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MULTI-CRITERIA METHODS FOR RANKING PROJECT ACTIVITIES

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Abstract: This paper presents multi-criteria methods (based on the Analytical Hierarchical Process (AHP), and Data Envelopment Analysis (DEA) used on the common ranking indexes) for ranking project activities according to several ranking indexes, and reviews ranking indexes of project activities for project management tasks. Ranking of project activities in one project is applicable for focusing the attention of the project manager on important activities. Selection of the appropriate ranking indexes should be done in accordance with managerial purposes: 1) Paying attention to activities throughout the execution phase and those in the resources allocation process in order to meet pre-determined qualities, and to deliver the project on time and within budget, i.e., to accomplish the project within the "iron triangle" 2) Setting priorities in order to share the managerial care and control among the activities. The paper proposes the use of multi-criteria ranking methods to rank the activities in the case where several ranking indexes are selected.

Keywords: Project Management (PM), Ranking Indexes (RI), Multi-Criteria Ranking Method (MCRM), Analytical Hierarchical Process (AHP), Data Envelopment Analysis (DEA).

MSC: 90B50, 65C05.

1. INTRODUCTION

A project is a complicated task that requires coordinated efforts to achieve a set of goals. These goals typically include complying with pre-determined parameters, delivering the project on time and within the budget and the required quality standards. These three requirements are known in project management as the "iron triangle". Other goals can include executing the project according to the policy of the organization, and minimizing interruptions to other activities. In [24], a formulation which reflects a triangular trade-off structure between the project objectives of time, budget, and quality is developed. The major challenge for the project manager is to carry out a balanced distribution of managerial efforts between various project tasks, activities, and objectives [20], [34].

The project program should be prepared initially, taking into consideration the set of project activities with their precedence priorities, as well as possible execution modes of each activity [30]. The planning of the project includes an optimization allocation of budgeting for the activities of the project, i.e., minimization of the total budget subject to on time accomplishment of the project. Such optimizations of multi-mode optimization problems are performed via the Critical Path Method (CPM), a time-cost tradeoffs procedure [22],[23], when the deterministic duration of all project activities is considered. In the case of a project with stochastic durations, a semi-stochastic time-cost tradeoffs procedure [17] or a stochastic time-cost procedure [32] should be performed. Recently, many heuristics for multi-mode resource-constrained scheduling optimization problems have been tested on sets of benchmark instances, sourced from the PSPLIB library [27], [28]. However, uncertainty throughout the lifecycles of the project is invariably disabled following the initial timetable. Thus, best practice requires a dynamic scheduling routine in cases of resource shortages during project execution decisions, and these should be reconsidered and taken via dispatching. When decision-making is based on the deterministic activities durations, the minimum slack dispatching rule was found very effective for the reestablishment of the time targets of the project [8]. Considering the uncertain durations of project activities, [30] introduced for this purpose a heuristic pair wise dispatching that raises the probability confidence of accomplishing the project on time. Dynamic scheduling determines which project activities are in process at each point during the execution of the project.

When several activities are processed simultaneously, it is important to rank the activities according to their relative importance in keeping project performances within the “iron triangle”. Such ranking enables the project manager to focus his or her managerial efforts and control on the most important activities. The ability to do that increases the probability of project success. This paper reviews several ranking indexes that help rank project activities, which are in process, by their importance as the aid for attaining project targets. By selecting an appropriate ranking index, a project manager can rank all these activities. If the project manager prefers to use several ranking indexes, he or she must set relative weights for each selected index. The most important activities would be directly managed by the project manager. The project manager will directly manage 20% of the activities that have effect of about 80%on the project success. This is similar to the Pareto principle which suggests that approximately 80% of all possible effects are generated by approximately 20% of all related causes.

The values of the relative weights can be determined by subjective methods such as: Analytical Hierarchical Process (AHP) [38], ELimination and Choice Expressing REality (ELECTRE) [36], [37]; Simple Multi-Attribute Technique (SMART) ([11], [12]), or objectively, by the decision makers. The values of the relative weights can be determined by objective methods via Data Envelopment Analysis (DEA) [3], such as the Super Efficiency [2]; Canonical Correlation Analysis [14]; Global Efficiency (GE) method [15]; Cross Efficiency method [39]. For reviews about the ranking methods via DEA, see [1], [19].

