OPERATIONS RESEARCH AND DECISIONS

No. 2 2017
DOI: 10.5277/ord170205

Ewa MARCHWICKA[1]
Dorota KUCHTA[1]

MODIFIED OPTIMIZATION MODEL FOR SELECTING PROJECT RISK RESPONSE STRATEGIES

The authors present modifications of the optimization model for selecting project risk response strategies proposed by Zhang and Fan. The weaknesses of the original model has been identified and an improved model with the main suggestions has been proposed. The main improvement concerned the objective function. The modified model was tested using a real project in the electrical industry – engineering and construction of the main low voltage switchboard for a live fish carrier (Helix Q7000) in Norway. Project team members report that the analysis is time consuming but results are satisfying – the model allows more systematic and efficient risk management.

Keywords: *risk management, optimization, linear programming*

1. Introduction

Zhang and Fan [6] treat the problem of project risk management, and more exactly that of evaluating and selecting strategies for mitigating project risk, which they call project risk response strategies. They propose an interactive qualitative model supporting project managers in this process. Selecting project risk response strategies is an essential element of project risk management, as there exists practically no project which would turn out as satisfactory as seems after the initial risk identification and evaluation step. However, as Zhang and Fan point out, there are practically no qualitative models which would support project managers in this process. This is shown by the literature review they present in [6]. Since then, to the knowledge of the authors of the present

[1]Department of Computer Science and Management, Wrocław University of Science and Technology, ul. Łukasiewicza 5, 50-371 Wrocław, Poland, e-mail addresses: dorota.kuchta@pwr.edu.pl, ewa.marchwicka@pwr.edu.pl

paper, only a few papers treating this subject have been published (e.g., [3, 4, 7]), which, however, do not present any general model either (the former one uses a fuzzy approach which represents a special case, the next one is a case study and the latter one proposes a generalisation of the model from [6]. Thus, the importance of the issue of proposing a quantitative model supporting the selection of risk response strategies is obvious and still valid. However, the model proposed in [6] has serious drawbacks, which means that it would not be useful in its present form. The main reason for its weakness is the impossibility of estimating certain parameters required in the model (the expected risk response effect expressed in monetary values). There are also several other reasons, which will all be discussed in the second section, but the main reason is the one mentioned above, listed as reason No. 4 in Section 2.

Thus, here we propose an improved model, after first explaining the drawbacks of the original model. Then, we assess our model using a real-world example, like Zhang and Fan did in their paper [6].

The outline of the paper is as follows: in the second section we point out the weaknesses of the original model, using somewhat modified notation, which we think is more appropriate, and already suggesting minor modifications. In the third section we propose an improved model (a major modification) and in the fourth section we illustrate its application using a real-world example. The fifth section proposes some conclusions and directions for further research.

2. The drawbacks of the model proposed by Zhang and Fan and suggestions of minor modifications

In this section, the model from [6] is presented using modified notation, and its drawbacks highlighted. Minor modifications will be proposed too, while major modifications will be presented in the next section.

The convention for the present section is as follows: unless we clearly state that we are presenting our modifications, it should be assumed that we are presenting what Zhang and Fan have proposed in [6], only using different notation.

Zhang and Fan [6] consider a situation where a project is composed of a set of activities: A_k $\{k = 1, ..., NA\}$, where NA is the number of activities. The precedence relations of the type finish-start between the activities are known, although in [6] they were not denoted in any formal way. This makes the formulation of the model formally incorrect – this is what we see as its first drawback (constraint (3) in the original paper). We will address this drawback below, by enumerating the parameters of each activity.

Each activity has the following parameters:

• t_k – the planned duration of the kth activity, $k = 1, ..., NA$, in e.g. days. We assume, without any loss of generality, that the first activity is an activity which is a predecessor of all the other activities of the project and the *NA*th activity is an activity that it is a successor of all the other project activities – its end is equivalent to the project's end,

- s_k – the planned starting moment of the *k*th activity, $k = 1, ..., NA$,
- P_k – the set of the indices of those activities which are immediate predecessors of the *k*th activity, $k = 1, ..., NA$ (P_1 is the empty set) (this is a new element with respect to [6] as we announced above),
- q_k – the planned quality of the product of the *k*th activity, $k = 1, ..., NA$, expressed in the units used to evaluate quality (in [6] this is expressed as a percentage, without any explanation of what these percentages mean – this is what we see as the second drawback of that model, we assume a more general approach, allowing any unit for measuring quality),
- c_k – the planned cost of the *k*th activity, $k = 1, ..., NA$, expressed e.g., in US $.

