

# An Integrated Risk-Based Technique for Project Plan Selection

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## KEYWORDS

Project plan selection; Project risk analysis; Quantitative risk analysis; Overall project risk; Efficient Frontier; Directed Acyclic Graph (DAG).

## ABSTRACT

*Selecting an effective project plan is a significant area in the project management. The present paper introduces a technique to identify the project plan efficient frontier for assessing the alternative project plans and selecting the best plan. The efficient frontier includes two criteria: the project cost and the project time. Besides, the paper presents a scheme to incorporate Directed Acyclic Graph (DAG) into the project risk analysis.*

*This scheme is used to estimate the expected impacts of the occurrence of the project risks on the project cost and the project time. Also, a theoretical model is defined to provide integration between project risk analysis and overall project planning using the breakdown structures. We believe that applying the proposed technique helps the company's managers in most effective manner dealing with his complicated project plan assessment and selection problems. The application of the technique was implemented in the companies in construction industry in which represented a considerable cost and time improvements.*

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## 1. Introduction

Uncertainty lies at the very heart of project management. Therefore, regarding the occurring risks, assessing the alternative project plans is recognized to be an important component of a sound project management. An important approach to assess the project plans is the risk efficiency concept, which was originally developed by [9] for managing portfolios of investment opportunities. According to [2], project plans can be viewed in a portfolio analysis framework. When assessing a particular project plan in relation to alternative plans, we can consider the project cost as the first basic measure of performance and the project time as the second one.

The project plan efficient frontier is the set of feasible project plans that provides a minimum level of project time for any given project cost, or minimum level of

project cost for any given level of project time. This concept is most easily pictured using a graph like Fig. 1. In this figure, A, B, C, D, E and F are the alternative project plans; the project plan efficient frontier is portrayed by the curve A-B-C-D. Any points inside the frontier, like E and F, represent risk inefficient plans. E is more efficient than F, but E can be improved on with respect to both project cost and project time (e.g. moving to B).

The present paper introduces a technique to identify the efficient frontier of the project plans. The provided efficient frontier could be used to assess the alternative project plans and to select the best case. For this purpose, a new modeling approach is proposed to estimate the expected impacts of project risks quantitatively in terms of the project cost and the project time. This model includes a scheme to incorporate Directed A-cyclic Graph (DAG) into the project risk analysis. Besides, the proposed technique integrates the project activities and the main characteristics of the identified risks.

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Paper first received. Feb. 20, 2007, and in revised form May. 13, 2009.

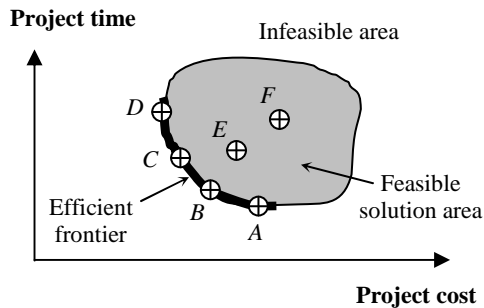


Fig. 1. Project plan efficient options

It is stressed that most significant risks will be subjected to quantitative risk analysis of their impact on project [11, 16].

Several quantitative models have been introduced to provide valuable predictions for decision-makers. The most common risk valuation technique is expert elicitation. Using this method, the magnitude of consequences may be determined, through the use of expert opinions.

This could be applied using techniques such as interviewing [11]. Risks can be represented by probability distribution functions. According to [7], probability distributions are not widely used, because they are perceived to unlink the assessment from every-day work of project managers. To avoid direct application of probability distributions, the point-estimates [7] are developed such as the Program Evaluation and Review Technique (PERT). Also, Critical Chain Project Management (CCPM) uses the same statistical basis as PERT, but only uses two estimates for the task duration, which are the most likely and the low risk estimates. Cagno et al. [1] implemented the Monte-Carlo simulation model in order to evaluate the probability distribution of the overall project duration. Also, Dey and Ogunlana [4] proposed a framework to cost risk analysis and time risk analysis. In a recent study, Fan and Yu [5] present a scheme to incorporate Bayesian Belief Network (BBN) in software project risk analysis. Dey [3] used Analytic Hierarchy Process (AHP) to determine probabilities and impacts of failures by guess estimation. Tuysuz and Kahraman [15] applied the fuzzy AHP as a way of evaluating project risks. Many assessment approaches deal with cost and schedule separately in order to simplify the process. Despite this, approaches such as the proposed method by [10] consider both cost and schedule, although schedule modeling tends to be at the aggregate level. Another method to deal with uncertainty is contingency allowance that is an amount of money used to provide for uncertainties associated with a project. The most common method of allowing for uncertainty is to add a percentage figure to the most likely estimate of the final cost of the known works. The amount added is usually called a contingency [14]. Sometimes a more aggregate approach may be used in quantifying the

impact of risks. Instead of considering the risks individually and trying to estimate their impacts, sometimes various project components are ranged. This approach has sometimes been termed range estimating and provides an approximate envelope for project costs [6].

The present paper is organized as follows. Firstly, we describe the model elements. Then, the proposed technique will be described. Finally, within a typical project, some analytical results will be reported and the some remarks regarding the applicability of our approach and future extensions will be discussed.

## 2. Model Elements

Assume an individual project and consider the following definitions:

**Scope Cost (SC):** It is the target cost of project.

**Scope Duration (SD):** It is the project aim on time.

**Risk event:** It is an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective [11]. Two main criteria is used to characterize risks:

- (I) Risk probability: It is the probability of occurring risk event [8].
- (II) Risk impact: It is the impact of occurring risk event [8]. In our model, risk impact reflects the significance of effect, either negative or positive, on SC and SD if a risk event occurs.

**Ultimate Cost (UC):** It is the ultimate state of the project cost with considering risk events. In the project plan efficient frontier, Fig. 1, the X-axis stands for UC.

**Ultimate Duration (UD):** It is the ultimate state of the project duration with considering risk events. In the project plan efficient frontier, Fig. 1, the Y-axis indicates UD.

**Work Breakdown Structure (WBS):** Complex projects can be overwhelming to the project managers. Instinctively, many project analysts break project down into smaller, more manageable parts. These decompositions are called breakdown structures that are additive models [16]. WBS is a top-down hierarchical chart of tasks and subtasks required to complete project. WBS can focus on a product, a function, or anything describing what needs to be accomplished [11].

**Cost Breakdown Structure (CBS):** For measuring SC and UC, the proposed technique uses CBS that is derived from WBS. Each item in WBS is generally assigned a unique identifier; these identifiers can provide a structure for a hierarchical summation of costs and resources [11]. Therefore, CBS represents the hierarchical breakdown of the project costs. Fig. 2 presents a part of the CBS within the typical project of Table 2.

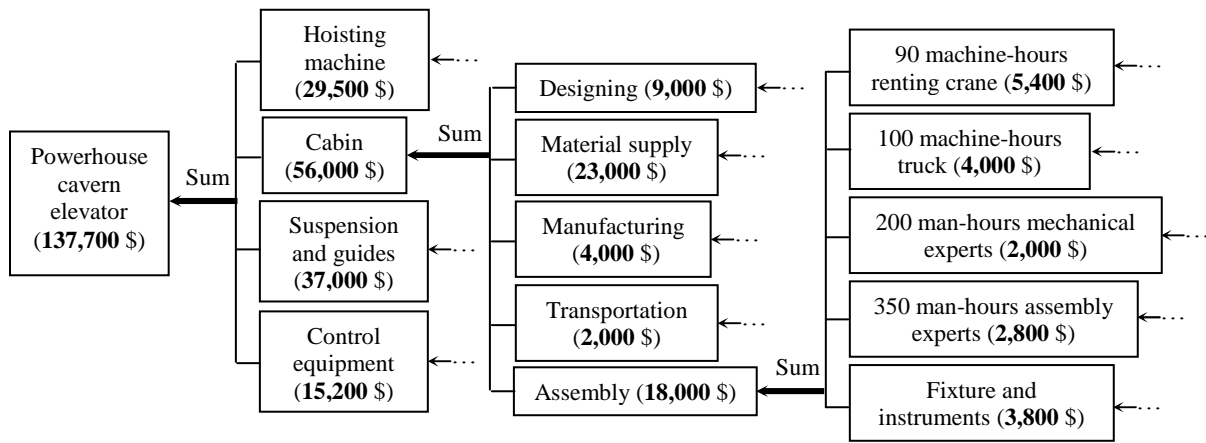


Fig. 2. A part of the instance CBS

**Risks network:** For calculating the risks probability and the risks impacts, the technique uses risks network that is a DAG with the following considerations:

(I)- It is a graph  $G(N, A)$ , where  $N = \{E_1, E_2, \dots, E_m\}$  is a finite set of nodes and  $A \subseteq N \times N$  a set of arcs.

Each node  $E_i$  ( $i=1,2,3,\dots,m$ ) refers to a risk event and each arc  $(E_i, E_j) \in A$  indicates direct conditional dependencies between two risk events  $E_i$  and  $E_j$ . If

two nodes  $E_i$  and  $E_j$  within arc  $(E_i, E_j)$  are ordered, then the arcs have a direction assigned to them. This is called a directed graph. For a given arc  $(E_i, E_j) \in A$ , the node  $E_i$  is called parent node and the node  $E_j$  is called child node.

(II)- A conditional probability of  $P_{ij}$  which equals  $P(E_j | E_i)$  is placed for each arc  $(E_i, E_j)$ . Also, for each node  $E_i$  a free probability  $P_i$  ( $i=1,2,3,\dots,m$ ) is dedicated that is the probability of its occurrence due to risk sources outside risks network. We assume that both  $P_i$  and  $P_{ij}$  are point estimates.

