauls. Obviously a smaller time between overhauls implies greater time between failures.

As far as time to overhaul and time to repair are concerned, we have assumed the *Erlang-2* distribution, even though considering overhaul time significantly lower than the repair time.

For our MFS, the variables used are the following:

1. Number of active machines (M);
2. Number of maintenance crews (L);
3. Number of spare machines (R);
4. Machine- Overhauls rate (λ_{rev})*;
5. Machine-Initial Failures rate (λ_f)*;
6. Crews-Repair rate (μ_{rep})*;
7. Crews-Overhaul rate (μ_{rev})*;
8. Failure cost (C_f);
9. Repair cost (C_{rep});
10. Overhaul cost (C_{rev});
11. Replacement cost (C_s);
12. Cost due to loss production (C_{lp});
13. Holding cost per time unit (h);
14. Labour cost per time unit (k);
15. Time to convey and install spare machine ($T_{ConvInst}$).

(*) This variable can be adjusted during the simulation run.

The developed simulation model for our MFS allows us to estimate the following global efficiency measures:

- a) Average system availability* ($AvgSAv$);

- b) Total maintenance cost per time unit ($AvgTCu$);

However, some other performance measures are also estimated, such as:

- c) Average number of missing machines at the workstation ($AvgM_{eq}$);
- d) Average number of machines in the maintenance waiting queue ($AvgLq$);
- e) Average waiting time in the maintenance waiting queue ($AvgWt$);
- f) Average operating cycle time ($AvgD$);
- g) Probability of existing 1 or more idle Machines ($Prob_{im}$);
- h) Probability of the system being fully active ($Prob_i$);

and still, some individual efficiency measures per machine or maintenance crew, i.e.,

- i) Utilization rate per machine;
- j) Utilization rate per maintenance crew;
- k) Number of overhauls and repair actions performed per maintenance crew;
- l) Average availability per machine.

INCREASING FLEXIBILITY OF THE SIMULATION MODEL

The Arena® simulation language environment, used in the previous development (see details on Peito et. Al 2011), has been now revisited, aiming to give flexibility to the previous model. The user, now, would be able to automatically generate a simulation program according to specific characteristics of the MFS, namely varying the number of active machines (M), the number of maintenance crews (L) and the number of spare machines (R). However, the steps towards the development of the previous simulation model were all kept and are presented in figure 2, for a better understanding of the simulation model developed.

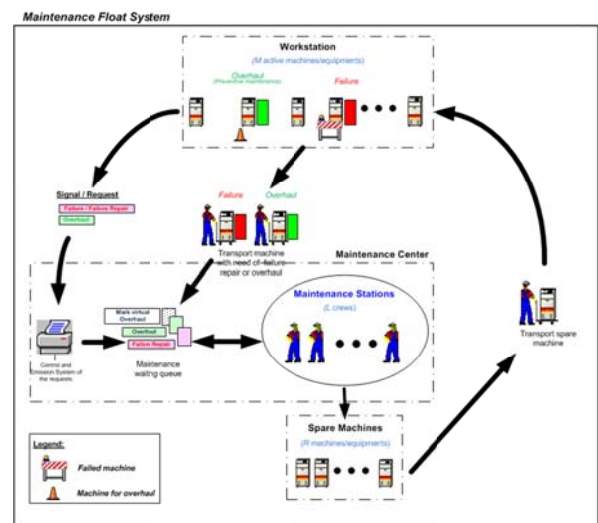


Fig. 2 - Steps for simulation model development

Figures 3 and 4 explicit the global logical simulation model before and after gaining flexibility, underlining its different developed components:

1. Active machines (*workstation*);
2. Statistics 1 (*Recording Machines T_{up}*);
3. Maintenance queue;
4. Machines' transportation (*by the maintenance crews*);
5. Spare machine request;
6. Maintenance center (*set of maintenance Stations*);
7. Release machines to the set of spare machines;
8. Statistics 2 (*Recording Machines T_{up} and T_{down}*);
9. Spare machines (*in the start of the system*).