It is assumed that the project manager has conducted risk identification and has identified *NR* risk events R_j $\{j = 1, ..., NR\}$. According to [6], a risk event is an uncertain event which, if it materializes, will affect some elements of the project in terms of time, cost and quality. This is in line with the definition from [1]: a risk event is defined there as a possible event with negative consequences for the project (negative consequences are deviations from the planned completion date, cost or the quality of the actual realisation of the project which are difficult or impossible to accept).

Zhang and Fan [6] assume that each identified risk event may influence a subset of activities A_k $\{k = 1, ..., NA\}$ in terms of time, cost and quality. In each case, if the *j*th risk event R_j $\{j = 1, ..., NR\}$ has an influence on the *k*th activity in terms of time, then TER_j^k denotes the estimated increase in the duration of the *k*th activity caused by the *j*th risk (in days). If it has an influence in terms of cost, then CER_j^k is the estimated increase in the cost of the *k*th activity caused by the *j*th risk (in US $). If the influence concerns quality, then QER_j^k is the estimated decrease in the quality of the *k*th activity caused by the *j*th risk (expressed in appropriate units).

According to the literature, e.g., [1] or [5], risk events are not characterized only by consequences but also by probabilities. Although Zhang and Fan [6] claim in the introduction that they take these probabilities into account, they are not present anywhere in their model. This is the third drawback of that model. We will refer to this in the next section.

In order to mitigate the influence of risk events, Zhang and Fan [6] propose to identify risk mitigation or risk response strategies S_i $\{i = 1, ..., NS\}$. These strategies can, but do not have to, be applied (the application of all of them is impossible, because of the limited budget available for risk mitigation). If they are applied, they will mitigate the increase in time or cost or the decrease in quality caused by some risk events. Their application costs money: the cost of applying S_i is cs_i $\{i = 1, ..., NS\}$.

Zhang and Fan [6] consider strategies which may potentially mitigate all types of negative effect: on time, cost and quality. In any case, the effects of such strategies will be denoted as follows:

- TES_{ij}^{k} – estimated mitigation in the delay of the *k*th activity due to applying the *i*th strategy (in days), applicable if the *i*th strategy is selected and the *j*th risk event causes a delay in the *k*th activity,
- CES_{ij}^{k} – estimated mitigation in the cost increase of the *k*th activity due to applying the *i*th strategy (in US $), applicable if the *i*th strategy is selected and the *j*th risk event causes an increase in the cost of the *k*th activity,
- QES_{ij}^{k} – estimated mitigation in the quality decrease of the *k*th activity due to applying the *i*th strategy (expressed in the "quality" units), applicable if the *i*th strategy is applied and the *j*th risk event causes a decrease in the quality of the *k*th activity.

In the model from [6], the decision variables x_{ij}, $i = 1, ..., NS$, $j = 1, ..., NR$, are binary variables, such that $x_{ij} = 1$ means that we use the *i*th strategy and it has an effect on the *j*th risk event, otherwise $x_{ij} = 0$. The necessary constraints assuring that x_{ij} is zero if the *j*th risk event is not affected by the *i*th strategy and other common sense constraints are given. Also, we can introduce binary decision variables y_i, $i = 1, ..., NS$ which assume the value 1 if the *i*th strategy is selected and 0 otherwise. The necessary constraints linking the x_{ij}, $i = 1, ..., NS$, $j = 1, ..., NR$ to the variables y_i, $i = 1, ..., NS$ are given too.