(III)- Risks network accepts only the acyclic relationships among the risk events. A cycle within a graph is a path that starts and ends at the same node.

Assume that in the typical project plan of Table 2, the project experts have identified four significant risk events and have determined dependencies between them as the risks network of Fig. 3.

In this risks network ( $m=4$ ), also, the free probabilities for occurring each risk event and the conditional probabilities among them has been represented.

*Path* is a sub-graph of risks network including series of nodes where each node is connected to another node by an arc and all connecting arcs are unidirectional. Each node can occur in the path once only.

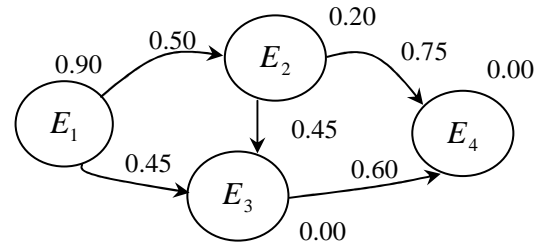


Fig. 3. The instance risks network

Each node can occur in the path once only. Each path starts with a source event and ends with a sink event. A path could be depicted as continuum  $E_1 \rightarrow E_2 \rightarrow E_3 \rightarrow \dots \rightarrow E_k$ .

To simplify this continuum, it could be presented as  $\overrightarrow{i_1 i_2 i_3 \dots i_k}$ .

We also, denote a specific path as  $Path_t$  ( $t=1,2,3,\dots,T$ ), which  $T$  is the number of the paths within risks network. All paths are placed in the set of  $R$  as (1).

$$R = \{Path_t \mid t=1,2,3,\dots,T\} \tag{1}$$

In a path, the first node is called source and the last node is called sink. As Eq. (2) and Eq. (3), the functions *Source()* and *Sink()* respectively indicates the source event and the sink event of a path.

$$Source(\overrightarrow{i_1 i_2 i_3 \dots i_k}) = E_{i_1} \tag{2}$$

$$Sink(\overrightarrow{i_1 i_2 i_3 \dots i_k}) = E_{i_k} \tag{3}$$

As Eq. (4) and Eq. (5) set  $S_i$  includes all the paths starting with risk event  $E_i$  and set  $F_i$  includes all the paths finishing with risk event  $E_i$ .

$$S_i = \{Path_t \mid Source(Path_t) = E_i, t=1,2,3,\dots,T_i\} \tag{4}$$

$$F_i = \{Path_t \mid Sink(Path_t) = E_i, t = 1, 2, 3, \dots, T_i\} \quad (5)$$

As Eq. (6), the plus function  $\oplus$  can be used to add a part to the end of a path.

$$\overrightarrow{(i_1 i_2 i_3 \dots i_k \oplus i_{k+1})} = \overrightarrow{i_1 i_2 i_3 \dots i_k i_{k+1}} \quad (6)$$

As in term (7)  $Path_1$  is subset of  $Path_2$ , if  $Source(Path_1) = Source(Path_2)$  and  $Path_1$  contains the complete structure of  $Path_2$ .

$$\overrightarrow{i_1 i_2 i_3 \dots i_{v-1} i_v i_{v+1} \dots i_{K-1} i_K} \subseteq \overrightarrow{i_1 i_2 i_3 \dots i_{v-1} i_v} \quad (7)$$

According to Eq. (8), each path has a probability, which is defined as the product of free probability of its source event and the conditional probabilities related to its arcs.

$$P(\overrightarrow{i_1 i_2 i_3 \dots i_k}) = P_{i_1} \times P_{i_1 i_2} \times P_{i_2 i_3} \times \dots \times P_{i_{k-1} i_k} \quad (8)$$

Probability of the intersection of some paths equals the product of the probabilities of these paths divided by probabilities of common source event or common arcs. The following equations show two examples:

$$\begin{aligned} P(\overrightarrow{123} \cap \overrightarrow{13}) &= P(\overrightarrow{123}) \times P(\overrightarrow{13}) / P_1 = \\ &= (P_1 \times P_{12} \times P_{23}) \times (P_1 \times P_{13}) / (P_1) \\ P(\overrightarrow{1234} \cap \overrightarrow{134}) &= P(\overrightarrow{1234}) \times P(\overrightarrow{134}) / (P_1 \times P_{34}) = \\ &= (P_1 \times P_{12} \times P_{23} \times P_{34}) \times (P_1 \times P_{13} \times P_{34}) / (P_1 \times P_{34}) \end{aligned}$$

Probability of the union of the paths, simply, could be calculated using conventional set union function. The following equation shows an example:

$$\begin{aligned} P(\overrightarrow{123} \cup \overrightarrow{13}) &= P(\overrightarrow{123}) + P(\overrightarrow{13}) - P(\overrightarrow{123} \cap \overrightarrow{13}) = \\ &= P(\overrightarrow{123}) + P(\overrightarrow{13}) - P(\overrightarrow{123}) \times P(\overrightarrow{13}) / P_1 = \\ &= (P_1 \times P_{12} \times P_{23}) + (P_1 \times P_{13}) - \\ &= (P_1 \times P_{12} \times P_{23}) \times (P_1 \times P_{13}) / (P_1) \end{aligned}$$

### 3. The Proposed Technique

We would like to design an integrated technique to identify the project plan efficient frontier and select the best project plan. Fig. 4 presents the proposed technique including three phases: *generation*, *analysis* and *evaluation*.