Ranking of the project activities can be done for two distinct goals. The first goal is to set priorities for performing the activities and for resources allocation in order to meet the due date. The second goal is to set priorities in order to share managerial care and control among activities. Ranking indexes that are important for meeting the due date in a stochastic case are the Significance Index (SI) in[43]; Activity Criticality Index (ACI) in [41][35]; Cruciality Index (CRI), [42], [13]; time–cost tradeoffs under uncertainty [32] and others. In a deterministic case, the minimum slack (the difference between the latest and earliest start time of the activity) is useful. These indexes are presented in the next section. Ranking indexes that are useful for sharing managerial care and control are related to the cost, duration, and risk of an activity. Several indexes of this type are also presented in the next section.

Furthermore, the importance of the activities is dynamic and can be changed during project execution. Therefore, at every major milestone, the project manager must recalculate the ranking indexes, taking into account the current status of the project. In other words, when several activities have been completed, the ranking of the uncompleted activities should be carried out again. Milestones are events in a project that divide the project into stages for the purposes of monitoring and measuring of work performance. These events typically indicate completion of a major deliverable of a project.

2. RANKING INDEXES FOR PROJECT ACTIVITIES

The Critical Path Method (CPM) was developed in the 1950s. It represents a project as an activity network, shown as a graph that consists of a set of nodes $N=\{1,\ 2,\ ...,\ n\}$ and a set of arcs $A=\{(i,\ j\ )\,|\,i,\ j\in N\}$. The nodes represent project activities, where the arcs that connect the nodes represent precedence relationships. Each activity j has either a deterministic activity duration, or a stochastic duration, denoted by t_j. Each activity can start after all of its predecessors have been completed. CPM uses an early-start schedule in which activities are scheduled to start as soon as possible. However, most projects are not deterministic because they are subject to risk and uncertainties due to external factors, technical complexity, shifting objectives and scope, and poor management. In practice, project risk management includes the process of risk identification, analysis, and handling [18].Ranking indexes allow project activities (or risks) to be ranked, based on the impact they have on project objectives. A distinction needs to be made between activity-based ranking indices (those that rank activities) and risk-driven ranking indices (those that rank risks) [5], [6], [7]. Because different ranking indices result in different rankings of activities and risks, one might wonder which ranking index is better to use. This paper proposes a method to weight several ranking

indexes in order to rank the project activities according to their importance instead of using only one ranking index.
This section presents the ranking indexes that will be used for calculating the scores of each project activity. The first indexes are related to the duration of the project and to the duration of the risks (2.2); the rest are related to cost and managerial care.

2.1. Notations

This subsection presents the notations that are used for determined the ranking indexes.

$\mu(t_i)$ - The expected duration of activity i $(i=1,2,...,n)$.

$\sigma(t_i)$ - The standard deviation of the duration of activity i $(i=1,2,...,n)$.

$\mu(c_i)$ -The expected cost of activity i $(i=1,2,...,n)$.

$\sigma(c_i)$ - The standard deviation of the cost of activity i $(i=1,2,...,n)$.

t_i^k - The duration of activity i $(i=1,2,...,n)$ in simulation runs k $(k=1,2,...,K)$.

c_i^k - The cost of activity i $(i=1,2,...,n)$ in simulation runs k $(k=1,2,...,K)$.

2.2.Ranking indexes for duration of an activity

In this subsection the ranking indexes for the duration of an activity are presented. For a more detailed discussion on the ranking indices presented below, refer to [13];[9].