The objective function in [6] is as follows:

$$\max z = \sum_{i=1}^{NS} \sum_{j=1}^{NR} e_{ij} x_{ij}, \ i = 1, 2, ..., NS, \ j = 1, 2, ..., NR \tag{1}$$

where: e_{ij} – expected effect of risk response after implementing risk response strategy S_i to cope with risk event R_j,

Here we come to the most important drawback, the fourth one of the model from [6]. In that paper there is no further information about e_{ij}, $i = 1, 2, ..., NS$, $j = 1, 2, ..., NR$. We can only deduce that they are expressed in monetary values. Thus, Zhang and Fan [6] assume that for the *i*th risk response strategy, which may mitigate the negative effects caused by the *j*th risk event on duration, cost and/or quality, the user is able to estimate the total expected effect of the risk response (in monetary values) from the application of the *i*th risk response strategy with respect to the *j*th risk event. Zhang and Fan [6] do not give any hint at all as to how to do this. Also, in their model no explicit relationship between e_{ij} and the parameters TES_{ij}^{k}, CES_{ij}^{k}, QES_{ij}^{k} $\{k = 1, ..., NA\}$ is stated, nor are the probabilities of the risk events given (the e_{ij}s are the only components in the model from [6] where these probabilities might be implicitly taken into account). In our opinion, such an approach is wrong, as no project manager would ever be able to estimate e_{ij} and use the model. If we have TES_{ij}^{k}, CES_{ij}^{k}, QES_{ij}^{k} $\{k = 1, ..., NA\}$, and even if we have the probabilities of the occurrence of the *j*th risk event and of its consequences (in [6] no hint of how to measure these is made), having read [6] we still have no idea how to calculate e_{ij}, which should represent a kind of monetary aggregate representation of TES_{ij}^{k}, CES_{ij}^{k}, QES_{ij}^{k} $\{k = 1, ..., NA\}$ and the corresponding probabilities. It is thus necessary to make the objective function more precise and this is what we are proposing in the next section.

In the next section, we present an improved version of the model, incorporating all the corrections to the drawbacks of the model from [6] identified above.

3. Proposal of a new model

The model proposed in [6] has the drawbacks outlined in Section 2 and is in our opinion incorrect. Therefore, we propose here a new model for obtaining the most desirable strategies.

Having in mind the notation introduced in Section 2, we can state that the duration of the *k*th activity after the occurrence of the *j*th risk event will be extended and can be denoted by the expression $t_k + \sum_{j=1}^{NR} TER_j^k$. Similarly, we can denote the increased cost of the *k*th activity due to the occurrence of the *j*th risk event as $c_k + \sum_{j=1}^{NR} CER_j^k$. The reduction in the quality of the *k*th activity due to the *j*th risk event will be expressed as $q_k - \sum_{j=1}^{NR} QER_j^k$. This notation is identical to that used in [6].

We can use one or more strategies S_i $\{i = 1, ..., NS\}$ that will have an impact on cost, quality or duration of an activity, which can be described by the following equations, similar to those from [6]:

- $t_k + \sum_{j=1}^{NR} \left(TER_j^k - \sum_{i=1}^{NS} x_{ik} TES_{ij}^k \right)$ – for the duration of a task due to the occurrence of the relevant risk events and the application of the selected risk response strategies,
- $c_k + \sum_{j=1}^{NR} \left(CER_j^k - \sum_{i=1}^{NS} x_{ik} CES_{ij}^k \right)$ – for the cost of a task due to the occurrence of the relevant risk events and the application of the selected risk response strategies,

• $q_k - \sum_{j=1}^{NR}(QER_j^k - \sum_{i=1}^{NS} x_{ik}QES_{ij}^k)$ – for the quality of the activity's product due to the occurrence of the relevant risk events and the application of the selected risk response strategies.

