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Performance evaluation of centralized maintenance workshop by using Queuing Networks

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Abstract: Maintenance workshop integrated in the job-shop system is required in order to maintain the production machines, to ensure the continuity of service and thus to contribute to the improvement of the availability. The objective is to propose a maintenance workshop where all corrective maintenance activities are centralized. When a failed equipment from the production workshop occurs, it is sent to the maintenance workshop in order to be repaired with a given arrival rate. The aim is to maximize the operational availability of the production workshop by reducing the sojourn time in the maintenance workshop. This paper proposes a methodology to design the Central Maintenance Workshop, which enables us to evaluate the performance in terms of cost and sojourn time, for a given budget. For that, we propose a modeling framework based on the queuing network models. Simulation results are given in order to illustrate the influence of different parameters, like arrival rate of the failed equipments and the waiting time of the equipment

Keywords: Availability, Maintenance workshop, Performance evaluation, Maintenance cost, Repairing process, Queuing network models.

1. INTRODUCTION

The growing complexity of the automation level has influenced almost all the industrial areas. The equipment complexity has forced the companies to increase the productivity performance by optimizing the costs and the manufacturing means. The design of systems that require operational availability cannot be done without a previously developed maintenance structure (Monchy, 2000). It is the case in some industrial areas, such as aeronautics and the power nuclear stations. The maintenance strategies are applied to the critical systems, whose failures have significant consequences on equipment availability and staff safety. However, in some other areas, the maintenance is not often considered in the system design (Rustenbug, 2000). The cost induced by the failures that cannot be predicted can sometimes damage the entire manufacturing system. Hence, taking into account the maintenance function is essential for the design of a workshop. Obviously, a sophisticated organization and cooperation between the maintenance workshop and the manufacturing system is required. During the development phase, the maintenance concepts are developed. According to the type of the production system, a maintenance workshop is designed and integrated in order to minimize the unavailability times of the failed equipment (Daniel, 1994, Simeu-Abazi, 2001). There are two maintenance types:

Preventive maintenance: different actions are programmed in cycle periods;

Corrective maintenance: the equipment is repaired after its failure in the maintenance workshop.

Moreover, there is a technique applied in the defense industry, called repair by replacement (Gomez 2009). The failed equipment is replaced by a new or ready-for-use equivalent one, in order to minimize the waiting time. Concurrently, the failed equipment will be repaired. Obviously, this requires new spare parts in the stock for the initial supply. We propose to integrate this technique in the maintenance workshop. Our aim is to maximize the operational availability of the production workshop by minimizing the sojourn time of equipments in the maintenance workshop. The challenge is to give the structure of the maintenance workshop, performing at a higher level, but under reasonable configuration cost. In order to do this, we develop a method, based on a queuing network model that enables to evaluate the maintenance workshop performance by simulation (Di Mascolo, 96). Note that, for relatively simple systems some analytical methods based on the queuing network can be used as in (Duri et al., 2000) and (Abbou et al. 2004). When the systems become more complex, simulation must be used. Our aim is to propose a simulation framework for analyzing any queuing system, with an illustration on a maintenance workshop.

The paper is composed of five sections. After the introduction, the second section is dedicated to the presentation of the maintenance workshop and describes its architecture. In the third section, we describe the corrective maintenance methodology. We use the queuing network to model and evaluate by simulation the maintenance workshop

performance. Based on the method developed, we determine the repair station to duplicate in order to minimize the equipment sojourn time. In the fourth section, we integrate the technique of repair by replacement. We describe the process, model the functioning and evaluate its performance. The method allows us to determine the stock level.

2. DESCRIPTION OF MAINTENANCE WORKSHOP

The maintenance workshop includes three principal services (Abbou 2004):

1. *Technical service*: There is an information exchange between this service and the technical service of the production workshop. The information flow concerns technical data of different equipments included in the production workshop. The purpose is to facilitate the repair.
2. *Maintenance service*: It is the service in which the failed equipment is repaired. It is composed of different stations, each of them with its function. Generally, the first station corresponds to the diagnosis. The purpose is to find the origin of the failure and determine the routing of repair. This station could contain, if necessary, the dismantling function. Also, the last station is dedicated to the test to validate the repair. An example of maintenance workshop is represented in fig.1.
3. *Stock of spare parts*: The configuration items of the production workshop have been identified in the development phase. The spare parts are selected from the set of configuration items. Then, for each spare part, stock levels have to be determined.

