Моделювання в економіці та управління проектами

UDC 005.8:65.012.25

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DEVELOPING THE MOST EFFECTIVE SET OF RISK MANAGEMENT ACTIONS FOR COMPLEX PRODUCTS DEVELOPMENT PROJECTS

Selecting the activities for responding to risks is one of the most important stages of project risk management, especially in complex product systems (COPs) development projects. In this study, the index of the risk management effectiveness (IRME) as a quantitative tool for evaluating the efficiency of project risk management is proposed. The simulated annealing (SA) algorithm, which is a local search metaheuristic optimization method is suggested for finding the optimal set of activities for managing the project risks. The goal of the optimization can be maximizing the IRME or minimizing the project realization time or cost. Results of this study help the project manager in finding the most effective set of risk management activities and applying the appropriate changes in project plan.

Keywords: *project management, uncertainty, complex product system, risk management effectiveness, simulated annealing.*

Introduction

One of the most important areas of project management is managing project risks. This knowledge area of project management has a great significance for complex projects. Projects of developing complex product systems (COPs) as a category of complex projects are characterized by high level of risk and uncertainty; therefore, they require special attention in this area.

The main steps of the project risk management process are common in almost all guidelines and risk management standards, and they include the following main steps: planning, identification, analysis, selecting responses and control [1]. Many researchers agree that the fourth step in which by considering the risks analysis results the suitable reactions for managing or mitigating the risk effects are suggested is one of the most important stages of project risk management. This step is carried out mostly by qualitative methods, which use mainly the experience of the project manager and project team as well as gathering the viewpoints of experts and project stakeholders. By performing this step, from different possible strategies an appropriate strategy for each risk is chosen [2].

However, there are some researches that have suggested quantitative based methods for selecting the most suitable risk management strategies for supporting the decision making process. These researches mainly focus on optimizing cost and sometimes time or quality of project implementation. In COPs development projects, one of the most prominent features is the high degree of uncertainty. Therefore, the minimization of uncertainty changes during the implementation of risk management methods is of interest. This work is dedicated to this aspect of risk management process.

Literature review and the problem statement. In [3] authors presented a model for evaluating different risk reduction actions which is able to consider the impacts of secondary risk events and overlapping effects of risk reduction actions. Zhang and fan [4] employed an iterative process for obtaining the most desirable risk response strategies by making trade-offs between the project budget, time and quality by considering the objective requirements and managers' judgments. In [5] authors proposed the modification of the objective function that was used in [4] and implemented the results in a real project in the electrical industry.

A fuzzy multi-objective method for solving the risk response strategy selection problem is proposed in [6]. In this work, the optimization problem is able to integrate the project cost, project schedule, project quality as the objective function. Fang and Marle in [7] developed a decision support system (DSS) framework for project risk management, which employs a simulation-based model and allows re-evaluating risks and their priorities for suggesting and testing mitigation actions.

In [8] Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH) is employed to evaluate the dependencies between the risks for solving the problem of selecting risk response actions. The authors of [9] used the data from project managers in IT field and by employing a series of regressions followed with Seemingly Unrelated Regression Equations (SURE) modeling investigated the effect of main risk response strategies.

In [10] for generating project risk response strategies a pragmatic method based on the case-based reasoning (CBR) is suggested and finally, Rodrigues et.al

[11] developed a graphical vectorial approach complemented by Mean-Variance calculations and Fuzzy analytic hierarchy process (FAHP) for selecting the most suitable option of the risk management in IT projects.

Investigating the related researches and approaches in this subject area shows that, especially in the case of COPs development projects, there is the requirement of developing an optimization method that suggests the most effective set of actions with minimum uncertainty for managing project risks. As the result of the performed analysis, it can be stated that this problem has not been solved completely and accurately so far.

Therefore, the main problems of this work are:

1. Presenting a quantitative index for assessing the effectiveness of a proposed set of activities for managing project risks;

2. Selection and application of an optimization method that can find the optimum value of this index or other important parameters of the project over the possible range of risk management options.