In the first phase, *generation*, the project analysts should generate the alternative project plans. In the

second phase, *analysis*, the technique includes a loop which; in each cycle, one of the generated project plans will be analyzed. In the analysis process for a given project plan, the project analysts should carry out the following stages:

(I) providing the project WBS & scheduling the project,

(II) identifying the project risks & establishing risks network,

(III) providing the project CBS,

(IV) Calculating UC & UD, and adding the related point to the project plan efficient frontier. Finally, in the *evaluation* phase, the efficient frontier will be evaluated and the best project plan will be selected.

**Generating the alternative project plans:** This preliminary phase is an important infrastructure for the second phase of the technique. In this phase, the project experts consider the alternative sub-plans, sub-contractors, resources, activities, etc. and generate different project plans.

**Calculating SC and SD:** SC could be calculated by providing WBS, and then providing CBS. Also, for calculating SD we require to provide WBS, and to schedule the project.

**Calculating the risks probability:** As Eq. (9), the occurrence probability of an individual risk event  $E_i$  equals the probability of union of all the paths ending with this event.

Also, as Eq. (10), the occurrence probability of at least one of the events equals union probability of all paths ending with these events. In addition, as Eq. (11), the occurrence probability of all of events equals intersection probability of all paths ending with these events.

$$P(E_i) = P\left(\bigcup_{\forall Path_t \in F_i} Path_t\right) \quad (9)$$

$$P\left(\bigcup_{k=1}^K E_{i_k}\right) = P\left(\bigcup_{k=1}^K \bigcup_{\forall Path_t \in F_{i_k}} Path_t\right) \quad (10)$$

$$P\left(\bigcap_{k=1}^K E_{i_k}\right) = P\left(\bigcap_{k=1}^K \bigcup_{\forall Path_t \in F_{i_k}} Path_t\right) \quad (11)$$

For the purpose of identifying the paths within risks network, a labeling algorithm is introduced as Fig. 6. In this figure,  $F_i$  is the set of labels for  $E_i$  (see Eq. (5));

$B_i$  is a binary index that equals zero until the algorithm completes labeling of risk event  $E_i$ .

To create the label of a specific risk event  $E_i$ , if  $(E_j, E_i) \in A$ , as term (12), the part “ $i$ ” is added to the end of the labels of risk event  $E_j$ . The algorithm

does not produce any labels for a risk event that its free probability is zero. The risks network of Fig. 3 is labeled as Fig. 5.

