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MULTI-CRITERIA DECISION MAKING IN PROJECT ENVIRONMENT USING DECISION TREES AND REAL OPTIONS – A COMPARISON OF METHODS

Summary: The complexity of modern projects makes the proper management crucial. The volatile environment of the XXI century means that it is important to choose the right decision at the right moment. During the life of project there is the need to make many decisions, which are embedded in time. Moreover, in many cases evaluation of these decisions depends on multiple criteria. Two approaches are poposed to deal with such situation: Multicriteria Decision Tree and Multi-State Real Options (MSRO). The paper compares areas of applicability, limitations and advantages of these methods. As result, it is concluded, that MSRO method is more specific and can be used only in situations where exist real options.

Keywords: decision tree, real option, multiple criteria decision making.

JEL Classification: C30, C44, G11.

Introduction

The volatile environment of the XXI century is multifaceted. This is particular important in projects of sustainable development. According to the principles of sustainable development, results of the project, depend on certain factors, which may be economic, social and environmental ones. If we consider more than one factor, the problem is converted from a simple valuation to a multicriteria evaluation problem. This approach is widely discussed in the literature. The framework for project-level decisions, leading to more sustainable management and development, is proposed in [Comello, 2012]. The ecological, economic and social sources of landscape valuation are discussed in [Plottu, Plottu, 2012]. Heidkamp's paper [2008], proposes a theoretical framework for the integration of economic and environmental aspects into the decision making process for sustainable development strategies.

Perceived opportunities and threats lead us to change the present state into a more desirable one. The most effective way to do this is by implementing projects. Project management is the most effective way of development. The complexity of modern projects makes the proper management crucial. It also forces us to new ways of looking at project management. When choosing a project, it is necessary to consider not only certain results but also the future possibilities. This is also important when we choose the right moment to make decisions in project environments.

Two ways of dealing with decisions in dynamic environment are considered here: decision trees and real options. The paper compares areas of applicability, limitations and advantages of these methods. Taking into account multifaceted environment, which leads to multi criteria decision making problems, we present multi-criteria extensions of these methods. Second section presents the basics of multi criteria decision trees. In third section we consider origin of real option method based on binomial tree method. In the fourth section multi-criteria extensions of these methods are compared.

1. Multi-criteria decision trees

Decision tree is a well known and widely used tool for modelling and solving multi-stage decision making problems under risk [Keeney, Raiffa, 1976; von Winterfeld, Edwards, 1986; Covaliu, Oliver, 1995]. Through a graphical representation, even complex decision situation can be clearly presented to the DM. Three types of nodes are used in a decision tree: decision nodes (represented by squares), chance nodes (represented by circles) and final nodes (represented by dots). The branches leaving decision nodes represent decisions that can be made at this node, while the branches leaving chance nodes represent states of nature, that are not controlled by the DM, but affect the decision process. The tree illustrates a multi-period decision making process, which starts at the initial decision node. The aim is to identify optimal decision for each decision node. Decision trees are also used in project environment [Chiu, Gear, 1979; Granot, Zuckerman, 1991; Hess, 1993].

Decision trees are typically used for single criterion decision problems. A Multi-criteria Decision Tree (MCDT) was analysed by Haimes, Li and Tulsiani [1990], who proposed a method for generating the set of efficient solutions. Lootsma [1997] combined decision tree with two cardinal methods: multiplicative AHP and SMART in order to aggregate multidimensional consequences. In [Frohwein, Lambert, 2000; Frohwein, Haimes and Lambert, 2000] conditional expected value as a measure of risk of rare events was used. More recently Frini, Guitouni and Martel [2012] solved the multi-criteria decision tree problem without generating the set of all efficient solutions. Their approach combined advantages of decomposition with the application of multi-criteria decision aiding (MCDA) methods at each decision node.

An alternate concept for modelling multi-period decision processes that was proposed recently uses hybrid anticipatory networks [Skulimowski, 2014]. It assumes that that the DM takes into account the anticipated outcomes of future decision problems linked by the causal relations with the present decision problem. The problem is represented by a multi-graph, where decision problems are modelled as nodes linked causally and by one or more additional anticipation relations. In [Nowak, 2013] an interactive technique based on INSDECM procedure presented in [Nowak, 2006] was used to solve a multi-criteria decision tree problem. This method has been extended in [Nowak, 2016].

