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TASK CRITICALNESS POTENTIAL: A MULTIPLE CRITERIA APPROACH TO PROJECT MANAGEMENT

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The paper proposes the method evaluating tasks criticalness potential, which has been analysed by various project management tools. The criticalness potential of tasks, as opposed to a simple differentiation of tasks to critical and non-critical using the CPM method, considers not only time, but also resource, cost and topological aspects of a project schedule. In the paper, the tasks criticalness potential is defined applying task criticalness indicators which are further used as input for three various multiple criteria decision models. These models enable taking into account the principal project success criteria, i. e. time, resources and cost. The tasks criticalness potential cannot be determined using one indicator or one characteristic only. A selected multi-criteria approach based on task criticalness indicators differentiates between tasks more and less threatening to a project. This paper suggests different multiple criteria approaches to the quantification of task criticalness potential, compares them and discusses their advantages and disadvantages.

Keywords: project management, task threat, criticalness potential, multiple criteria evaluation

Classification: 90B50, 90B99

1. INTRODUCTION

The main challenge of project management is to accomplish project objectives and constraints: scope, time, quality and cost mostly optimising the allocation of necessary resources. For a successful project realisation, one needs to know restraints that can cause the delaying of a project due date, increasing project cost or the failure of the project scope and quality. The first work about quantitative approach within the project management appeared in the middle of the last century and dealt with the time analysis mainly [24, 27]. But not only due date and its reaching is important for successful completion of the projects. The evolution of modern project management is a direct consequence of the necessity of making effective use of the data generated by the schedulers in an attempt to manage and control the critical path [36].

Nowadays, many papers focus on the estimation of project objectives achieving in the phase of project initiation. Unfortunately, most of the methods applied in project

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management are not based on quantitative approaches. As a result, most of the methods used in project management are derived from common planning tools.

For instance the BOSCARD (Background, Objectives, Scope, Constraints, Assumptions, Risks and Deliverables) is used to provide the terms of reference for a newly proposed project in the phase of project initiation with a question "Which future events may affect the project?" [21]. The MoSCoW (Must have, Should have, Could have, and Would like but won't get) method is applied when establishing a clear understanding of the customers' requirements and their priorities [13]. The RACI (Responsibility, Accountability, Consultation, and Information) is a tool for communication settings and used for identifying roles and responsibilities and avoiding confusion over those roles and responsibilities during a project [34]. SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis [3] involves specifying the purpose of a project and identifying the internal and external factors that are favourable or unfavourable to achieving the project goal. Another approach is SMART (Specific, Measurable, Achievable, Realistic, and Timed) goals evaluation [16, 20, 40]. Each of these tools is, of course, based on evaluation of several different points of view but does not quantify them.

The threatening of project tasks is not only given by the surroundings and environment of the project but also by the internal arrangement and structure of the project. The success of the project is conditioned by the level of recognition of weak spots in the project. The project risk deals with risk management, however, without a quantitative view of the sequence and arrangement of project tasks and its other quantitative qualities. In the area of risk management, a number of different techniques and approaches have been derived in order to reduce the risk of a project and its partial tasks [37].

The quantitative approach in the project management defines a successful project as: finishing the project on time, in full (all objectives), on budget (with planned cost). A crucial problem in project management concerns measuring and quantifying the importance of project tasks and determining the amount of an effect that each task has on the successful completion of a project.

Fatemi Ghomi and Teimouri [18] and Madadi, Iranmanesh [26] present overview on some indices (mainly for stochastic networks) from the literature and proposed new one for quantification of the task importance. Mota and Almeida [30] proposes a multiple criteria decision model based on the ELECTRE TRI-C method to assign tasks in project management to priorities classes for helping project managers to focus on the proper tasks to ensure a successful project realization.

Also problems related to the delay of cost sharing among the delayed tasks are studied. Authors often propose cooperative game for cost allocation in the delayed projects [5, 7, 17, 8, 9].

The criticality of project tasks is often defined only from the time perspective, using stochastic approaches [6, 15], fuzzy sets methods [11, 39] or using the findings of a network analysis [10, 19]. Gong and Rowings [19] mention that ignoring the impact of non-critical tasks, which may easily become critical, is the most frequent criticism of project duration analysis methods. Another point of view on tasks criticalness is given by the structure of relations in the project. Bowers [6] or Williams [38] deal with a stochastic analysis of a project network where the criticality of tasks in the project is derived from the relation between task duration and the whole project, and on the basis of a number of resources used for a task and the whole project.

A deeper insight into the issue is presented by Bowers [6], who defines the criticality of a task as uncertainty given by task duration and a number of resources. A different approach to a project network has been adopted by Madadi and Iranmanesh [26], who analyse the growth or decline in the criticality of tasks in the project during network structure changes. A number of preceding and following tasks have always a direct impact on the criticality of the task. Madadi and Iranmanesh [26] claim that if a project network is composed of several parallel on-going chains, then a lower variability and criticality of tasks in the project can be expected.

Multiple criteria approach to so called criticalness potential is also presented by Jakubik [23]. This approach uses Multiplicative model with two basic parameters: the task duration and the probability of a critical path gateway through the task. The probability of a critical path depends on the project topological structure.

The criticalness of tasks in the project and search for its weak spots needs to be accepted from various perspectives. It is impossible to expect a generally valid principle to determine the criticalness of tasks. Each project and each situation in the project is unique.

The main aim of the paper is to introduce new quantitative approach finding weak points in a project completion process, and identifying tasks which are potentially dangerous for meeting project objectives. In the paper we introduce five task criticalness indicators; we suppose different multiple criteria approaches to criticalness potential calculations and compare Multiplicative and Additive models.

2. QUANTITATIVE APPROACH TO TASK CRITICALNESS

Quantitative approach to successful project completion is typically based on the analysis of critical path. Unfortunately it is rare for this single objective to adequately represent a real project management. In reality a project management consists of critical tasks analysis on one hand and scheduling of various resource or analysis of cost driven indicators on the other hand. Each project tasks can represent the project threats from very different points of view. In fact every task parameter represents a risk for successful project completion. Moreover combination of some risks may cause project fatal failure. Nevertheless, quantitative multiple criteria approach, for several analysis of this type, is used very rarely. In the literature some applications of Multi-attribute Utility Theory (MAUT) and Multi-criteria decision making (MCDM) in Project Management appeared. Mota and Almeida [30] propose the iterative outranking MCDM method for classifying of the project activities according to the tasks characteristic using ELECTRE TRI-C method [31, 32]. Application of the PROMETHEE method for critical path analysis is shown in [29]. The decision maker seeks to prioritize tasks which are the most risky, with a high variability of duration, have high cost, need more resources, require large number of experts and have a high impact on commissioning.

Very important MAUT approach is based on aggregation of all criteria and leads to ordering of the alternatives according to the single-criterion [1, 2]. San Cristobal Mateo evaluates critical path using Weighted Sum method, TOPSIS or VIKOR method [29]. Criteria aggregation or synthesis is compensatory and does not allow the veto concept which is an important issue to be considered. Nevertheless MAUT has wide applicability in decision problems, when the decision maker's rationality has the compensatory notion between the criteria and the decision maker does not refuse a very bad performance in some criterion, which usually is not included in the aggregation process. On the other hand even when the compensatory rationality is not verified, the use of Utility Theory with non-compensatory problems can be carefully handled.

In this paper the proposed model is based on MAUT. Application of simple methods of multi-criteria decision making meet the requirements of project management and assume that easier approach will be more accepted. This model consists of five criteria: task duration, task slack evaluating variability of duration, task total cost of qualified staff, task total work of recourses and last but not least degree of impact on commissioning evaluated by topological location of task. At the end the project manager receives the order of the project tasks and can mainly focus on the most risky tasks.

2.1. Critical task and task criticalness

In the traditional way critical tasks are always identified with zero total slack in project schedule. Thus, critical tasks are tasks, which will jeopardize a project in terms of its deadline if they are delayed. From this point of view, resource usage or task cost are not taken into account. The differentiation of tasks according to their total slack and position on a critical path may not be sufficient for project management. Tasks impact on a project can be given as an aggregation of many aspects [14, 30]. According to the commonly used the project triangle, i. e. time, scope and cost balance, there are at least these three fundamental aspects of a project. It is also appropriate to take into account the sequence of tasks with respect to the project structure. These aspects fundamentally determine the success or failure of a project in terms of its deadline and budget.

Many authors deal with measurement of the criticality of the project tasks in stochastic networks. Martin [28] proposes the activity criticality index and the path criticality index reflecting the probability that the activity would fall on the longest path. Many methods for its computation in the case of stochastic or fuzzy projects were developed. Williams [38] defines two concepts of task importance. The cruciality index involves the risk by the uncertainty in project completion time and the significance index involves the task effect on project completion time. Cho and Yum [12] propose a model to measure the effect of the variability in task durations on the variability of the project completion time by indices Uncertainty Importance Measure (UIM) for task and pair of tasks. Generally, all these indices are oriented on the time, on the task duration, project duration and time variability based on the stochastic character of the project.

Therefore, we propose tasks criticality evaluation from the various points of view and for deterministic projects. We suppose the expert deterministic evaluation of the task parameters. To express the impact of the project tasks on a successful project completion, we define the concept of **task criticalness potential**. The task criticalness potential evaluates an expected size of the negative impact of the task on a project. Such evaluation combines several indicators, i. e. the **indicators of task criticalness**.

2.2. Indicators of task criticalness

The suggested approach to the evaluation of a task in relation to a project success is based on the crisp quantitative approach. This approach suggests providing an overall evaluation of the task criticalness without soft knowledge of the task nature. The estimation of overall criticalness potential of the project tasks is based on the multiple attributes decision-making method MAUT using five criteria: topological location, duration, slack, cost, and work and corresponding criticalness indicators which are defined as utility function for each criterion. The real value of all these criteria have to be normalized into the interval $\langle 0, 1\rangle$ so that the worst value of the criteria is transformed to value 1. Using such transformation we obtain task criticality indicators. After the aggregation of partial indicators the task with the highest value of overall criticalness potential is the most threatened task. The project manager can set his/her own preferences which can be used in this aggregation.

We define five indicators of the task criticalness:

(i) topological criticalness,

(ii) time criticalness,

(iii) slack criticalness,

(iv) cost criticalness, and

(v) work criticalness.

These indicators are subsequently used as an input data for the multiple attribute evaluation of the task criticalness potential.

2.2.1. Topological criticalness

The important attribute of the task criticalness is its topological location. Madadi and Iranmanesh [26] propose to measure the location of the tasks by relative number of the successors of each task. Jakubík [23] suppose an index, which reflects the probability that the critical path would pass through the current task. This concept is based on the following idea: Suppose the analysed task lies on all paths in some set of the paths in the project network. The probability that at least one of these paths is critical increases with number of paths in this set and so probability that analysed task is critical increases too. The topological criticalness of one task depends on the topological criticalness of its predecessors and their successors. The topological criticalness of one task also affects topological criticalness of its successors. Here in such definition of the topological criticalness the importance of both predecessors and successors is included. This parameter is thus closely related to the project structure. Tasks with higher value of this parameter can have greater impact on the project completion on time. For a model with tasks on nodes (Activity on Node project type) we firstly need to calculate the probability of some (maybe critical) path gateway through task as

$$p_0 = 1 \quad \text{and} \quad p_i = \sum_{j \text{ predecessor } i} \frac{p_i}{h_j}, \quad i = 1, 2, \ldots, N \tag{1}$$

where p_0, p_i, p_j resp., are the probabilities of a critical path gateway through tasks $0, i, j$ resp., h_j is the number of tasks following task j, N is the number of the tasks in the project.

The starting dummy task 0 is always part of the critical path. Therefore, the probability that starting dummy task is a component of the critical path is equal to 1. The probabilities of a critical path gateway through other tasks are comprised of an adequate part of these probabilities of its predecessors.

It is possible to suppose that the task with higher topological criticalness is more critical and has a greater impact on the project completion. The indicator of the task topological criticalness will be transformed using the following formula

$$cp_i = \frac{p_i - \min\limits_{k=1,\dots,N} p_k}{\max\limits_{k=1,\dots,N} p_k - \min\limits_{k=1,\dots,N} p_k}, \quad i = 1, 2, \dots, N \tag{2}$$

where cp_i is the topological criticalness of the task i, N is the number of the tasks in the project.

2.2.2. Time criticalness

The duration of the project depends on the duration of the project tasks. The longest sequence of the tasks represents the critical path and duration of the whole project and this sequence generally depends of the relatively long tasks. However, in modern project management the study of critical mass leads to a necessity to a proper management of the short tasks, which can be provided without some strong time limits. This can be very important for the successful project completion [25]. Therefore, in this index we assume that the longer task will cause more probably the prolongation of the project than a shorter one. Therefore, longer duration indicates higher criticalness.

The indicator of the time criticalness is calculated as follows

$$ct_i = \frac{t_i - \min\limits_{k=1,\dots,N} t_k}{\max\limits_{k=1,\dots,N} t_k - \min\limits_{k=1,\dots,N} t_k}, \quad i = 1, 2, \dots, N \tag{3}$$

where ct_i is the time criticalness of the task i, t_i, t_k resp., are the durations of tasks i, k, resp., N is the number of the tasks in the project.

Value of the task criticalness of task i is equal to 1, if the task is the longest one of the project, and is equal to 0, if the task is the shortest one typically milestones, i. e. tasks or points in project plan with 0 duration serving for segmentation of the project schedule. The milestone is a significant date in a project, such as the completion of a project phase, or the date a particular report is due.

2.2.3. Slack criticalness

The task slack identifies the time available for a task delay without delaying the project due date. This slack can be used if a resource needs more time on a task, or if a resource needs to be assigned to another task. The task with nonzero slack when prolonged within slack value has no effect on the project due date, but in general the task with smaller slack is more risky than a task with a higher one. The indicator of the slack criticalness is based on the slack value and is transformed, so the higher value shows higher criticalness.

$$cs_i = \frac{\max\limits_{k=1,\dots,N} s_k - s_i}{\max\limits_{k=1,\dots,N} s_k}, \quad i = 1, 2, \dots, N \tag{4}$$

where cs_i is the slack criticalness of the task i, s_i, s_k resp., are the time slack of the tasks i, k resp., N is the number of the tasks in the project.

This indicator expresses the relationship between the actual task slack and the maximum time slack in the project schedule.

2.2.4. Cost criticalness

This indicator is defined from the perspective of minimizing project cost. We can assume the task with low cost has a smaller impact on the total cost of the project than an expensive one. This indicator expresses the relative cost of each project activities.

$$cc_i = \frac{c_i - \min\limits_{k=1,\dots,N} c_k}{\max\limits_{k=1,\dots,N} c_k - \min\limits_{k=1,\dots,N} c_k}, \quad i = 1, 2, \dots, N \tag{5}$$

where ck_i is the cost criticalness of the task i, c_i, c_k resp., are the cost of tasks i, k, resp., N is the number of the tasks in the project.

The cost criticalness indicator of the task transforms the task cost so that the higher value of this indicator shows higher criticalness.

2.2.5. Work criticalness

Work criticalness computation is based on the same idea as the cost criticalness. The task work amount related to the project work is used as an indicator of the work criticalness of the task. This type of criticalness is closely related to the usage of renewable resources in a project. Thus this criticalness would also be called "renewable resource criticalness". The higher value shows higher criticalness.

$$cw_i = \frac{w_i - \min\limits_{k=1,\dots,N} w_k}{\max\limits_{k=1,\dots,N} w_k - \min\limits_{k=1,\dots,N} w_k}, \quad i = 1, 2, \dots, N \tag{6}$$

where cw_i is the work criticalness of the task i, w_i, w_k resp., are the total amount of work fo the tasks i, k, resp., N is the number of the tasks in the project.

This indicator evaluates the project tasks according to the total amount of work assigned to it in relation to demands of other tasks.

2.3. Evaluation of task criticalness potential

Indicators of the task criticalness described above are used as an input for multiple criteria decision-making models. Values of all indicators are within interval $\langle 0, 1\rangle$ and used as an input for multiple attribute analysis model. We suppose Multiplicative and Additive multiple criteria approach for evaluation of the criticalness potential of tasks. These models are based on the idea that the higher value of indicators leads to higher criticalness potential of a task.

2.3.1. Multiplicative model

In the Multiplicative approach, all previously defined indicators are multiplied using the following formula [22].

$$\Gamma M_i = cp_i \times ct_i \times cs_i \times cc_i \times cw_i, \quad i = 1, 2, \ldots, N \tag{7}$$

where ΓM_i is global evaluation of the task i criticalness potential, $cp_i, ct_i, cs_i, cc_i, cw_i$ are the indicators of each component of task i criticalness, N is the number of the tasks in the project.

The evaluation of the task by this model is higher, if the values of indicators are higher, and the task has higher potential of criticalness. This is true if all indicators of one task are not equal to 0. If one task criticalness indicator is equal to 0, task criticalness potential is equal to 0 too and the task is marked as a task without negative impact on project completion although some other indicator can have high value and the task should be supposed as a task with high criticalness potential. Such high degree of compensation principle is a weak point of this approach but from another point of view the advantage of this model is that it shows all tasks with non-zero values of task criticalness indicators. The Multiplicative model is dimensionless and, therefore, weights are irrelevant to emphasize the importance of individual indicators because its mathematical structure eliminates any units of measure [35].