2.2.1. Rank Positional Weight (RPW)

[20]suggested the use of the Rank Positional Weight (RPW) index that was developed by [21] for a ranking index for the duration of activity. The RPW of an activity is the sum of the duration of all activities, following the activity in the precedence network, including the duration of the activity itself. The RPW is calculated by:

$$RPW = \frac{1}{K}\left(RPW^1 + RPW^2 + ... + RPW^K\right) \quad (1)$$

where

RPW^k -The RPW index of simulation runs k $(k=1,2,...,K)$ is computed by the equation $RPW^k = A \times t^k$. In this equation, A is the $(n \times n)$ fixed precedence matrix with elements: $a_{i,j} = \begin{cases} 1 & \text{if } i = j \text{ or } i \prec j \\ 0 & \text{otherwise} \end{cases}$

2.2.2. Significance Index (SI)

The Significance Index (SI) was developed by [42]. In order to better reflect the relative importance between project activities, the sensitivity index of activity i has been formulated as follows:

$$SI_i = \frac{1}{K}\sum_{k=1}^{K}\left(\frac{t_i^k}{t_i^k + TF_i^k}\right)\left(\frac{T_{\max}}{\bar{T}}\right) \tag{2}$$

The SI is usually estimated by simulation methods [42], and is calculated by:

$$SI_i = \frac{1}{K}\sum_{k=1}^{K}\left(\frac{t_i^k}{t_i^k + TF_i^k}\right)\left(\frac{T^k}{\bar{T}}\right) \tag{3}$$

where

t_i^k - duration of activity i $\left(i = 1, 2, ..., n\right)$ in simulation runs k $\left(k = 1, 2, ..., K\right)$.

TF_i^k - total float of an activity i $\left(i = 1, 2, ..., n\right)$ in simulation runs k $\left(k = 1, 2, ..., K\right)$. (Refer to [9] for a definition of total float).

T - total project duration (a random variable).

T^k - total project duration in simulation runs k $\left(k = 1, 2, ..., K\right)$.

$\bar{T}$ - average project duration over K simulations.

2.2.3. Coefficient of Variation (CV) for activity duration

The Coefficient of Variation (CV) is often used as a risk measure for time and cost [33]. [44]claimed that the CV can be used as a reasonable measure of cost variation and as a complement to sensitivity measures. [25], [26], [27] used the CV for project evaluation and selection. The coefficient of variation for the duration of activity i is computed by:

$$CV(t_i) = \frac{\hat{\sigma}(t_i)}{\bar{t}_i} = \frac{\left(\frac{1}{K-1}\sum_{k=1}^{K}\left(t_i^k - \bar{t}_i\right)^2\right)^{\frac{1}{2}}}{\bar{t}_i} \tag{4}$$

2.2.4. Activity Criticality Index (ACI)

A common practice in project risk management is to focus mitigation efforts on the critical activities of the deterministic early-start schedule [16]. One index that enables determination of the critical activities is the Activity Criticality Index (ACI). The ACI was developed by [41] and later by [35]. The ACI index of activity i is computed by:

$$ACI_i = \frac{1}{K}\sum_{k=1}^{K}\delta_i^k, \quad \text{where } \delta_i^k = \begin{cases} 1 & \text{if } i \text{ is critical in simulation run } k \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

For more details about the activity criticality index see [5].

2.2.5. Cruciality Index (CRI)

The Cruciality Index (CRI) was developed by [42] and [13]. This index is defined as the absolute value of the correlation between activity duration and total project duration. The CRI of activity i is computed by:

$$CRI_i = \left|\text{corr}\left(t_i^k, T^k\right)\right| \tag{5a}$$

[4]suggested calculating the CRI according to Spearman's rank correlation. This measure is computed as follows:

$$CRI_i = \left|1 - \frac{6}{K(K^2-1)}\sum_{k=1}^{K}\left(\text{Rank}(t_i^k) - \text{Rank}(T^k)\right)^2\right| \tag{5b}$$

2.2.6. Schedule Sensitivity Index (SSI)

Cho and Yom [4]proposed their Uncertainty Importance Measure (UIM) to measure the impact of the variability in activity durations on the variability of the project completion time. The UIM is evaluated as follows:

$$UMI_i = \frac{Var(t_i)}{Var(T)} \tag{6a}$$

The PMI Body of Knowledge [40] and [42] defined the Schedule Sensitivity Index (SSI) ranking index, which combines the ACI and the variance of t_i (duration of activity i) and T (total project duration). The SSI is computed as follows:

$$SSI_i = ACI_i\sqrt{\frac{Var(t_i)}{Var(T)}} \tag{6b}$$

2.2.7. Critical Delay Contribution (CDC)

The Critical Delay Contribution (CDC) was developed by [7]. The CDC redistributes the project delay over the combinations of activities and risks that cause the delay. The term $CDC_{i,e}^{(E)}$ represents the proportion of the project delay that originates from the impact of a risk $e : e \in E$ on an activity i ,and is computed as follows:

$$CDC_{i,e}^{(E)} = \frac{1}{K} \frac{\sum_{k=1}^{K} m_{i,e,k} \times \delta_{i,k}^{(E)} \left(T_k^{(E)} - T \right)}{\sum_{i \in N} \sum_{e \in E} \sum_{k=1}^{K} m_{i,e,k} \times \delta_{i,k}^{(E)}} \tag{7}$$

where $m_{i,e,k}$ is the random variable of the risk impact of a risk e on the duration of an activity j in simulation k . $\delta_{i,k}^{(E)}$ equals 1 if j is critical in simulation k ,and 0 if j is not critical.

2.3. Ranking indexes for cost

In this subsection the ranking indexes for the cost of an activity are presented. For more details see [20].

2.3.1. Expenditure Rate (ER)

The Expenditure Rate (ER) was used by [20] as a ranking index for project activities. The ER of activity i , ER_i , is calculated by:

$$ER_i = \frac{1}{K} \sum_{k=1}^{K} \frac{c_i^k}{t_i^k} \tag{8}$$

where c_i^k is the cost of activity i in simulation run k .

2.3.2. Coefficient of Variation (CV) for activity cost

The Coefficient of Variation (CV) is often used as a risk measure for cost [33].The CV for the cost of activity i is computed by:

$$CV(c_i) = \frac{\hat{\sigma}(c_i)}{\bar{c}_i} = \frac{\left(\frac{1}{K-1} \sum_{k=1}^{K} \left(c_i^k - \bar{c}_i \right)^2 \right)^{\frac{1}{2}}}{\bar{c}_i} \tag{9}$$

3. RANKING METHODS

This section presents three common ranking methods that enable determination of the relative weights of the ranking indexes that were selected by the decision makers for ranking project activities: the Analytical Hierarchical Process (AHP); The Data Envelopment Analysis (DEA), and the Global Efficiency (GE) method via DEA. The advantage of the AHP as a multi-criteria ranking method is that it generates common weights identical for all the activities. On the other hand, the AHP is useful only when the decision makers can subjectively determine the relative importance of several ranking indexes. The DEA method does not need any subjective evaluations because the weights are calculated by mathematical methods. The disadvantage of the DEA is that it does not generate common weights and the weights vary among the activities.

3.1. Analytical Hierarchical Process

The Analytical Hierarchical Process (AHP) methodology developed by Saaty[38]is used to quantify the value of qualitative or subjective criteria. AHP has been widely used in real-life applications (see surveys in [20]). In our case, each project activity is evaluated according to several indexes. The output of AHP produces relative weights of each selected ranking index. These weights allow full ranking of all project activities. The input of the AHP is a pairwise comparison matrix for every pair of ranking indexes selected for ranking by the decision makers. A common scale of values for pairwise comparison ranges is from 1 (indifference) to 9 (extreme preference). The pairwise comparison matrix $A=\left(a_{i,j}\right)_{S\times S}$ has an element $a_{i,j}=1/a_{j,i}$, $a_{i,i}=1$, and each element in the matrix is strictly positive - $a_{i,j}>0,\ i=1,2,...,S,\ j=1,2,...,S$. For S-ranking indexes, the number of comparisons to be carried out is $S\left(S-1\right)/2$. According to Saaty's definition, the eigenvector $\vec{W}$, of the maximal eigenvalue λ_{max} , of each pairwise comparison matrix, is utilized for ranking the activities. For more detail about AHP methodology see [38]. AHP has been widely used in real-life applications (see a survey in [19]). In [38], a statistical measure to test the consistency of the respondent is defined. The statistical measure of the consistency index (CI) is:

$$CI=\mu=\frac{\lambda_{max}-S}{S-1},$$

and the Consistency Ratio (CR) is given by:

$$CR=\left(\frac{CI}{RI}\right)100\%,$$

where:

λ_{max} - is the maximal eigenvalue of the matrix,

S - is the number of rows and columns of the matrix,

RI - is the random index, which is the average of the CI for a large number of randomly generated matrices. The values of RI can be found in the table developed by[38].