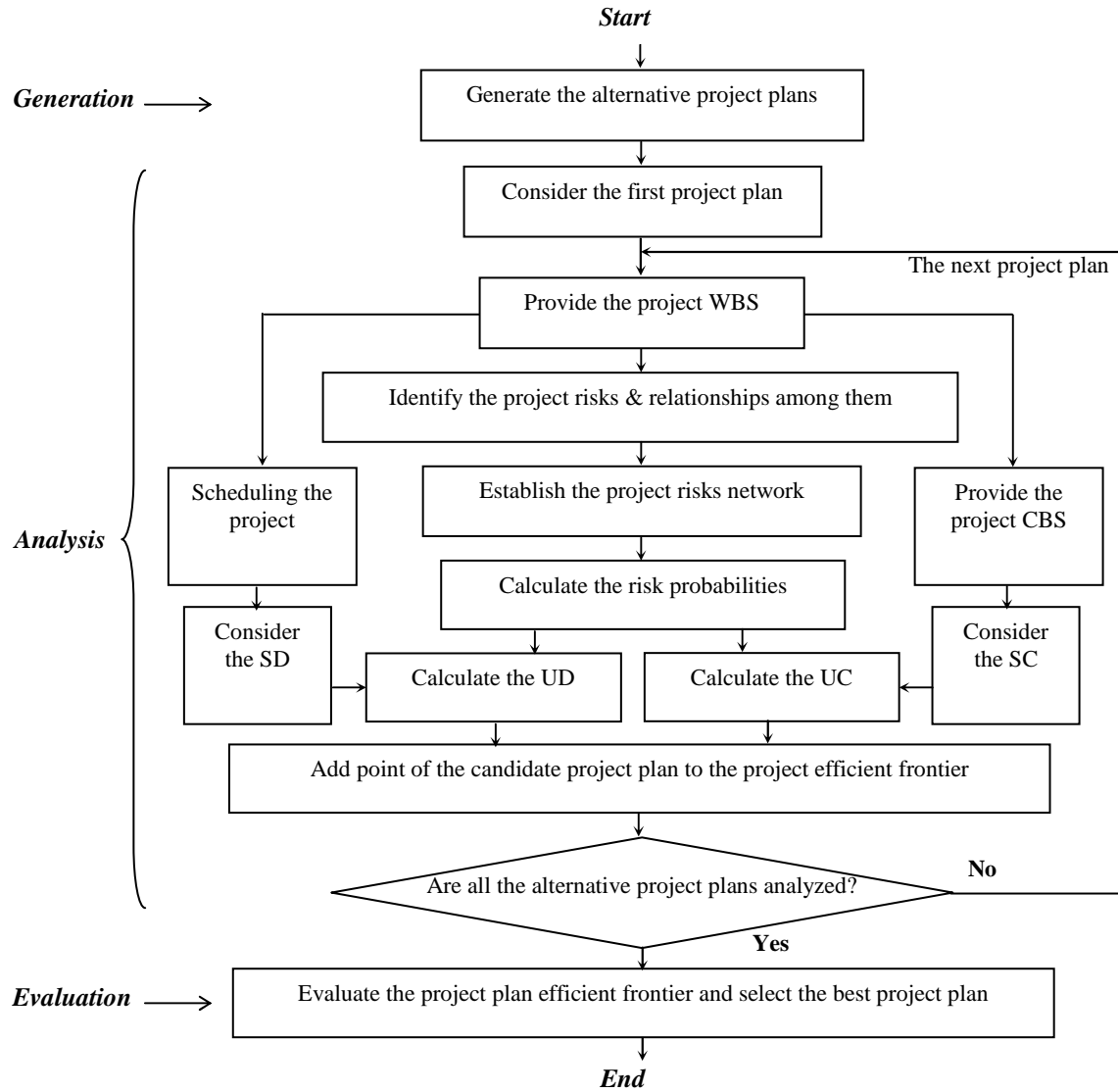


Fig. 4. Procedure of the proposed technique

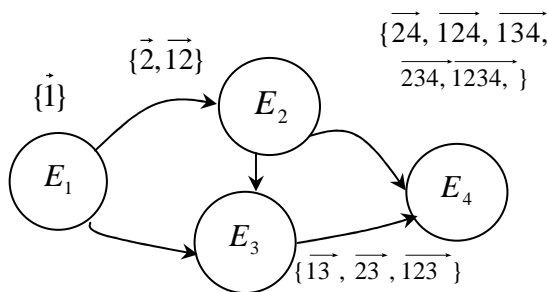


Fig. 5. The labeled risks network of Fig. 3

$$F_i = F_j + \{Path \oplus i | Path \in F_j, \{j | (E_j, E_i) \in A\} \} \quad (12)$$

**Calculating UC and UD:** The project owners may be interested in knowing the total risk level of their project. Indeed, it is often desirable to combine the various risk events into a single quantitative project risk estimate. This estimate is overall project risk that may be used as input for a decision about whether or not to execute a project, as a rational basis for setting a contingency, and to set priorities for risk response actions [16]. The proposed technique uses the overall project risk for calculating UC and UD. The core concept here is the relationship between two nodes in risks network. According to Fig. 7, the occurrence of  $E_i$  affects the occurrence of  $E_j$ , consequently, the impacts of occurrence of  $E_j$ , also, is transferred to  $E_i$ .

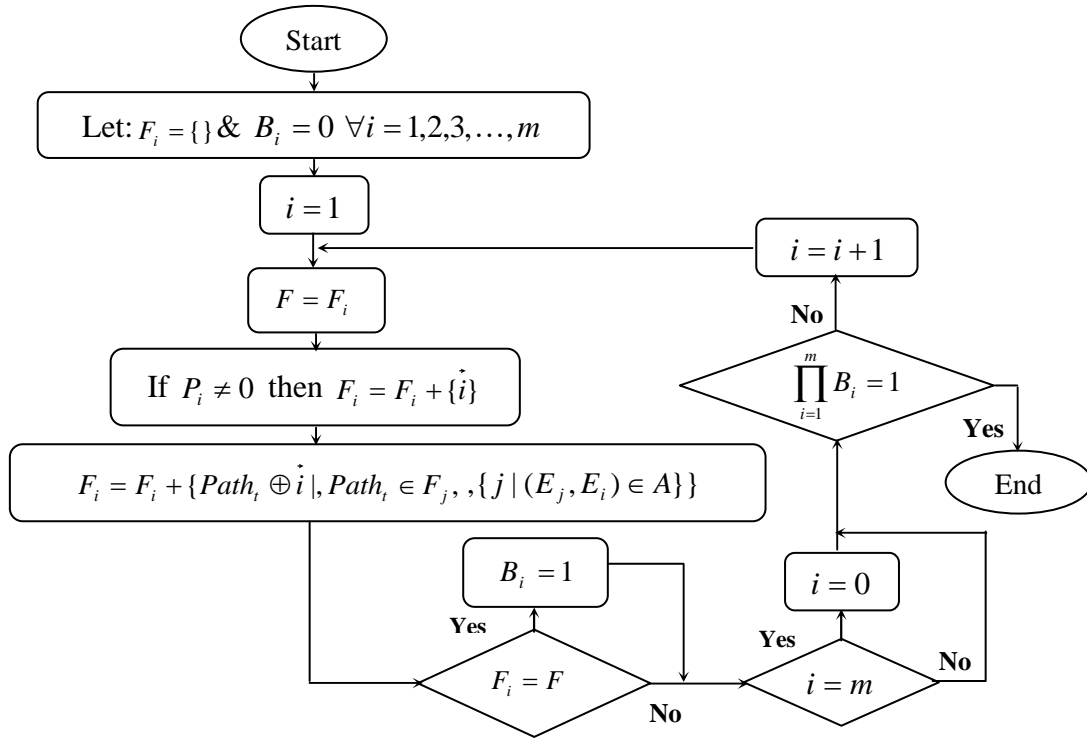
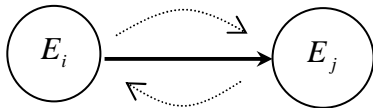