The essential difference with respect to [6] is in the objective function. We claim that the objective function (1) is inappropriate, because its coefficients are impossible to determine. We propose to construct a multi-criteria model. As criteria functions we propose the following:

Cost objective function (COF) – minimise the cost of all the activities in the project

$$\sum_{k=1}^{NA}\left(c_k + \sum_{j=1}^{NR}\left(CER_j^k - \sum_{i=1}^{NS} x_{ik}CES_{ij}^k\right)\right) \to \text{min.}$$

• Time objective function (TOF) – minimise the completion time of the last activity in the project (the length of the critical path): $S_{NA} \to \min$ (this objective is equivalent to that of minimizing the duration of the project). Here we decided to put emphasis on the end of the whole project, which is usually the most important time-related parameter of the project. However, if the durations of the individual activities are important too, even when they are executed in parallel (for example, because of resource consumption), another time-related objective can be considered, for example the total time that is spent on all the activities:

• $\sum_{k=1}^{NA}\left(t_k + \sum_{j=1}^{NR}\left(TER_j^k - \sum_{i=1}^{NS} x_{ik}TES_{ij}^k\right)\right) \to \text{min.}$ Other time related objectives might be possible too, for example the sum of deviations from the planned completion times of each of the activities.

• Quality objective function (QOF) – maximise the total quality of all the products of the activities in the project: $\sum_{k=1}^{NA}\left(q_k + \sum_{j=1}^{NR}\left(QER_j^k - \sum_{i=1}^{NS} x_{ik}QES_{ij}^k\right)\right) \to \text{max.}$

Of course, each multicriteria model has to be ultimately turned into a one criterion model. This can be done, for example, by aggregating the three criteria above into one using a weighted sum. Any other approach to multicriteria programming can be applied too. The final choice depends on the decision maker: he/she has to decide how important time, cost and quality are in a given case.

Now we describe the constraints in this model, based basically on [6], but corrected, in particular to address the identified weaknesses:

1. $\sum_{i=1}^{NS} cs_i y_i \le BC$ (where BC is the budget available for risk response – the cost of implementing the selected strategies must fit within the budget for response strategies).

2. $t_k + \sum_{j=1}^{NR} \left(TER_j^k - \sum_{i=1}^{NS} x_{ik} TES_{ij}^k \right) \le T_k$, $k = 1, ..., NA$, where T_k is the upper limit on the duration of the *k*th activity – the actual duration of an activity cannot be greater than the given upper limit, thus, if the effect of risk events in terms of time is too high for a particular activity, some risk response strategies will have to be applied.

3. $c_k + \sum_{j=1}^{NR} \left(CER_j^k - \sum_{i=1}^{NS} x_{ik} CES_{ij}^k \right) \le C_k$ – a constraint analogous to 2, but for costs.

4. $q_k - \sum_{j=1}^{NR} \left(QER_j^k - \sum_{i=1}^{NS} x_{ik} QES_{ij}^k \right) \le Q_k$ – a constraint analogous to 2, but for quality.

5. $\sum_{i=1}^{NS} x_{ik} TES_{ij}^k \le TER_j^k$, $k = 1, ..., NA$ – the effect of the selected strategies in terms of time cannot be greater than the risk effect for a specific task.

6. $\sum_{i=1}^{NS} x_{ik} CES_{ij}^k \le CER_j^k$, $k = 1, ..., NA$ – a constraint analogous to 5, but for costs.

7. $\sum_{i=1}^{NS} x_{ik} QES_{ij}^k \le QER_j^k$, $k = 1, ..., NA$ – a constraint analogous to 5, but for quality.

8. $s_1 = 0$.

9. $s_k \ge s_p + t_p + \sum_{j=1}^{NR} \left(TER_j^p - \sum_{i=1}^{NS} x_{ip} TES_{ij}^p \right)$, $k = 2, ..., NA$, $p \in P_k$ (standard dependencies between the starting times of predecessors and successors in a project, taking into account the effect of risk events and of selected strategies).

4. Assessing the proposed method based on a real project

This section presents how to use the proposed method to select strategies that respond to project risk based on the example of a project from the electricity industry. The goal of the project is the engineering and construction of the main low voltage switchboard for a live fish carrier (Helix Q7000) in Norway.

4.1. Data collection

Data collection was based on interviews with the project manager of the project in question. The first step was to determine a list of activities in the project. A project network diagram for the analysed project is shown in Fig. 1.