Obviously, we assume that the equipment can be transferred into the maintenance workshop. Otherwise, the sectorized antennas move to repair the equipment in the production workshop.

The aim is to maximize the operational availability by minimizing the sojourn time of the failed equipment in the maintenance workshop, but under reasonable configuration cost. For that, we develop a method to evaluate the maintenance workshop performances (Simeu-Abazi 1998). We must determine the number of stations included in the maintenance workshop and define the spare parts stock level. From the simulation method developed, the required parameters allow to design suitably the resources of the maintenance workshop, in order to minimize the sojourn time of failed equipment.

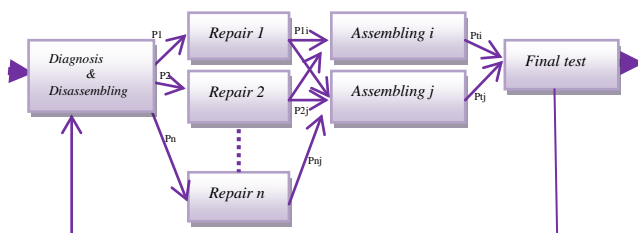


Fig. 1 Various stations for the repair process.

When the failed equipment arrives in the maintenance workshop, it is put in the input buffer in order to be repaired. The diagnosis determines its failures and describes the repair cycle. The failed equipment is affected to different stations according to failure probabilities. After that, the test is required to validate the repair. Finally, the failed equipment becomes ready-for-use. It is stored in the output buffer before its transfer to the production system. In order to illustrate these aspects, we consider a structure given in figure 1 where different stations are represented: diagnosis, disassembling repair, assembling and test. For each case, we will operate on the adequate parameters.

3. MODELING AND PERFORMANCE EVALUATION

A method for the evaluation of the maintenance workshop performances is developed by using queuing network formalism. As represented in fig.1, the maintenance workshop can be composed by a set of interconnected a single service center. The association of one queue to each station enables us to model the maintenance workshop as a network of queues.

In each single service center (see model of station in Fig.4), customers arrive at the service center, wait in the queue if necessary, receive service from the server, and depart. In fact, the service center and its arriving customers constitute a queuing network model with two parameters. First, we must specify the rate at which customers arrive (e.g., one customer every two seconds, or 0.5 customers/second). Second, we must specify the service demand, which is the average service requirement of a customer. These two parameters correspond to the arrival rate of failed equipments denoted by λ and the service rate in each station denoted by μ . For specific parameter values, it is possible to evaluate this model by solving some simple equations, yielding performance measures such as utilization (the proportion of time the server is busy), sojourn time (the average time spent at the service center by a customer, both queuing and receiving service), queue length (the average number of customers at the service center, both waiting and receiving service), and throughput (the rate at which customers pass through the service center) (Jackson, 1963). In our application only sojourn time is calculated. It is what characterizes time during which the equipment is unavailable.

We must determine the number of stations included in the maintenance workshop and define the spare parts stock level. From the method developed, the required parameters allow to design suitably the resources of the maintenance workshop, in order to minimize the sojourn time of failed equipment.

3.1. Model description

We consider a standard repair process as shown in Fig.2. The equipment is composed of different parts. We assume that the equipment failure is due to precisely one part, which is detected in the production system. Also, we assume that all failures can be repaired. The entire equipment is transferred

in the maintenance workshop. It is dismantled and the failed part is diagnosed.

The proposed approach is illustrated on an example given in fig.2. The input of the maintenance workshop corresponds to arrival rate λ of failed equipment. Only two failure modes are considered. Then, according to the diagnostic result obtained by M1, the failed equipment is sent to station M2 with probability 0.7 for repair 1, or to station M3 with probability 0.3 for repair 2. Then, the repaired part is sent to adjustment (M4) before assembly in M5. The assembled equipment is sent to the test station M6 for the final verification.

For each station, we evaluate the sojourn time w_i and the total sojourn time for each equipment denoted by W_T .

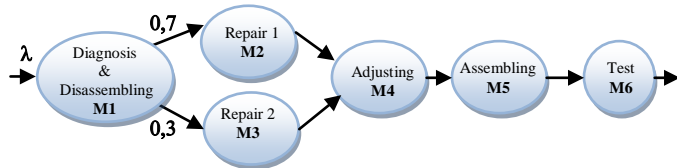


Fig.2. Example of a repair process.

3.2. Modeling with Queuing Network

Queuing networks are used for the modeling of the repair process. For all the equipments, failures occur according to a Poisson process with rate λ (per hour). Each station includes one server with service lead to the time $T_i = 1/\mu_i$ (hours).