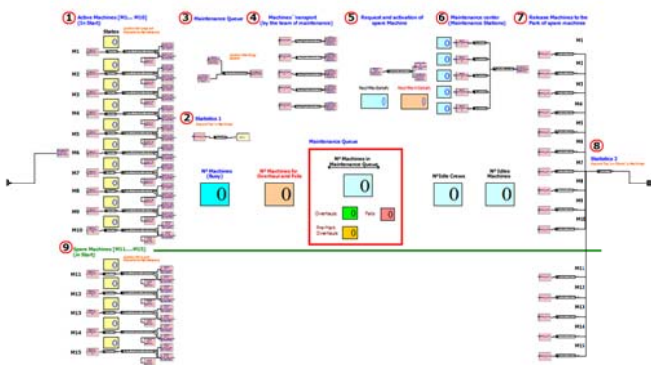


Fig. 3 - Arena® Logic Model before increasing flexibility

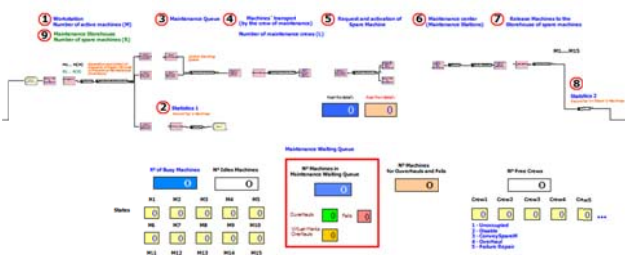


Fig. 4 - Arena® Logic Model after increasing flexibility

This logical model configuration choice was kept identical for the MFS (Fig. 3 and 4), providing again a clear global visualization of the undergoing operations and a great simplicity to make changes in the model. In fact the logical model, after increasing flexibility, will appear even more simplified – see figure 4. The implementation of Arena resource sets, the inclusion of indexed variables and data arrays and also a set of control variables, replacing previous Arena internal variables, have definitely contributed to a simplified model.

The components 1 and 9 after increasing flexibility (Fig. 6) include now a generation and control system for all repair and overhaul requests of all machines, this was not the case in the previous model (Fig. 5). For this control

system to be effective, it would also be necessary to guarantee absolute independence of each type of request for every machine. For this purpose, a mechanism for attribute identification was developed. With this mechanism, it is now possible to identify the state of each machine and the occurrence of every type of machine request (failure or overhaul), at any instant – entity number and color (see figure 6, zone A).

In Fig. 6 (Zone B), a small change has occurred. In fact, some Arena Blocks have been replaced by Arena Modules. This way, planned changes to some parameters are now easy to implement once Arena shows data in a simple table format.

Finally, figure 6, Zone C shows four ReadWrite Arena modules, allowing the registration, in an excel worksheet, of the failure instants and the number of failures for each machine.

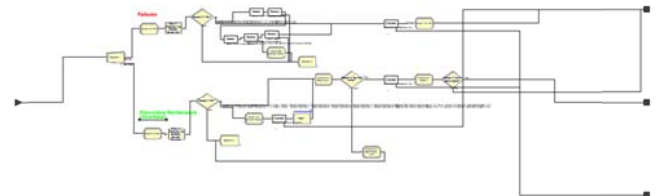


Fig. 5 - Generation and control system for repair and overhaul requests before increasing flexibility

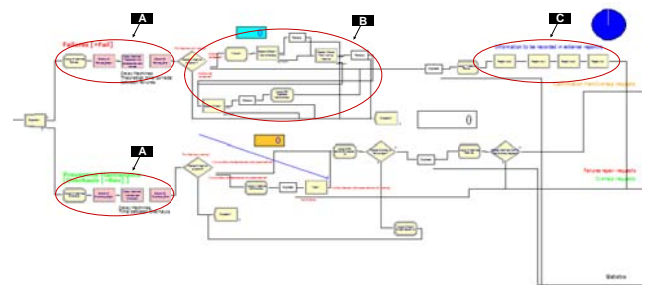


Fig. 6 - Generation and control system for repair and overhaul requests after increasing flexibility

The maintenance waiting queue is defined through a synchronization of events between the component 3 and 4. In the component 4 (figures 7 and 8) there is a "control mechanism", which only allows a request to proceed if there is a free maintenance crew. Component 4 will now include the use of an Arena Resource Set for the maintenance crews, selecting the available maintenance crew that has the least number of services allocated.

The rules for the maintenance queue management were all kept unchanged. In fact, FIFO (First In First Out) is the rule for the maintenance queue management, except for the case when the total number of maintenance requests (overhauls plus repair actions) exceed the number of maintenance crews available – in this case, machines requiring repair action have priority over machines requiring overhauls.