By solving these problems, the project manager and project team will be able to define and implement the corresponding corrective actions and modifications in the project plan.

In the following sections, we will propose an index for measuring the effectiveness of risk management by employing the entropy concept and the authors' previous works. In addition, using the simulated annealing algorithm is suggested for solving the second stated problem and then, the application of this method in our subject area will be described.

Basic part

1. The index of the risk management effectiveness

The authors have proposed a quantitative measure of the project uncertainty by employing the entropy concept [12]. Our proposed index shows the effects of the risk factors and uncertainties in the project in a quantitative manner. This index is obtained as a function of the project realization time by the simulation program which is developed by the authors and is presented by the following equations:

$$U_{project} = \left(\frac{1}{K+1}\right)\left(U_{t_{project}}(t) + KU_{c_{project}}(t)\right), \qquad (1)$$

where $U_{project}$ = overall index of project uncertainty and we have $0 \le U_{project} \le 1$; $U_{t_{project}}$ = duration uncertainty index of the project and is obtained by equation 2; $U_{c_{project}}$ = cost uncertainty index of the project and is obtained the same manner as $U_{t_{project}}$ and K= factor of importance for project cost uncertainty in relation with duration uncertainty.

$$U_{t_{project}}(t) = \frac{1}{U_{t_{project}}\big|_{t=0}} \sum_i k_i U_{t_i}\ ; \qquad (2)$$

$$i \in \{1, 2, ..., N \mid w_i \neq 0\}, \qquad (3)$$

where U_{t_i} = duration uncertainty index of activity *i* which is obtained by equation 4; N = the total number of project activities; k_i = the remained work fraction of i^{th} activity at time t and is equal to w_i and $U_{t_{project}}\big|_{t=0}$ = maximum value of duration uncertainty index of project, which occurs at the beginning of project (t=0).

$$U_{t_i} = H_{t_i}\bar{t}_i(1 + I_{t_i}), \qquad (4)$$

where H_{t_i} = non-dimensional entropy of activity; $\bar{t}_i$ = average (mean) value for duration of activity and I_{t_i} = uncertainty propagation factor of the i^{th} activity.

This index (equation 4) can be calculated in relation with time, cost or any other project parameter if its probabilistic distribution can be achieved or modeled. Moreover, this index can be obtained for different cases, such as in the presence of risk factors, without considering risk effects and when risk management strategies are applied.

Therefore, after obtaining the project uncertainty index as a function of project realization time, the index of the risk management effectiveness (IRME) can be defined by considering this index for different cases.

In order to explain this index more clearly, figure 1 is presented. In this figure, the uncertainty index curve (equation 1) is shown in three cases. The first case shows this index without considering the risk effects or $U_{wr}(t)$, second curve is $U_r(t)$ which takes into account the effects of all possible risks and the third one represents the uncertainty index when risk management methods are applied in the project, represented by $U_{rm}(t)$. The main purpose of the risk management activities is to get the third curve as close as possible to first curve and the most desired situation for managing project risks occurs when this curve coincides completely with the first curve.

We define the index of risk management effectiveness (IRME) by the next equation:

$$IRME = \frac{\int_0^1 \left[U_{rm}(\bar{t}) - U_{wr}(\bar{t})\right] d\bar{t}}{\int_0^1 \left[U_r(\bar{t}) - U_{wr}(\bar{t})\right] d\bar{t}}. \qquad (5)$$

And we have $0 \le IRME \le 1$.

$$\bar{t} = \frac{t}{T_{project}}, \qquad (6)$$

where U_{wr} = Project uncertainty index without considering the risk effects; U_r = Project uncertainty index with considering the effect of all project risks; U_{rm} =

Project uncertainty index with considering the effect of risk management reactions and $\bar{t}$ = the non-dimensional time of project realization.