The consistency of the decision makers can be checked by the value of CR. Generally, if the CR is 10% or less, the respondent is considered consistent and acceptable, and the computed comparison matrix can be used [38]. If the CR is greater than 10%, the respondent is not consistent and his or her pairwise estimations must be corrected.

3.2. Data envelopment analysis

In our case,the ranking indexes are complex and it is not always easy for the decision makers to perform a pairwise comparison. In situations like ours, where the decision makers cannot perform pairwise comparison between the indexes, the AHP pairwise matrix cannot be generated. We therefore proposed the use of the DEA methodology developed by [3]to determine the relative weights of the ranking indexes. DEA finds different weights for each activity, such that any activity obtains the optimal weights that maximize its score. In DEA, the weights vary from activity to activity.

DEA methodology uses inputs and outputs to calculate relative efficiency. In our case, we use a special form of DEA with only outputs (the ranking indexes). Adjustment of the DEA model is done according to the following steps:

Step 1: Normalize the values of the selected ranking indexes. This is done by dividing the values of each index by its maximum value. For example, if the value of the type r ranking index for activity i is $V_{r,i}$, the normalized value is calculated as follows:

$$Y_{r,i} = \frac{V_{r,i}}{\max\limits_{i}\left\{V_{r,i}\right\}} .$$

Step 2: Solve the linear programming formulation (10) for each activity.

$$\begin{aligned} & Max\ E_i = \sum_{r=1}^{S} U_r^i \times Y_{r,i} \\ & \text{Subject To} \\ & \sum_{r=1}^{S} U_r^i \times Y_{r,i} \le 1 \quad i = 1, 2..., n \\ & U_r^i \ge \varepsilon > 0 \quad r = 1, 2, ..., S \end{aligned} \tag{10}$$

Step 3: The average of the optimal weights for the type r ranking index (as obtained for all the activities by formulation (10)) is the common weight of the type r ranking index. The common weights for all the selected ranking indexes are calculated as follows:

$$W_r = \frac{\sum_{i=1}^{n} U_r^i}{n} \quad r = 1, 2, ..., S \tag{11}$$

Step 4: The ranking score of each activity is calculated as follows:

$$S_i = \sum_{r=1}^{S} W_r \times Y_{r,i} \quad i = 1, 2, ..., n \tag{12}$$

3.3. Global Efficiency

In [15], the Global Efficiency (GE) method to find the best common weights is proposed. Their method was to maximize the sum of scores of all the activities. In other words, if the optimal efficiency score E_i^*, based on the optimal common weights, is $E_i^* = \sum_{r=1}^{S} U_r^* \times Y_{r,j}$, these common weights will be obtained by linear programming, as in the following DEA-like formulation:

$$\begin{aligned} & MaxZ = \sum_{i=1}^{n} E_j = \sum_{i=1}^{n} \sum_{r=1}^{S} U_r \times Y_{r,i} \\ & \text{Subject To} \\ & \sum_{r=1}^{S} U_r \times Y_{r,i} \le 1 \quad i = 1, 2..., n \\ & \sum_{r=1}^{S} U_r = 1 \\ & U_r \ge \varepsilon > 0 \quad r = 1, 2, ..., S \end{aligned} \tag{13}$$

One drawback of the GE method is that it commonly provides a solution such that all the weights (excluding one) receive a value of the lower bound $U_r = \varepsilon$, and one weight receives a value of $1 - S\varepsilon$.

4. A PROCEDURE FOR RANKING PROJECT ACTIVITIES

In order to rank project activities according to their importance, the following procedure is proposed:

Step 1: Plan the project and collect data: Build the CPM network and set milestones. Determine duration, and budget for each activity. Estimate the excepted values and the variances for each activity.

