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MULTI-CRITERIA SCHEDULING APPROACH FOR E-MAINTENANCE SYSTEM

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Abstract: *This article deals with a database model created by computer simulation using Witness® software. The database model was conceived as an e-maintenance system module and can be easily interconnected with any system. The database model is used to support scheduling or human resource management during the course of centralized planning maintenance. Maintenance with centralized human control is favourable for companies supplying expensive and special technologies (e.g. manufactures of machine tools) or for international companies having several locations in different parts of the world (e.g. the automotive industry). The aim is to improve the efficiency of maintenance workers and thus ensure lower prices, quick re-planning, and decrease travel costs, accommodation costs, etc.. Random failures and non-expected phenomena are also considered. Random situations or alternatives can be simulated before they actually occur.*

Key words: *e-maintenance, multi-criteria function, simulation.*

1. INTRODUCTION

Modern equipment control and maintenance systems based largely on remote internet management are called e-maintenance systems. They present a collection of technical tools which are used to monitor machines remotely and also to perform some specific corrections. Error-predicting analytical tools can be used for monitoring, the interconnection of machines, control systems, camera systems, diagnostic systems and machine management systems.

Remote management technical support, which e-maintenance systems are largely based upon, should be in accordance with direct support provided by trained workers: specialists on specific machines and devices directly on site. The e-maintenance system also brings considerable savings by using a minimum number of workers for the maintenance of machines, special tools and devices. The e-maintenance system also tends to use specialists for specific machines, thus providing a more professional approach to problem diagnosis and especially the speed with which these problems are solved.

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In this article we propose a decision support model for managers. A computer simulation module is created using Witness® simulation software. It deals with the optimization of the number of workers or specialists needed to perform maintenance of machines with common malfunctions where maintenance needs to be performed. The module includes both preventive maintenance and pseudo-random malfunctions of common operations. An optimization module is used to evaluate the results. The complete computer support system can be interconnected with pre-existing basic e-maintenance systems. Actual data can be loaded and operations can be optimized to achieve maximum effectiveness. Classical measures such as time, accessibility, productivity, etc., are used for evaluation together with measures set using the multi-criteria functions.

2. CONTEXT OF THE PROBLEM

To stay competitive, companies must decrease their costs as much as possible and optimize their means of production. One of the objectives of maintenance service is to increase the availability of equipment. This improvement requires good management of the workforce and its skills.

It is difficult to precisely determine the required number of staff in maintenance service [5 and 7]. Employees have different skills and different qualification levels. Then, the duration of a task and thus the service reactivity will depend on the selection of the employees assigned to the task.

There are various forms of maintenance management. Indeed, if the company itself does not conduct mainten-

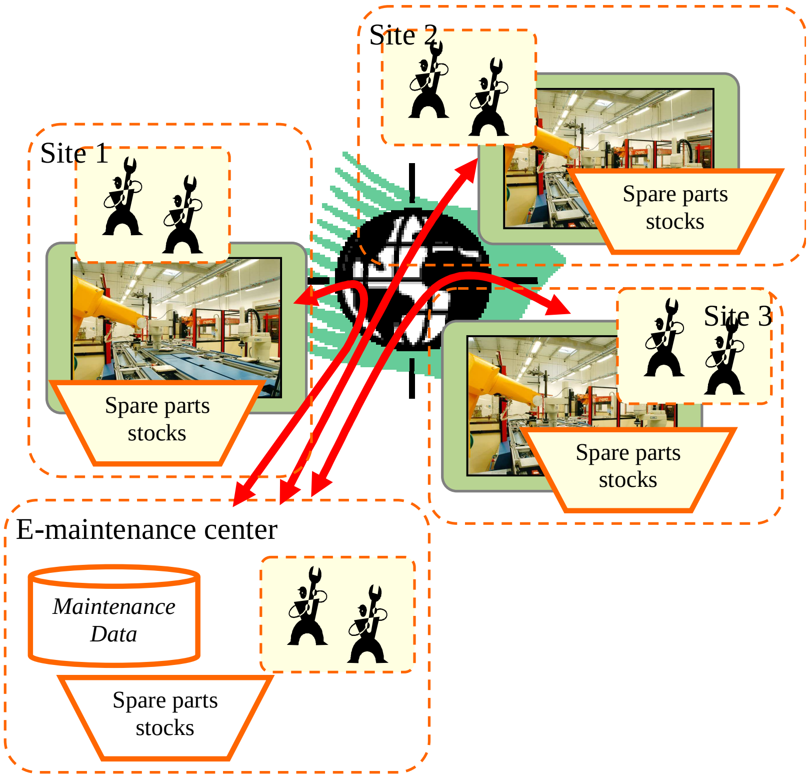

Fig. 1. The context of e-maintenance.

ance, this can be sub-contracted. The monitoring, preventive, and corrective maintenance can thus be entrusted directly to the manufacturer of the equipment (the expert on this type of equipment) or with a company specialized in industrial maintenance (an expert in the field of monitoring and remote maintenance for the equipment involved). The equipment can also be rented, and if maintenance is not conducted by the user company, it can also be sub-contracted [4].

The emergence of new technologies has change maintenance service management. Indeed, if equipment can be remotely monitored or better maintained, new organisation can be set up. Our activity deals with this new context. We consider an e-maintenance service that has to maintain equipment in different sites (Fig. 1).

One of the problem in such a context is the management of human resources [5]. When maintenance has to be performed on the equipment, one has to define which human resource is well adapted to do the operation. This decision should take into consideration the availability and location of the resource, the nature of the operation, the priority of the maintenance task, etc. The decision-maker will take also take into account cost, importance and other factors, such as limited resources, to prioritize the work [1, 8 and 3.

3. SIMULATION SYSTEM AND MODEL DESCRIPTION

The computer simulation is based on a computer model that describes the behaviour of a devoted real system. The model created serves for later experiments to find reserve funds, or to simulate situations which apply to “What will happen if ...” (e.g. drop flow, draw a new machine, rebuild layout, increase production, ...).

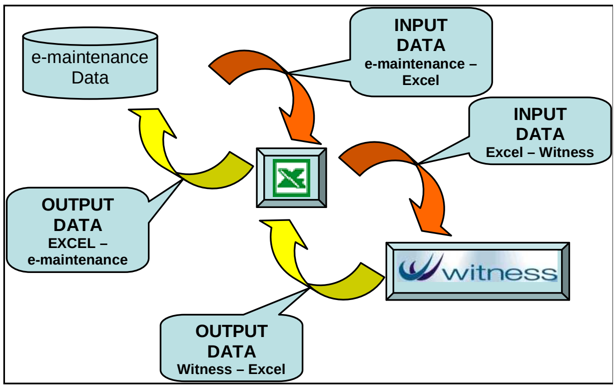

Fig. 2. Simulation data for e-maintenance-simulation software.

To address the needs of e-maintenance it is possible to create a model that will simulate all situations. These are, for example, the creation of a layout of machines anywhere in the world, respecting necessary transportation times from place *A* to place *B*, etc. The model created in simulation software can be directly connected with an e-maintenance system using standard means. The data can be inserted directly from a single database or from Microsoft Excel, etc. The models created can possibly be expanded for random disturbances, not only of machines, but also of transport or other random phenomena (Fig. 2).

These combinations are made by the Optimizer module which is already implemented in the Witness system. Here, all combinations can be optimized (which is time-consuming when we have many variations) or we can use some algorithms to lower the number of combinations. In this case we run the risk of not finding the optimum combination but what is known as sub-optimum. When performing all the combinations we

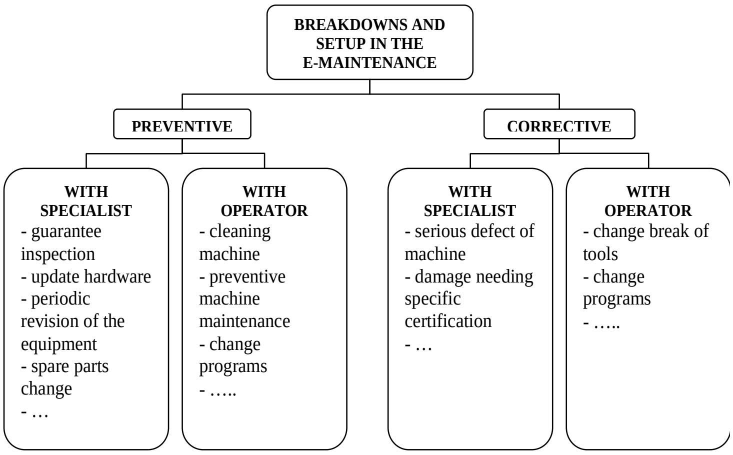

Fig. 3. Types of maintenance.