By associating one station to each step of the repair process, one obtains the queuing network model shown in figure 3.

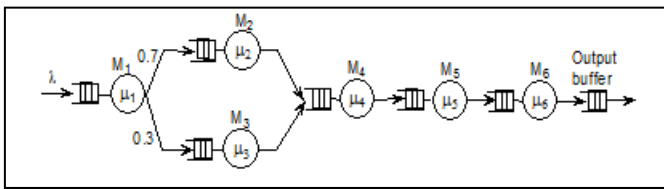


Fig.3. Queuing Network model for repair process.

3.3. Simulation model

MATLAB software is used for the simulation of queuing network model for repairing process.

As represented in Fig. 4, each station is composed by two blocks. The first one corresponds to the parts arrival and the second one for the calculation of waiting time.

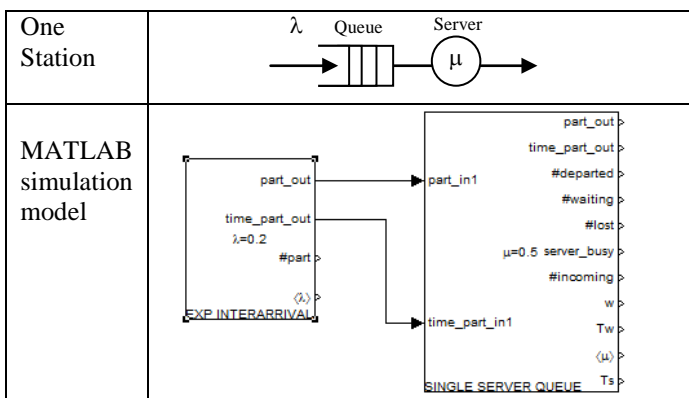


Fig.4. Simulation model for one station.

For a given arrival rate λ , the first block generate parts arrival using intergeneration times from an exponential distribution. The second block needs some inputs like width arrival, size of queue and the service rate. If the width arrival is upper than one, the traffic merging is generated with a given probabilities. The simulation of this queue single server enables us to obtain the average rate of arrival (to be compared to the input data) as well as the average of waiting time.

3.4. Performance evaluation

The performances of the maintenance workshop are evaluated through the sojourn time of the failed parts in this workshop. The objective is to propose a structure of workshop which makes it possible to minimize this time corresponding to the unavailability of the equipment.

From the queuing network model, the maintenance workshop performance can be evaluated.

We assume that the progress of the customers in the stations is Markovian and the service time is exponentially distributed.

For this application, we chose: $\lambda = 0.2/\text{hour}$, which corresponds to 8 equipments per week and the simulation results are given for an average of 10 000 parts which leads to a relative error of around 0.5% on the service rate.

The obtained results for the configuration of maintenance workshop in figure 3 are given in the following (Table 1).

Table 1 - Simulation values of average sojourn time for each station

		M_1	M_2	M_3	M_4	M_5	M_6
10017 Parts ($\langle \lambda \rangle = 0.2005$)							
Service rate	μ	0,65	0,40	0,48	2,00	0,40	1,80
Average sojourn time at station i	w_i	2,22	<u>4,05</u>	2,34	0,54	<u>4,99</u>	0,62
Average sojourn time at workshop	W_T	11.94					

3.5. Improvement of the performance by duplication

We have two methods to reduce the sojourn time. Either we duplicate the stations, which implies an important response lead time, or we store new interchangeable equipments and parts in the stock in order to replace the failed equipments or parts. Therefore, we present here the first method using the same example. The second manner will be explained in the next section.

The simulation result given in table 1, shows that the duration of repair of failed equipment is on average equal to 11.94 h. We notice that the waiting times of equipment in the stations M2 and M5 are the most significant. A solution is to duplicate the stations whose waiting time is important.

We duplicate each station M2, M3 and M5, one by one and evaluate for each case, the profit for 5 years.

a- Station M_2 duplicated

We duplicate the station M_2 by adding another station. We have the stations M_{21} and M_{22} , with the same service rate $\mu_{21} = \mu_{22} = \mu_2$. Also, the probability that the failed part will be transferred to the station M_{21} or to the station M_{22} is 0.35. The queuing network model for the new repair process is shown in Fig. 5. The performances with M_2 duplicated are given in Table 2.