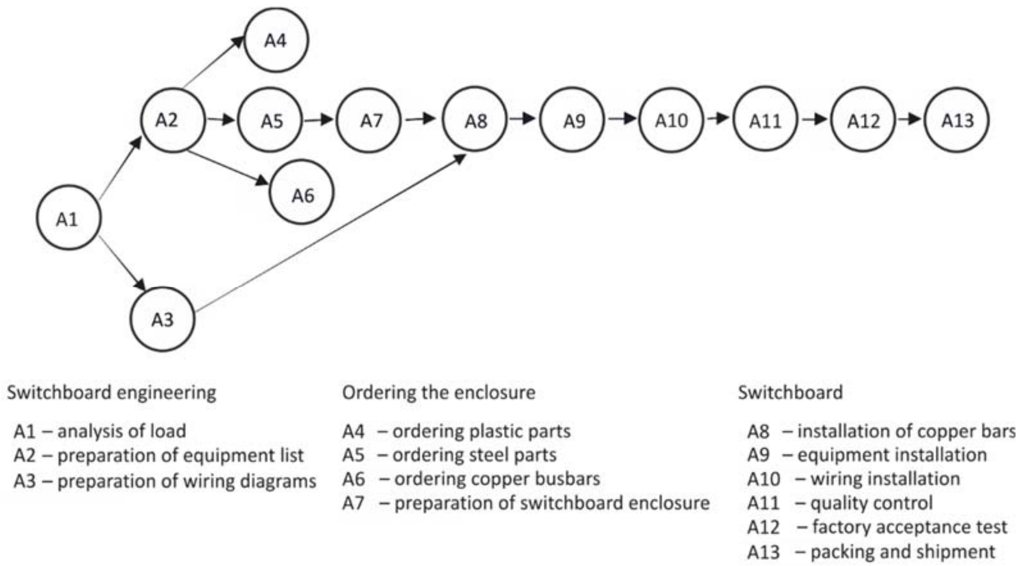

Fig. 1. Project network diagram

The next step was to determine a list of risk events for the project and a list of risk response strategies, together with their costs.

The following risk events were identified:

R1 – delays in deliveries from suppliers,
R2 – lack of human resources,
R3 – documentation errors,
R4 – installation errors,
R5 – variable exchange rate and prices of raw materials,
R6 – lack of certificate of approval,
R7 – errors during loading and unloading,
R8 – loss of the company's financial liquidity,
R9 – lack of the contractor's involvement.

The following risk response strategies were identified:

S1 – outsourcing of human resources,
S2 – outsourcing of equipment,
S3 – double verification of documentation,
S4 – ordering raw materials in "higher lows" (sign of a bullish market),
S5 – recruitment of experienced human resources,
S6 – regular legal analysis.

The estimated budget for response strategies is 800 000 PLN.

The project manager has determined the currently planned (c_k) and the highest acceptable (C_k) cost, the currently planned (q_k) and the lowest possible (Q_k) quality for each activity and the currently planned duration (t_k) of each activity in the project. No limit for the duration of each activity (constraint 2) was set, thus the T_k are equal to infinity for $k = 1, ..., 13$. The results are shown in Table 1.

Table 1. Currently planned (c_k) and the highest (C_k) possible cost, currently planned (q_k) and the lowest (Q_k) possible quality for each activity and the currently planned duration of each activity in the project (t_k)

Activity	t_k [day]	c_k [PLN]	C_k [PLN]	q_k [%]	Q_k [%]
A_1	24	90	280 000	100	70
A_2	14	630	800 000	100	70
A_3	7	500	700 000	100	90
A_4	7	590	900 000	100	50
A_5	25	0	800 000	100	50
A_6	36	400	700 000	100	50
A_7	38	1000	3 000 000	100	30
A_8	10	0	200 000	100	30
A_9	30	200	600 000	100	60
A_{10}	60	100	800 000	100	60
A_{11}	15	0	400 000	100	0
A_{12}	10	400	550 000	100	100
A_{13}	6	0	100 000	100	100

The next step was to estimate the effects of the risk events on the duration, cost and quality of activities. Here we would like to underline that the project manager stated that estimating the effects of the risk events and selected risk response strategies purely in aggregated monetary units – in the way it was proposed in [6] – is not possible (not realistic). The approach represented by the objective function (1) was definitely rejected by the company analysed. They said that they would have no idea how to estimate the coefficients of (1). Results of the estimation are shown in Table 2.