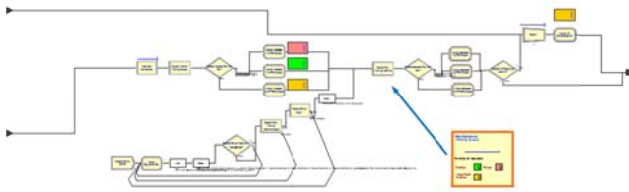


Fig. 7 - Maintenance waiting queue before increasing flexibility

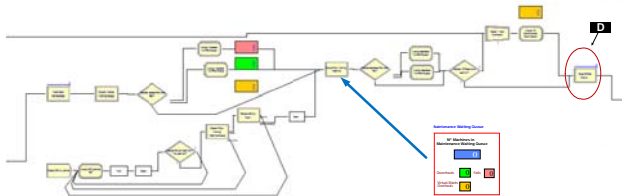


Fig. 8 - Maintenance waiting queue after increasing flexibility

Component 4 (figures 7 and 8) has also been changed and now includes an *Assign Module* in Zone D. Besides the identification of the maintenance crew and the machine transport state (for a spare machine or a failed machine or even a machine needing overhaul), this Module also updates the number of maintenance crews that are free.

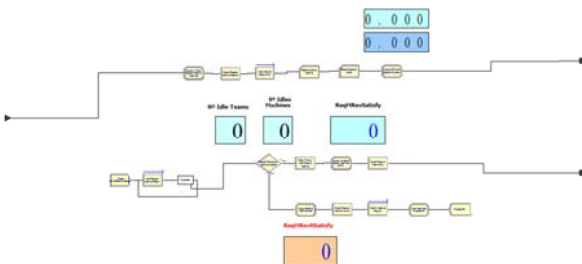


Fig. 9 - Request and activation of spare machines before increasing flexibility

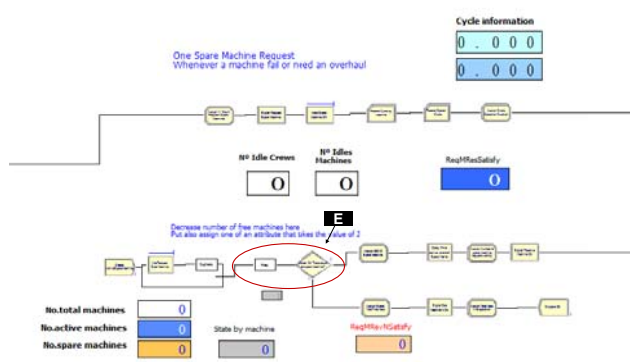


Fig. 10 - Request and activation of spare machines after increasing flexibility

In component 5 (figures 9 and 10) that performs the request of a spare machine, performed by a maintenance crew, there is only a small change in Zone E, that is related with the demand with one free available machine. Now the model includes a *Search Block* that searches for a free machine.

In component 6 (Fig. 11), the change is in the structure of the component. In fact, the discrete variables

are now indexed discrete variables – this way, it is possible to individually save a set of performance indicators for both types of maintenance operations.

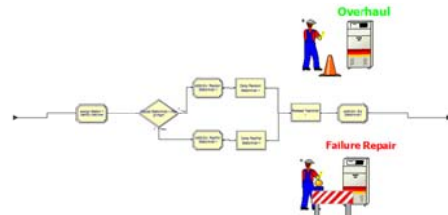


Fig. 11 – Identification and statistics of the states of the maintenance crew

In component 7, responsible for releasing machines under maintenance crew actions whenever they finish their work, either repairing or performing overhauls, all *Release Modules* have been replaced by a single *Release Block* – this was possible once now only a single indexed discrete variable is capable of saving all the information related to each machine.



Fig. 12 – Record statistics

Components 2 and 8 (Fig. 12) which are responsible to record fundamental statistical data to calculate adequate efficiency measures, do not suffered any change.