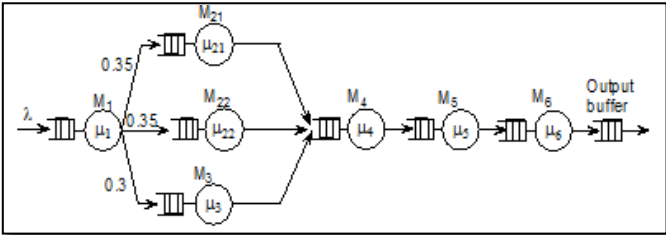


Fig.5. Queuing Network model with station M_2 duplicated.

Table 2 – Simulation results of average sojourn time when station M_2 is duplicated

10043 Parts ($\langle \lambda \rangle = 0.2010$)		M_1	M_{21}	M_{22}	M_3	M_4	M_5	M_6
Service rate	μ_i	0,65	0,4	0,40	0,48	2,00	0,40	1,80
Average sojourn time at	w_i	2.21	3.16	2.87	2.37	0.57	5.11	0.63
Average sojourn time at	WT	11.36						

The duplication of M_2 does not give satisfying results because the average sojourn time decreases only by 0.58 h.

b- Station M_3 duplicated

The queuing network model for the new repair process is shown in Fig. 6.

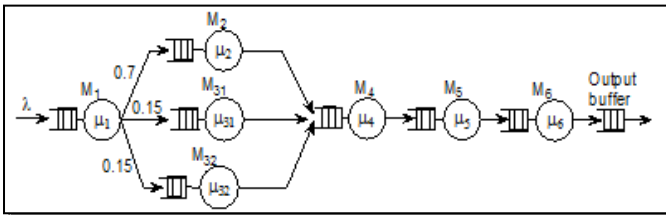


Fig.6. Queuing Network model with station M_3 duplicated.

We conserve the same input data. The performances with M_3 duplicated are given in the Table 3.

Table 3 - Simulation results of average sojourn time when station M_3 is duplicated

10043 Parts ($\langle \lambda \rangle = 0.2010$)		M_1	M_2	M_{31}	M_{32}	M_4	M_5	M_6
Service rate	μ_i	0,65	0,4	0,48	0,48	2,00	0,40	1,80
Average sojourn time at station i	w_i	2.22	3.84	2.22	2.22	0.55	5.00	0.62

Average sojourn time at workshop	WT	11.76
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The duplication of M_3 does not give satisfying results because the average sojourn time decreases only by 0,18 u.t. The duplication of M_2 gives the better results.

c- Station M_5 duplicated

The queuing network model for the new repair process is shown in Fig. 7.

By duplicating M_5 , we have the stations M_{51} and M_{52} , with the same service rate $\mu_{51} = \mu_{52} = \mu_5$. Also, the probability that the failed part will be transferred to the station M_{51} or to the station M_{52} is 0,5. The performances with M_5 duplicated are given in Table 4.

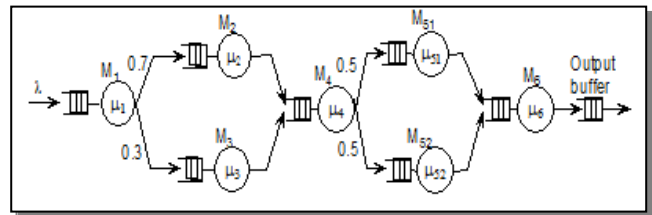


Fig.7. Queuing Network model with station M_5 duplicated.

Table 4 - Simulation results of average sojourn time when station M_5 is duplicated.

10043 Parts ($\langle \lambda \rangle = 0.2010$)		M_1	M_2	M_3	M_4	M_{51}	M_{52}	M_6
Service rate	μ_i	0,65	0,40	0,48	2,00	0,40	0,40	1,80
Average sojourn time at station i	w_i	2.29	3.88	2.35	0.56	3.36	3.37	0.61
Average sojourn time at workshop	WT	10.28						

The duplication of the M_5 station makes it possible to minimize the sojourn time in the maintenance workshop. Compared to the cost of this solution, the investment on a station makes it possible to have a significant profit.

Let us suppose that the capital cost of a new station (M_2 or M_5) is estimated at $C_{Res} = 7\,500\text{ K €}$ the cost associated with the unavailability of the equipment is of 500 €/h and the annual operating cost with $OC_A = 600\text{ €/year}$.

By comparing the results obtained for the 3 cases (the initial model, the model with duplicated M_2 and model with duplicated M_5) compared to the costs which each case generates, we obtain the results given in table 5.