Fig. 6. The labeling algorithm to identify the paths within risks network

**Forward circuit:** the occurrence of  $E_i$  affects the occurrence of  $E_j$



**Backward circuit:** the impacts of occurrence of  $E_j$ , also, are transferred to  $E_i$

Fig. 7. Relationships between child and parent nodes of an arc in risks network

$$C = [c_{ij}]_{m \times c} = \begin{matrix} E_1 & \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1c} \\ c_{21} & & & \\ \vdots & & & \vdots \\ E_m & \begin{bmatrix} c_{m1} & & \dots & c_{mc} \end{bmatrix} \end{matrix} \end{matrix} \quad (14)$$

$$c_{ij} = \begin{cases} 1 & \text{If occurring } E_i \text{ causes cost } C_j \\ 0 & \text{Otherwise} \end{cases} \quad (15)$$

$$UC = SC - \sum_{j=1}^c C_j \times P\left(\bigcup_{\{i|c_{ij}=1\}} E_i\right) \quad (16)$$

that by use of a suitable level of CBS, the risk impacts on the project cost are as vector (13) that is named as Cost Impact Vector (CIV). It should be noted that each  $C_j \in CIV$  is negative value for cost increment (threat) and is positive value for cost decrement (opportunity).

Now, one can establish the cost matrix (14) in which the rows indicate risk events and the columns stand for the elements of vector (13). The elements of cost matrix (14) are binary parameters  $c_{ij}$  as definition (15). Using CIV and cost matrix, UC could be calculated as Eq. (16).

$$CIV' = [C_1 \quad C_2 \quad \dots \quad \dots \quad C_c] \quad (13)$$

For calculating UD, let  $N' \subseteq N$  contain all the risk events that affect the project WBS scheduling. Consider the set  $\beta$  including all non-empty subset of  $N' \subseteq N$  as Eq. (17).

Now, for all  $\beta_w \in \beta$  calculate Eq. (18) in which  $SD_w$  is the project duration for subset  $\beta_w$ . For calculating  $SD_w$ , we should consider the occurrence of all risk events  $E_i \in \beta_w$ . In Eq. (18), the second part  $\ddot{P}(\bigcap E_i)$  indicates that all risk events  $E_i \in \beta_w$  must have occurred. The double-dots sign on the top of this term means that before calculating this probability we are required to apply some conditions related to the third

part of Eq. (18). For calculating  $\ddot{P}(\bigcap E_i)$ , temporarily, remove all risk events in which  $E_i \in N'$  and  $E_i \notin \beta_w$ . The third part of Eq. (18) indicates that all risk events in which  $E_i \in N'$  and  $E_i \notin \beta_w$  should not occur. Finally, PUD could be calculated as Eq. (19).

$$\beta = \{\beta_w \mid \beta_w \subseteq N', w = 1, 2, 3, \dots, W\} \tag{17}$$

$$\lambda_w = (SD - SD_w) \times \ddot{P}(\bigcap_{E_i \in \beta_w} E_i) \times 1 - P(\bigcup_{E_i \in N' - \beta_w} E_i) \tag{18}$$

$\forall w = 1, 2, 3, \dots, W$

$$UD = SD - \sum_{w=1}^W \lambda_w \tag{19}$$

$$\left\{ \begin{array}{l} \text{Then } \left( \frac{UC_i - UC_j}{UD_j - UD_i} \right) \leq \alpha \text{ if } \begin{cases} i \text{ then remove the project plan } \neq UD_i \geq UD_j \text{ If} \\ j \text{ then remove the project plan } \neq UD_i < UD_j \text{ If} \end{cases} \\ \text{Then } \left( \frac{UC_i - UC_j}{UD_j - UD_i} \right) > \alpha \text{ if } \begin{cases} i \text{ then remove the project plan } \neq UC_i \geq UC_j \text{ If} \\ j \text{ then remove the project plan } \neq UC_i < UC_j \text{ If} \end{cases} \end{array} \right. \tag{20}$$

**4. Analytical Results**

For analyzing the proposed technique, we consider a project that is a real case taken from the construction industry. This project includes Engineering, Procurement, and Construction (EPC) of a powerhouse cavern elevator, which has been drawn from a hydro-mechanical power plant.

As in Table 2, the project has four sub-products including cabin, hoisting machine, suspension & guides and control equipments. In the first phase of the technique, the project experts considered the following alternatives and generated nine project plans as Table 1.

**Evaluating the analysed project plans:** In the first stage of the evaluation phase, the inefficient project plans are removed. In the next stage, the reminded efficient project plans should be pair wise compared. In each pair wise comparison, one of the project plans is removed as Eq. (20).

The parameter  $\alpha$  is defined as the payment (\$) that project owners will be admitted for one-time unit (i.e. 1 day) increment in the project duration. More  $\alpha$  results in more importance of the project time than the project cost. Regarding Eq. (20), it should be noted that the best project plan is the nearest point to the tangent point between the efficient frontier and the line with gradient  $-\alpha^{-1}$ .

- Two alternatives for supplying the elevator cabin: (a1) fabricating the cabin in the firm and then transporting it to the erection site, and (a2) fabricating the cabin in the erection site.
- Three alternatives for supplying the elevator hoisting machine: (b1) buying the hoisting machine from the foreign supplier 1, and (b2) buying the hoisting machine from the foreign supplier 2, (b3) buying the hoisting machine from the present inside supplier.

Two alternatives for designing the elevator control equipment: (c1) employing a sub-contractor for designing the control equipment, and (c2) buying a present design.

**Tab. 1. The generated plans for the typical project**

Project plan	Main items of the project plan	UC (\$)	UD (days)	State
A	(a1), (b1), (c1)	148,900	540	Inefficient
B	(a2), (b1), (c2)	158,800	350	Efficient
C	(a1), (b2), (c2)	165,800	485	Inefficient
D	(a1), (b2), (c1)	137,000	390	Efficient
E	(a1), (b3), (c2)	192,900	340	Efficient
F	(a1), (b3), (c1)	125,975	525	Efficient
G	(a2), (b3), (c1)	138,000	500	Inefficient
H	(a2), (b2), (c2)	175,698	490	Inefficient
I	(a2), (b3), (c2)	210,550	335	Efficient

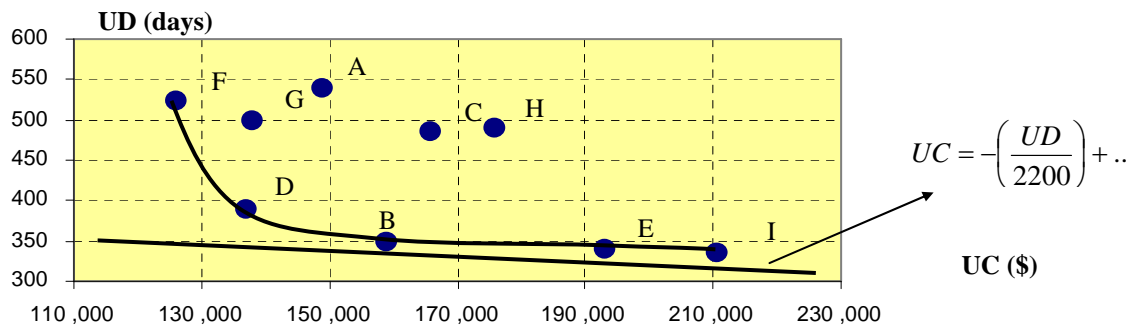


Fig. 8. The plan efficient frontier for the typical project

Tab. 2. The typical project WBS and CBS

#	WBS	Activity	Duration (days) (Project plan C)	CBS (\$) (Project plan C)
1	1	<b>Powerhouse cavern elevator</b>	<b>420</b>	<b>137,700</b>
2	1.1	<b>Cabin</b>	<b>420</b>	<b>56,000</b>
3	1.1.1	Designing	44	9,000
4	1.1.2	Material supply	90	23,000
5	1.1.3	Manufacturing & Assembly	310	4,000
6	1.1.4	Transportation to erection site	10	2,000
7	1.1.5	Erection	40	18,000
8	1.2	<b>Hoisting machine</b>	<b>401</b>	<b>29,500</b>
9	1.2.1	Designing	37	6,600
10	1.2.2	Material supply	110	12,800
11	1.2.3	Manufacturing & Assembly	50	2,200
12	1.2.4	Transportation to erection site	17	1,300
13	1.2.5	Erection	20	6,600
14	1.3	<b>Suspension and guides</b>	<b>381</b>	<b>48,000</b>
15	1.3.1	Designing	60	4,200
16	1.3.2	Material supply	115	2,600
17	1.3.3	Manufacturing & Assembly	155	19,200
18	1.3.4	Transportation to erection site	19	1,400
19	1.3.5	Erection	32	9,600
20	1.4	<b>Control equipment</b>	<b>240</b>	<b>21,800</b>
21	1.4.1	Designing	35	3,200
22	1.4.2	Material supply	100	5,100
23	1.4.3	Manufacturing & Assembly	75	4,500
24	1.4.4	Transportation to erection site	15	1,100
25	1.4.5	Erection	15	1,300

