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REAL OPTIONS IN A SYSTEMIC APPROACH
TO THE TIMING PROBLEM IN DEVELOPMENT PROJECTS

The management environment at the beginning of the XXI century is characterized by high volatility. Development projects should take into account not only certain deliverables but also any opportunities that may arise. These opportunities are called real options. The paper describes a systems approach to various types of real options that can be found in a project's environment. A method is presented for using such options in the timing problem.

Keywords: *real options, project management, multicriteria decision making*

1. Introduction

Perceived opportunities and discovered threats make us want to change the present state into a more desirable one. The most effective way to do this is by conducting projects. In a situation with limited resources, it is essential to choose the right project. Selection of the right project is based on an evaluation of a project's deliverables.

Traditional evaluation of a project is based on the method of discounted cash flow (DCF) as described by Guthrie [6]. The main measure of effectiveness is the net present value (NPV). When this value is positive, a project is approved, when negative, it is rejected but this approach sometimes leads to the abandonment of profitable projects. The reason for this is that the DCF method does not take into account the role of managerial flexibility. The project manager has the right to take appropriate action. Such a situation is called a real option. Using real option valuation (ROV), we can provide a quantitative assessment of such a situation.

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In ROV, methods from the financial market such as the Black–Scholes model presented in [1] or the Cox–Ross–Rubenstein (CRR) model presented in [4] were used first. An approach based on the Monte Carlo simulations [2] has also been used. The CRR model is based on binomial trees. This approach was also adopted by Guthrie [6] on which this study is based.

The standard approach in the valuation of real options is based on one factor, called the state variable. There have been attempts to take into account many state variables. The first attempt, based on financial options, was made by Boyle [3] who took into account two assets. Guthrie [6] also described problems for which it is necessary to take into consideration a number of variables. In these solutions, different criteria are brought to a common financial denominator. There are no solutions in the literature for the situation in which the evaluation of a project depends on many independent factors. Such a situation occurs in projects related to sustainable development, which should take into account not only financial factors, but also social and environmental ones.

The ROV-based approach not only makes it possible to evaluate a project, but it can also assist in the decision making process [6]. For example, if a project is divided into phases, there is a problem of selecting the start time of the next stage. It is also possible to delay the start of the project. The right moment to begin has to be chosen. If the result of the project depends on some external factors that change over time, it is possible to use ROV methods in selecting the start time. One condition is that these factors can be modeled using stochastic processes.

This paper presents various real option situations which may occur in development projects. The first section presents a real option situation. Differences to the classic problem of decision making are described. The second section describes simple real options. The next section deals with compound real options. The third explains valuation methods that are also used to determine the time for exercising an option.

The aim of this paper is to illustrate the possibilities of using a real option situation to choose the start time of project activities. This possibility is demonstrated based on the example of selecting the start time of a noncritical activity using the CPM method.

2. A dynamic decision making problem

Project management produces an environment in which many decisions are made. When choosing between the variants $\mathbf{x}$ and $\mathbf{y}$ under the classical model of decision making (Fig. 1), we consider the criteria scores that characterize the variants. These are denoted as $f(\mathbf{x})$ and $f(\mathbf{y})$. A variant is chosen based on the comparison of criteria scores.

The values of the criteria scores may change over time. This creates a new dynamic situation. The value of the criterion score $f(\mathbf{x})$ can increase to $f'(\mathbf{x})$. It can also decrease to $f''(\mathbf{x})$. If decisions are irreversible, the timing of a decision is crucial. In our case, this

is the moment of choosing between variants **x** and **y**. An option situation occurs if the following three conditions are satisfied:

- the criteria scores depend on time,
- decisions are irreversible,
- the value of a decision depends on an external factor, called the state variable.
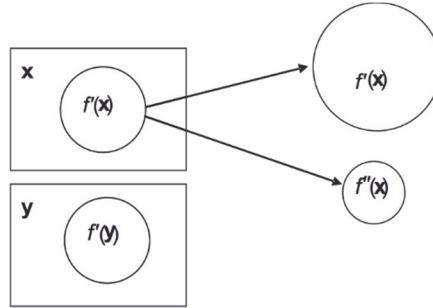

Fig. 1. Considered situation

These conditions also occur during the life of a project. An option situation can be independent of any other decision. In this case, it is called a simple real option. In some cases, an option situation depends on the decision taken in a different situation. This is known as a compound real option.