Table 2. Estimation of effects of risk events on duration [day], cost [thousand PLN] and quality [%] of activities

Activity	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
TER_1	–	–	–	14	10	10	21	–	–	–	–	–	–
CER_1	–	–	–	–	–	–	–	40	200	400	–	–	30
QER_1	–	–	–	20	20	20	20	10	–	–	40	–	–
TER_2	6	4	2	2	6	9	8	3	9	18	4	–	–
CER_2	100	200	200	300	400	300	1500	100	200	400	200	–	–
QER_2	50	50	50	30	30	30	30	50	50	50	50	–	–
TER_3	21	8	4	1	4	6	11	2	12	18	–	10	2
CER_3	200	400	200	120	160	120	1200	40	160	320	–	200	40
QER_3	30	20	10	–	–	–	20	5	–	–	50	–	–

Table 2. Estimation of effects of risk events on duration [day], cost [thousand PLN] and quality [%] of activities

TER_4	–	–	–	–	–	–	–	5	15	30	15	–	–
CER_4	–	–	–	–	–	–	–	60	120	240	400	–	–
QER_4	–	–	–	–	–	–	–	40	30	30	50	–	–
TER_5	–	–	–	–	–	–	–	–	–	–	–	–	–
CER_5	–	–	–	30	16	60	300	–	–	–	–	–	–
QER_5	–	–	–	–	–	–	–	–	–	–	–	–	–
TER_6	4	3	2	–	–	–	–	2	9	18	15	8	–
CER_6	60	120	120	–	–	–	–	40	120	240	400	160	–
QER_6	–	–	–	–	–	–	–	5	–	–	10	–	–
TER_7	–	–	–	5	20	30	28	10	30	60	15	10	5
CER_7	–	–	–	600	800	600	3000	200	400	800	400	200	100
QER_7	–	–	–	–	–	–	20	5	–	–	50	–	–
TER_8	–	–	–	2	6	9	8	–	–	–	–	–	–
CER_8	–	–	–	–	–	–	150	–	–	–	–	–	–
QER_8	–	–	–	–	–	–	20	–	–	–	–	–	–
TER_9	21	4	1	–	–	–	–	–	3	–	–	1	2
CER_9	40	80	40	–	–	–	–	–	–	–	–	–	–
QER_9	10	10	10	–	–	–	–	–	–	–	–	–	–

In the next step, the project manager defined which strategies and risks are connected and then estimated the effects of selected risk response strategies on the duration, cost and quality of activities. The results are shown in Table 3.

Table 3. Estimation of the effects of selected risk response strategies on the duration, cost and quality of activities

Duration [day]													
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
TES_{12}	3	2	2	1	3	4	4	2	5	9	2	–	–
TES_{27}	–	–	–	2	10	15	14	5	15	30	8	5	3
TES_{33}	7	4	2	1	2	3	5	1	6	9	–	5	1
TES_{34}	–	–	–	–	–	–	–	2	7	15	7	–	–
TES_{36}	2	1	1	–	–	–	–	1	5	8	7	5	–
TES_{45}	–	–	–	–	–	–	–	–	–	–	–	–	–
TES_{51}	–	–	–	7	5	5	10	–	–	–	–	–	–
TES_{52}	2	1	1	2	2	3	4	1	4	8	1	–	–
TES_{53}	6	3	3	2	2	2	4	2	5	8	–	4	1
TES_{54}	–	–	–	–	–	–	–	1	8	14	8	–	–
TES_{56}	1	2	2	–	–	–	–	2	6	7	7	4	–
TES_{57}	–	–	–	2	10	14	14	5	15	30	8	5	3
TES_{63}	7	3	3	2	3	3	3	2	6	10	–	6	2
TES_{64}	–	–	–	–	–	–	–	3	7	15	8	–	–
TES_{66}	1	1	1	–	–	–	–	2	6	8	8	6	–

