Anikó Pribojszki - Németh

MATRIX-BASED PLANNING OF MAINTENANCE PROJECTS

Ph.D. Thesis Summary

Thesis Supervisor: Dr. habil Zsolt Tibor Kosztyán

University of Pannonia

Doctoral School of Management Sciences and Business Administration

Veszprem

2021

Contents

Introduction

The complexity of the equipment is constantly growing. In parallel, the scope of the maintenance is now not only concerned with the preservation and restoration of the state of the equipment, but also with the equipment units. The economic constraints and reliability requirements encourage companies to increase the reliability of their production equipment. At the same time, they need to rationalize their maintenance and repair costs and errors due to failures in maintenance. Larger maintenance tasks can be organized into a so-called maintenance project. These maintenance projects (time, cost, and resource) limit the experts in the field. As much as possible, the reliability of the system should be improved as quickly as possible so that the costs we use are minimal.

The task (which I undertook during my doctoral course) is complex. It is necessary to solve at the same time a project screening and a time-quality-cost trade-off problem between the time-cost-quality parameters of the activities. While one or more corrective preventive actions can be used to improve the reliability of all equipment/units, even in the event of a so-called "turnaround", all possible preventive preventative activities will not be performed. The first question is when compiling a maintenance project, which should then be answered in terms of what activities can be implemented in a given cost and time frame?

Activities can usually be implemented in a variety of ways, with different cost, time and quality parameters available. The project manager needs to find the balance between these parameters so that he can implement/enforce all corrective-preventive activities beyond the limitations.

The specialty of the job is that here the so-called quality parameter will be calculated from the improvement of reliability values, which is not a trivial task. The reliability block diagram describing the system can even follow a completely different structure than the structure followed by the maintenance project itself. I usually order more repair-preventive activities for an item of equipment, which can increase the reliability of the device element and thus the reliability of the system. Or in another calculation, the availability of the system may increase.

In my dissertation, I have introduced the Multi-domain Maintenance Management Method = M^4 developed during my research, which can be used to plan equipment maintenance. My goal is to make maintenance planning more transparent and simpler using this method. I do all that, in order to achieve maximum system reliability, I strive for the reliability of the higher unit units, in addition to maintaining the resultant maintenance project scenario/structure within the cost and time frame of the company.

1 Research objectives and assumptions

Nowadays it is undeniable that maintenance is an essential tool/method to bring our equipment into the right state. However, among the methods known so far, there is such a way as to **indicate which equipment or equipment components need to be maintained to achieve overall system reliability gains?** We want to avoid both over-maintenance and under-maintenance.

We want to use our resources in the right place. However, we need a new plan process that solves this problem and simplifies our work. So far, maintenance strategies have not given me a satisfactory answer after my research and to my knowledge. Furthermore, we do not yet have a planning method that would help to set up a maintenance order of priority between equipment and components. That is the first one to be kept last. The goal of maintenance is to doubt that the reliability of our system will increase in addition to our equipment. For companies, one of the most painful points is when a project exceeds the planned budget during execution or takes longer than planned. **They ask themselves the planning was inappropriate? Or did the planning process used be inaccurate? Are the planning methods known and applied in their area at all suitable?**

I got acquainted with the latest planning methods and project planning approaches. The latest planning procedures are already in the agile aspect, as within the available framework, only those activities that fit within the frames are considered. **However, in the field of maintenance, the question arises, is it sure that we have chosen the right one? Can the known matrix project planning methods be used to plan maintenance projects? Can it create a project planning method that helps to build a maintenance plan that takes into consideration the maintenance constraints set by your company during the planning?**

2 Maintenance project planning

2.1 Difficulties in managing maintenance tasks as projects

After knowing the maintenance theory (Chapter 2.1.) and the project planning (Chapter 2.2.) methods, I came to the point when I looked at what planning strategies for which maintenance strategies have been applied so far. However, I had to come to the conclusion that these two areas did not even touch each other in practice.

I cannot declare that companies based on RCM and/or RBM strategy planning their activities using MPM and/or CPM or even matrix methods because the search results showed nothing useful. If I replace the words network planning methods with matrix planning, I find publications published with my colleagues. So I approach the topic on the other hand.

Let's go ahead in time again when there was no other feature in the maintenance area than reactive maintenance. This kind of attitude towards the technical state of technical devices is more of a failure than the use of any strategy, but it is undoubtedly the most effective solution for some of the devices. Use this device until it meets the features you expect from it, and in case of a malfunction, we will take the necessary action. Here, the (project) planning could be realized after the failure occurred, when the damage was measured and the activities needed for restoration. Time, cost, and human resources have been associated with the activities. However, the point is that failure does not happen. However, other maintenance strategies have been used to reduce this probability. First round the PPM itself.

PPM (planned preventive maintenance) is common in both industry and service. The steady state of the machines and equipment they achieve by systematic repetitive planning and repairs. PPM is a cycle-based maintenance strategy that does not require the use of project planning methods. Suffice it to capture the actual and necessary tasks to be performed and the required checks, which are taken in the best way possible, taking into consideration the message of the strategy. However, in the case of companies in excess of the size of small and medium-sized companies, it is expedient and advisable to bring maintenance activities into line with each other. In many cases, they could work with cyclograms. The method is simple and transparent. Their use is advisable if the pace of predetermined activities is unchanged for each subsequent period.

Among the maintenance strategies, the following is Condition Based Maintenance - CBM which starts with the wear and tear of the components, and the conclusions drawn from them. Here, it is possible to use a project planning methodology much better. Maintenance planning starts with the data entry and management of operational data. Maintenance planning depends on maintenance management. Governance sets the direction of maintenance, oversees the process, and provides the tools (financial, financial) and human resources. You can use a bar graph (Gantt diagram) for a visualization of the recovery plan, but it can be used for a limited number of activities. You can also use CPM and/or MPM charts for planning.

CPM and MPM work with deterministic time data. One of the main benefits of CPM is that it can be used for analysis and control too. It is also possible to logical linking between different time data and activities. Independently of the MPM activity, it can also detect logical relationships and many of them. In both cases, it can be said that they are not lucrative and used for a limited number of activities. With CPM, you cannot give a look at expectations, overlaps, and strict end-to-end relationships.

It can be exploited that CPM helps you easily identify critical activities during recovery, and MPM is used to calculate backup times. However, it is felt that this type of pairing still has savings potential. During maintenance, it is not uncommon to return to repeating an activity that needs to be taken into consideration during the planning. If this is true, then activity-arrow or activity-node planning procedures cannot be used. It has to resort to a somewhat more complicated planning method that can handle circles.

This is how we can get GERT, which is a PERT-like technique and capable of managing several possible project scenarios or circles. Compared to the above, these two methods can handle not only deterministic data but also stochastic ones.

PERT also works with stochastic time data, as it provides an optimistic, pessimistic, and most likely estimate of time data for activities. Handles activity times as probability variables. In the decision-making context, the GERT method already considers relationships between activities as a probability variable, capable of handling decision situations. In both methods, the duration of the activities is assumed to be independent, which is not always true when compiling a maintenance plan, since checks and unexpected errors can be expected during recovery and we are unable to complete our activity within the planned time.

However, I am still saying that planning is easy to implement in case of a single installation (despite the disadvantages). However, how can we easily perform a maintenance plan for a complete machine fleet? How do I see the completed maintenance plan? How can I keep track of my costs per area? At this point, traditional planning methods become ineffective and need to think of complex systems that are capable of representing the interdependence of system elements. Now we have to think about matrix planning and presentation. When compiling a maintenance plan, you may be responsible for which maintenance work to be performed. This deterministic logic planning technique does not provide an adequate answer as the technological process of repairing a device is bound. Here, the individual steps cannot be exchanged, but which ones need us to repair, it can already be a function of a priority order, as well as the available time, cost and resource requirements.

Some projects require a specific approach as well as maintenance projects. In the field of project management, two main approaches were introduced, namely traditional and agile. In the case of traditional project approaches, the desired goal is achieved, which must be achieved within our 'time' and 'budget' within our capabilities. In the case of agile "philosophy", however, time and cost are limited. To be within the constraints set within the set of activities that I set for the target, it is no longer the most important factor. For traditional projects, the question is always how much the project budget will be. By the traditional approach, we treat a goal as a rigid barrier, what we want to achieve, but the time and cost will vary according to the requirements. In the case of an agile approach, the following question arises: how many projects activity can be carried out in addition to a given cost and time limit, how long do I get in project implementation? These constraints are given by the owners and company executives, which are best defined in cooperation with the maintainers. However, this practice always refutes.

Their purpose is not to overcome the constraints to change the result or target In the case of maintenance projects, the use of the latter approach is beginning to widen. For here, besides the time and cost constraints, the result is not known, they only have a plan and a vision, that is, have better equipment. The principles of the agile method emphasize the following. The shorter period should be preferred. The requirements change is accepted, even at the late stage of the project. The highest priority is to preserve the state, functions, and lifecycle of valuable equipment that meets your needs. The most effective way of communicating information within the maintenance team is personal communication.

The disadvantages of being immature. An agile approach does not yet have a really good methodology. It is too much to change the maintenance culture to work agile approaches, but a maintenance planning approach can provide a good starting point.

Based on these parallels, there is still a further question as to what happens if the parameters describing the status are changed in the meantime and/or the budgets are narrowed and/or the time available has been reduced and my planned project plan has to be updated (this is an agile approach accepted). Parameters used during planning can be specified by RCM or even RBM analysis that will define a more accurate state. The analyzes can be incorporated into the maintenance project plan, so you can shift the focus to the restorative actions that are really important. Because the resulting RCM or RBM results provide a ranking for the planners, and it may be that these values show that it is not necessary to perform any maintenance or restoration of each device at that time.

Based on the Reliability-Centered Maintenance (RCM), reliability-centered maintenance strategy, maintenance activities are ranked based on the likelihood of failure of individual equipment within the maintenance planning period. Maintenance activities are given a higher priority and are carried out sooner, where the equipment has a higher failure probability and thus have lower expected failure time. The consequence of the failure is weighted with the likelihood of occurrence. In the case of major stops, if the prioritization is based on RBM or RCM strategy, we can produce a more accurate plan.

It requires a planning process that meets the challenges described above and is easy to apply to users as well. Another challenge for maintenance planning is to planning a project plan that considers the cost plan and time plan provided by the company as a starting point.

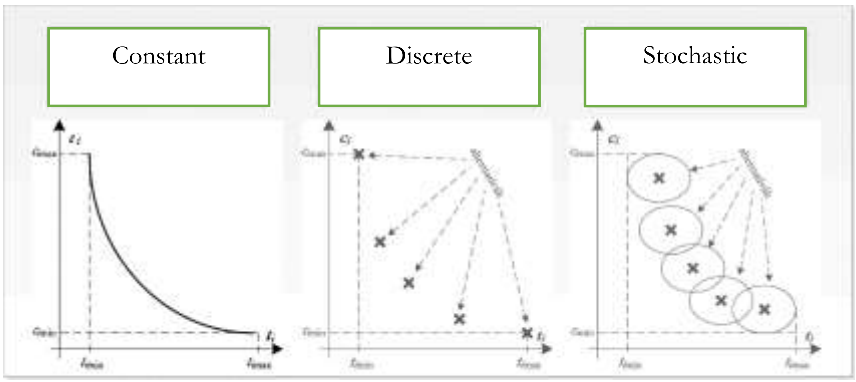
Expectations from the maintenance companies to achieve the goals (reliability, low risk) as little as possible and at the least possible cost.

The maintenance planning problem can be modeled using a matrix planning method.

2.2 Time-Cost trade-off problems

The importance of the time-cost trade-off problem (TCTO) was recognized over five decades ago, almost simultaneously with the development of project planning techniques [1]. In the 1960-80s, variations of the problem where the time-cost relationships are assumed to be continuous have been addressed rather extensively in the literature ([2], [3], [4], [5], [6]. This problem called a **continuous time-cost trade-off problem** (CTCTP). The **discrete time-cost trade-off problem** (DTCTP), which can be treated as a specific resource allocation problem is also a well-known problem from the project management literature.

However, while CTCTP can be solved within a polynomial computation time [7], [8], [9] in general case of DTCTP the resulting conditional time and cost minimization problems except for several special network structure [10], [11]. These models mainly focus on deterministic situations. However, during project implementation, many uncertain variables dynamically affect activity duration, and the costs could also change accordingly. The stochastic nature of time and cost adds an additional dimension of complexity to the already hard to solve the combinatorial problems [12].



1. Figure: Time-cost trade-off problems (based on [1], [10], [11], [12] own editing)

Since in a cyclic maintenance strategy in order to characterize a maintenance project, the deterministic and discrete version of TCTP is the adequate model, however, at the planning process, besides time and cost, the desired system reliability level is also regarded.

Therefore we need a third parameter besides time and cost demands, which is a kind of quality parameter, namely (in this study), the increase of system component reliability due to the maintenance task.

Considering the intertwined effects of time, cost and quality in project management, it seems reasonable to develop a mathematical model for discrete time-cost-quality trade-off problem (DTCQTP), which considers project duration, cost and quality simultaneously. In DTCQTP, the task of a project is performed in one of several alternatives. For each activity a set of time, cost and quality triplet, referred to as mode, are given. The recent two decades lots of considerable papers of literature dealing with DTCQTP [13] are published. Since DTCTP is an NP-hard problem, the DTCQTP is also an NP-hard problem, therefore usually solved approximately by some kind of heuristic or meta-heuristic method [14], [15].

Rastegari and Mobin [16] did a trade-off analysis among the failure of the machines (reliability), time of maintenance, and the cost; and proposed an optimum maintenance strategy for a manufacturing facility. Li [17] proposed a trade-off analysis among the cost, time, and reliability improvement of a system and provided the optimum reliability growth plan for the system in the early stages of developing the new product. However, every TCTP and TCQTP/TCRTP method assumes fix logic plans, however, the tasks of maintenance project can vary, even within a (monetary) year of the planned period/ time-span the priorities can change according to the current state of the system component. Especially for the continuous preventive maintenance, one of the most important decision question is: which (preventive) maintenance tasks should be completed within the project deadline project budget in order to increase the system reliability to the required level. This paper shows how to combine a (maintenance) task selection and scheduling problem. The proposed flexible approach helps the decision makers to specify the set of maintenance tasks and the optimal project schedule at the same time.

While the characterization of preventive maintenance projects as a DTCQTP is obvious, that the preventive maintenance project cannot be specified by classical DTCQTP problem directly. The first reason is that the quality parameter cannot be assigned directly to the maintenance task. The reliability model of the system is separated from the project network. Calculation of system reliability based on the system model. Therefore this problem should be called a discrete time-cost-reliability problem (DTCRTP) instead of DTCQTP. The other problem is that preventive maintenance project does not contain all possible maintenance task. The task should be prioritized by the reliability or the criticality value of the system component. Maintaining different kinds of system components can be completed in a serial, but also in a parallel way. Therefore we have to consider a flexible project plan. The specified problem is a combination of DTCRTP and a project selection problem, therefore we call this problem as Hybrid Discrete Time-Cost-Reliability Trade-Off problem (HDTCRTP). The set of activity can be specified, when a project selection method specified a project structure.

I limited my research to preventive maintenance planning (cost-cutting, time-saving, and reliability-enhancing). Within this, I have also developed a planning process that uses the analytical information that was previously done. Thus, not only do I assume that maintenance plans can be modeled using a matrix planning process, but also that the

Preventive maintenance projects can be described as a time-quality-cost trade-off problem.

2.3 The major role of project planning in maintenance

Most of the maintenance tasks should now be realized through projects where engineering and technical parameters are at the core of management methods and techniques that support the efficient and effective execution of tasks [18], [19]. Project-based maintenance activities focus on areas such as project planning, project participant selection, management and motivation, detailed project planning and tracking, etc. We can conclude that in case of maintenance projects a system-oriented project view is essential [20], [21].

When compiling a maintenance plan, you may be responsible for which maintenance work to be performed. For this, deterministic logic design techniques do not provide an adequate response, since the process of repairing single equipment generally is bound. There is no way to interchange the technological sequence of operations. Mostly, there is no way to duplicate operations. However, it is a matter of deciding which equipment and in what order to keep in mind in the forthcoming period. Maintenance of individual equipment is often an independent process, so if we take into account the time and resource constraints available, we can greatly assist in designing a method, a process that, apart from the expected failure of equipment, takes these constraints into account when designing the maintenance plan. It is important for companies to maintain maintenance and achieve the required levels of reliability in the shortest possible time and at the lowest possible cost. This requires reverse thinking from the designers of the plans.

For traditional projects, the question is always how much the project budget will be. By the traditional approach, we treat a goal as a rigid barrier, what we want to achieve, but the time and cost will vary according to the requirements. In the case of a reverse approach, the following question arises: how many project activities can be carried out in addition to a given cost and time limit, how long do I get in project implementation?

These constraints are the owner (s), company manager (s), which are best defined in cooperation with the maintenance staff, but this practice always refutes. Their purpose is to limit the constraints (time and cost) to the result or target change. In the case of maintenance projects, the use of the latter approach is beginning to widen, as here the output outcomes are not known in terms of time and cost constraints, they only have a design and have a vision, that is, have better and more reliable equipment, so the reliability needs to reach the required level following the repair.

I will summarize the theory of maintenance, within the reliability theory of complex systems, and then formulate the following project hypotheses:

The optimal solution of the preventive maintenance planning problem can be determined for a given target function (shortest possible lead time, minimum cost).

Companies do not have enough time or cost to allow maintenance. If we have been doing/performed analytical work, why not think about it and prioritize the equipment units. If we have the financial resources and the time required, it is necessary to improve each unit for the reliability of the equipment? Would it not be enough to only restore the selected units and thus increase the reliability of the equipment? To solve this problem, we must first decide which activities are to be performed and finally choose the implementation alternatives. Throughout the maintenance and project management, I searched for the modeling method that simply illustrates the results of long-time analyzes and which could provide a good basis for counting overall system reliability. In addition, as a series of simple steps, show us what equipment maintenance can be carried out between a limited budget and time frame so that the overall level of reliability of my equipment reaches the required level of reliability upon completion of maintenance.

To summarize, I have formulated the following hypotheses:

H1 Preventive maintenance projects can be described as a time-quality-cost trade-off problem.

H2 The maintenance planning problem can be modeled using a matrix planning method.

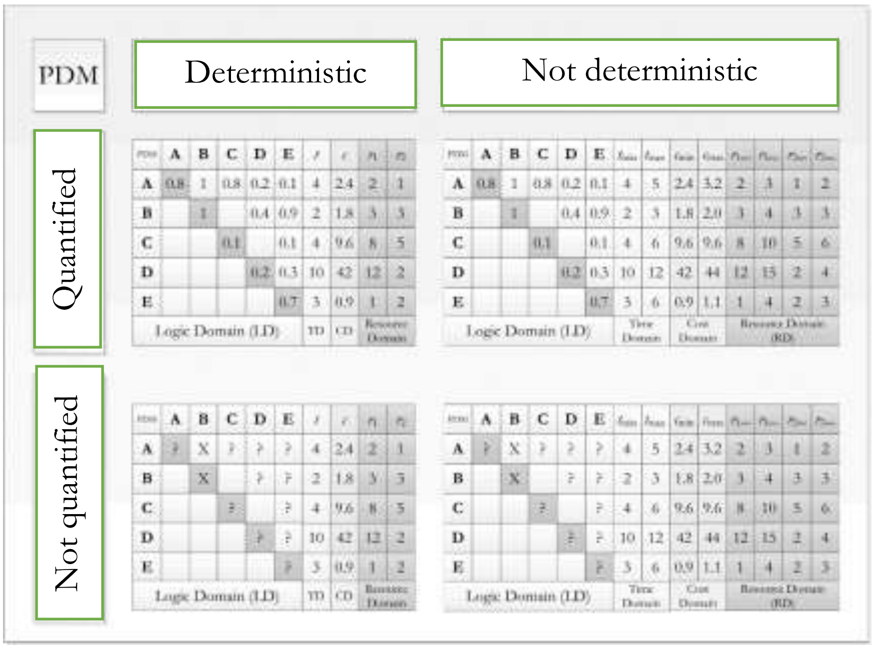
H3 The optimal solution of the preventive maintenance planning problem can be determined for a given target function (shortest possible lead time, minimum cost).