The following sections of this paper describe a typical real option situation that may arise in development projects.

3. Simple real options

Simple options are inherent in any project. The simplest examples are timing options: the delay option or the abandon option.

The delay option describes a situation in which we can choose the start time of a project. Starting a project is an irreversible decision. The resulting cash flows are not recoverable. This is one of the earliest described real options and was considered in [9].

If the start is planned in advance, the situation is static; the decision maker is not able to react to changes in the environment and in the project itself. If extending the duration of the project is allowed and the decision maker is allowed to freely decide about the start time, a completely new situation arises as presented in Fig. 2. The decision maker may start the project (decision *A*), then move from the current state (initialization of the project) to the last state (end of the project). The decision maker may wait (decision *W*), but then the project will remain in its starting state. After one period, the situation is repeated. The decision maker may start the project (decision *A*), then move

from the current state (initialization of the project) to the last state (end of the project). The decision maker may also wait (decision W), but in this case the project will fail.
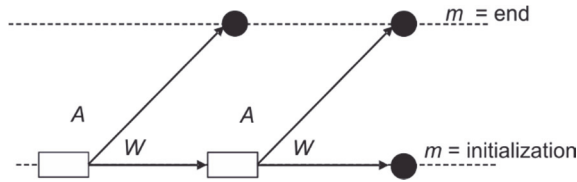

Fig. 2. Simple delay option

The ability to delay the project for one time period creates a real option, expanding managerial flexibility. The project manager has the possibility of using this real option freely, depending on the situation in the environment. If the current environment is favorable, then the project manager will begin the project. If it is not beneficial, then he or she can wait for a development in the situation. This increase in flexibility is associated with the problem of when to use this option. In the case presented, this is the problem of choosing the best moment to start the project. Is it better to start the project now, or rather wait for a development in the situation? It is possible that historical data do not indicate positive developments, or on the contrary, that there is a chance in the future to obtain benefits from the project.

The abandon option describes a situation in which we can choose to close an uncompleted project at some point in time. The abandonment of the project is also an irreversible decision. Incurred costs cannot be refunded. Myers and Majd [10] first described this real option.

If the decision maker is allowed to freely decide about the abandon time, an option situation arises as presented in Fig. 3. The decision maker may continue the project (decision C) or make a decision to abandon it (decision A). In this case, the project moves from the current state (Operating) to the next state (Abandoned). Such a decision may be possible at various times.
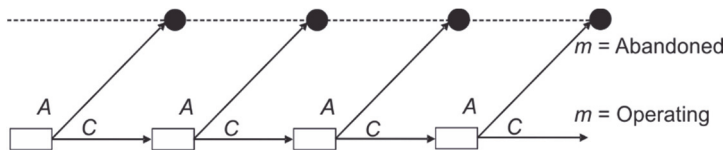

Fig. 3. Simple abandon option

The general structure of the situation can be summarized as follows. A project in one state can be transformed into another state. The moment of this change is determined by the decision maker based on observations of the project's environment. This

change is completely irreversible. The ability to choose when a decision is made may be limited. The change in the state of the project also alters the cash flow profile.