As the size of the tree increases roughly exponentially with the number of variables [Kirkwood, 1993], it can be successfully used only for relatively small-size problems.

2. Multi-State Real Options

Spotted opportunities and perceived threats lead us to change the present state, striving for continuous development. The most effective way to make this change is through conducting projects. When resources are limited, it is essential to choose the right project and start it at the most appropriate time. This choice is based on an evaluation of the project value.

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 multiple state variables. The first attempt, on the basis of financial options, was made by Boyle [1988], who took into account two assets. Guthrie [2009] also described problems for which it was necessary to consider a number of variables. In these attempts, different criteria were brought to a common financial denominator.

Valuation of Multi-State Real Options (MSRO) are based on the CRR method proposed by Cox, Ross and Rubinstein [1997]. Since many factors are assumed to be relevant, an extension of this method was proposed [Targiel, 2013b]. The new method consists of several steps: creating a decision tree (D-Tree), building a tree of state variables (X-Tree), building a project value tree (V-Tree), and at the end, determining efficient decisions. In a D-Tree, all the possible states of the project are recognized. They may represent different phases or specific stages for activities. The possible decisions that could be made when considering a state, are also recognized. Making a decision leads to a transition from one state to another. All possible transitions are identified. The X-Tree shows the possible changes in state variables and comprises the set of possible scenarios. This is a discrete approximation of stochastic process which describes state variable. In CRR method binomial tree is used, which parameters are estimated based on historical data in the calibration process.

Next step is building a tree of the project values (V-Tree). If a project evaluation is based on many state variables, values are therefore presented in a vector. The calculation of the value of the V-Tree begins from the end (final value). We assume that the final value of the project is a function of state variables. On this basis, the remaining values of the V-Tree are successively calculated.

The most important thing is to determine efficient decisions. The application of the proposed method leads to backward induction, in which we consider sets of efficient decisions based on the value of the project. Effective decision also gives an effective moment of decision. Several methods have been used for this purpose. In [Targiel, 2013a] weighted average method was proposed, while in [Targiel, 2015] TOPSIS method was applied.

3. Comparison of methods

Multi-Criteria Decision Trees are used to solve problems where dynamic multicriteria decision making problem under risk is considered. It is defined as follows:

1. The decision process consists of T periods. At each period, a decision must be made. Any decision made at period t determines the characteristics of the problem at period $t + 1$.
2. Risk is taken into account. It is assumed that states of nature are defined for each period and are modelled by probabilistic distributions.
3. Multiple conflicting criteria are considered.

Under following notation:

- T – number of periods,
- N^t – the set of decision nodes of period t (for $t = 1,...,T$):

$$N^t = \left\{ n_1^t, ..., n_k^t, ..., n_{m_d(t)}^t \right\} \tag{1}$$

- N^{T+1} – the set of terminal nodes,
- $A_k^t = \left\{ a_{1(k)}^t, ..., a_{i(k)}^t, ..., a_{m_a(k)}^t \right\}$ – the set of alternatives at node n_k^t,
- $E_{k,i}^t = \left\{ e_{1(k,i)}^t, ..., e_{j(k,i)}^t, ..., e_{m_e(k,i)}^t \right\}$ – the set of states of nature emerging from alternative $a_{i(k)}^t$,
- $p_{j(k,i)}^t$ – probability that $e_{j(k,i)}^t$ occurs.

Of course for all $t = 1, \dots, T$, $k = 1, \dots, m_d(t)$, $i = 1, \dots, m_e(t,k)$ the following condition must be satisfied:

$$\sum_{j=1}^{m_e(k,i)} p_{j(k,i)}^t = 1 \tag{2}$$

Under this notation, we can define transition function as follows:

$$k_{t+1} = \Omega_t(k_t, i(k_t), j(k_t, i(k_t))) \tag{3}$$

where k_t is index of decision node, $i(k_t)$ states for the index of the decision, and $j(k_t, i(k_t))$ represents the index of the state of nature.