Table 3. Estimation of the effects of selected risk response strategies
on the duration, cost and quality of activities

Cost [thousand PLN]													
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
CES_{12}	50	100	100	150	200	150	100	50	100	300	100	–	–
CES_{27}	–	–	–	200	400	200	200	100	200	400	200	150	100
CES_{33}	100	200	100	100	60	100	600	20	100	150	–	100	30
CES_{34}	–	–	–	–	–	–	–	50	20	140	200	–	–
CES_{36}	20	100	50	–	–	–	–	30	20	120	200	80	–
CES_{45}	–	–	–	30	10	40	200	–	–	–	–	–	–
CES_{51}	–	–	–	–	–	–	–	30	100	200	–	–	30
CES_{52}	40	90	100	100	200	150	800	40	50	200	150	–	–
CES_{53}	150	150	150	150	50	100	500	20	150	150	–	100	50
CES_{54}	–	–	–	–	–	–	–	30	30	100	100	–	–
CES_{56}	10	100	40	–	–	–	–	40	30	100	200	90	–
CES_{57}	–	–	–	200	400	200	2000	100	200	400	200	150	100
CES_{63}	100	190	110	110	50	90	500	30	110	150	–	100	20
CES_{64}	–	–	–	–	–	–	–	30	30	100	150	–	–
CES_{66}	20	100	50	–	–	–	–	40	40	100	190	90	–
Quality [%]													
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
QES_{12}	50	50	50	30	30	30	30	50	50	50	50	–	–
QES_{27}	–	–	–	20	20	20	30	5	20	20	50	20	20
QES_{33}	30	20	10	–	–	–	20	10	–	–	50	–	–
QES_{34}	–	–	–	–	–	–	–	5	–	–	10	–	–
QES_{36}	–	–	–	–	–	–	–	5	–	–	–	–	–
QES_{45}	–	–	–	–	–	–	20	–	–	–	–	–	–
QES_{51}	–			30	30	20	20	20	–	–	40	–	–
QES_{52}	50	50	50	40	30	40	30	50	60	60	50	–	–
QES_{53}	40	30	20	–	–	–	20	10	–	–	50	–	–
QES_{54}	–	–	–	–	–	–	–	10	–	–	–	–	–
QES_{56}	–	–	–	–	–	–	–	10	–	–	40	–	–
QES_{57}	–	–	–	–	–	–	10	10	–	–	–	–	–
QES_{63}	30	10	10	–	–	–	10	5	–	–	–	–	–
QES_{64}	–	–	–	–	–	–	–	5	–	–	40	–	–
QES_{66}	–	–	–	–	–	–	–	10	–	–	–	–	–

4.2. Calculations and results

After analysing the case study and an interview with the project manager, we decided to divide the multicriteria model into three separate models: one model with *TOF* as the objective function, one with *COF* and one with *QOF*, each time applying constraints 1–9 from Section 3. From the perspective of a decision maker, this is an efficient approach, because in practice we may deal with various situations, where one of the project parameters – time, cost or quality – is the most important one. The other two can also be included in the model as constraints. Based on the collected data, we implemented these three models using the free GUSEK package (GLPK Under SciTE Extended Kit). Table 4 summarizes the results.

Table 4. Comparison of the results from applying different models

Model	Selected strategies	Quality [%]/ as a percentage of the optimum QOF	Time [day]/ as a percentage of the optimum TOF	Cost [PLN]/ as a percentage of the optimum COF	Cost of implementing the selected strategies [PLN]	Total cost [PLN]/ as a percentage of the optimum
Model 1 (minimising project duration TOF)	S1, S2, S3, S5, S6	855/96	350	10 956 000 /280	197 000	11 153 000 /270
Model 2 (minimising project cost COF)	S1, S2, S3, S4, S5, S6	665/74	539/154	3 910 000	224 000	4 134 000
Model 3 (maximising project quality QOF)	S1, S2, S3, S5, S6	895	734/210	14 660 000 /375	197 000	14 857 000 /359

It has to be underlined that the term cost in Table 4 (5th column) refers to the expected cost of the project itself, the cost of implementing the selected strategies is excluded. The last column presents the total cost, i.e., the sum of the cost of the project (5th column) and the cost of implementing the selected strategies (6th column).