4. Compound real options

In some projects, whether an option occurs or not depends on the realization of the project up until that point in time. Many methodologies of project management recommend dividing a project into stages. This gives rise to sequential compound options. The implementation of each step depends on the performance at previous steps. It also depends on the assessment of the profitability of the next stage. This can be seen as a sequence of simple real options. The implementation of an option depends on the implementation of previous ones. Such a situation is shown in Fig. 4, where a project is divided into two stages.
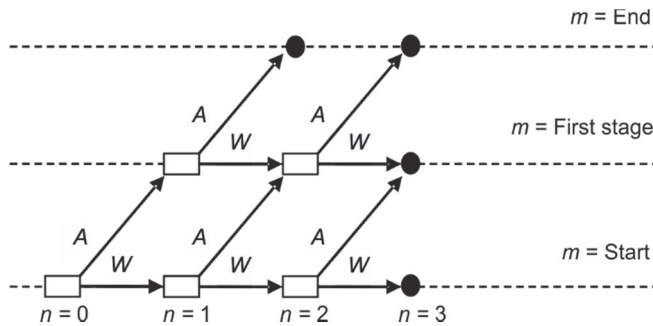

Fig. 4. Compound option

If extending the duration of the project is allowed and the decision maker is allowed to freely decide about the start of each stage, an option situation arises, as presented in Fig. 4. The decision maker may start the first stage (decision A), then move from the current state (Start) to the next state (First stage). The decision maker may wait (decision W) but then the project will remain in its starting state. After one period, the situation is repeated but depending on the first decision, the project can reach the first state (First stage) or last state (End).

The general structure of the situation can be summarized as follows. A project in one state can be transformed into another, and then into another and so on. The project moves through a specified sequence of states. Each moment of change is determined by the decision maker based on observations of the project's environment. Each change in state is completely irreversible. The ability to choose when a decision is made may be limited. Each change in the state of the project also changes the cash flow profile. The key is that project states are achievable only in a specific sequence.

5. Real options valuation

The presented increase in flexibility in a project's environment is associated with the problem of successively determining the appropriate time to execute stages. This problem requires a quantitative assessment of a project's implementation, provided by ROV methods.

The decision maker makes decisions based on changes in factors. These factors vary stochastically according to a certain random process. The idea behind the CRR method is to model possible future states of a variable using a binomial tree. This is a role-specific scenario of possible changes in the value of state variables (X_k). At each stage, we consider only the possibility of an increase or decrease in value. The probabilities of such changes can be estimated based on historical variation in the state variable. Using the proposed procedure, the decision making process is simplified.

This issue is discussed in the literature [6]. Guthrie considered one factor, and this paper extends his approach by binding the results of the project to two factors. The solution to this problem requires a multi-criteria approach, which is achieved using an extension to the methodology of ROV. The application of this methodology leads to backward induction, in which we consider sets of efficient solutions based on the value of the project. In this case, the values at the $(k-1)$-th stage are:

$$\{V(k-1, X_{k-1}, d_{k-1})\} = \sup_{d_k \in D_k} \{e^{-r\Delta t_m} E[V(k, X_k, d_k)]\}, \quad k = n, ..., 1 \tag{1}$$

where: X_k is the state variable in period k, D_k – set of feasible decisions in period k, d_k – decision in period k, $V(k, X_k, d_k)$ – value of project in period k, r – risk free interest rate.

The decision adopted, d_k, also defines the effective moment of that decision. In classical approaches, the value V only depends on the financial factor. In sustainable development projects this may be an overly simplified approach. In this case, other, non-financial results of the project should be considered. If we consider more than one factor that affects usability and design considerations as occurs in many areas, the problem is converted from a simple valuation to a multi-criteria evaluation problem.

Considering sustainable development projects, we choose one factor for each criterion. The project value according to a given criterion will depend on the appropriate factor. This leads to the replacement of a single project value by a vector, as depicted in the following formula:

$$\mathbf{V}^m(i, j, l, n) = \begin{bmatrix} f_1(X_1(i, n), V_1^m(i, j, l, n+1)) \\ f_2(X_2(j, n), V_2^m(i, j, l, n+1)) \\ f_3(X_3(l, n), V_3^m(i, j, l, n+1)) \end{bmatrix} \tag{2}$$

We denote the present value of the project according to the k-th criterion, which depends on three state variables, as $V_k^m(i, j, l, n)$, where m denotes the state, n the period, i, j, l – the numbers of falls in the first, second and third state variables, respectively.