The aim of the analysis is to specify the strategy that should be implemented by the DM. It is defined by a decision at the initial node and decisions at all nodes that may be achieved as a result of decisions made in previous periods. Each strategy is composed of partial strategies, which consists of decisions made at the particular node of period t and decisions made in next periods. We will denote partial strategy by $s_{l(k)}^t$ As we assume that a single decision node is defined for the first period, so $s_{l(k)}^1$ a strategy for the whole decision process.

Expected value is a common measure of performance for decision making in the face of risk. The strategy optimizing this measure can be identified using folding-back and-averaging-out procedure, which makes possible to eliminate inferior policies at intermediate nodes. If multiple criteria are considered and all are evaluated by expected values, the similar procedure can be applied to identify efficient strategies [Haimes, Li and Tulsiani, 1990].

In Multi-State Real Options (MSRO), D-Tree is defined using following notation. For $t = 0,..., T$ we define sets:

- Y_t – set of all feasible states in time t,
- $D_t(y_t)$ – set of all feasible decision in time t, in state $y_t \in Y_t$,
- R_t – the set of all period realization r_t in time t. (r_t is (y_t, d_t)).

We can define transition function:

$$\Omega_t : (Y_t, D_t) \to Y_{t+1}, \tag{4}$$

$$\Omega_t : y_{t+1} = \Omega(y_t, d_t). \tag{5}$$

D-Tree is defined as:

$$R = \left\{ r = (r_0, ..., r_T) : \forall_{t \in 0,...,T-1} \quad y_{t+1} = \Omega(y_t, d_t) \wedge d_t \in D_t(y_t) \right\}. \tag{6}$$

Under some assumption we can transfer this model into decision tree:

- D-Tree, X-Tree and V-Tree nodes are defined in the same time moments t,
- decisions d_t in each step are alternative a^t to take action or not,
- action can be taken only once,
- in each node only one of two events can occur: value of state variable moves up or moves down to the same extent for each node. This extent can be estimated during calibration,
- probability p_u^t of move up gives probability of move down $1 - p_d^t$ and they are the same during all time. Those probabilities can also be estimated during calibration.

Under such assumptions process realization r is equivalent with strategy for the whole decision process $s_{l(k)}^1$. Series of period realization beginning in moment t – $(r_t, r_{t+1}, ..., t_T)$ is partial strategy by $s_{l(k)}^t$.

In both methods partial strategies are evaluated using multi-criteria methods. In MCDT different measures of effectiveness are considered, like expected value, probability of some events, conditional expected value. In MCRO only expected value is used. Moreover, according to assumption that project is proper managed in each stage we can choose final effective alternative (in each decision node). This approach radically reduce number of considered strategies, avoiding curse of dimension. Calculated expected values creates V-Tree, Nodes of this tree are used in calculations further evaluations for previous stages.

Conclusions

In paper we compare two methods of multi-criteria decision-making Multi--Criteria Decision Tree (MCDT) and Multi-State Real Options (MSRO), which were considered in the project environment. MCDT method is more general. With some assumptions, which have been presented in the work, the problem described as a real option can be transferred to this method.

MCRO method as more specific, can be used in situations where exist real options. There must exist more than one variable, which can be modelled using stochastic processes. Advantage of this method is the way of calculation probabilities, which in MCDT method is not specified.

In this paper, we focused only on one aspect of the described methods, namely the description of the decision-making process. Equally interesting is to compare the ways of decisions valuation, that is the criteria system. This is the subject of future research. Applications of those methods in various areas, like project portfolio management, innovation management and supply chain management must also be considered.

References

Boyle P.P. (1988), *A Lattice Framework for Option Pricing with Two State Variables*, "Journal of Financial and Quantitative Analysis", Vol. 23, No. 1, pp. 1-12.

Chiu L., Gear T.E. (1979), *An Application and Case History of a Dynamic R&D Portfolio Selection Model*, "IEEE Trans. Eng. Manage", Vol. 26, pp. 2-7.

Comello S.D., Lepech M.D., Schwegler B. (2012), *Project-Level Assessment of Environmental Impact: Ecosystem Services Approach to Sustainable Management and Development*, "Journal of Management in Engineering", Vol. 28, No. 1, pp. 5-12.

Covaliu Z., Oliver R.M. (1995), *Representation and Solution of Decision Problems Using Sequential Decision Diagrams*, "Management Science", