

Handling Maintenance Projects with Matrix-based Methods

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Abstract - Creating a maintenance plan for production and service processes can be handled as a special area of project planning, because the order of the tasks are negotiable in most cases, but the order of the operations within the tasks are fixed. In this paper we present an expert system which is capable of finding the optimal maintenance plan by applying risk based ranking of the tasks with consideration of time and resource constraints. Estimating reliabilities, theory of stochastic process and expression of measurement uncertainty are also applied and improved in order to handle decision errors and their consequences. The expert system determines when a given task should be accomplished and the time, cost and resource demands of the realization.

I. INTRODUCTION

In the case of a high number of devices the planning and scheduling of maintenance tasks are very difficult. The reliability of the devices or the risk of its failure must be considered as well as the time, cost and resource constraints.

In this paper an expert system is introduced that uses the measurement results of the observed characteristics of the processes or devices as input and determines the priority of maintenance tasks. It specifies which operations should be realized in different kinds of maintenance tasks, what maintenance tasks should be realized, how to realize these tasks, how long does the realization take and how many resources these tasks require.

II. BACKGROUND

A. Reliability- and Risk-Based Ranking of Maintenance Tasks

According to Reliability-Centered Maintenance (RCM) [1] the maintenance tasks are ranked by the probability of the device failure in the time interval of the maintenance planning. Those devices that have higher failure rates and therefore have lower operating time between failures are given priority and their maintenance tasks are completed first. The order of priority can be more exact if the costs and required time of the inspection and preventive maintenance are compared to the costs and required time of the corrective maintenance and both the material and immaterial loss of the failures. The severity of the failures consequences are weighted by the probability of the failure so the classification and decisions are carried out on a risk base (RBM – Risk-Based Maintenance) [2]

However, in the measurement of the observed characteristic of a device measurement error must be taken into consideration. A number of our previous papers [3-5] deal with the consideration of uncertainty resulting from the measurement and sampling. The consideration of measurement uncertainty

is necessary to make a proper decision. The decision errors result from sampling and measurement uncertainty in the case of the inspection of the degradation of a device.

The costs of decision errors must also be determined. If maintenance is performed before it is required some parts of the productivity will not be fully utilized. The extent and therefore the cost of the unutilized productivity decrease with time. On the other hand if the maintenance is not performed and the device failure occurs beside the breakdown additional costs (health, environmental, economic) might appear. These additional costs are independent from the time of the failure. Therefore there are time dependent and independent costs. The control limit belonging to the minimal total risk can be determined from these costs and probabilities for every point of the time. For the specification of the curve of minimal total risk simulations and analytic calculations have been used.

The process of the observed characteristic can be treated as time series and after the decomposition the next values of the characteristic can be predicted with linear stochastic models. These models predict the next value based on actual and previous values of real process and prediction error. However, this prediction can also contain uncertainty so the lower and upper bound of confidence interval appears below and above the time series. After the validation of the stochastic model it can be used for forecasting. The further ahead we try to forecast the higher the uncertainty will be.

With a given time interval of the maintenance planning we calculate (or determine with simulation) the confidence level for each device with its observed value which just reaches the curve of minimal total risk. With our approach probabilities can be assigned to the devices. These probabilities can be the probabilities of the operation in the time interval of the maintenance planning, or just the opposite, the probability of the failure within this interval. With the consideration of these probabilities (and the costs of consequences) the maintenance plan can be optimized.

B. Planning and Organizing Maintenance Projects

Realization of maintenance tasks can be regarded as a special maintenance project. However, traditional network planning methods have several deficiencies and throw difficulties in the way of using project planning methods in maintenance. The first shortcoming of network planning methods is the handling of circles. A frequently occurring problem is to realize a task more than once in a project (i.e. diagnose and revise a part of equipment until it works). In spite of the fact that GERT

method [6] can handle circles for detecting and managing circles the matrix-based methods give better alternatives.

The other problem is to determine the sequences of the maintenance task. Traditional logic planning methods are hard to use for these projects, because on the one hand the sequence of the operations of a maintenance task can be described with a deterministic logic plan (network plan, Gantt chart etc.). On the other hand, most sequences of maintenance tasks (e.g. repairing different kind of equipments) are independent from each other. This means that the sequence of maintenance tasks can be reversed, or can be ranked by their values of reliability or risk. Since network planning methods cannot be used for ranking maintenance tasks, hereinafter matrix-based methods are introduced. These methods can handle circles and also can be used for ranking maintenance task sequences.

C. Matrix-Based Project Planning Methods

In case of scheduling production development projects mainly matrix-based methods are used for planning and scheduling. These matrix methods are based on DSM (Design Structure Matrix/Dependency Structure Matrix) methods published by Steward [7]. Tasks of the project are represented in the rows and columns of a matrix. This method can handle the iterations between two tasks, as well. Iterative relation between task *A* and *B* means that the sequence of task *A* and task *B* has to be realized more than once. This relation is the simplest cyclic dependency. The cyclic dependencies are called “Circuits” or “Cycles”. Cycles can contain more than two tasks. Detecting cycles is very important in project management, because the iteration can cause the increase of project duration. When using matrix-based methods for project planning one of the most important functions is to determine the sequence of the tasks. If the project plan does not contain cycles the matrix of the project plan can be reordered into an upper triangular matrix and the activity-on-node graph of the project plan can be topologically ordered. This method is called sequencing [8,9].

Formerly introduced methods show how to use matrix-based methods for project planning. However, DSM matrices can also be used for scheduling [10] and resource allocation [11] or in addition this method can be used for reorganizing the projects. [12,13]. This way duration, cost or resource demands of tasks can be represented in the diagonal or an additional column. Numbers in the off-diagonal cells can show the lags of successors/predecessors. [14]

III. METHODS

Yassine [15] and Tang [16] showed that in case of project planning there could be uncertain relations between two tasks. They introduced a new method called numerical DSM (NDSM), which handle the strength of the relations between two tasks. When using NDSM matrices the level of the dependency of relations between two tasks can be represented. Numbers instead of “X” in NDSM can be used to represent [17] i.e. Dependency Strength. This can be a measure between 0 and 1, where 1 represents an extremely strong dependency. The matrix can now be partitioned by minimizing the sum of the dependency strengths below the diagonal.

TABLE I.
EVALUATING THE PROJECT EXPERT MATRIX

PEM	NDSM/SNPM	DSM	AoN Network																	
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Despite the fact that these methods handle the uncertain relations they cannot handle the realization priority of the tasks. Authors have formerly published a Stochastic Network Planning Method (SNPM) [18] for generating all possible project networks. The acronym SNPM alludes to uncertain project networks. Enhanced method of SNPM called Project Expert Matrix (PEM) can handle the uncertain realization of the tasks, as well [19,20]. Similarly to uncertain relations the uncertain realizations of the tasks can refer to (1) the probability of task realizations; (2) or the otherwise relative importance of task realizations. The uncertainty of the task realizations can be notated in the diagonal of the PEM matrix (see Table 1). The certain task realizations denoted as 1 or “X” in the PEM matrix.

A. Applying Matrix-Based Project Planning Methods for Organizing Maintenance Projects

In this chapter we show how to apply previously introduced matrix-based methods for planning and organizing maintenance projects. Maintenance operations (i.e. servicing equipment, evaluating results of diagnostics etc.) usually can be described as a deterministic logic plan (using a task list, Gantt chart etc.). In this case the operations have to be realized in a sequence following the task list. These operations can be represented by a DSM matrix or can be contracted into a maintenance task. However, realization order of maintenance tasks can be determined considering the values of reliabilities and risks. Duration, costs, resources can be assigned to the maintenance tasks.