If we consider the compound option shown in Fig. 4, at each stage we have to choose between the two decisions Act (A) or Wait (W). Each of these decisions is assessed using the vectors defined as follows:

$$\mathbf{V}^A(i, j, l, n) = \begin{bmatrix} V_1^A(i, j, l, n) \\ V_2^A(i, j, l, n) \\ V_3^A(i, j, l, n) \end{bmatrix} \tag{3}$$

$$\mathbf{V}^W(i, j, l, n) = \begin{bmatrix} V_1^W(i, j, l, n) \\ V_2^W(i, j, l, n) \\ V_3^W(i, j, l, n) \end{bmatrix} \tag{4}$$

The selection of efficient decisions was made using the TOPSIS method, originally developed by Hwang and Yoon [8], presented in [19]. The computations are based on an evaluation matrix, as shown in Table 1.

Table 1. Evaluation matrix

Decision – D_c	V_1	V_2	V_3
A	$V_1^A(i, j, l, n)$	$V_2^A(i, j, l, n)$	$V_3^A(i, j, l, n)$
W	$V_1^W(i, j, l, n)$	$V_2^W(i, j, l, n)$	$V_3^W(i, j, l, n)$

In Table 1 we denote the c-th decision by D_c ($c = 1, 2$), V_k is the project value according to the k-th criterion ($k = 1, 2, 3$). Additionally, we define weights of assessments, $w_k \geq 0$, which sum to one.

First, we normalize the matrix:

$$\mathbf{N} = \begin{bmatrix} \widehat{x}_{11} & \widehat{x}_{12} & \widehat{x}_{13} \\ \widehat{x}_{21} & \widehat{x}_{22} & \widehat{x}_{23} \end{bmatrix} \tag{5}$$

where:

$$\widehat{x}_{ck} = \frac{x_{ck}}{\sqrt{\sum_{s=1}^{3} x_{sk}^2}} \qquad \text{for } c = 1, 2 \text{ and } k = 1, 2, 3 \tag{6}$$

and x_{ck} is the appropriate element in the evaluation matrix. Then we weigh this matrix:

$$\mathbf{V} = \begin{bmatrix} w_1\widehat{x}_{11} & w_2\widehat{x}_{12} & w_3\widehat{x}_{13} \\ w_1\widehat{x}_{21} & w_2\widehat{x}_{22} & w_3\widehat{x}_{23} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \end{bmatrix} \tag{7}$$

Next, we determine the worst alternative (A^-) and the best alternative (A^+):

$$\mathbf{A}^- = \left(v_1^-, v_2^-, v_3^- \right) \tag{8}$$

$$\mathbf{A}^+ = \left(v_1^+, v_2^+, v_3^+ \right) \tag{9}$$

where:

$$v_k^- = \min_c \left(v_{ck} \right)$$

$$v_k^+ = \max_c \left(v_{ck} \right) \qquad \text{for } k = 1, 2, 3$$

assuming that all the factors have a positive impact. We then calculate the distance between the target decisions and the worst (A^-) and the best (A^+) alternatives:

$$d_c^- = \sqrt{\sum_{k=1}^{3} \left| v_{ck} - v_k^- \right|^2} \qquad \text{for } c = 1, 2 \tag{10}$$

$$d_c^+ = \sqrt{\sum_{k=1}^{3} \left| v_{ck} - v_k^+ \right|^2} \qquad \text{for } c = 1, 2 \tag{11}$$

We then calculate the similarity of each decision to the best alternative:

$$S_c = \frac{d_c^-}{d_c^+ + d_c^-} \qquad \text{for } c = 1, 2 \tag{12}$$

It is clear that $0 \le S_c \le 1$. A higher value of S_c means that the solution is closer to the ideal solution, so the decision with the greatest value of this index should be chosen. Such a choice is made at each stage. These choices are determined by recursion, i.e. assuming that a decision has been selected for a particular stage, this allows us to calculate the value of the project at the previous step. This approach is an extension of valuation based on Eq. (1).

The weights in Eq. (7) can be obtained by Saaty's AHP method [13], by pairwise comparison of state variables.

6. A numerical example

This example is based on a real problem that occurred during the expansion of a lo-cal airport. This was a construction project with a budget of several million euros. The problem considered is real, while the data used are fictitious.

A special case of a simple defer option is choosing the moment to start an activity which is non-critical according to the CPM method. The construction of a new runway requires the construction of taxiways. Since the construction of a runway takes more than a year, while the construction of taxiways, most frequently made of concrete, does not occupy more than a few months, they are not critical activities in the timetabling of a project. In the case considered, runway construction started in 2013, and was planned to be completed by the end of 2014. The problem of selecting the moment to start taxi-way construction arose in late 2013. This construction should be completed in six months, including the tender procedure. The choice was to launch this construction ei-ther at the beginning of 2014, or in the middle of this year, in order to complete the construction of the taxiways by the end of 2014. We can start the procedure at the be-ginning of 2014, but in this way we lose the opportunity of gaining a more favorable contract in the second half of this year.
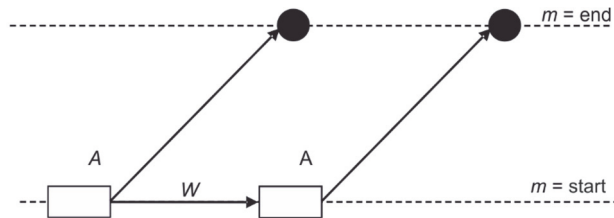

Fig. 5. Decision tree (D-tree)

The decision tree (D-tree) is shown in Fig. 5. We can start the process and the con-struction at the beginning of the year (decision A) or wait half a year for the development of the situation (Decision W). After half a year, the only possible decision is to start the tender procedure.

Analysis of this problem enabled to determine three factors that could affect the contract. They will be our state variables, denoted respectively:
- X_1 – indicator of the general business tendency climate in construction,
- X_2 – price index for road constructions,
- X_3 – EUR/PLN exchange rate.

Based on the observation of these state variables in 2013 together with the procedure described in [17], the probability of an increase or decrease in these factors by mid-2014 was assessed.

For the first state variable, X_1 – indicator of the general business tendency climate in construction, we use the model of Brownian motions. Based on monthly data, we compute the probability of possible changes in the first half of 2014. The X-tree obtained is presented in Table 2.

Table 2. X-tree for the general business
tendency climate in construction

X_1 [%]	n	
i	0	1
0	−26.00	−18.08
1		−35.52

The probabilities calculated using the Guthrie procedure [6], are $\pi_u^1 = 0.69$, $\pi_d^1 = 0.31$, where π_u and π_d denote the probabilities of an increase and a decrease, respectively.

For the second state variable, X_2 – price index for road constructions, we use the model of Brownian motions. Based on monthly data for the prices of materials for constructing road surfaces (Polish Classification of Types of Constructions, PKOB2112 /SST 05) [7], we compute the probability of possible changes in the first half of 2014. The X-tree obtained is presented in Table 3.

Table 3. X-tree for the price index
for road construction

X_2 [%]	n	
j	0	1
0	100.00	100.48
1		99.71

The probabilities calculated using the Guthrie procedure [6], are $\pi_u^2 = 0.22$; $\pi_d^2 = 0.78$.

For the third state variable, X_3 – EUR/PLN exchange rate, we use a model of geometric Brownian motion. Based on daily data we compute the probability of various changes in the first half of 2014. The X-tree obtained is presented in Table 4.

Table 4. X-tree for EUR/PLN exchange rate

X_3 [EUR/PLN]	n	
l	0	1
0	4.1472	4.3374
1		3.9653

The probabilities calculated using the Guthrie procedure [6], are $\pi_u^3 = 0.61$, $\pi_d^3 = 0.39$.

Analysis of the problem indicated that X_1 is moderately more important than X_3. The state variable X_2 is moderately more important than X_1 and strongly more important than X_3. Using the Saaty fundamental scale [13] and the AHP method, the following weights were obtained for each state variable: $w_1 = 0.258$, $w_2 = 0.637$ and $w_3 = 0.105$ for state variables X_1, X_2 and X_3, respectively. The consistency index CI was 0.037.

The final value according to the first criterion is calculated from the following utility function. If the value of the index of the business climate is higher than –20%, then the final value according to the first criterion is 0, otherwise it is 100.

$$f_1^e\left(X_1(i, n)\right) = \begin{cases} 0 & X_1(i, n) > -20.0\% \\ 100 & X_1(i, n) \leq -20.0\% \end{cases} \tag{13}$$

The final value according to the second criterion is also calculated from the utility function. If the price index is greater than 100%, then the final value according to the second criterion is 0, otherwise it is 100.

$$f_1^e\left(X_1(i, n)\right) = \begin{cases} 0 & X_2(j, n) > 100.0\% \\ 100 & X_2(j, n) \leq 100.0\% \end{cases} \tag{14}$$

The final value according to the third criterion is based on the additional cost :

$$f_1^e\left(X_1(i, n)\right) = -KX_3(l, n) \tag{15}$$

where $K = 0.5$ M € is the estimated cost of imported materials.

For the nodes in Fig. 5 marked by shaded circles, we calculate the final results of the activity. The calculated final values are presented in Table 5.

Table 5. Final values after the decision made at $n = 1$

(f_1^e, f_2^e, f_3^e)		
$l = 0$		
i, j	0	1
0	(0.00, 0.00, –2.17)	(0.00, 100.0, –2.17)
1	(100.00, 0.00, –2.17)	(100.00, 100.00, –2.17)
$l = 1$		
i, j	0	1
0	(0.00, 0.00, –1.98)	(0.00, 100.00, –1.98)
1	(100.00, 0.00, –1.98)	(100.00, 100.00, –1.98)

Using backward induction, from Eq. (1) we calculate the vector of values after the decision Wait. We used the values $r_1 = r_2 = 0\%$, as they are not financial values, and $r_3 = 4\%$.

We obtain the value vector $\mathbf{V}^W(i,\ j, l, 0))^T = (30.61, 78.50, -2.05)$. If we decide to act immediately, we obtain a vector of values equal to $\mathbf{V}^A(i, j, l, 0)^T = (100.00, 100.00, -2.07)$. The current index of the business tendency climate is low (–26%), so we can get a favorable contract. Prices in the construction industry are satisfactory, while the cost of imported materials is about 2.07 M PLN.

Using the TOPSIS method, we can compare these two vectors. This gives us $S_A = 0.99$ and $S_W = 0.01$. The optimal decision is to act immediately. Other problems solved using this method can be found in [16] and [18].

7. Conclusions

This paper has presented a systematic approach to the timing problem in development projects. In this approach, real options are taken into account. The real options considered are typical situations that occur in a project's environment. Examples of such options are delaying, abandonment and compound options.

This article has carried out a review of typical real options occurring in projects. It presents an outline of methods for multi-criteria evaluation aiding in deciding when to start a project or the next phase. From this point of view, the accuracy of valuation is not crucial. The approach presented is important when e.g. considering sustainable development projects, i.e. when we take into account more than one, namely financial, aspect of a project.

Awareness of the existence of real options in a project requires their proper use. Using backward induction, it is possible to calculate the correct time to exercise an option. This is connected with the necessity of a quantitative evaluation of the option. As mentioned before, as it is used to choose the right moment for an action, high accuracy is not required. Therefore, we used a method based on a binomial tree. Although this method is not very accurate, due to its simplicity, it can be understood and used by practitioners.

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