Table 5 – Performance comparison

	Initial model	M_2 duplicated	M_5 duplicated
Average sojourn time at workshop (hour/week)	11.94	11.35	10.28
Production loss at the end of 5 years	4040.94	3840.84	3477.60
Capital cost at the end of 5 years	-	10.48	10.48
Profit at the end of 5 years	-	200.10	563.33

The loss of production and the capital cost are the parameters which make it possible to judge performances of this workshop of maintenance. Then for each structure, the loss of production, the capital cost and the profit at the end of 5 years are calculated to choose the structure of workshop which gives best the performances. The results show that the structure with M5 duplicated gives the best performances.

4. MAINTENANCE OPTIMISATION

The method that enables us to minimize the sojourn time of equipments in the maintenance workshop is the integration of the repair by replacement technique. As it was explained before, interchangeable equipments and parts have to be kept on stock in order to react rapidly to unexpected equipments failures.

The maintenance by replacement can be carried out at various levels. Two levels of replacement are taken into account:

- The replacement of **level 1** consists in replacing failed equipment by equipment while drawing from stocks of the repaired equipment in the workshop of maintenance.
- The replacement of **level 2** consists to replace part of the failed equipment by another in stocks of the repaired equipment. In this case a station of disassembling is necessary.

We consider now the same repair process as described in Fig. 3 with two levels of replacement described above.

3.6. Replacement level 1

The principle of this technique is as follows: as soon as faulty equipment is present in the maintenance workshop, its repair starts. In parallel, if another equipment is available in stock, this one is taken for the replacement. Thus, the unavailability time is reduced to its installation and transfer time of the new equipment. The queuing network model corresponding to this workshop with replacement of level 1 is illustrated by the figure 8.

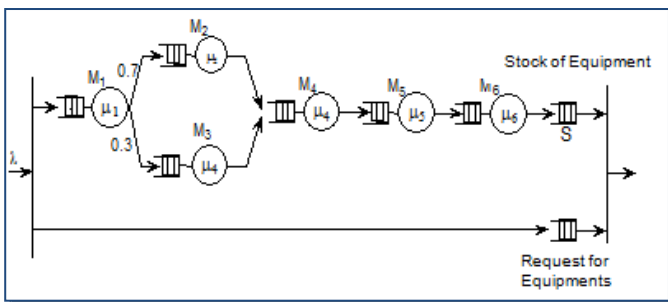


Fig.8. Queuing Network model for replacement level 1.

For this case, the queuing network model is a base stock system composed of one stage. The purpose is to satisfy requests or demands and to lead the stock of equipments to its nominal level S.

Failures occur according to a Poisson process with rate λ . When failed equipment arrives at the maintenance workshop, it is immediately sent into repair and, simultaneously, a

request for ready-for-use equipment is sent. The failed equipments follow the upper stream of the repair process described in Fig. 7 and the requests for ready-for-use equipments follow the lower stream.

If equipment is available in the stock of level S, it is picked from the stock to replace the failed equipment in the production workshop, and hence the request is satisfied. In the maintenance workshop, when the equipment is repaired, it becomes a ready-for-use and constitutes an increment for stock S.

Table 6 describes different performances of the maintenance workshop according to the stock level of equipments.

Table 6 - Simulation results: sojourn time as a function of the size of stock

Stock size	0	1	2	3	4
Average sojourn time at workshop	11.94	7.25	3.44	1.82	0.93

These results show well that the higher the storage capacity is, the lower sojourn times are. It is of course necessary to make a trade-off between the unavailability cost and the storage cost.

3.7. Replacement level 2

The queuing network model of the repair and replacement process is shown in Fig. 9.

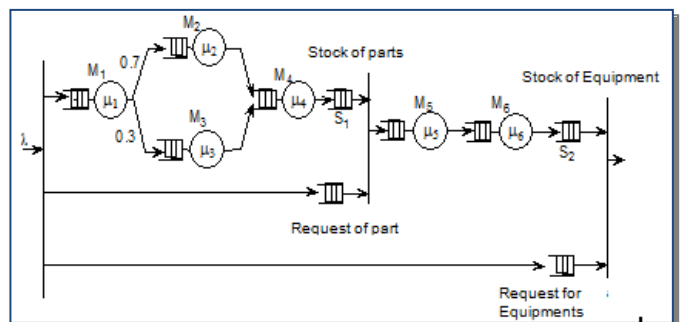


Fig.9. Queuing Network model for replacement level 2.