We developed a method called Maintenance Project Planning and Scheduling (MPPS): Values of risks or reliabilities of equipment can be represented in the diagonal of Project Expert Matrix. These values can be determined as introduced in chapter II. Realized maintenance tasks are categorized by level of risk or reliability. Maintenance tasks with low level risk or low level reliability can be realized within a succeeding project. If the level of risk of a maintenance task is high the probability of realization of this task is also high. This probability is marked as *p*. (In this case $1-p$ is the probability of leaving out this task from the project. If *p* is the importance of realization of the task, then $1-p$ is the value of ignorance). The probable project scenarios can be ranked by their probabilities. The Probability of a project scenario is the geometric average of the probability of realizations (of realized tasks) and probability of ignorance (of non realized tasks). Using a PEM matrix maintenance tasks will be ranked by their realization probabilities.

Similarly, the probability of a project structure can be defined. If two maintenance tasks can be realized both parallelly and in a sequence and the sequential and parallel realization is indifferent, the probability of relation between two tasks can be notated as 0.5. If sequential realization is preferred, probability of relation between two tasks are higher than 0.5 otherwise lower than 0.5. The objective function is to select the most probable project scenario according to the project budget, and the most probable project structure according to the time and resource constraints.

When constructing an aggregated PEM matrix (aPEM) the plan of operations of a maintenance task is an input data and can be described with a DSM matrix or a network plan. These operations can be contracted into different kind of maintenance tasks. The probabilities of task realizations can be determined from the values of reliabilities or level of risks and are represented in the diagonal of the aPEM matrix (see Fig. 1 and Appendix). Maintenance tasks should be ordered by their probabilities of realizations. Preferred sequential and parallel realization can be expressed by the strength of relation between two tasks. According to the budget feasible project scenarios are specified and ranked by the probability of project scenarios. Project scenarios are represented by an SNPM or an NDSM matrix. In this phase we can answer *WHAT* maintenance tasks should be realized in agreement with the project budget. According to the time and resource constraints feasible project structures can be specified and can be ranked depending on the probabilities. In this phase we can answer *HOW* to realize the maintenance tasks. The logic plan of project structures can be represented by a DSM matrix. Duration and resource demands can be represented by a resource sheet. At the end we can also answer *HOW LONG* the maintenance tasks take, *HOW MUCH* are the cost and resource demands.

A project plan is *infeasible* if (time, cost, resource) demands are higher than the project constraints. The optimal project plan is the feasible project plan that possesses the highest probability.