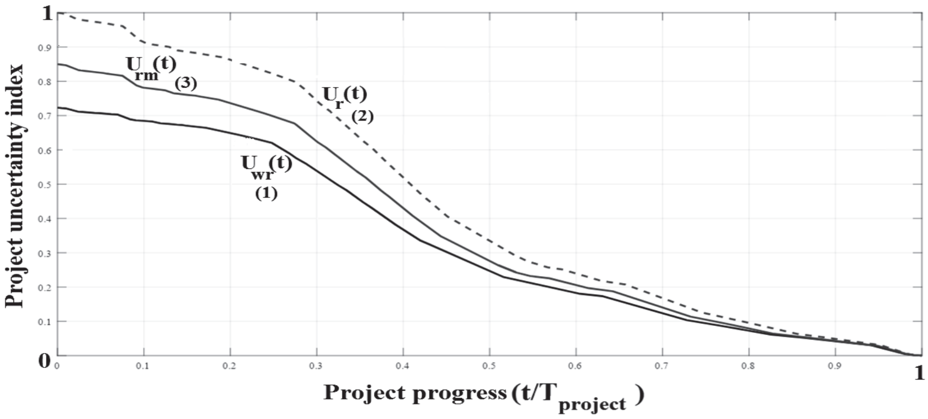

Fig. 1. Project uncertainty index for different cases

This index can be calculated for the project as a whole or at each stage of its realization and IRME=1 indicates that the selected risk management reactions are able to eliminate the risk effects completely.

2. Risk management strategies

Risk management is defined as the determination of procedures and methods for mitigating the negative consequences of risk events and taking advantage of possible benefits. The main strategies for managing negative consequences of risks can be represented in four main categories [2], which are avoidance, mitigation (reducing the probability or impact of the risk), transfer and acceptance.

The two main parameters of each risk are the probability of occurrence (p) and the impact of the risk (I). The effect of implementing any of the risk management strategies can be presented quantitatively by using these parameters. In fact, different risk management methods are focused mainly on reducing the probability or impact of the risks. The influence of each risk management strategy on the probability and impact of risks is shown in tabl. 1. Moreover, the impact of implementing different risk management methods on the time or cost of the related activity or project as a whole is presented in this table.

The suggestion of a suitable strategy for managing project risks depends on several factors. In this process, the risk characteristics (probability and impact) are considered, as well as the required cost and time for the implementation of each strategy.

Table 1

Characteristics of the main risk management strategies

Risk management strategies	Effect on risk characteristics		Effect on cost and duration	
	Probability (P)	Impact (I)	Activity duration (t)	Activity cost (C)
Avoidance	P→0	Doesn’t change	t↑	C↑
Mitigation	P↓	I ↓	t↑	C↑
Transfer	Doesn’t change	I ↓ or I→0	Doesn’t change	C↑
Acceptance	Doesn’t change	Doesn’t change	Doesn’t change	Doesn’t change

3. The optimization problem

Depending on the complexity and characteristics of the project, a number of risks of different types can exist, in other words, we have:

$$R = \{R_i \mid i = 1,...,n\} ; \quad (7)$$

$$R_i = \langle p_i, I_i \rangle , \quad (8)$$

where n= the total number of identified project risks, p_i =probability of occurring ith risk and I_i =impact (or consequence) of ith risk.

Considering the characteristics of risks, it is possible to suggest different risk management reactions from strategies of table 1 in order to confront with each risk. Implementation of each reaction is defined by four main parameters that include the amount of change in the probability of risk occurrence (Δp), the amount of risk impact decrementation (ΔI), required time (t) and cost (C) for implementation of the proposed reaction. Therefore, for the set of reactions suggested for managing ith risk we have:

$$M_i = \{ m_j \mid j = 1,...,s_i \} ; \quad (9)$$

$$m_j = \langle \Delta p_{i,j}, \Delta I_{i,j}, C_{i,j}, t_{i,j} \rangle , \quad (10)$$

where m_j = jth reaction for managing ith risk.