Failures occur in the maintenance workshop according to a Poisson process with rate λ (per hour). The failed equipment is sent into repair and, simultaneously, two requests, one for ready-for-use equipment and one for request for ready-for-use part, are sent. If a new or ready-for-use equipment is available in the stock of level S₂, it replaces the failed equipment. Then, after diagnosis and dismantling in the station M₁, the defective part is sent into repair.

On the same way, when a new or ready-for-use part is available in the stock of level S₁, it replaces the defective one. The queuing network model is a base stock system composed of two stages. In the first stage, we have stock of equipments with nominal level S₂. In the second one, we have stock of parts with nominal level S₁.

We assume that:

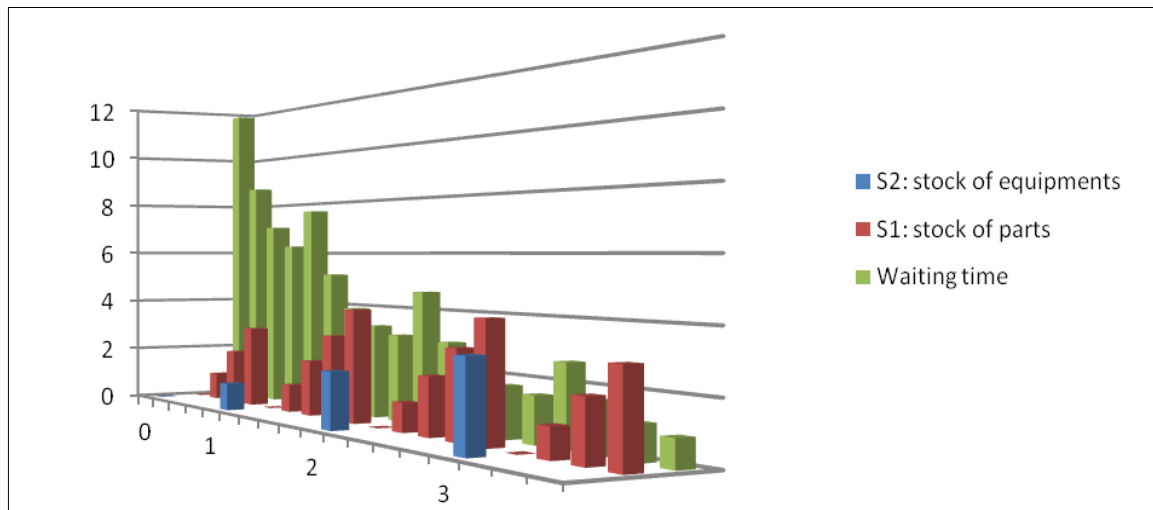


Fig.10 Study of the variation of the sojourn time to the storage capacity of S1 and S2

The part price is about 4 K Euro (guarantee 1 year).

Annual additional expenses estimated at 2 K Euro.

Different combinations from the stock levels are established. Fig. 10 shows, respectively, the investigation costs for the various levels of equipments and parts stocks. That allows carrying out the trade-off between the investigation cost in order to reduce the sojourn time in the maintenance workshop and the benefit on 5 years. As example, for the data used, it is preferable to store 2 parts and 3 equipments ((S1; S2) = (2; 3)), to only store 3 parts ((S1; S2) = (3; 0)). Indeed, starting from the results obtained, for the case (S1; S2) = (2; 3) where the waiting time is equal to 1.74 hour/week, the capital costs during the 5 years are estimated at 124.70 K € and profit at the end of 5 years with 3481.44 K Euros. On the other hand, for the case (S1; S2) = (3; 0), the waiting time is equal to 2.69 lead to the capital costs estimated at 128.70 K€ with a profit at the end of 5 years with 3205.11 K Euros only.

It is obvious that if we investigate in spare parts for the initial supply, we will considerably reduce the waiting time, and hence the operational availability will be increased. However, limited budget is imposed. Then, the stock levels have to be determined.

5. CONCLUSION

In this paper, we are interested in the maintenance workshop. We have defined this workshop and determine its different services. The corrective maintenance methodology is described. We have proposed to integrate *the repair by replacement technique* in the maintenance workshop, in order to reduce the waiting time.

In order to evaluate the maintenance workshop performances, we have developed a simulation framework based on the Queuing networks. For each situation, the required parameters have allowed reducing the sojourn time, and hence improving the profit. Optimization consists in researching the best trade-off between the availability

resulting from the repaired equipment, the size of the maintenance workshop and the maintenance costs.

As further directions of our work, we propose to develop an algorithm enabling to determinate automatically the stations that must be duplicated and define the stock level.

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