According to model 1 and model 3, the same set of strategies is selected. According to model 2, the selected set is greater by one element: the strategy S4. That is why the application of the strategies selected according to model 2 is more expensive than according to the other models. However, the cost of applying the additional strategy is compensated by a much lower expected project cost and the total cost is also much lower than according to the other two models.

Thus, obviously the lowest expected project cost is obtained for model 2, the greatest quality for model 3 and the shortest project duration for model 1. Applying the last model makes us pay for the best quality: it gives the worst results in terms of time and cost (210% and 375% of the minimum values, respectively). The gain in quality by applying model 3 is relatively low in comparison to the losses in terms of time and cost. However, if one needs to keep the quality high, not paying attention to costs or time, applying model 3 gives the desired results.

Applying model 1, minimizing the duration, is also very good as far as quality is concerned, and less expensive than applying model 3. Thus the final choice was made between model 1 and model 2. The final decision of the manager was to apply model 2, because it was easier to convince the client to accept a delay in the project than to pay more money for its execution.

5. Conclusions and further research

A modification of the model proposed by Zhang and Fan [6] for solving the problem of selecting a risk response strategy in project risk management has been proposed. The main modification concerned the objective function – in the opinion of the authors of the present paper the objective function proposed in [6] was inappropriate and unrealistic, as well as being impossible to understand or apply. The modified model has been tested using a real life project. During the assessment of the method, interviewees underlined that it was difficult for them to estimate the parameters used in the model proposed here and analysis was really time consuming. However, the results were satisfying for them, because the model allows more systematic and efficient risk management. The interviewees also underlined that the model proposed in [6] would have been completely impossible to apply, as the coefficients from the objective function would have been impossible to estimate.

Of course, the proposed model still requires further improvements. Further improvement of the model could consist of including estimates of the probabilities of risk events and enabling the estimation of parameters by experts by means of linguistic expression, which can be converted into a quantitative form by using fuzzy numbers. Thanks to this, data collection will take less time and seem more natural to the interviewees.

Further research could also focus on analysing the multicriteria model. Various methods of solving multicriteria problems might be used, including interactive ones. In this way, the decision maker would actively participate in choosing the objective and based on this the appropriate risk response strategies would be chosen.

Also, the objectives might be changed or enhanced, as today the mere project triangle (time, cost, quality) is not considered sufficient for evaluating whether a project is successful or not. The perception of individual project stakeholders is becoming more and more important (e.g., [2]). What is more, the representation of a project as a set of activities and the relations between them might take more complicated forms (e.g., dependencies of the type finish-to-finish, start-to-start, or start-to-finish with slack variables representing the gap between activities should also be considered, as well as resources and their levelling [5].

References

[1] COURTOT H., *La gestion des risques dans les projets*, Ed. Economica, Paris 1998 (in French).
[2] DAVIS K., *An empirical investigation into different stakeholder groups' perception of project success*, Int. J. Proj. Manage., 2017, 35 (4), 604–617.
[3] FAN Z.P., LI Y.H., ZHANG Y., *Generating project risk response strategies based on CBR. A case study*, Expert Systems with Applications, 2015, 42 (6), 2870–2883.
[4] KUCHTA D., SKORUPKA D., *Choice of countermeasures in project risk management using fuzzy modelling*, Int. J. Comp., Comm. Control, 2014, 9 (5), 584–592.
[5] *A Guide to The Project Management Body of Knowledge PMBOK Guide* (3rd Ed.), Project Management Institute Inc., Newtown Square 2004.
[6] ZHANG Y., FAN Z.P., *An optimization method for selecting project risk response strategies*, Int. J. Proj. Manage., 2014, 32 (3), 412–422.
[7] ZHANG Y., FAN Z.P., *Selecting risk response strategies considering project risk interdependence*, Int. J. Proj. Manage., 2016, 34 (5), 819–830.

Received 18 December 2016
Accepted 4 July 2017