In order to obtain all variants of managing project risks, which are all possible combinations of reactions for project risks, the Cartesian product of sets can be employed. Therefore, we have:

$$M = \prod_{i \in I} M_i = M_1 \times M_2 \times ... \times M_n = \left\{ (m_1, m_2, ..., m_n) \middle| m_i \in M_i, i \in \{1, ..., n\} \right\}; \quad (11)$$

$$I = \{1, .., n\}. \quad (12)$$

In fact, M is a set of all possible cases in which each set member contains one of the suggested reactions for each risk. Hence, the size of each member of M is *n* (total number of project risks). In addition, the total number of possible cases or risk management variants is equal to the size of the M and is calculated by the next equation:

$$S = |M| = \prod_{i=1}^{n} |M_i| = \prod_{i=1}^{n} s_i. \quad (13)$$

It can be found that for the large number of project risks (n) and/or large number of proposed reactions for managing each risk (s_i), the number of risk management variants increases significantly. Moreover, there is another factor, which affects the problem size. As the result of the random nature of risks, simulation methods are used often for modeling the project in the presence of risks. As an example, for our subject area we have developed a computer program [13], which uses a discrete event based Monte Carlo method. For simulating the project with risk effects, this program performs the required number of simulation runs (iterations) to achieve the determined accuracy.

In order to obtain the effects of implementing each set of risk management reactions (each member of M) on project parameters, this iterative simulation process should be performed one time. Therefore, for the required time of modeling and analyzing all possible risk management variants we have:

$$T \cong S * t_{sim} \;, t_{sim} \propto n_{iter}. \quad (14)$$

Where T= total simulation time for all variants of managing project risks, t_{sim} = simulation time for one risk management variant and n_{iter} = required number of iterations for each risk management variant.

Therefore, the number of iterations in Monte Carlo simulation, as well as the number of risk management variants, affects directly the time of problem solution. In our subject area, which is COPs development projects with high number of risks, simulating all risk management variants requires significant time. Hence, employing an optimization method that decreases the problem simulation time seems inevitable. The corresponding optimization problem can be expressed as:

$$\underset{M}{\text{minimize}}\; F(M), \quad (15)$$

where F= objective function and M= the set of all risk management variants (equation 11).

The objective function in equation 15 is determined by the project manager or main stakeholders and depends on the project goals and conditions of the project realization. One of the most suitable parameters can be index of risk management effectiveness (IRME) as were defined by equation 5, in other words:

$$F(M_i) = -IRME(M_i). \quad (16)$$

Other variables that can be used as objective function include project uncertainty index ($U_{project}$ in Eq. 1) the project realization time ($T_{project}$) or cost ($C_{project}$).

Moreover, if it is desirable to optimize more than one objective function simultaneously, multidisciplinary optimization (MDO) techniques can be employed. In this work, we assume that the objective function of the optimization problem is single-variable one.

In order to select the most appropriate method for solving this optimization problem, it is necessary to identify its main features and characteristics. In our case, the problem is a *discrete* one since M is a finite and discrete set; it is *nonlinear* as the value of the objective function is calculated by employing the simulation program for each member of the set M; it is *constrained* because the time and cost of managing risk and reduction of the probability and impact of risks have limited values; and finally it is an *uncertain* problem because the objective function values are not calculated precisely and the accuracy depends mainly on the number of performed iterations of the simulation program. Considering these characteristics of the optimization problem, among suitable methods of solving this problem the simulated annealing (SA) method has been chosen. The next section describes this method and its implementation for our problem in detail.

4. Simulated annealing, basics and implementation

Simulated annealing is one of the probabilistic methods for solving optimization problems, which are used for searching and finding the global optimum of the objective function. This method belongs to the local search and metaheuristic methods and is mainly used for solving discrete optimization problems. It was introduced and developed first time in [14]. The method's name is derived from the annealing process of metals in metallurgy science in which the controlled cooling of the metal occurs in such a way that at the end of the process, the molecules are located in the most regular mode of its crystalline network (this state has minimum energy). The SA method relates this thermodynamic process to the problem of searching for the global minimum in a discrete optimization problem.

By imitating this process, a set of points is found and for these points the minimum value of the objective function $F(\overline{m})$ is reached, where $\overline{m} = (m_1, m_2, ..., m_n) \in M$ and M is the solution domain or the set of all possible cases (in our problem it is all possible variants of managing project risks and is defined by equation 11) and n is the size of $\overline{m}$ (in our problem it is the total number of project risks).The optimum solution is searched by successive computations for points $\overline{m_0}, \overline{m_1}, ...$ of domain M; starting from $\overline{m_1}$, every next point "pretends" to better than former points get close to or approximate the optimum solution. The algorithm takes the point $\overline{m_0}$ as the initial guess. At each step, the algorithm reduces the temperature value and performs calculations for the new point.

Based on the current point $\overline{m_i}$, the next point $\overline{m_{i+1}}$ is obtained as follows. The operator A applies on the point $\overline{m_i}$ and randomly modifies this point and generates a new point $\overline{m^*}$. Point $\overline{m^*}$ becomes $\overline{m_{i+1}}$ with the probability of $P(\overline{m^*}, \overline{m_{i+1}})$ that is calculated in accordance with the Gibbs distribution:

$$P(\overline{m^*} \to \overline{m_{i+1}} \left| \overline{m_i} \right.) = \begin{cases} e^{-\frac{\Delta F_i^*}{T_i}} & \text{if } \Delta F_i^* \geq 0; \\ 1 & \text{if } \Delta F_i^* < 0; \end{cases} \quad (17)$$

$$\Delta F_i^* = F(\overline{m^*}) - F(\overline{m_i}), \quad (18)$$

where T_i is an arbitrary decreasing positive number that converges to zero at the end of the solution, and serves as an analog of the temperature parameter in the annealing process. The initial temperature and its decreasing schedule can be determined by various ways and depends on the problem characteristics and programmer's choice. One of the most famous and widely used relationships for determining the temperature at each step is the exponential decrementation. Therefore, we have:

$$T_{i+1} = \alpha T_i \;, i = 1, ..., k \;; \quad (19)$$

$$T_k = \alpha^k T_0 \;, 0 < \alpha < 1 \;, \quad (20)$$

where α = the decrementation factor, the best range for this factor is in [0.7, 0.95] interval and T_0, T_k = the initial and final temperatures respectively (as mentioned, T_k often is set to approximately zero).

In comparison with gradient-based methods, the approach of simulated annealing provides a means that falls into the local minima less often by allowing *hill-climbing* moves. It must be mentioned that the annealing simulation like other metaheuristic methods does not guarantee finding the global minimum of the objective function, but the correct policy of generating random points and choosing the suitable solution parameters, improves the performance of the algorithm. Figure 2 illustrates the algorithm of simulated annealing, which is adapted for solving the problem of finding the optimum variant of the project risk management.

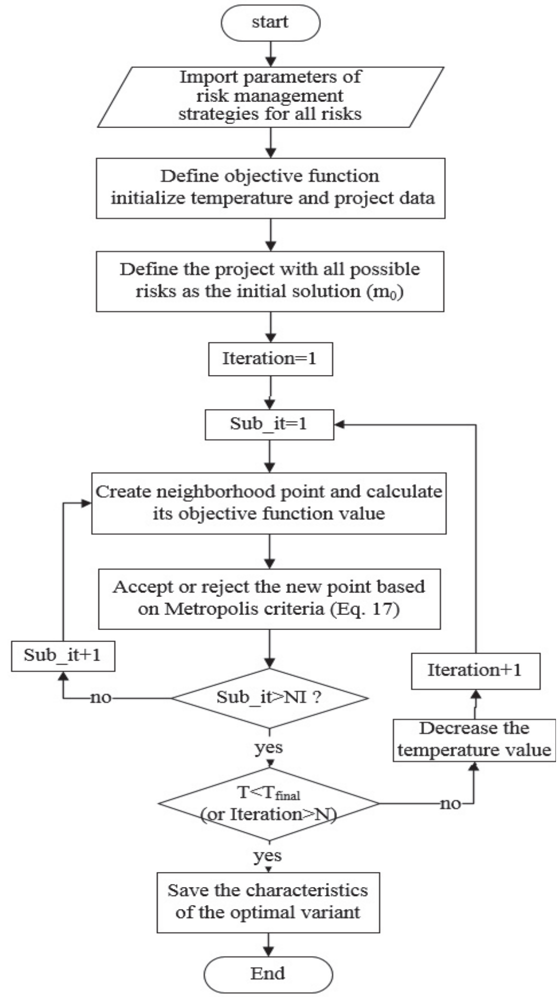

Fig. 2. Simulated annealing algorithm

Conclusions

The results of this study in contrast with other methods help the project manager to evaluate the effectiveness of the various risk management activities with a quantitative measure and therefore, allowing him to compare the effectiveness of different risk management strategies. The proposed index of the risk management effectiveness (IRME) represents the fraction of risk and uncertainty effects of the project that can be eliminated by implementing risk management methods. Moreover, a method was proposed by employing simulated annealing (SA) optimization algorithm for finding the optimum set of risk management activities in projects. The objective function can be maximizing the IRME or minimizing the project realization time or cost. This method especially is useful for implementing in COPs projects, where the risks and their consequences have highly nonlinear character.

Accordingly, after finding the best risk management variant, the relevant actions and modifications in the project plan can be developed for implementation by the project manager. By this way, it is guaranteed that most effective combination of reactions for managing project risks has been planned.

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Надійшла до редколегії 3.05.2017

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ФОРМУВАННЯ НАЙБІЛЬШ ЕФЕКТИВНОГО НАБОРУ ЗАХОДІВ З УПРАВЛІННЯ РИЗИКАМИ ПРОЕКТІВ РОЗРОБКИ СКЛАДНОЇ ТЕХНІКИ

Алі Ченарані, Є.А. Дружинін

Вибір заходів з реагування на ризики є одним з найбільш важливих етапів управління ризиками проекту, особливо в проектах розробки складних технічних систем (СТС). У даній роботі, запропоновано показник ефективності управління ризиками (IRME) в якості кількісного індикатора оцінки ефективності управління ризиками проекту. Запропоновано використання алгоритму імітації відпалу, який відноситься до методів метаеврістіческой оптимізації, для знаходження оптимального набору заходів з управління проектними ризиками. Метою оптимізації може бути максимізувати IRME або мінімізувати час або вартість реалізації проекту. Результати дослідження допомагають керівнику проекту знаходити найбільш ефективний комплекс заходів з управління ризиками та застосувати відповідні зміни в плані проекту.

Ключові слова: *управління проектами, невизначеність, складна технічна система, ефективність управління ризиками, імітація відпалу.*

ФОРМИРОВАНИЕ НАИБОЛЕЕ ЭФФЕКТИВНОГО НАБОРА МЕРОПРИЯТИЙ ПО УПРАВЛЕНИЮ РИСКАМИ ПРОЕКТОВ РАЗРАБОТКИ СЛОЖНОЙ ТЕХНИКИ

Али Ченарани, Е.А. Дружинин

Выбор мероприятий по реагированию на риски является одним из наиболее важных этапов управления рисками проекта, особенно в проектах разработки сложных технических систем (СТС). В данной работе, предложен показатель эффективности управления рисками (IRME) в качестве количественного индикатора оценки эффективности управления рисками проекта. Предложено использование алгоритма имитации отжига, который относится к методам метаэвристической оптимизации, для нахождения оптимального набора мероприятий по управлению проектными рисками. Целью оптимизации может быть максимизировать IRME или минимизировать время или стоимость реализации проекта. Результаты исследования позволяют руководителю проекта находить наиболее эффективный комплекс мероприятий по управлению рисками и внести соответствующие изменения в план проекта.

Ключевые слова: *управление проектами, неопределенность, сложная техническая система, эффективность управления рисками, имитация отжига.*