Step 2: Determine managerial objectives (such as meeting due dates or sharing managerial care and control) and select the appropriate ranking indexes that would support these objectives.
Step 3: Simulate the project and obtain the needed values for calculation of the selected ranking indexes (durations, costs, variances, criticality, and so on). Calculate the values of the indexes for each activity.
Step 4: If only one ranking index is selected, all the activity should be ranked according to the value of this index (step 5). If several ranking indexes are selected, a multi-criteria ranking method must be selected (such as AHP, DEA, GE). The weights of the indexes must be determined and the weighted score of each project activity must be calculated.
Step 5:Rank uncompleted activities of the project in descending order according to their scores. For example, one rank could be for supporting the objective of meeting the due date and another rank could be for sharing managerial care and control.
This procedure must be performed at each milestone for the uncompleted activities.

5. THE CASE STUDY

An Activity-on-Node (AON) project network with 17 activities is presented to illustrate the applicability of the proposed activity ranking method (Figure 1). For each network activity, $i = A1, A2, ..., A17$, the expected value and the standard deviation of its duration (μ_{t_i} and σ_{t_i}), and the expected value and the standard deviation of its cost (μ_{C_i} and σ_{C_i}), were determined.

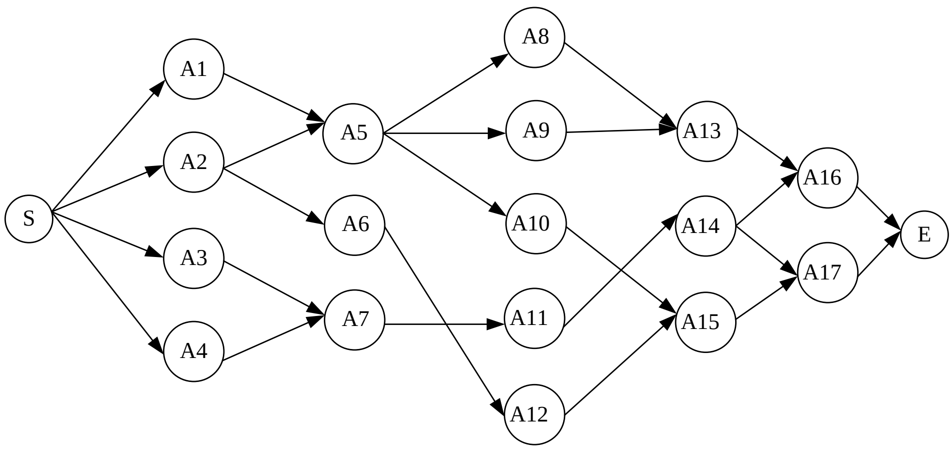

Figure 1: A project network

The ranking indexes were dividedinto two groups: 1) Indexes related to the durations. 2) Indexes related to the costs. In this case study, the following indexes related to durations were selected: ACI, CRI, $CV(t)$,SI and RPW. The following indexes, related to cost were selected: Cost (shown as C in Table 2), CV for activity cost and ER. For any pair of indexes, the decision maker set the following AHP pairwise matrixes (Table 1 and Table 2).

Table 1: Pairwise matrix for the duration indexes

	ACI	CRI	$CV(t)$	SI	RPW
ACI	1	3	7	1	3
CRI	1/3	1	3	1/3	1
$CV(t)$	1/7	1/3	1	1/7	1/3
SI	1	3	7	1	1
PRW	1/3	1	3	1	1

The maximum eigenvalue of the matrix in Table 1 is $\lambda_{max} = 5.1372,$ and the consistency measure of the respondent is:

$$CI = \mu = \frac{\lambda_{max} - n}{n-1} = \frac{5.1372-5}{5-1} = 0.0343$$

$$CR = \left(\frac{CI}{RI}\right)100\% = \left(\frac{0.0343}{1.12}\right)100\% = 3.06\% < 10\%$$