3 Matrix project planning of maintenance projects

Before I introduce the matrix-based method, I give fist a mathematical description of them. I modeled the problem by using a matrix model [22], [23]. The algorithm proposed to solve the problem consists of three phases [24], whose first two phases lead to a preventive maintenance task in a polynomial order for a discrete time-cost-cost trade-off problem that can already be solved by tools previously developed and the solution I proposed.

The most important difference is that here the worst case scenario will be that all corrective and preventive activities will take place. This is no exception to either the overhaul or the so-called periodic check no major examinations.

Possible returns, such as circuit processes, would not necessarily require matrix planning since Pritsker [25] had already addressed this problem very early in the late sixties, but the eligibility of certain repair-preventing activities already exacerbates mesh design procedures. Kosztyán published in 2015 about the PDM matrix [26] which contains four sub-matrices (domain) The first $n\ by\ n$ domain describes the logical connections (Logic Domain, **LD**) of the tasks [27].



2. Figure: Project Domain Matrix (based on [28] own editing)

It is not necessary to use the method to logical relationships and to quantify the activities. It is sufficient to only determine whether activity occurrences or relationships are certain ("X") or uncertain ("?"). Blank cells are responsible for not interpreting relationships between two activities.

Different quantified data can be associated with activity occurrences or contact potencies. These may be, for example, the likelihood of activity/relationship occurrence eg. based on similar projects. They can also have priority or priority values. Now, in the proposed model, I deny that I quantify these values, so I use a non-quantified version of PDM.

The next domain (Time Domain, **TD**) shows the duration of the activities. If the duration of each activity is characterized by a single number, time data is considered deterministic. It is also possible to provide time data for different implementation alternatives. In the last column of Figure 2, only the minimum and maximum duration are indicated.

The third domain (Cost Domain, **CD**) characterizes the direct cost of the activities. Costs may also be deterministic, so we only assign one cost alternative to an activity. Similarly to activities, there may be even more cost-related costs for a single activity, modeling that activities can be carried out in different ways and consequently with different cost requirements. Cost claims can be interpreted here as wider, non-renewable resources. The last partial matrix of the PDM model is the Resource Domain (**RD**) containing renewable resources. If we have *r* resources, then this sub-matrix is a deterministic case of r columns. Here, however, it is possible to assign different resource requirements to each alternative.

Kosztyán [26] beyond the proposed matrix model, a polynomial, a fast algorithm is proposed to evaluate quantified deterministic PDM matrices. The method utilized the option of choosing between two possible alternatives in case of an uncertain occurrence, namely: either implementing or leaving the project activity. At each step, it is possible to calculate what is the least cost project plan (the omission of all uncertain activities other than those obliged), what is the shortest possible project plan [28]. If either of the two possible alternatives is met to exceed the minimum cost requirement as a limit, even if the project scenario with the least costly need is exceeded, it is not worth revaluation of the decision branch because the project cannot be implemented within the constraints set. The method is described in detail at Kosztyán's [29] study.

In this case, score scores, cost, and resource requirements for project scenarios and project structures could be determined by point scores assigned to activity occurrences and link strengths. In polynomial order, the first *N* most likely, most important, shortest, or least cost project plans could be determined without the need to define all project plans.

In the present work, however, I deal with project plans in which. I may not be able to assign a score value to the activity occurrences in the project plan. Based on these, I cannot determine the points of the project scenarios. The compilation of the maintenance project plan is carried out with corrective preventive activities that can be different technologies, with different cost and time requirements, so the PDM matrices shown in Figure 2., **must be applied to the non-quantified non-deterministic scenario or a confidence block diagram for the equipment elements we can further develop an orderly preventive action and increase the estimated reliability increase.**

3.1 Define the maintenance problem

The problem can be considered as a discrete version of a so-called Hybrid Time-Cost-Quality Trade-off Problem, HTCQTP. I formalize in this work a Preventive Maintenance Project Scheduling Problem - PMPSP, which, as we will see, can be considered as a generalized of a discrete time-quality-cost trade-off problem (DTCQTP).

I considered the preventive maintenance planning task as a generalization of a discrete time-quality-cost trade-off problem, which I took into consideration when built up my model.

The reliability block diagram is assumed to be characterized by a simple graph, therefore the diagonal of the neighborhood matrix contains 0 values, which I will later use to indicate the criticality, reliability or availability data (see the relevant section of my thesis paper for more detail).

In this case, the reliability function shows the reliability of the element $R_i = R(k_i)$ at the fixed time$t > 0$. In case if the reliability value falls below a critical criterion of cr_i, then it will be necessary to maintain the equipment.

If the number of uncertain connections is $|\widetilde{A}|$ then the number of possible project scenarios is$2^{|\tilde{A}|}$. The activities and their relationships can be represented by an $n\ by\ n$ PEM matrix. A selected project scenario contains no longer uncertain activity-occurrences.

A matrix representation of $S = (S, \prec, \sim, \bowtie)$ is described by an SNPM matrix Since neither uncertain activity occurrences nor uncertain relationships are quantified, so in the matrix representations, secure relationships can be labeled "X" or "1", uncertain relationships or uncertain occurrences are "?" or 0.5. In matrix representations, the relations/ activities that are left out of the project are labeled by empty cells, "0" or 0.

A project structure contains no longer uncertain relations. The matrix representation of project structures logical plan is an adjacent or DSM matrix. In scheduling and especially in trade-off problems, it is very common to assume that the activity graph, which is characterized by the project structure here, does not contain a circle.

This can be described here as $\prec$ a relation is partially sorted on *S*. At the same time, initial matrix planning methods [30] were also modeled and detected [31], and they have been solved on feedbacks less than one. For this reason, for the sake of simplicity, I assume that a project structure no longer contains circles.

In the proposed algorithm, we decide whether or not to take any uncertain activity occurrences. Then, we decide on any uncertain connection to be required (serial implementation) or not (parallel implementation). We will continue the method until the uncertain relationships would not be included in the model. As a result we will get a project matrix plan which has no "?" symbol in it.

After determining what activities are being performed (Phase 1) and determining the order in which they are being executed (Phase 2), you have to choose how the activities are performed (Phase 3). As a result, we get a so-called project plan, which includes the activities to be performed and how it is implemented.

You can calculate the Total Project Time (TPT), which is designated $t\ (\vec{s}\ x\ )$, and the Total System Reliability (TSR) increment for the *K* systems equipment's, to be labeled $\Delta TSR(K, \vec{s}\ x\ )$. Also, denote $r_{max}(\vec{s}\ x\ )$ the *r* element vector containing the maximum resources.

With the introductory markings (detailed in Section 4.1 of my doctoral thesis), the preventive maintenance project planning problem can already be formulated.

The problem (a). *Preventive Maintenance Project Scheduling Problem, PMPSP, search for the shortest project timing plan:* *Let* $K := \{k_1,\ k_2, \dots, k_z\}$ *be a finite set of equipment elements. Let* $A := \{a_1,\ a_2, \dots, a_n\}$ *be a set of finite activities. Let* $S \in\asymp (A)$ *denote a selected project scenario* $S \subseteq A$*, and designate a project structure* $X\ =\ (S; \prec; \sim)$. *Indicate a possible project plan for the project structure* $\vec{s}\ x$. *Let* $C_c\ \geq 0$ *be the cost* $C_t\ \geq 0$ *a and time* $C_r\ \geq 0$ *is the resource limit vector. Also, indicate* $1 \geq C_{\Delta TSR} \geq 0$ *the minimum system reliability increment that can be considered as a requirement.*

$$\begin{gathered}\arg\min t(\vec{s}\ x) \quad \text{s.t.}\\ c(\vec{s}\ x)\ \leq\ C_c\\ r_{max}(\vec{s}\ x)\ \leq\ C_r\\ 1 \geq \Delta\mathrm{TSR}(\mathrm{K}, \vec{s}\ x) \geq C_{\Delta TSR}\end{gathered}$$

In the above task, we must define the $\vec{s}\ x$ project plan, which takes into consideration the cost and resource constraints, achieving a minimum system reliability increase and corrective-preventing activities as soon as possible. Since this task is practically occurring mostly in practice, I will continue to deal with this task. For the continuous operation, the most important thing is to get the maintenance project done as soon as possible. At the same time, the presented method is suitable for defining the project plan that has the lowest cost that meets the given constraints or which is the largest system reliability increment.

Then the tasks can be described as follows.

The problem (b). *Preventive Maintenance Project Scheduling Problem, PMPSP,* ***search for the lowest cost project plan****:*

$$\begin{gathered}\arg\min c(\vec{s}\ x) \quad \text{s.t.}\\ t(\vec{s}\ x)\ \leq\ C_t\\ r_{max}(\vec{s}\ x)\ \leq\ C_r\\ 1 \geq \Delta\mathrm{TSR}(\mathrm{K}, \vec{s}\ x) \geq C_{\Delta TSR}\end{gathered}$$

The problem (c). *Preventive Maintenance Project Scheduling Problem, PMPSP,* ***search for a project plan with maximum system reliability increment****:*

$$\arg\max \Delta\mathrm{TSR}(\mathrm{K}, \vec{s}\,x) \quad \text{s.t.}$$
$$t(\vec{s}\,x) \le C_t;$$
$$c(\vec{s}\,x) \le C_c$$
$$r_{max}(\vec{s}\,x) \le C_r$$

The proposed model generalizes the traditional time-cost-cost conversion problem, expanding it with the possibility of handling uncertain occurrences of activity and uncertain relations. An *O(u+v)* algorithm (where *u* is for uncertain activities and *v* is the number of unstable connections) returns the proposed maintenance design problem to a traditional trade-off problem.

When constructing and testing my model, the formulas in the first hypothesis proved to be applicable, so it can be stated that

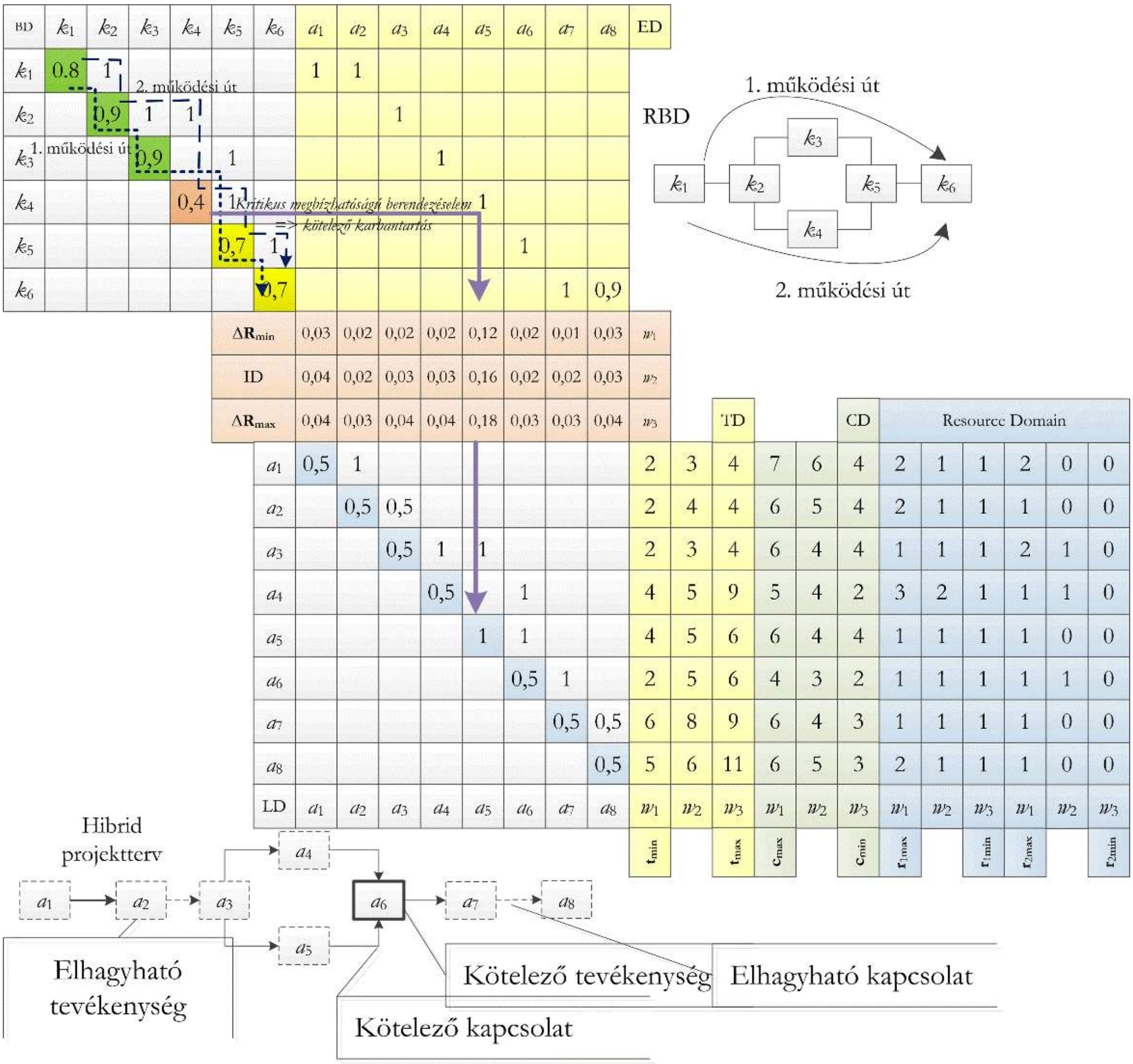
T1 Preventive maintenance projects can be described as a hybrid time-quality-cost trade-off problem.

3.2 Multi-domain Maintenance Management Matrix

My suggestion is to use M^4 (Multi-domain Maintenance Management Matrix) matrix model for compiling maintenance plans, which contains 7 different kinds of domains =see Fig.1).

1. **Block domain (BD)**: is a $z\ by\ z$ matrix, where z is the number of system components. Block Domain is a matrix representation of the reliability block diagram (RBD). The diagonal cells represent the reliability of system components.
2. **Equipment-task mapping domain (ED)**: is a $z\ by\ n$ -es matrix, where n is the number of maintenance activities and z is the number of system components.
3. **An increase of reliability domain (ID)**: is an $m\ by\ n$ matrix, where n is the number of maintenance activities and m is the number of nodes of activities. After deciding which tasks will be completed and if we decide which mode of activity will be selected the increase of reliability for given system component k_i can be calculated.
4. **Logic domain (LD)**: is an $n\ by\ n$ matrix, where n is the number of maintenance activities. Diagonal cells represent the score value of task completion, and off-diagonal cells represent the score values of task dependencies. Cell value 1 represents strict dependencies in off-diagonal and the mandatory tasks in the diagonal, while between 0 to 1, e.g. 0.5 represents the flexible dependencies in off-diagonal and supplementary tasks in diagonal cells. If the reliability of a system component is low then the assigns maintenance task will be a mandatory task (see Fig. 1.)
5. **Time domain (TD)**: is an $n\ by\ m$ matrix, where n is the number of maintenance activities and m is the number of modes. The cell represents the duration of activity a_j completed in mode w.

6. **Cost domain (CD)**: is also an $n\,by\,m$ matrix, where n is the number of maintenance activities and m is the number of modes. The cell represents the costs of activity a_j completed in mode w
7. **Resource domain (RD)**: is an $n\,by\,rm$ matrix, where n is the number of maintenance activities, r is the (renewable) resource needs, m is the number of modes.



BD	k_1	k_2	k_3	k_4	k_5	k_6	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	ED
k_1	0.8	1					1	1							
k_2		0,9	1	1					1						
k_3			0,9		1					1					
k_4				0,4	1						1				
k_5					0,7	1						1			
k_6						0,7							1	0,9	
					ΔR_{min}		0,03	0,02	0,02	0,02	0,12	0,02	0,01	0,03	w_1
					ID		0,04	0,02	0,03	0,03	0,16	0,02	0,02	0,03	w_2
					ΔR_{max}		0,04	0,03	0,04	0,04	0,18	0,03	0,03	0,04	w_3

											TD			CD	Resource Domain					
a_1	0,5	1							2	3	4	7	6	4	2	1	1	2	0	0
a_2		0,5	0,5						2	4	4	6	5	4	2	1	1	1	0	0
a_3			0,5	1	1				2	3	4	6	4	4	1	1	1	2	1	0
a_4				0,5		1			4	5	9	5	4	2	3	2	1	1	1	0
a_5					1	1			4	5	6	6	4	4	1	1	1	1	0	0
a_6						0,5	1		2	5	6	4	3	2	1	1	1	1	1	0
a_7							0,5	0,5	6	8	9	6	4	3	1	1	1	1	0	0
a_8								0,5	5	6	11	6	5	3	2	1	1	1	0	0
LD	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	w_1	w_2	w_3	w_1	w_2	w_3	w_1	w_2	w_3	w_1	w_2	w_3
									t_{min}		t_{max}	c_{max}		c_{min}	r_{1max}		r_{1min}	r_{2max}		r_{2min}

3. Figure: The proposed matrix-based maintenance management model; (edited by his own research work)

Just look at the example below. It is assumed that the critical intervention value for all equipment elements is $cr = 0{,}5$. As Figure 3 (’n) for k_4 equipment element $R(k_4) = 0{,}4 < cr$, therefore, the reliability of k_4 must be improved in any case. As a result, activity a_5 must, in any case, be accomplished to achieve a minimum confidence value 0,5. From the point of view of reliability k_3 and k_4 are coupled in parallel with each other, with all these other components in series. The indicated operating two paths can be specified. Therefore, the reliability of the system is: $TSR = R(k_1)R(k_2)(1-(1-R(k_3))(1-(R(k_4))R(k_5)R(k_6)$.

In block to block presented model and also the Figure 3 illustrates itself, that the particularity of the model is that I can represent in one place the reliability and technological structure of the system, which we have been able to accomplish so far.

T2 With the proposed M^4 matrix modeling process, the preventive maintenance planning problem can be modeled.

3.3 Determination the possible solutions

To model maintenance plans is not enough. It is necessary to be able to determine which equipment is needed to maintain.

To do this, I developed an algorithm (called the PMPSA – Preventive Maintenance Project Scheduling Algorithm), by which I can calculate the available time, cost, resource, and maximum reliability values without deciding on all possible project scenarios.

Most of the costs arise when all repair and preventive activities are performed by maintenance workers and they choose the most cost-effective alternative (C_{max}). The least cost project scenario is provided by the project plan where only compulsory activities are included. and here is also the least costly alternative (C_{min}).

Much like the cost, if the expected impact of the activities can be determined, the maximum reliability improvement (ΔTSR_{max}) can be estimated. This value is reached when all of the corrective-preventive activities are performed. If we restrict ourselves to the obligatory only, the minimum reliability improvement will be (ΔTSR_{min}).

In order to calculate the time requirement, the relations between the activities should also be taken into consideration. We will get the shortest project plan if we plan all uncertain activities into a later project. That is, leaving the project and releasing all non-technologically binding links and executing the actions parallel (T_{min}). By contrast, the longest lead time (T_{max})will result in the execution of all activities and compliance with all business relations.

When scheduling activities for the earliest time, we get the maximum resource (r_{max}) when we perform all the uncertain activities, but we resolve all insecure relationships (parallel execution) and select the implementation paths where the resource requirement is maximized. Likewise, the least resource (r_{min}) is generated if we leave all the uncertain activities out of this project (we will reschedule it to a later project), but the relations of obligatory occurrences will be left (serial execution) and resource requirements the minimum is calculated.

In the first (Figure 4) and in the second phase (Figure 5), we always choose from two possible alternatives, namely in the first phase: realization or rescheduling the activity and in the second phase: prescribe or dissolve the connection between two activities.

As a result, the decision tree, which we must walk, will be a special binary tree. For each decision branch, we can calculate the possible minimum and maximum time, cost, resource requirements, and the minimum, maximum system reliability increase, provides that activities are implemented or abandoned. Then the decision tree will be a binary heap. At the top of the tree, we can tell what is the shortest time, cost, and resource that you definitely need for any project scenario. By deciding about implementing or not implementing an activity, we can always calculate the minimum time, cost or resource requirements or the maximum system reliability increase.

It is very important that after each decision we get an M^4 matrix representation, but in the first phase, one step in each step is to reduce uncertain activities, and in the second phase the number of unstable connections. They will either be omitted or ordered according to our decision.

The proposed method gives preference to alternatives whose target function value is more favorable. After each decision, we will tell you the maximum system reliability that is available and the minimum time and cost requirements. For the first two phases, the following cutting rules can be defined.

1. **Rule (TSR_CUT).**
   If the maximum system reliability increase is less than the required reliability increment, neither the project scenarios that can be derived nor the derived versions of the project nor the project structures derived from the project scenario are allowed.
2. **Rule (TPC_CUT).**
   If the minimum cost requirement for a project scenario is higher than the cost limit, neither project scenarios, nor project versions derived from it, nor project structures derived from the project scenario are allowed.
3. **Rule (TPT_CUT).**
   If the minimum time requirement of a project scenario or project structure is higher than the time limit, neither the project scenario/project structure nor the project plans that can be derived from it are allowed.

I did not make a cutting rule for resources, because here I'm going to perform a resource smoothing process in phase three. For activities scheduled for the earliest time, the maximum resource requirement can be reduced. However, its calculation requirement is much higher than, for example, the schedule. To illustrate the first phase of the method, see the following example.

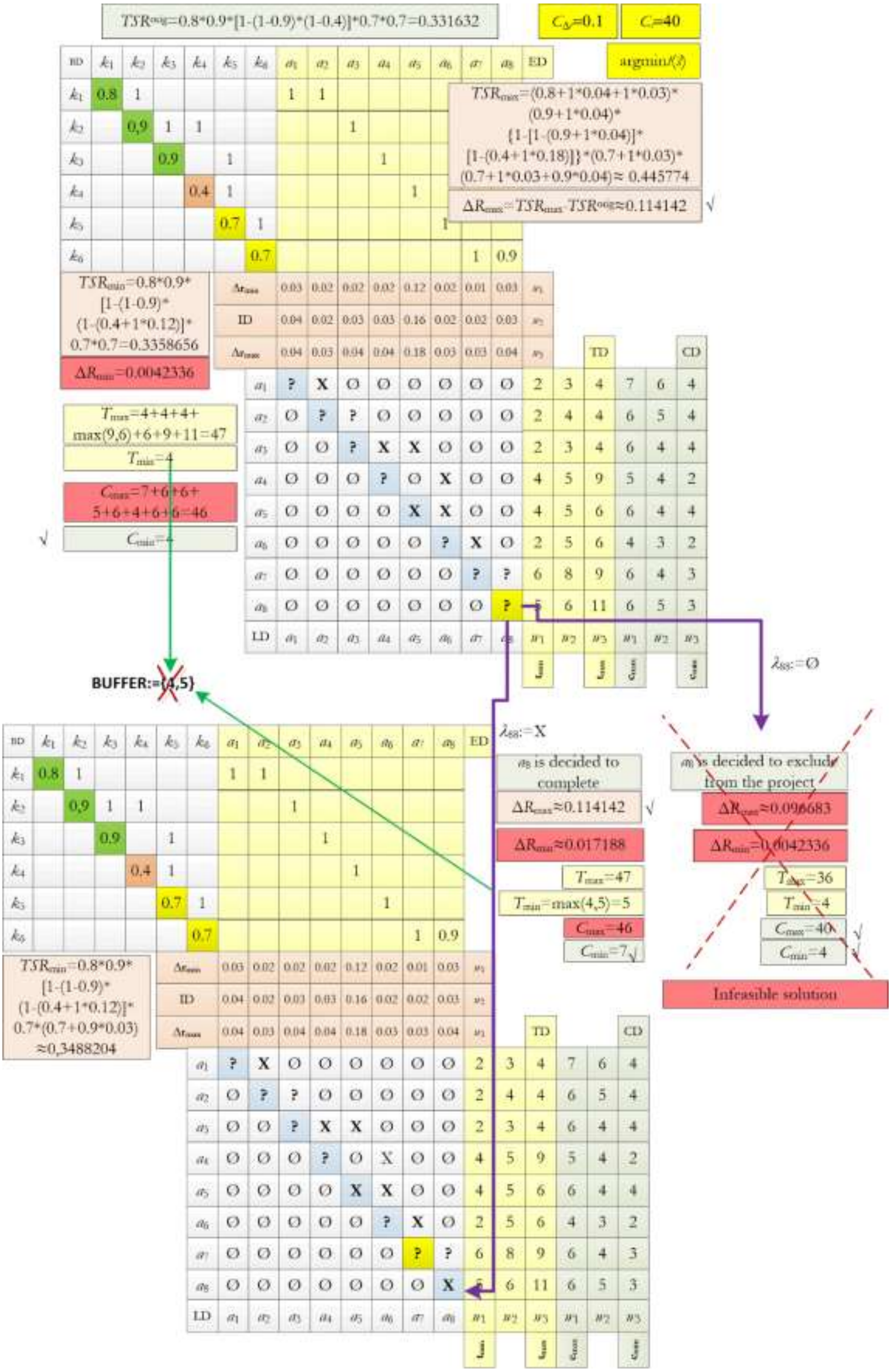
1. Example. A matrix schedule for the preventive maintenance plan was given (see Figure 4). The task is to carry out the maintenance project at the earliest time so that the reliability of the system is at least 10% (CTSR=0,1), but we will not exceed the cost of € 40000 (Cc=40). The task must be performed with 3 maintenance and 2 machine adjusters (Cr = [3; 2]T). It is assumed that, regardless of the reliability chart, each device element must have a confidence level of at least 0.5 (cr = 0; 5).

Since the goal is to find the shortest possible run time, so in the first phase we prefer those project scenarios that contain less activity. So in every step, if the activity is on the critical path, we will try to leave the project because we get shorter lead times. At the same time, if the implementation of a project scenario with the highest system reliability increased for this matrix cannot guarantee a 10% reliability-increase then this branch and all its subsectors should be removed from the decision tree.

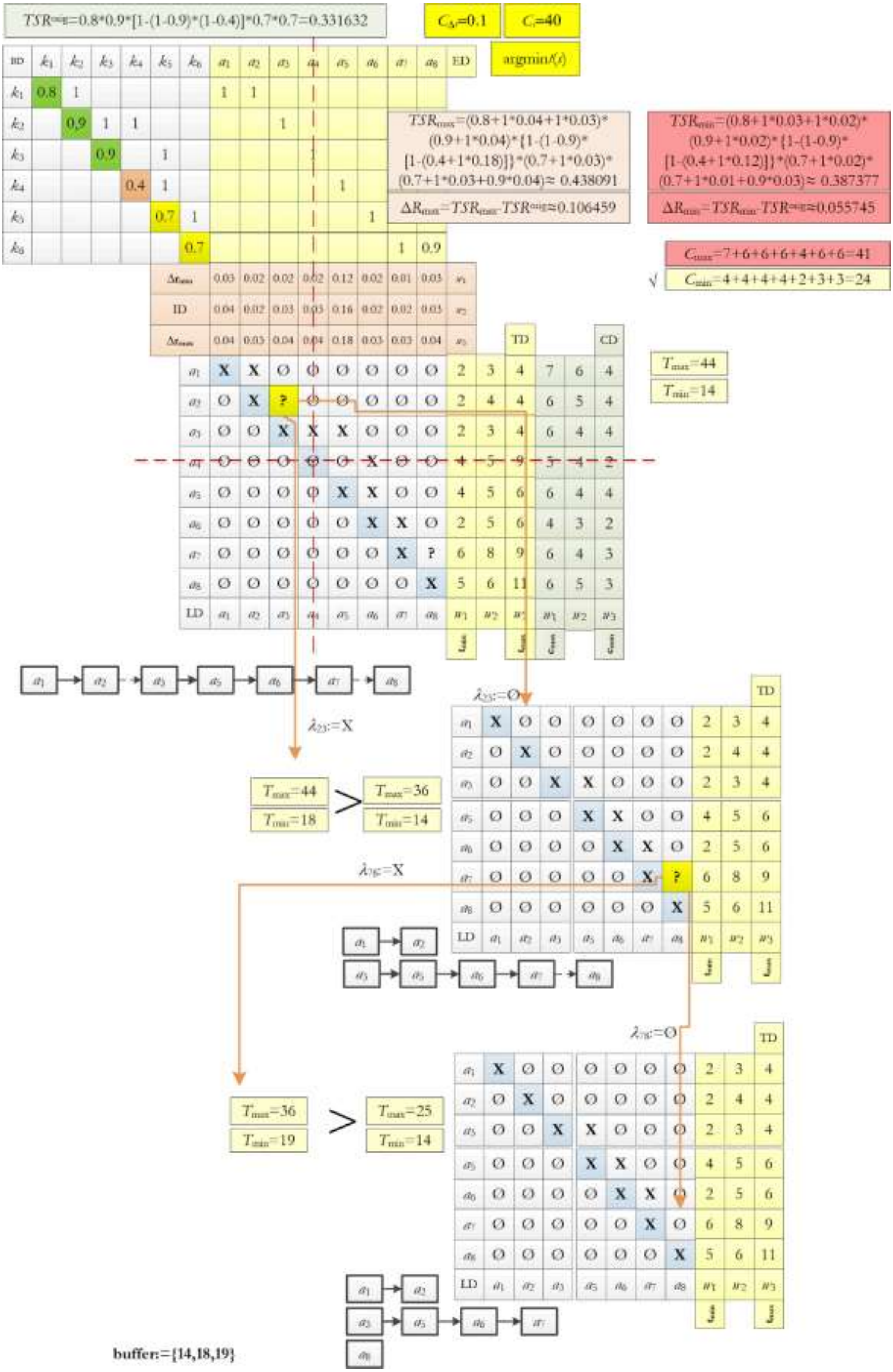
In the example of Figure 5, we decide to implement the a_8 activity. Although we strive to find the best solution, we may need to find the second or third best solution. The shortest possible lead times are stored in an ordered BUFFER set. In the second phase, we decide which order of activities will be carried out. It is important to note that since we have decided whether or not to perform an activity, the minimal and maximum cost of the system and the minimum and maximum incremental reliability of the system will not be affected by the sequence of execution of the actions. Therefore, it is only sufficient to calculate the minimum and maximum possible times of action. To do this, it is enough to give a logical plan and a sub-matrix with time requirements.

Only the TPT_CUT cutting rule can be used to determine the most appropriate project structure for the target function. By the end of the second phase, we get a project structure where the goal is to define the project plan that best suits the target function and does not exceed the constraints. If we do not have too many alternatives, then we can go forward with the first two phases. In each step, we decide which one of the possible ways to implement a given activity. Each vertex has a child in the decision tree since we can solve all activities in many ways. At each point, we calculate project plans that have the lowest / highest lead time, cost-intensive, and the lowest / largest system reliability increments.

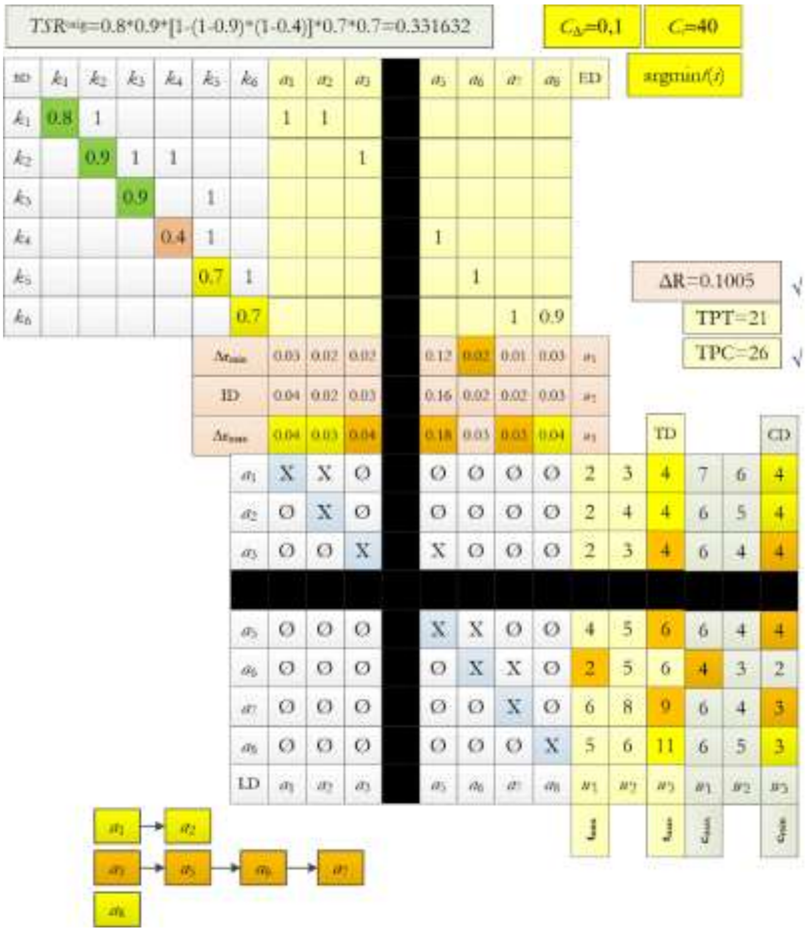
Using the cutting rules 1, 2, 3, we get a project plan that best suits a given target function. The resultant timeline is a resource simulation task. If we get a solution that does not go beyond limitations (in this case it is r = [3; 1] T, which does not exceed Cr = [3; 2] T limit), we can recommend this project plan to the maintenance team. If resource planning does not succeed, we will need to go back to the next best solution and reset the resource finishing.



4. Figure: Finding best project scenarios (1. stage); (edited by his own research work)



5. Figure: Best project structure (2. stage); (edited by his own research work)



$TSR=0.8*0.9*[1-(1-0.9)*(1-0.4)]*0.7*0.7=0.331632$

$C_\Delta=0,1$

$C=40$

argmin $f(s)$

ΔR=0.1005 √

TPT=21

TPC=26 √

ED	k_1	k_2	k_3	k_4	k_5	k_6	a_1	a_2	a_3	a_5	a_6	a_7	a_8	ED		TD			CD
k_1	0.8	1					1	1											
k_2		0.9	1	1					1										
k_3			0.9		1														
k_4				0.4	1					1									
k_5					0.7	1					1								
k_6						0.7						1	0.9						
Δt_{min}							0.03	0.02	0.02	0.12	0.02	0.01	0.03	w_1					
ID							0.04	0.02	0.03	0.16	0.02	0.02	0.03	w_2					
Δt_{max}							0.04	0.03	0.04	0.18	0.03	0.03	0.04	w_3					
a_1							X	X	Ø	Ø	Ø	Ø	Ø	2	3	4	7	6	4
a_2							Ø	X	Ø	Ø	Ø	Ø	Ø	2	4	4	6	5	4
a_3							Ø	Ø	X	X	Ø	Ø	Ø	2	3	4	6	4	4
a_5							Ø	Ø	Ø	X	X	Ø	Ø	4	5	6	6	4	4
a_6							Ø	Ø	Ø	Ø	X	X	Ø	2	5	6	4	3	2
a_7							Ø	Ø	Ø	Ø	Ø	X	Ø	6	8	9	6	4	3
a_8							Ø	Ø	Ø	Ø	Ø	Ø	X	5	6	11	6	5	3
LD							a_1	a_2	a_3	a_5	a_6	a_7	a_8	w_1	w_2	w_3	w_1	w_2	w_3

6. Figure: Final project schedule (3. stage); (edited by his own research work)

3.4 An optimal solution for specific target functions

In the first two phases, we take advantage of the fact that we always have to choose only two possible alternatives, namely to implement or leave uncertain activities. In the second phase, we provide or relieve insecure relations.

In all branches of the tree, we can say what the longest and shortest lead time is. We can tell what the smallest and largest project cost is or what the smallest and greatest increase in reliability is. We can do this without defining all project variants and the resulting project structure. With the help of the cutting rules, project scenarios and their project structures derived from them should not be evaluated either, which does not meet a minimum (time, cost, reliability increment) constraints. In the first two phases, we can get to a project structure without having to go back to the decision tree. If the number of uncertainties u, and the number of unstable connections is v, then a project structure can be obtained in $O(u + v)$. The third phase is a discrete trade-off problem where, in addition to the proposed methods [10], [11], several heuristic methods can be used [13], [32].

The model presented by block to block and Figure 3 itself illustrates also that the proposed M^4 matrix modeling procedure can be used to model the preventive maintenance design problem.

T3 The optimal solution for a preventive maintenance planning problem can be determined for a given target function (shortest possible lead time, minimum cost).

4 Summary

The presented method is a result of long, continuous research work. During the creation of the Multi - domain Maintenance Management Method - M4 was played a great deal of role to establish a priority order between the equipment to be maintained and the number of occasionally emerging circuits in the quantified form during the planning.

Specifies the priority of repairs the risk classification of maintenance activities. If you have a cost, resource or time limit, you can use the matrix logic planning methods that I created to plan a project that allows you to plan and schedule the most needed tasks/repairs.

Using the presented method, we get an output as a maintenance plan that includes which equipment or equipment components need to be maintained. In the maintenance plan, an integrated M^4 is used, which includes the risk or reliability values for the equipment, and includes the access sequence. Expenditure on the activities, competent human resources and the maintenance period for the activities are also presented.

Although the technologic order of maintenance operations is usually concluded with the repair of single equipment, the repair of each equipment can be done in different order, even interrupted, and can be restarted for inspection or work for the unit. If you have a cost, resource or time frame, you can use this method to create a project plan that allows you to plan and schedule the most needed fixes.

Within the available budget for companies, we strive to integrate as many of the equipment as possible into the plan, and by restoring them, we achieve the expected overall system-level reliability value. In compiling the plan, we will keep in mind the available time frame and monitor the number of competent maintenance staff on the given equipment. The maintenance plan is then assembled using M^4 to achieve our goal, that is, within the constraints set by the company, the expected overall system reliability.

5 References

[1] D. R. Fulkerson, "A network flow computation for projetct cost curves," *Management Science,* vol. 7., no. 2., pp. 167-178, 1961.

[2] S. Elmaghraby, Activity networks: Project planning and control bí network models, NewYork: Wiley, 1977.

[3] J. Kelley, "Critical-Path Planning and Scheduling: Mathematical Basis," *Operations Research,* vol. 9, pp. 296-320, 1961.

[4] E. B. Berman, "Resource Allocation in a PERT Network Under Continuous Activity Time-Cost Functions," *Management Science,* vol. 10, no. 4, pp. 128-137, 1964.

[5] L. R. Lamberson and R. R. Hocking, "Optimum Time Compression in Project Scheduling," *Management Science,* vol. 16, no. 10, pp. 597 - 606, 1970.

[6] J. E. Falk and J. L. Horowitz, "Critical Path Problems with Concave Cost-Time Curves," *Management Science,* vol. 19, pp. 446-455, 1972.

[7] R. K. Ahuja, T. L. Magnanti and J. B. Orlin, "Some Recent Advances in Network Flows," *SIAM Review,* vol. 33, no. 2, pp. 175-219, 1993.

[8] A. V. Goldberg, "An Efficient Implementation of a Scaling Minimum-Cost Flow Algorithm," *Journal of Algorithms,* vol. 22, no. 1, pp. 1-29, 1997.

[9] J. B. Orlin, "Algorithm, A Faster Strongly Polynomial Minimum Cost Flow," *Operations Research,* vol. 41, no. 2, pp. 338-350, 1993.

[10] P. De, E. J. Dunne, J. B. Ghosh and C. E. Wells, "The discrete time-cost tradeoff problem revisited," *European Journal of Operational Research,* vol. 81, no. 2, pp. 225-238, 1995.

[11] P. De, E. J. Dunne, J. B. Ghosh and C. E. Wells, "Complexity of the Discrete Time-Cost Tradeoff Problem for Project Networks," *Operations Research,* vol. 45, no. 2, pp. 302-306, 1997.

[12] C. Feng, L. Liu and S. Burns, "Stochastic Construction Time-Cost Trade-Off Analysis," *Journal of Computing in Civil Engineering,* vol. 14, no. 2, pp. 117-126, 2000.

[13] A. Babu and N. Suresh, "Project management with time, cost, and quality considerations," *European Journal of Operational Research,* vol. 88, no. 2, pp. 320-327, 1996.

[14] E. Afruzi, A. Najafi, E. Roghanian and M. Mazinani, "A multi-objective imperialist competitive algorithm for solving discrete time, cost and quality trade-off problems

with mode-identity and resource-constrained situations," *Computers and Operations Research,* pp. 50; 80-90, 2014.

[15] N. Pour, M. Modarres, M. Aryanejad and R. Moghadam, "The discrete time-cost-quality trade-off problem using a novel híbrid genetic algorithm," *Applied Mathematical Sciences,* vol. 4 (42), pp. 2081-2094, 2010.

[16] A. Rastegari and M. Mobin, "Maintenance decision making, supported by computerized maintenance management system. In 2016 Annual Reliability and Maintainability Symposium (RAMS)," 2016.

[17] Z. Li, M. Mobin and T. Keyser, "Multi-objective and multi-stage reliability growth planning in early product-development stage," *IEEE Transactions on Reliability,* vol. 65(2), pp. 769-781, 2016.

[18] A. Németh, "Karbantartási tevékenységek megbízhatóság alapú mátrixos projekttervezése," in *XXX. OTDK Közgazdaságtudományi Szekció*, Gödöllő, 2011.

[19] A. Németh, G. Péczely and Z. T. Kosztyán, "Karbantartási tevékenységek mátrixos projekttervezése," in *XXIII. Nemzetközi Karbantartási Konferencia Kiadványa*, Z. Gaál and L. Szabó, Eds., Veszprém, Pannon Egyetem, 2011, pp. 173-182.

[20] J. Kiss, Z. T. Kosztyán, A. Németh and F. Bognár, "Matrix-based methods for planning and scheduling maintenance projects," in *Carl Hanser Verlag*, München, 2011.

[21] Z. T. Kosztyán and A. Németh, "Reliability-Risk Project Expert Matrix for Handling Maintenance Projects," *Awerprocedia Information Technology and Computer Science,* vol. 3, pp. 1577-1583, 2013.

[22] Z. T. Kosztyán, C. Hegedűs, J. Kiss, A. Németh, I. Borbás and P. Cserti, "Projekt szakértői rendszer karbantartási projektek menedzselésére," *A karbantartás kihívása- a tudás tőke -felértékelődése,* pp. 178-193, 2010.

[23] Z. T. Kosztyán, C. Hegedűs, J. Kiss and A. Németh, "Handling Maintenance Projects with Matrix-Based Methods," *Lecture Notes in Electrical Engineering,* vol. 151, pp. 357-366, 2013.

[24] A. Németh, "Berendezések karbantartásának mátrixos projekttervezése," *E-CONOM,* vol. 2, pp. 79-88, 2013.

[25] A. B. Pritsker, GERT: Graphical Evaluation and Review Technique, Memorandum, RM-4973-NASA, 1966.

[26] Z. T. Kosztyán, "Exact algorithm for matrix-based project planning problems," *Expert Systems with Applications,* vol. 42, no. 9, pp. 4460-4473, 2015.

[27] A. Németh and Z. T. Kosztyán, "Maintenance on Scale-Free Networks," 2015.

[28] Z. T. Kosztyán, "Mátrix alapú stratégiai projekttervezési eljárások," *Szigma,* vol. 44, no. 1-2, pp. 65-94, 2013.

[29] Z. T. Kosztyán, "Költség- és időcsökkentési eljárások alkalmazása a projekttervezésben és a nyomon követésben," *Vezetéstudomány,* vol. 46, no. 6, pp. 45-57, 2015.

[30] D. Steward, "The design structure system- a method for managing the design of complex systems," *IEEE Transactions on Engineering Management,* vol. 28, no. 3, pp. 71-74, 1981.

[31] R. Xiao, T. Chen and Z. Tao, "Information modeling and reengineering for product development process," *International Journak of Management Science and Engineering Management,* vol. 2, no. 1, pp. 64-74, 2007.

[32] P. Brucker, A. Drexl, R. Mohring, K. Neumann and E. Pesch, "Resource-constrained project scheduling: Notation, classification, models, and methods," *European Journal of Operational Research,* vol. 112, no. 1, pp. 3-41, 1999.

[33] K. El - Rayes and A. Kandil, "Time-Cost-Quality Trade-Off Analysis for Highway Construction," *Journal of Construction Engineering and Management,* vol. 131, no. 4, pp. 477-486, 2005.

[34] A. Goldberg and R. Tarjan, "Solving Minimum-cost Flow Problems by Successive Approximation," *Proceedings of the Nineteenth Annual ACM Symposium on Theory of Computing, ACM,* pp. 7-18, 1987.

[35] A. Németh and Z. T. Kosztyán, "Matrix-based Maintenance Management (M3)," in *Élenjáró karbantartás, mint a vállalkozás sikerének előfeltétele*, Veszprém, Pannon Egyetem, 2015, pp. 189-204.

[36] M. Rahimi and H. Iranmanesh, "Multi-objective particle swarm optimization for discrete time, cost and quality trade-off problem," *World Applied Sciences Journal,* vol. 4, no. 2, pp. 270-276, 2008.

[37] H. R. Tareghian and S. H. Taheri, "On the discrete time, cost and quality trade-off problem," *Applied Mathematics and Computation,* vol. 181, no. 2, pp. 1305-1312, 2006.

Related Publications

International Journal Articles:

Zsolt T. Kosztyán and **Anikó Németh**: Matrix Planning Method For Handling Maintenance Projects; Global Journal On Information Technology [Online]. 2014/ 5, Available from http://www.world-education-center.org/index.php/P-ITCS/issue/view/139 Proceedings of 4th World Conference on Information Technology (WCIT-2013) 01-207, 26-28 November 2013, -, Belgium. ISSN 2147-5105, pp. 85-91.

Zsolt T. Kosztyán and **Anikó Németh**: Reliability-Risk Project Expert Matrix For Handling Maintenance Projects; AWER Procedia Information Technology & Computer Science. [Online]. 2013/ 3, Available from http://www.world-education-center.org/index.php/P-ITCS Proceedings of 3rd World Conference on Information Technology (WCIT-2012), 14-16 November 2012, University of Barcelona, Barcelona, Spain. ISSN 2147-5369, pp. 1577-1583.

Zsolt T. Kosztyán, Csaba Hegedűs, Judit Kiss and **Anikó Németh**: Handling Maintenance Projects with Matrix-Based Methods; Lecture Notes in Electrical Engineering Vol. 151; Emerging Trend in Computing, Informatics, Systems Sciences, and Engineering; January 2013, ISSN 1876-1100, ISBN 978-1-4614-3557-0; pp. 357-366.

Hungarian Journal Articles:

Kosztyán Zs T, **Pribojszki-Németh A**, Kovács Z, Karbantartási projektek mátrix-alapú tervezése, Alkalmazott Matematikai Lapok, 33:(1) Budapest, 2016, ISBN pp. 27-56.

Németh Anikó: Berendezések karbantartásának mátrixos projekttervezése, Taylor Gazdálkodás- és Szervezéstudományi Folyóirat: A Virtuális Intézet Közép-Európa Kutatására Közleményei, Szeged, 2015, 18-19:(1-2), ISBN 2064-4361pp. 152-162.

Németh Anikó, Kosztyán Zs T: M3 – Matrix-based Maintenance Management, XXVII. Nemzetközi Karbantartási Konferencia: Élenjáró karbantartás, mint a vállalkozás sikerének előfeltétele. Veszprém: Pannon Egyetem, 2015. ISBN:978-963-369-071-4, pp. 189-204.