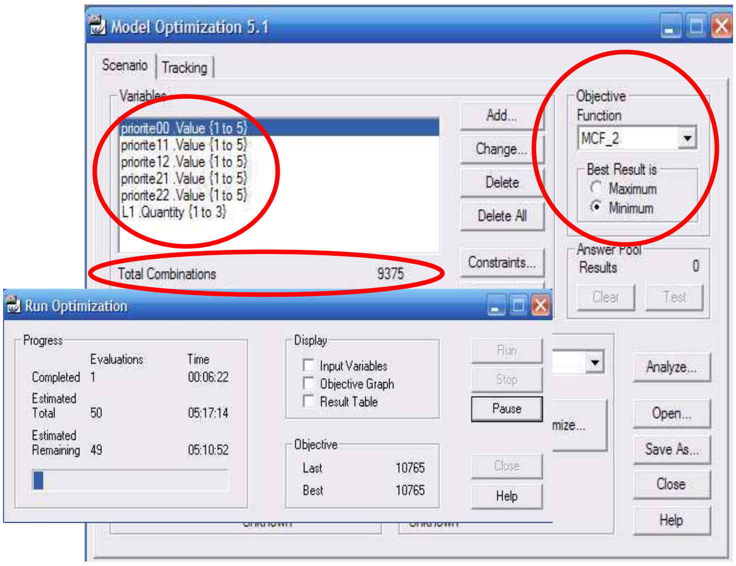

Fig. 4. Optimizing criteria and MCF.

check the impact of k-factors having $q1$, $q2$ …, qk of various levels. Then, to analyze the combinations in which the simulation experiment must be carried out N simulation runs would need to be preformed with the simulation model. If none of the runs repeat, then for N will be valid:

$$N = q1 * q2 * \ldots * qk. \quad (1)$$

To decrease the selection of the number of combinations, the Optimizer module is able to exploit, for example, Adaptive Thermo statistical Simulated Annealing, Hill Climb, Random Solutions, user defined Algorithms, etc. With these methods the time needed to search for the optimal variant can be decreased down to a tenth of the original time. Each of the stated methods has its particularities and their reliability is described in the literature.

4. EVALUATION AND ORDINATION OF VARIANTS

The evaluation and ordination of variants runs based on a selected parameter or value of the multi-criteria function. In this model, we focus on the functions evaluating production systems or their parts from more than a single point of view. Almost always they are combinations of several indicators with assigned importance coefficients. In effectiveness function we make use of quantitative as well as qualitative parameters and thus we have to quantify the qualitative units. For example, process quality can be quantified using *ppm* indicators, number of complaints, number of rejects, etc.

5. KINDS OF MAINTENANCE

For the suggested model to correspond more closely to reality, five kinds of maintenance are purposely set for each machine (Fig. 3) [6].

1) Preventive Maintenance by specialist workers - planned checks - preventive checks and maintenance, like guarantee checks, etc.

2) Corrective Maintenance by specialist workers - this covers malfunctions caused by a collision with a machine. In the majority of cases these major malfunctions demand replacement of damaged parts by specialized technicians.

3) Preventive Maintenance by the machine operator - this kind of maintenance is also defined as machine cleaning. Many companies incorporate a fixed time in the production plan for such idle time.

4) Corrective Maintenance without a specialist worker - this kind of operation is unscheduled and can be

handled by local operators. It covers especially tool-wear program corrections or the replacement of a tool if it breaks down.

5) Corrective Maintenance by an e-maintenance specialist − in this kind of e-maintenance, specialist technicians analyze the machines remotely. They intervene in the machines, programs and control systems remotely (the main benefit of e-maintenance).