Due to this reason the Multiplicative model has to be used very carefully and we advise against it as shown in application of the task criticalness potential below.

2.3.2. Additive model

In this model all criteria evaluations are aggregated using the formula [22].

$$\Gamma A_i = cp_i + ct_i + cs_i + cc_i + cw_i, \quad i = 1, 2, \ldots, N \tag{8}$$

where ΓA_i is global evaluation of the task i criticalness potential, $cp_i, ct_i, cs_i, cc_i, cw_i$ are the indicators of each component of task i criticalness, N is the number of the tasks in the project.

This approach does not allow the inclusion of criteria weights which describe the project manager view on the importance of individual criterion. In this model all criteria have the same preference. We suppose that giving the project managers an opportunity to express preferences of different evaluation of the impact of tasks on completion of the project the best results will be reached. We prefer to use the following weighted approach.

2.3.3. Weighted Sum model

This is the most widely applied model. We assume all criteria preferences are known. All criteria evaluations are combined using the formula [22].

$$\Gamma W_i = u_1 cp_i + u_2 ct_i + u_3 cs_i + u_4 cc_i + u_5 cw_i, \quad i = 1, 2, \ldots, N \tag{9}$$

where ΓW_i is global evaluation of the task i criticalness potential, $cp_i, ct_i, cs_i, cc_i, cw_i$ are the indicators of each component of task i criticalness, u_1, u_2, u_3, u_4, u_5 are the weights of the components of criticalness, N is the number of the tasks in the project.

Both form of the Additive models suppose a fixed trade-off rate between each pair of criteria indicators of task criticalness. It means that these models are based on constant exchange rate. These models compare differences in indicators values, it is possible to say, that this value is greater than the other by a certain value [35]. Even though that some indicator is equal to 0, the potential task criticalness can still be high and the task can be evaluated as high potentially critical.

Another advantage is that the Additive model allows expressing the importance of individual indicators of the criticalness. This advantage is important due to different contents of the project and due to different problems that can occur during its completion. As a result, different types of criticalness can have more important role. Also the sensitivity analysis of weights changes can be performed to improve the quality of results.

Also this Weighted Sum approach allows compensation of criteria evaluation but the degree of this compensation is not so high as in case of Multiplicative approach.

2.4. Task analysis using task criticalness potential

In the initial phase of the project management for each project manager is important to know which activities are of particular focus for the successful completion of the project. After creating the project baseline the individual evaluation of the criteria - topological location, duration, slack, cost, and work of each task are known. Their values are then recalculated into the partial task criticalness indicators. Comparing these task criticalness indicators and analysis of their values provides initial guidance on the nature of the task thread. Multiplicative model used in the next step determines the project activities that are threatened from all points of view (the value of each of their criticalness indicators is non-zero). In the last step Simple Additive model or Weighted Sum model is used for comparison and ordering of the tasks from the tasks with the highest value of the criticalness potential. These tasks need the most focus of the project management. If the project manager is able to determine the weights of each criteria or indicators, the Weighted Sum model has to be advantageously used.

3. APPLICATION OF THE TASK CRITICALNESS POTENTIAL

Evaluating a project as a whole from the point of view of a task threat is not easy at all. An unambiguous and fully sufficient approach still does not exist. Tasks on a critical path are considered the most threatening tasks. Finding of the critical path and a follow-up analysis of reserves is not always sufficient. In practice, we can often observe that even tasks outside a critical path have an extreme impact on the course and success of a project. To demonstrate the contribution of derived indicators of the project task criticalness, and proposed multiple criteria decision models for evaluation of the task criticalness potential, the following small-scale project was used as an illustrative example. This project is based on a real project of new software purchase and it is simplified for illustrating the evaluation of task criticalness potential.

The entire project is grouped into three summary tasks (main phases) - Tender preparation, Creation of tender documents, and Evaluation of the bids - to break down the task list into more easily manageable sections. Each summary task consists of at least four subtasks that detail how to complain each project phase. The critical tasks of a project (Table 1, Figure 1) with zero time slack are marked grey. We derived the proposed task criticalness indicators for all tasks based on the data presented in Table 1. The last two lines of Table 1 present the lowest and the highest real values of tasks criticalness indicators.

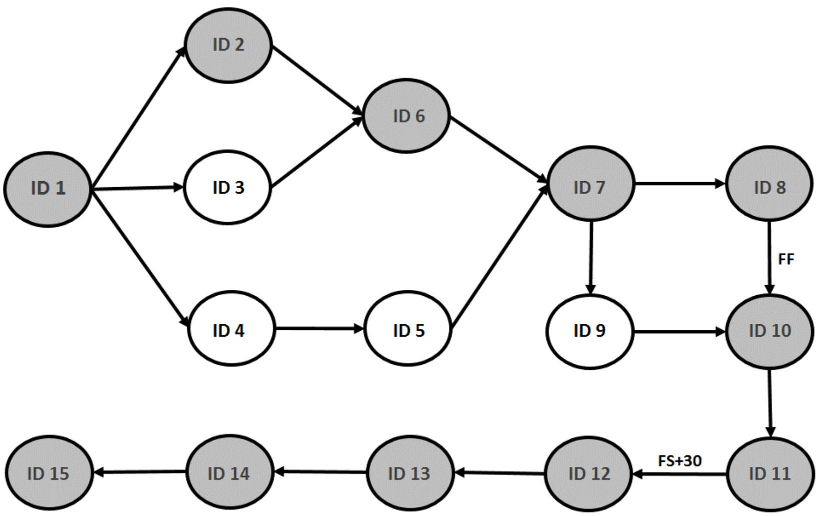

Fig. 1. Small-scale project with the indication of critical tasks (authors).

The necessary weights of criticalness indicators for proposed models are used according to the survey of Bartoška et al. [4]. In this survey, the authors interviewed 11 professionals (experts from praxis), 24 students of specialisation Project Management at Faculty of Economics and Management (FEM), Czech University of Life Sciences (CULS) Prague, and 39 students of the subject of Project Management at Czech Technical University (CTU) Prague. In total, 74 responses were collected using a simple questionnaire containing the practical explanation of pairwise comparison method [33] and the table for comparison of used indicators. The weights were calculated for every questionnaire using MS Excel functions and macros. The performed ANOVA test, i. e. a single-factor test of analysis dispersion proves that the elicited weights do not statisti-

ID	Tasks	Predecessors	Probability of critical path gateway	Duration (days)	Time slack (days)	Work (hours)	Cost (CZK)
	Purchase of the software - Tender			**62.2**		**537.6**	**421360**
	Tender preparation						
1	Analysis of client's needs		1	5	0	60	70000
2	Formulation of the client's needs	1	0.333	5	0	80	46000
3	Market research	1	0.333	2	3	16	100000
4	Selection of a procurement mode	1	0.333	0.1	6.8	0.8	400
5	Processing internal documents	4	0.333	0.1	6.8	1.6	560
6	Specifications of a subject matter	2; 3	0.667	2	0	32	24000
7	Specification of evaluation criteria	5; 6	1	1	0	16	8000
	Creation of tender documents						
8	Tender documents	7	0.5	3	0	24	24000
9	Commenting on the tender documents	7	0.5	1	1	8	4000
10	Approval of the tender final version	8 (FF); 9	1	1	0	8	4000
11	Notice of the tender	10	1	1	0	8	8000
	Evaluation of the bids						
12	Opening the bids and checking formal correctness	11 (FS+30 days)	1	0.1	0	2.4	1600
13	Selection of the bid according to the evaluation criteria	12	1	5	0	120	80000
14	Award notification	13	1	0.1	0	0.8	800
15	The contract	14	1	10	0	160	120000
	MIN		0.333	0.1	0	0.8	400
	MAX		1	10	6.8	160	120000

Tab. 1. Small-scale project data, default links FS (finish to start), link FS+30 (finish to start with delay), link FF (finish to finish) (authors).

cally differ within the groups. The weights can be combined within the groups for each aspect (Table 2).

The task criticalness indicators from Table 1 are transformed (Table 3) and used as inputs in three basic multi-criteria decision making models: Multiplicative model, Additive model and Weighted Sum model. These models represent three different approaches to expressing tasks criticalness potential, i. e. a composite impact of tasks on a project. Each task is evaluated by five different indicators, which have different meaning and whose usage can be difficult for aggregation and interpretation (Table 3). Each indicator could be used within a partial project analysis, e. g. work criticalness indicators within Resource Project Management or cost criticalness indicators within Earned Value Management. What is important though is the possibility of their suitable aggregation.

Sample	Average	Variance
Task duration	**0.164**	0.003
Task cost	**0.288**	0.004
Task total slack	**0.129**	0.002
Task topological location	**0.189**	0.002
Task work	**0.230**	0.009

Source of variation	SS	DF	MS	F	P value	F crit
Treatments	0.045	4	0.011	2.994	0.073	3.478
Error	0.038	10	0.004			
Total	0.083	14				

Tab. 2. Analysis of variance of the mean weights of characteristics of activity criticalness (authors).

ID	Tasks	Criticalness indicators				
		Topological criticalness	Time criticalness	Slack criticalness	Work criticalness	Cost criticalness
	Purchase of the software - Tender					
	Tender preparation					
1	Analysis of client's needs	1	0.495	1	0.372	0.582
2	Formulation of the client's needs	0	0.495	1	0.497	0.381
3	Market research	0	0.192	0.559	0.095	0.833
4	Selection of a procurement mode	0	0	0	0	0
5	Processing internal documents	0	0	0	0.005	0.001
6	Specifications of a subject matter	0.5	0.192	1	0.196	0.197
7	Specification of evaluation criteria	1	0.091	1	0.095	0.064
	Creation of tender documents					
8	Tender documents	0.25	0.293	1	0.146	0.197
9	Commenting on the tender documents	0.25	0.091	0.853	0.045	0.030
10	Approval of the tender final version	1	0.091	1	0.045	0.030
11	Notice of the tender	1	0.091	1	0.045	0.064
	Evaluation of the bids					
12	Opening the bids and checking formal correctness	1	0	1	0.010	0.010
13	Selection of the bid according to the evaluation criteria	1	0.495	1	0.749	0.666
14	Award notification	1	0	1	0	0.003
15	The contract	1	1	1	1	1
	Weights	0.189	0.164	0.129	0.23	0.23

Tab. 3. Task criticalness indicators, input values for multiple criteria approach for evaluation (authors).

The contribution of the proposed models (Table 4) is unambiguous comparability of tasks not only among themselves, but also with regard to their overall impact on a project and its success (tasks with zero time slack are marked grey).

In Table 4 and Figure 2, tasks are ranked according to their criticalness potential values adopted from the Weighted Sum model, and the evaluation based on all applied models is shown as well. The graph reveals that the task, which is significantly threatening and which criticalness potential towards a project is enormous, is task ID15 - The contract. Total criticalness potential of this task is significantly greater than that of other tasks. This task can be regarded as restrictive for a project with respect to its success. All project tasks can be divided into three groups according to the criticalness potential values received by Weighted Sum model.

The first group contains tasks with the highest criticalness potential Figure 2, these are ID15 – The contract, ID13 – Selection of the bid according to the evaluation criteria, and ID1 – Analysis of client's needs. These tasks have the highest global evaluation of criticalness criticalness potential calculated by Weighted Sum model is higher than 0.6. These tasks are on the top in sequence in each applied model. Based on the Multiplicative model, these tasks do not have a zero value of the criticalness potential. When implementing a project, we should pay a greater attention to these tasks and give precautions regarding to e. g. Risk Project Management or Resource Management. However, this Multiplicative approach does not distinguish the criticalness potential of other tasks.

ID	Tasks	Task criticalness potential		
		Multiplicative approach	Additive approach	Weighted Sum approach
	Purchase of the software - Tender			
15	The contract	1	5	1
13	Selection of the bid according to the evaluation criteria	0.247	3.909	0.763
1	Analysis of the client's needs	0.107	3.449	0.652
2	Formulation of the client's needs	0	2.374	0.434
7	Specification of the evaluation criteria	0.001	2.25	0.373
3	Market research	0	1.679	0.365
11	Notice of the tender	0	2.2	0.362
6	Specifications of the subject matter	0.004	2.085	0.357
10	Approval of the tender final version	0.000	2.166	0.352
12	Opening the bids and checking formal correctness	0	2.020	0.323
14	Award notification	0	2.003	0.319
8	Tender documents	0.002	1.886	0.315
9	Commenting on the tender documents	0	1.269	0.191
5	Processing of the internal documents	0	0.006	0.002
4	Selection of the procurement mode	0	0	0

Tab. 4. Ranking of the tasks based on their criticalness potential using Weighted Sum approach (authors).