Hence, the respondent can be considered consistent, and the comparison pairwise matrix can be used. The weight of each index is calculated by the following normalized eigenvector:

$$\vec{N}_1^T = \{0.3628,\ 0.1269,\ 0.0464,\ 0.2983,\ 0.1656\}$$

Table 2: Pairwise matrix for the cost indexes

	C	$CV(C)$	ER
C	1	3	5
$CV(C)$	1/3	1	3
ER	1/5	1/3	1

The maximum eigenvalue of the matrix in Table 2 is $\lambda_{max} = 3.0385,$ and the consistency measure of the respondent is:

$$CI = \mu = \frac{\lambda_{max} - n}{n-1} = \frac{3.0385-3}{3-1} = 0.0193$$

$$CR = \left(\frac{CI}{RI}\right)100\% = \left(\frac{0.0193}{0.58}\right)100\% = 3.32\% < 10\%$$

Hence, the respondent can be considered consistent, and the comparison matrix can be used. The weight of each index is calculated by the following normalized eigenvector:

$$\vec{N}_1^T = \{0.6370, 0.2583, 0.1047\}$$

The following milestones were set:

1. At the beginning of the project.
2. After the completion of the activities A1,A2,A3,A4.
3. After the completion of the activities A5,A6,A7.
4. After the completion of the activities A8,A9,A10,A11,A12.
5. After the completion of the activities A13,A14,A15.
6. After the completion of the activities A16,A17, at the end of the project.

Table 3 presents the expected values and the standard deviations for the durations and costs of each project activity, $i = \text{A1,A2,...,A17}$. Moreover, Table 3 includes the same parameters as obtained by 100 simulation runs, assuming that the durations and costs come from normal distribution.

Table 3: Data for the case study project

i	Values of the parameters				The simulation results			
	Duration		Cost		Duration		Cost	
	μ_{t_i} months	σ_{t_i} months	μ_{m_i} $	σ_{m_i} $	$\bar{t}_i$ months	$\hat{\sigma}_{t,i}$ months	$\bar{C}_i$ $	$\hat{\sigma}_{C,i}$ $
A1	7.12	1.38	7,125	658	7.0406	1.4263	7,078	671
A2	3.28	0.58	2,446	179	3.4181	0.5675	2,439	165
A3	6.91	1.47	5,199	413	6.9646	1.5465	5,184	413
A4	2.15	0.37	958	109	2.1909	0.3376	965	112
A5	3.05	0.43	1,357	187	3.0509	0.3921	1,334	180
A6	4.13	0.99	3,249	127	4.1107	1.0426	3,254	127
A7	1.81	0.15	1,151	184	1.8055	0.1348	1,133	182
A8	3.33	0.74	1,304	191	3.2778	0.7294	1,326	194
A9	4.78	1.13	4,218	139	4.6056	1.1562	4,196	145
A10	1.36	0.21	1,021	114	1.3667	0.1967	1,020	110
A11	8.16	0.39	7,134	617	8.1971	0.3796	7,119	624
A12	7.12	1.04	5,836	481	7.1251	1.1061	5,843	394
A13	1.17	0.09	1,215	97	1.1872	0.0855	1,230	88
A14	3.91	0.13	6,082	108	3.8991	0.1193	6,096	111
A15	6.48	1.08	5,473	279	6.4024	1.0888	5,469	302
A16	4.36	0.73	3,875	402	4.2918	0.6163	3,823	430
A17	3.81	0.47	4,316	87	3.7851	0.4678	4,323	84

Table 4 presents the values of the ranking indexes as obtained after 100 simulation runs using equations (1-9).

Table 4: Values of the ranking indexes (via 100 simulation runs)