The malfunction times in the first two cases are shortened by 1/3, compared to standard maintenance. The specialists are able to analyze the majority of problems beforehand. They can download error conditions directly from the machine and perform the maintenance before actually arriving at the machine.

6. OPTIMIZING CRITERIA

The justification for using optimalization with computer simulations for business processes, or rather, computer simulation in e-maintenance is not rare. The most important consideration in computer simulations is to find an optimal model setting, depending on the resultant values of the of multi − criteria function. When optimizing a future state it is possible to select a different number of criteria than when optimizing a critical state in e-maitanance (e.g. future: no. of workers and machines are variable, Critical: no. of workers are variable, no. of machines is constant.). Except for the number of criteria it is possible to solve their priority.

Some optimizing criteria were selected to allow us to perform advanced experiments with the model. The first criterion selected was the optimum number of specialists needed for the management of machines in the model. The function is performed using a number of workers, the value of which is a function variable in the range of $1 \div x$. The subsequent function with a variable parameter is machine priority with the range of $1 \div n$, where n is the current number of machines in the model.

Another variable function is the quantity of machines in the range of $1 \div m$ where situations are simulated with an increasing number of machines in the process.

The variable of criteria and defined priority are applied to create the Multi-criteria function.

7. MULTI-CRITERIA FUNCTIONS

Multi-criteria functions are created to evaluate an optimum variant as well as the order of the variants. When this function features a single criteria (parameter), it is a single-parameter function with a single-parameter evaluation. When we use functions made up of many parameters, we have a multi-criteria evaluation. The Optimizer module arranges the order of individual variants according to these defined functions.

To define multi-criteria functions, we used multi-criteria decision-making theory. Each of the multi-criteria functions consists of individual criteria and their weights. A function must always be either maximizing or minimizing and individual criteria must be defined accordingly. In order to set the weight of individual criteria, we used expert estimation method [2].

Two multi-criteria functions are used in the model (MCF_1 and MCF_2). The first one defines the optimum number of specialists and the other finds the number of setup workers depending on an increasing number of machines.

$$MCF\_1 = \begin{pmatrix} (\text{lodging}*\text{cf}_1) + (\text{travelling cost}*\text{cf}_2) \\ +(\text{scale wage}*\text{cf}_3) \end{pmatrix} , \quad (2)$$

$$\left(\sum_{x=3}^{1} cf_x = 1 \right)$$

$$MCF\_2 = \begin{pmatrix} (\text{lodging}*\text{cf}_1) + (\text{travelling cost}*\text{cf}_2) + \\ (\text{scale wage}*\text{cf}_3) + \\ +((\text{max.parts}_1 - \text{actual parts}_1)*\text{cost}_1 + \\ (\text{max.parts}_2 - \text{actual parts}_2)*\text{cost}_2 + \\ +(\text{max.parts}_3 - \text{actual parts}_3)*\text{cost}_3 + \\ ... + (\text{max.parts}_x - \text{actual parts}_x)*\text{cost}_x) \\ *\text{cf}_x \end{pmatrix} \quad (3)$$

$$\left(\sum_{x=n}^{1} cf_x = 1 \right)$$

8. SAMPLE MODEL

The goal of the sample model is to determine the optimal number of special workers for e-Maintenance. Multi-criteria functions are applied to determine the optimum number of workers.

Witness® simulation software is developed and distributed by Lanner Group Ltd. The software is used for the complex simulation of corporate processes.

8.1. Description of simulation model

Suppose there are three separate workplaces (Paris-Bordeaux-Lyon) and an e-maintenance central office located in one of these cities. To find the time needed to relocate workers from one place to another we use the route planning software Route66®.

Single machines in the model have five types of basic malfunctions and maintenance implemented (Fig. 5). Some of them are directly loaded from the e-maintenance system using an MS Excel spreadsheet program, while others are produced by means of a pseudo-random generator of random numbers directly implemented in the simulation software. The results of the simulation are obtained in tables and graphs of workloads on single workplaces, workers etc.