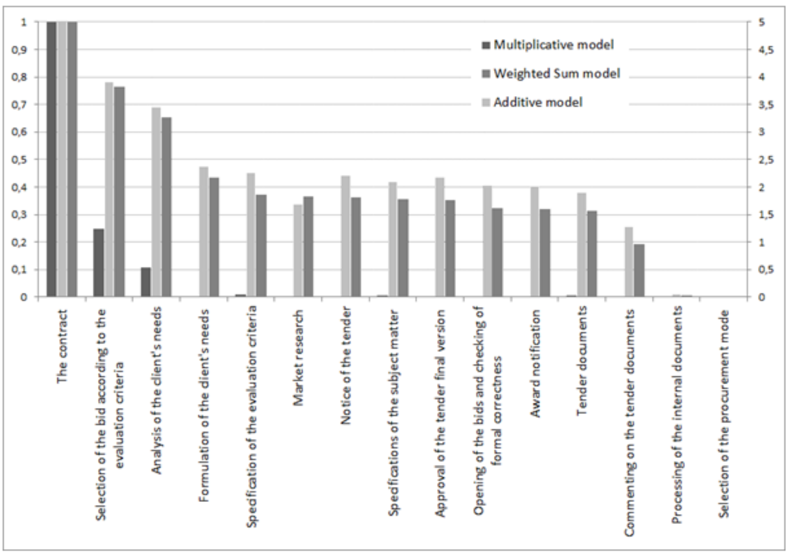

Fig. 2. Comparison of task criticalness potential using three different models (authors).

The second group includes next nine tasks in the project, ID2 – Formulation of client's needs, ID7 – Specification of the evaluation criteria, ID3 – Market research, ID11 – Notice of the tender, ID6 – Specifications of a subject matter, ID10 – Approval of the tender final version, ID12 – Opening the bids and checking formal correctness, ID14 – Award notification, and ID8 – Tender documents with criticalness potential values calculated by Weighted Sum model higher than 0.3 but significantly lower comparing to the first three tasks. These tasks lie on a critical path except the task ID 3 – Market research which criticality is based mainly on its costs. In this group there are also three tasks with non-zero value of the criticalness potential according to the Multiplicative model, ID7 – Specification of the evaluation criteria, ID6 – Specifications of a subject matter, and ID8 – Tender documents. This evaluation of both tasks is a signal for the project manager to be very careful in their management.

The third group of tasks consists of the three remaining tasks out of critical path, task ID9 – Commenting on the tender documents, ID5 – Processing of the internal documents, and ID4 – Selection of the procurement mode, whose criticalness potentials are very low. Despite this, the criticalness potential of the first of those tasks almost reaches the value 0.2.

4. CONCLUSION

The contribution of the paper is in the proposal of a new approach to the comparison of tasks regarding their impact on project success. This approach is based on the new multiple attribute definition of so called task criticalness and task criticalness potential.

Criticalness of the task is usually expressed only by the zero value of total slack reflecting the risk of project delay caused by a task. We derive the task criticalness potential from the project structure (number of parallel tasks), the nature of task duration (known or random), resource assignments (in the right time and right place), and task cost (relatively high or low) using indicators such as topological criticalness, time criticalness, slack criticalness, work and cost criticalness.

The first advantage of this group of the tasks criticalness indicators is in covering the various influences on the successful completion of the project. Additionally the different weights of individual task criticalness indicators can express the expected level of their influence.

For the calculation of the total task criticalness potential, we used three different multi-attributes approaches - Multiplicative, Additive and Weighted Sum approach. All these decision models rank tasks by the value of the criticalness potential. Thanks to partial task criticalness indicators and complexly to the criticalness potential, project tasks can be more sophisticatedly classified and analysed from the perspective of the whole context, i. e. risk prevention, resources allocation and reserve planning, or multitasking elimination.

All applied models have a greater information value, i. e. all models express the task criticalness potential towards the project completion. Nonetheless, we assume that the Weighted Sum model is the most convenient because each of the partial indicators affects its value and, moreover, enables the use of weights, which illustrate the importance or significance of individual indicators from the perspective of a project context.

Compensation principle of this method is a week point of this approach and must be handled with care. But on the other hand, the Multiplicative model is not suitable for ordering of project tasks if at least one criticalness indicator equals to 0. In this case task criticalness potential is equal to 0 regardless of its other evaluation. In our method the real values of all used criteria are normalized into interval $\langle 0, 1\rangle$ so that the best value of the criteria is transformed to 0 and thus normalized criterion value of at least one task is equal to 0 for each criterion. On the contrary the Multiplicative model is useful for highlighting the tasks with all non-zero criticalness indicators and therefore task criticalness potential higher than 0.

Our approach can be beneficial for both Resource Project Management and Risk Project Management. The task criticalness potential is based on the definition of tasks criticalness in a project without a strong relationship to existing critical path. Our results are usefull for a more profound analysis of project tasks regarding its threats.

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