i	Duration					Cost	
	RPW_i	SI_i	$CV(t_i)$	ACI_i	CRI_i	$CV(c_i)$	ER_i
A1	35.2793	0.6489	0.2171	0.0300	0.1653	0.0905	1,052.93
A2	38.6545	0.7918	0.1805	0.3900	0.1645	0.0712	767.30
A3	29.0082	0.9256	0.2081	0.5800	0.7002	0.0790	773.96
A4	3.9117	0.2846	0.1784	0.0000	0.1635	0.1048	480.22
A5	23.9741	0.4792	0.1209	0.0300	0.1256	0.1262	446.65
A6	21.4226	0.8015	0.2615	0.3900	0.2808	0.0377	887.82
A7	21.9300	0.8366	0.0752	0.5800	0.2659	0.1487	665.75
A8	8.6830	0.3244	0.2106	0.0000	0.0602	0.1333	413.15
A9	10.2098	0.4779	0.2327	0.0100	0.0047	0.0339	937.29
A10	11.6491	0.2864	0.1515	0.0200	0.0122	0.1069	787.21
A11	20.1344	0.9409	0.0439	0.5800	0.0684	0.0751	879.26
A12	17.4226	0.8702	0.1530	0.3900	0.3912	0.0847	846.80
A13	5.4284	0.2016	0.0679	0.0100	0.0609	0.0747	1,064.44
A14	11.9892	0.8979	0.0364	0.5800	0.1961	0.0174	1,554.85
A15	10.3159	0.8710	0.1514	0.4100	0.3519	0.0572	863.14
A16	4.2673	0.8802	0.1644	0.4500	0.3597	0.0968	910.26
A17	3.8087	0.9176	0.1225	0.5500	0.3432	0.0204	1,151.72

One can see that according to all seven criteria, not one of the activities can be defined as the most important (Table 4).All values of the indexes in Table 4 were normalized by dividing each value by the maximum value in its column. The scores of each activity according to the duration indexes were then weighted by AHP weights.

Table 5 indicates that activity A3 has the highest score (0.9443). This means that A3 requires special care. An example for such special care is that it would be directly managed by the project manager. Similarly, the scores of each activity according to the cost indexes were weighted by AHP weights. Table 5 also indicates that activity A1 has the highest score (0.8614) with respect to the cost.

Table 5: The weighted scores of the ranking criteria for each activity

	Duration scores	Cost scores
A1	0.4441	**0.8614**
A2	0.7224	0.3936
A3	**0.9443**	0.6532
A4	0.1683	0.3007
A5	0.3176	0.3687
A6	0.6871	0.4164
A7	0.7835	0.4045
A8	0.1883	0.3780
A9	0.2436	0.4975
A10	0.1823	0.3300
A11	0.7675	0.8267
A12	0.6925	0.7270
A13	0.1165	0.3115
A14	0.7408	0.6804
A15	0.6674	0.6468
A16	0.6731	0.5715
A17	0.7351	0.4998

When the project begins (after the first milestone), activities A1,A2,A3,A4 are executed in parallel. The aim of the project manager is to rank these four activities in order to share managerial efforts among them. According to duration, the order of ranks is A3,A2,A1,A4 According to cost, the rank is A1,A3,A2,A4. To prevent ambiguity between ranks, the project manager can set weights for the two dimensions, duration and cost. For example, by setting a weight of 60% for the duration, and 40% for the cost, the combined rank is A3,A1,A2,A4. At the second milestone (after the completion of A1,A2,A3,A4), the same procedure is performed, taking into account that A1,A2,A3,A4 were completed and their duration and cost are now known values. In general, this should be done at every milestone because some of the index values can be changed with the progress of the project.

If the decision maker cannot perform pairwise comparisons between the indexes, DEA methodology can be used. The DEA weights (see section 3.2) for the five duration ranking indexes are presented in Table 6. These weights are different from the weights that were obtained by AHP methodology.

Table 6: The relative weights via DEA

RPW_i	SI_i	$CV(t_i)$	ACI_i	CRI_i
0.1670	0.2448	0.3370	0.1755	0.0757

6. CONCLUSION

This paper proposes a method for ranking project activities where each activity is evaluated by several indexes. The proposed model allows ranking of the activities according to several indexes, without demanding the project manager to select only one index. Thus, a project activity ranking, based on several indexes, may provide more accurate evaluation with respect to the correct rank of project activities. The method is especially useful for projects with many activities. In such projects, the project manager is unable to share equally his efforts and managerial attention to all project activities.

The paper also reviews ranking indexes of project activities for project management tasks. The ranking indexes can be used for focusing the attention of the project manager on important activities and to correctly focus his or her managerial efforts, seeking control among the activities. The ranking of project activities is useful for two distinct goals: 1) Prioritizing activities in execution and in allocation of resources in order to meet due dates. 2) Setting priorities in order to share managerial care and control among the activities. The paper proposes the use of multi-criteria ranking methods in order to rank the activities in the case where several ranking indexes are selected.

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