8.2 Setting and results model

1) Preventive Maintenance with specialist worker - planned checks - Extent of these checks ranges from 8 hours up to a week and data is downloaded from production scheduling using MS-Excel spreadsheet software. In the future, a direct link to the e-maintenance system database is planned.

2) Corrective Maintenance with specialist worker - Recovery time ranges from 8 hours up to three days. When simulating, these malfunctions are defined by normal distribution and for random times. Malfunctions are generated directly by the Witness® system.

3) Preventive Maintenance with machine operator − in the model it is fixed as 1 hour a week (each Friday

	Description	Check Only At Start Of Cycle	Breakdown Mode		
			Mode	No. of Operations	Time Between Failures
1	Breakdown	☐	Busy Tim		Interval21
2	Breakdown	☑	No. of Op	172800.0	
3	Breakdown	☐	Available		7 * 24 * 60
4	Breakdown	☐	Busy Tim		673.0
5	Breakdown	☑	No. of Op	30 * 24 * 60	

Fig. 5. Turning machine breakdowns in the simulation software.

Table 1

Table for setting MCF

	number travell	cost PHM	km	coast SUM		
Paris - Bordeaux	7	82.70 €	583	678.01 €		
Paris - Lyon	9	79.20 €	463	791.51 €		
Bordeaux - Lyon	2	103.85 €	592	308.34 €		
				1,777.86 €		
	number of parts	cost/part		cost parts		Number-MAX
Bordeaux - P1	4554	0.20 €		910.80 €		5182
Lyon - P2	3339	0.40 €		1,335.60 €		3867
Paris - P3	3087	0.35 €		1,080.45 €		3323
SUM	10980			3,326.85 €		12372
	number of labours			cost labours/term	MCF - 1	18855.572
specialist w. - L1	1			18,000.00 €	MCF - 2	8272.406

from 15.00 to 16.00). Another case of this kind of maintenance can be resetting the machine for a new type of production, e.g. a batch change, etc.

4) Corrective Maintenance without specialist worker – the time required to clear such malfunctions ranges from 2 minutes up to 2 hours. Malfunctions are generated directly by the Witness® system and they are defined by normal distribution and for random times.

5) Corrective Maintenance with e-maintenance specialist – idle time on a machine is defined again by Witness® system in the range from 5 up to 120 minutes using a random separation of approximately once a month (Fig. 5).

The link between software Witness® and MS Excel is provided using OLE communication. It is based on a criteria variables (Travel, repair time, ...) in the simulation system, whose values are either loaded or written to the tables in the external software (Table 1) (*maintenance.xls*).

Commands in the simulation software:

```
XLWriteArray
("\\maintenance.xls","Travel","$B$2",P_B
)
RowNumber11 = 3
RowNR11 = 2
RowOutput11 = 2
XLReadArray
("\\maintenance.xls","repair-M11","$A$"
+ RowNumber11,ProcessTime11)
```

8.3. Simulation

A table processor is used for a more user-friendly interface and easier connections to other enterprise information systems and sensor data obtained directly from the machines.

The Optimizer module retrieves data from a table processor and sends it to Witness® simulation software, which is carried out by computer simulation and the partial results are re-entered into the tables. The table processor then calculates the multi-objective function with assigned weights (Table 1). The next step is that Optimizer again retrieves the results of the multi-criteria function and assigns a given set of results in ascending or descending order for further evaluation. This process is repeated for all variants of the set or the number of options for the chosen optimization algorithm.

The selected optimal variant is then introduced into practice.

9. CONCLUSIONS AND PERSPECTIVES

The article describes a simulation model created for the purpose of testing the use of computer simulation of corporate processes in e-maintenance, specifically with advanced human planning taking random conditions into account, their workload, the impact of the number of machines on the number of specialists, etc.

The computer simulation of corporate processes using a multi-criteria decision-making method seems to be a tool which usefully compliments e-maintenance systems and is able to increase the competitiveness of the systems.

Further work can extend these results. We can combine scheduling approaches with this simulation model. It would be interesting to define more precisely the priorities assigned to each task with an adapted scheduling method. An efficient scheduling method for this problem is not trivial and needs to be explored. Another possible extension could be to add the spare parts management to the e-maintenance simulation model proposed.

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