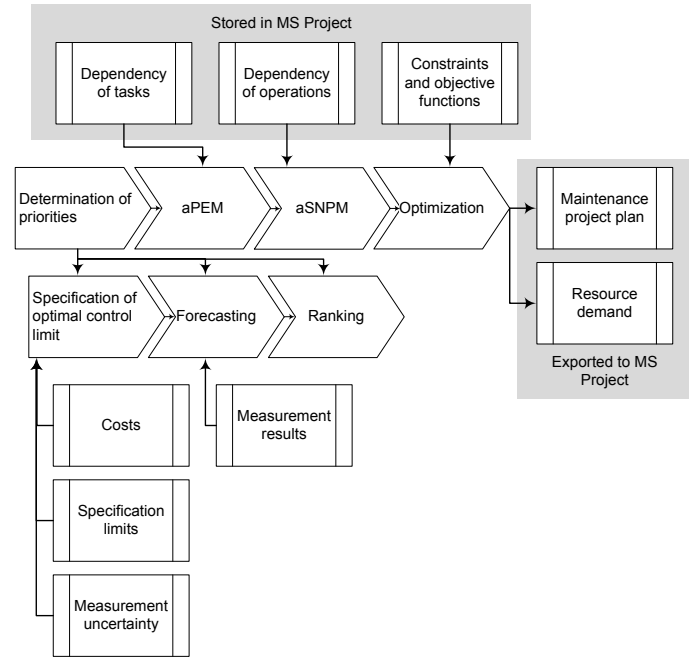


Fig. 1. The logical structure of the expert system

B. Use of genetic algorithms

For determining feasible project scenarios and feasible project structures genetic algorithms can be used in order to decrease the need of computation resources. Genetic algorithms can be used for NP complete or NP hard problems [21] and when optimal solution is determined from the large set of probable/feasible solutions. When using genetic algorithms for project scheduling, the initial population will be the set of probable project scenarios and project structures of a project scenario represented by DSM matrices. Evolution operators (selection, mutation, recombination, etc.) are executed on the entities of the population. In the course of recombination (or crossover) the DSM matrix of the parent entities are split along the antidiagonal and the child entity inherits one half of the fathers DSM and the other half of the mothers DSM. There is an other case of recombination with the probability of 30%, the child inherit each cell of the parents DSM with equal chance. The mutation operator changes the value of a DSM cell from 0 to 1 or from 1 to 0. The selection is realized by a tournament selector. Every entity has a fitness value. To increase effectiveness, and decrease computation time the fitness value is the combination of probability/importance within the project scenario, resource and time constraints. If the project scenario or project structure is infeasible, the fitness value is 0. Effectiveness of genetic algorithms can be improved if we use distributive architectures (CPUs or computers). For handling the numerous probable solutions and computations we used a promising distributive technology called Compute Unified Device Architecture (CUDA) [22], which distributes computation tasks amongst the Graphical Process Units (GPUs).

Genetic algorithms do not surely find the optimal solution however with the help of appropriate fitness function and evo-

lution operators the optimal solution can be approximated. In order to compare various genetic algorithms all possible project scenarios and all possible project structures are ranked, and the most important/ the most probable feasible project structures are selected for the test projects. Henceforth, the formerly introduced MPPS method referred to as the naive MPPS method. Using genetic algorithms for this problem is called genetic MPPS method, and using distributed genetic algorithm (applying CUDA) for this problem is called distributive genetic algorithm for Maintenance Project Planning and Scheduling.

During the course of developing we had to write some interface programs between maintenance diagnostic systems and MPPS as well as between MS Project (where the operations of maintenance tasks are) and MPPS. After the genetic algorithm framework finds and ranks the possible project scenarios and structures the interface program exports the optimal project structure to MS Project.

IV. RESULTS

To compare different kinds of methods, different sizes of random PEM matrices are generated, where the number of uncertain tasks and number of uncertain relations can be defined as a percentage of all tasks and possible relations. Duration of the tasks, project budget and 3 different kinds of resource demands of the tasks are generated randomly. In the comparison test the time constraint was specified. This time constraint was the half of the project duration, when all uncertain relation specified to 1. In this case all uncertain relations between tasks were considered as certain dependencies. The resource constraints were half of maximal resource demands, when all uncertain relations are considered as a certain independency and the tasks scheduled for earliest start time. the percentage of uncertain task realizations was 80% of all probable tasks. The percentage of uncertain relations between two tasks was 20% of all possible relations. And the time budget was 15% lower than all tasks were realized.

For the comparison of the run time of different kinds of methods it needs to be emphasised that all methods were run in the same computer architecture, which was a Pentium PC, with Intel Core i7-720QM CPU, 6GB RAM, 320 GB HDD. The

GPU was the 1GB NVidia GeForce GT 230M. For the implementing distributive genetic algorithms, the CUDA technology was applied. Table 2 shows specifications and the efficiencies of different kind of MPPS methods.

TABLE 2.
COMPARING VARIOUS MAINTENANCE PROJECT PLANNING AND SCHEDULING METHODS

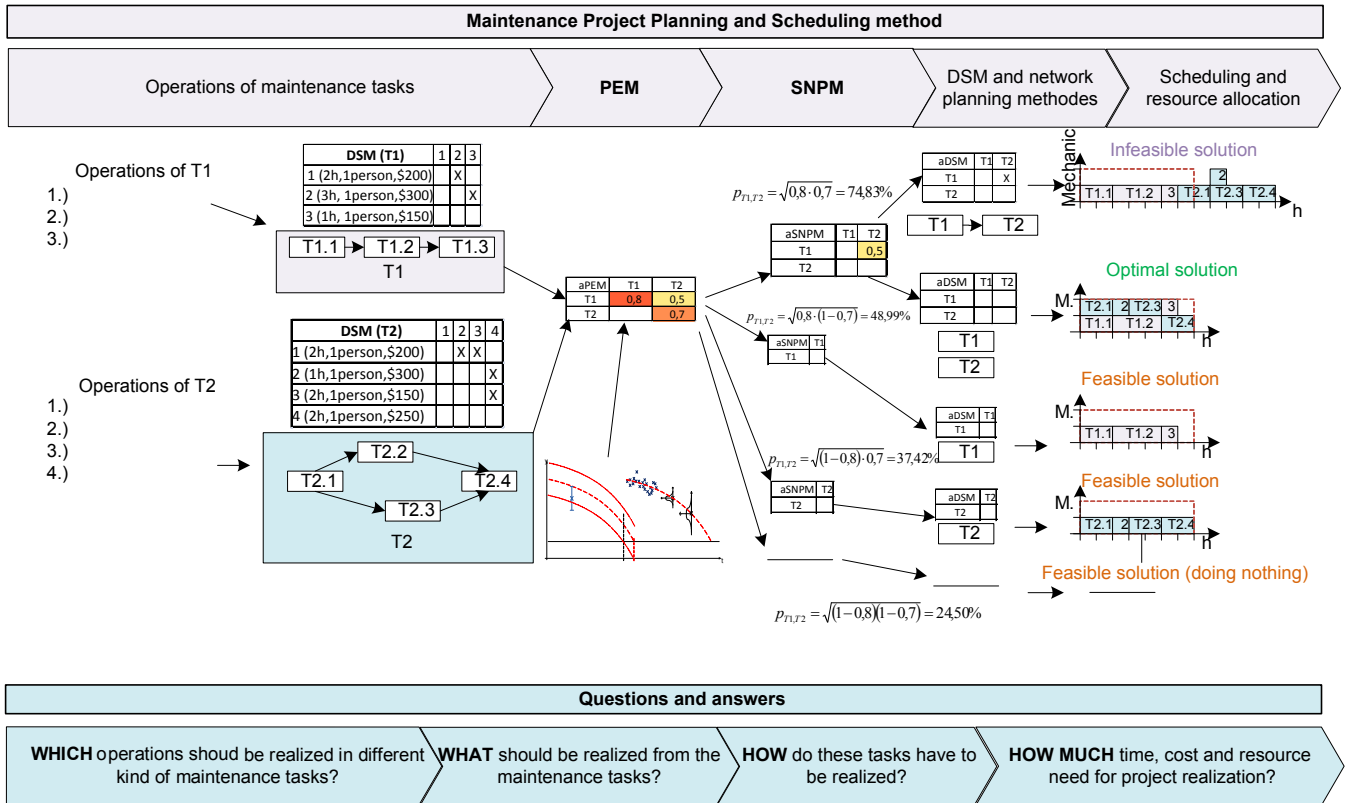
Size of PEM matrices	Runtime of full evaluating algorithm	Runtime of genetic algorithm	Runtime of distributive genetic algorithm
10x10	62 ms	42 ms	38 ms
20x20	2,1 hours	493 ms	451 ms
50x50	12,2 hours	48 sec	37 sec

Using genetic algorithms the computation time can be extensively decreased. When the number of tasks is more than 300 naive MPPS cannot be used because the computation time is more than a week. Nevertheless, using genetic algorithms for Maintenance Project Planning and Scheduling, the computation time is less than an hour for 300 tasks (the formerly specified constraints are taken into account).

V. SUMMARY

The introduced methods are the results of a four-year research. Taking measurement uncertainty into consideration in maintenance related decision and forecasting is one of the basic concepts of our model. This way maintenance can be planned. With our forecasting method the degradation can be predicted more accurately considering incorrect decision consequences. Using this model the probability of maintenance task realization can be specified and can be used for project planning. The other main concept is using PEM matrix for project planning and scheduling. Since finding the optimal project plan (considering the project constraints) is a combinatorial problem, using genetic algorithms can be applied to decrease computation time extensively. The introduced expert system can interact with project planning applications (like MS Project) and other diagnostic applications.

APPENDIX



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