Németh Anikó: Karbantartás tervezés új köntösben, Pro Scientia Aranyérmesek XII. konferenciája Eger, 2015. ISBN:978-615-5509-42-1, pp.

Németh Anikó: Berendezések karbantartásának projekttervezése, Tavaszi Szél, 2014 konferenciakötet. 1 kötet, Közgazdaságtudomány, Budapest, 2015. ISBN 978-963-89560-5-7, pp. 368-380.

Németh Anikó: Karbantartás tervezés új köntösben – Berendezések karbantartásának mátrixos projekttervezése, Virtuális Intézet Közép-Európa Kutatására Közleményei

(VIKEK), TAYLOR Gazdálkodás- és Szervezéstudományi folyóirat, 2015/1-2. Szám; VII. évfolyam 1-2. Szám (no. 18-19), Szeged, 2015. ISSN 2064-4361, 99.152-162.

Németh Anikó, Dr. Kosztyán Zsolt Tibor: Teljes körű hatékony karbantartás a Lean szíve lelke?, Virtuális Intézet Közép-Európa Kutatására Közleményei (VIKEK), TAYLOR Gazdálkodás- és Szervezéstudományi folyóirat, 2014/3-4. Szám; VI. évfolyam 3-4. Szám (No 16-17), Szeged, 2014. ISSN 2064-4361, pp. 196-208.

Németh Anikó, Berendezések karbantartásának mátrixos projekttervezése, E-conom, Online Tudományos Folyóirat, 2013/2 (II. évf. 2. sz.), Nyugat-magyarországi Egyetem Kiadó/ University of West Hungary Press, Sopron, ISSN 2063-644X, 2014. április 28., pp. 79-98.; http://e-conom.hu/e-conom_2013_2.html?&L=1

Németh Anikó: Berendezések karbantartásának mátrixos projekttervezése, Logisztikai Híradó 2014. február, XXIV.évf.1. szám, ISSN 2061-6333, pp. 29-32.

Németh Anikó: Karbantartási projektek tervezése, Virtuális Intézet Közép-Európa Kutatására Közleményei (VIKEK), TAYLOR Gazdálkodás- és Szervezéstudományi folyóirat, 2014/1-2. Szám; VI. évfolyam 1-2. Szám (No 14-15), Szeged, 2014. ISSN 2064-4361, pp. 50-58.

Németh Anikó, Dr. Kosztyán Zsolt Tibor: Berendezések karbantartásának megbízhatóság központú mátrixos projekttervezése, Virtuális Intézet Közép-Európa Kutatására Közleményei, IV. évfolyam 4. szám (No.10.) A-sorozat 2. Gazdálkodás- és Szervezéstudományi tematikus szám, Szeged, 2012, ISSN 2062-1396, pp. 235-248.

Hungarian Book Chapters:

Németh Anikó, témavezető: Dr. Kosztyán Zsolt Tibor: Berendezések karbantartásának mátrixos projekttervezése, Tudós Bagoly avagy Válogatás a XXXI. Országos Tudományos; Diákköri Konferencia Közgazdaságtudományi Szekciójában bemutatott díjnyertes dolgozatokból, Válogatott Kéziratok, Veszprém, 2014; ISBN 978-963-396-054-7; pp. 308-365

Németh Anikó: Almanach, Tudományos Diákköri Füzetek, Pro Scientia Aranyérmesek és Mestertanárok 2013; az Országos Tudományos Diákköri Tanács Kiadványa, 2013, ISSN 1215-7775; ISSN 1215-7767; pp. 27.; pp. 107-110.

Németh Anikó, témavezető: Dr Kosztyán Zsolt Tibor: Berendezések karbantartásának mátrixos projekttervezése, XXXI. Országos Tudományos Diákköri Konferencia, Közgazdaságtudományi Szekció, Előadások Kivonatai, Pannon Egyetemi Kiadó, 2013, ISBN 978-615-504-478-6, pp. 576.

International Conferences:

Zsolt Tibor Kosztyán, ***Anikó Németh***, Csaba Hegedűs: What to do? How to do? – Novel Models for Managing Large- scale Project Portfolios?; Whither Europe? Evaluating the past and forecasting the future; 20th Summer University of ISES, 21 June – 3 July 2015, University of Pannonia, Kőszeg Centre, Kőszeg, Hungary

Lajos Szabó, ***Anikó Németh***, Nikoletta Kaszás: Students' workshop on EU Project Management; Whither Europe? Evaluating the past and forecasting the future; 20th Summer University of ISES, 21 June – 3 July 2015, University of Pannonia, Kőszeg Centre, Kőszeg, Hungary

Anikó Németh, Zsolt Tibor Kosztyán: Matrix planning methods for handling maintenance projects, 4th World Conference on Information Technology, Brussels, Belgium, November 26-28, 2013

Anikó Németh, Zsolt Tibor Kosztyán: New way in maintenance project planning, PMUni WS (Project Management University Workshop) – szakmai találkozó, Veszprém, October 4-5, 2013

Anikó Németh, Zsolt Tibor Kosztyán: MPPM? The new way of planning and modeling, 4th Annual Conference of the European Decision Sciences Institute, Budapest, Hungary, June 16-19, 2013

Anikó Németh: Risk and Reliability-Based Project Planning, PMUni WS (Project Management University Workshop) – szakmai találkozó, Utrecht, Netherland, 18-19. October 2012.

Anikó Németh, Zsolt Tibor Kosztyán: Developing matrix based project planning methods for maintenance – Reliability-Risk Project Expert Matrix, 3rd World Conference on Information Technology, University of Barcelona, Spain, November 14-16, 2012

Hungarian Conferences:

Pribojszki-Németh Anikó, Projekttervezési módszerek alkalmazása a karbantartási stratégiák függvényében, A generációváltás informatikai vonatkozásai: XIII. OGIK Gazdaságinformati-kai Konferencia. OGIK'2016. Konferencia helye, ideje: Dunaújváros, Magyarország, 2016.11.11-2016.11.12.

Pribojszki-Németh Anikó, Kosztyán Zsolt Tibor, Maintenance on Scale-Free Networks OGIK'2015 - 12. Országos Gazdaságinformatikai Konferencia. Konferencia helye, ideje: Veszprém, Magyarország, 2015.11.06-2015.11.07.pp. 32-33.

Kosztyán Zsolt Tibor, **Németh Anikó**, Kovács Zoltán: Karbantartási projektek mátrixos-alapú tervezése, XXXI. Magyar Operációkutatási Konferencia, Cegléd, 2015. június 10-12. http://www.gazdasagmodellezes.hu/images/stories/konferenciak/csb3koneko.pdf

Németh Anikó, Dr. Kosztyán Zsolt Tibor: M3 - Matrix-based Maintenance Management, XXVII. Nemzetközi Karbantartási Konferencia: Élenjáró karbantartás, mint a vállalkozás sikerének előfeltétele, Veszprém, 2015.április.16-17., ISBN 978-963-369-071-4, pp. 189-204.

Németh Anikó: Karbantartás tervezés új köntösben, Pro Scientia Aranyérmesek XII. konferenciája, Eszterházy Károly Főiskola, Eger, 2014. november 6-8.

Németh Anikó: Karbantartás tervezés új köntösben, 4. Vezetéstudományi konferencia „A vezetés aspektusai Taylor után 101 évvel", Szeged, 2014. május 30.

Németh Anikó, Karbantartások mátrixos projekttervezése – Karbantartástervezés új köntösben, Interdiszciplináris Konferencia 2014, III. IDK2014 - I. PSZN - Mandulavirágzási Napok, Pécsi Tudományegyetem, ISBN 978-963-642-597-5, pp.42-43., Pécs, 2014. április15-17.

Németh Anikó, Berendezések karbantartásának projekttervezése, Doktoranduszok Országos Szövetsége, Tavaszi Szél Konferencia 2014, Debreceni Tudományegyetem, Debrecen, 2014. március 21-23.

Németh Anikó, Karbantartások mátrixos projekttervezése, Nemzeti Kiválóság Program konferenciája a Pannon Egyetemen, Veszprém, 2014. március 05.

Németh Anikó, Dr. Kosztyán Zsolt Tibor: Berendezések karbantartásának „karcsú" projekttervezése, 10. Országos Gazdaság-informatikai Konferencia OGIK'2013, Győr, 2013. november 8-9**.**

Németh Anikó, Dr. Kosztyán Zsolt Tibor: Teljes körű hatékony karbantartás a lean szíve lelke!, V. Régiók a Kárpát-medencén innen és túl, Kaposvár, 2013. október 11.

Németh Anikó: Karbantartási projektek tervezése és modellezése, 3. Vezetéstudományi konferencia „Vezetés és hatékonyság Taylor után 101 évvel", Szeged, 2013. május 31.

Németh Anikó: Kvantitatív módszerek kidolgozása a karbantartási projekttervek készítésének támogatására, XXII. Diagon Műszaki Diagnosztika-EDU Karbantartási Konferencia és Szakmai Továbbképzés, Siófok, 2013. április 22-24.

Németh Anikó: Karbantartási anyagmenedzsment? – Igen; XV. Energorep-EDU, Tudással a termelékenységért, a megbízható üzemelésért és biztonságért karbantartási Konferencia és szakmai továbbképzés, Zalakaros, 2012. november 26-28.

Németh Anikó, Dr. Kosztyán Zsolt Tibor: A karbantartás tervezhetőségének bűvöletében?!, 20. MLBKT Kongresszus, „Gazdálkodj okosan! Bizalom és együttműködés; A fenntarthatóság záloga", Siófok, 2012. november 14-16.

Németh Anikó: Megbízhatóság-kockázat központú projekt szakértő mátrix, 2. Vezetéstudományi konferencia „Vezetés és hatékonyság Taylor után 101 évvel”, Szeged, 2012. június 01.

Full publication list can be viewed at the Hungarian Scientific Works' House under number 10037748.