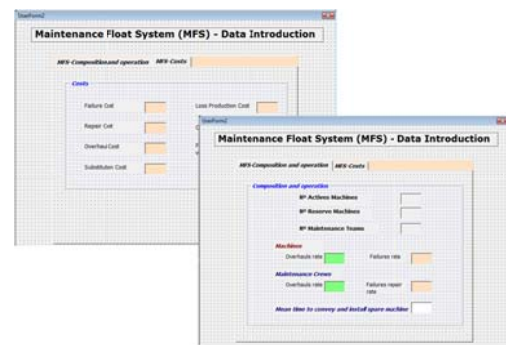


Fig. 13 – Data input area sample screenshot before increasing flexibility

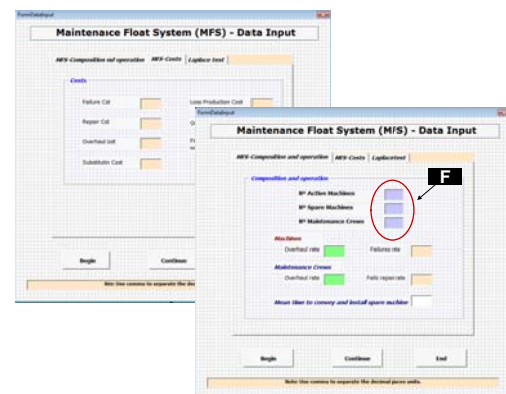


Fig. 14 – Data input area sample screenshot after increasing flexibility

This work, making previous simulation model gaining flexibility, allows the user to get a simulation model for any *Maintenance Float System* desired – regardless the number of active machines, the number of maintenance crews and the numbers of spare machines. After inputting these three values (Zone F, figures 13 and 14), the user will instantly get the appropriate simulation model automatically generated.

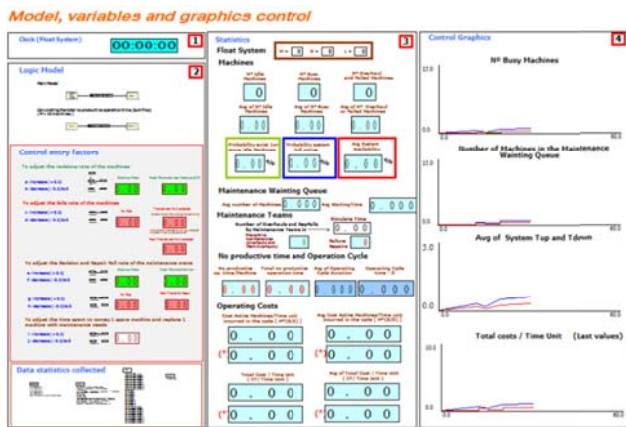


Fig. 15 - Variables and graphics control

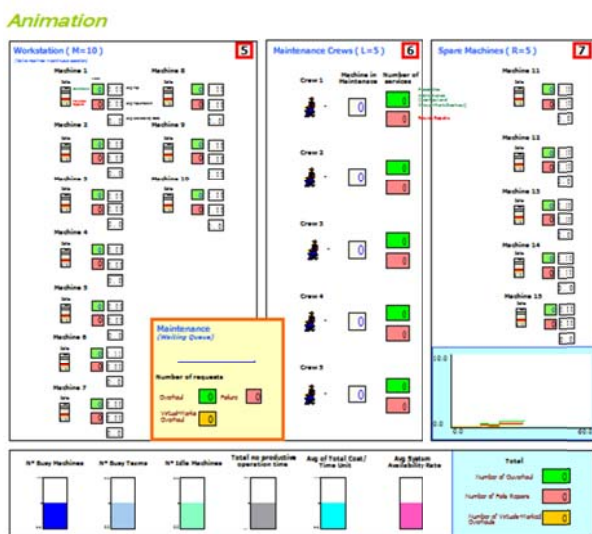


Fig. 16 – Animation area sample screenshot

The presentation of output statistics (Fig. 15) and the model animation (Fig. 16) had no changes.

CONCLUSIONS AND FUTURE DEVELOPMENTS

This new development of our simulation model for our *Maintenance Float System* presents:

- More flexibility

This was the main challenge for the work presented in this paper. The automatic generation of simulation models, depending on the three main maintenance system variables – M , number of active machines; L , number of maintenance crews; R , number of reserve machines. In fact, the user would just have to introduce M , L and R and,

instantly, he will get the adequate simulation model to run and experiment.

- More interactivity

Now the user has the possibility to interact with the simulation model during each simulation run. In fact the user can now modify some parameters of the maintenance system under analysis and can, therefore, evaluate system behavior under different maintenance strategies.

- Better information

This model now offers much better maintenance information. Indeed, the strong visual aspect offered by the developed model clarifies the actual process inside the system. This allows a better understanding of the different interactions in the model and of the simulation results.

The simulation model here presented, incorporating analysis of usual performance measures, also drives its concern towards new efficiency measures, enabling new trends for the analysis and discussion of the best decisions as far as a specific *Maintenance Float System* is concerned. Nevertheless the authors are now aiming to the development of an advanced simulation model, incorporating still more flexibility. This target would be reached by developing and incorporating new modules in our simulation tool, in order to also incorporate maintenance systems where failure rates would also vary while the model runs, i.e., where a *Non Homogeneous Poisson Process* (NHPP) is present. These mentioned future developments also intend to potentiate the known capability of simulation to efficiently communicate with managers and decision makers, even if they are not simulation experts.

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