In the analysis phase of the technique, nine generated project plans were analyzed to determine their UC and UD. For instance, Table 2 exhibits the top-level WBS and CBS for the project plan C. Also, Fig. 3 presents the risks network for the project plan C. According to Table 2, for the project plan C,  $SC=137,700$  \$ &  $SD=420$  days; by considering the occurrence of the risk events as in Fig. 3, the ultimate project cost became  $UC=165,800$  and the ultimate project time became  $UD=485$  days. Table 1 shows UC and UD for nine generated project plans that, also, have been portrayed in Fig. 8. In Fig. 8, the points B, D, E, F and I indicate the efficient project plans, and the points A, C, G and H stands for the inefficient project plans that are removed from the candidate list of the project plans. For selecting the best project plan among the plans B, D, E, F and I, the experts did the pair wise comparisons as Eq. (20). For instance the term  $((158,800-137,000)/(390-350))=545$  \$/day was calculated for the

pair wise comparison between the plans B & D. By assuming  $\alpha=220$ (\$/day, in comparison between the plans B & D, because  $545 < \alpha$  &  $350 < 390$  thus the plan D was removed; also, in comparison between the plans B & E, because  $3410 > \alpha$  &  $158,800 < 192,900$  thus the plan E was removed; besides, in comparison between the plans B & F, because  $188 < \alpha$  &  $350 < 525$  thus the plan F was removed, and finally, in comparison between the plans B & I, because  $3450 > \alpha$  &  $158,800 < 210,550$  so the plan I was removed. So the plan B was considered as the best project plan. As it has been shown in Fig. 8, the project plan B is the nearest point to the tangent point between the efficient frontier and the line with gradient  $-1/2200$ . The plan B contains fabricating the cabin in the erection site, buying the hoisting machine from the foreign supplier 1, and buying a present design for control equipment.



## 5. Discussions

Several aspects of the proposed technique are worthwhile emphasizing:

**(a):** The risk researchers believe that project risk analysis should be strongly integrated to the project elements [2, 8, 12, 13, 17]. In our approach, WBS plays a central role in the quantification of risks. So, the main contribution of the proposed technique is in demonstrating how overall project plan and project risk analysis could be integrated through a united framework. It should be explained that a common technique in estimating the risk probability and risk impact is the use of scales that are usually quantified directly through the expert elicitation. We believe that there is a gap between the scale tablets and the expert's opinion. The proposed model acts a means for bridging the mentioned gap.

**(b):** Another key feature of the model is explicitly allowing for dependency relationships among risk events. This is made possible by using DAG.

**(c):** The model considers both upside and downside risks within a united perspective. Therefore one can observe that this perspective is a step toward the uncertainty management [17].

**(d):** Regarding the project environment, since no data record was available about project risk analysis in previous similar projects, probability distribution elicitation for task duration or cost may be difficult for projects, which in turn could limit the applicability of techniques.

According to [2], too often this precision is false, because the initial data may be too vague to be fitted into a probability function or the assumptions behind the distributions do not hold true. So, in the proposed technique, all of input data to the model is considered to be one-point estimates. These estimates are easy to understand [7], and do not include a range of values, standard deviation and variance, or confidence intervals, so they do not include the effects of uncertainty and are simply based on the summation of a number of point estimates for items of work.

The technique presented here can be expanded to allow for additional features of the problem. Based on the two-polar concept of project risk management [12], one such extension is considering the implementation of risk response actions to calculate UC and UD that results in more effective the technique. Another extension of the model aims to address the cyclic dependencies among the risk events. Finally we recall that the proposed technique does not guarantee the inclusion of the technical aspects of project. It could be worthwhile to investigate the risk impacts on the project quality. Regarding this area, the reader is encouraged to study in the reference of [13].

## 6. Conclusion

In this paper, we proposed a risk-based technique including a modeling approach to support assessing the alternative project plans and selecting the best plan. In our model, the project cost and the project time play a central role to identify the project plan efficient frontier. Also, we introduced the development and application of DAG for the estimation of the expected impacts of the project risks. The main contribution of this research was in demonstrating how overall project plan and project risk analysis could be integrated through a united framework. We conclude that applying the proposed integrated model helps the project experts to assess the project plans in most effective and productive manner dealing with in real world's uncertainties.

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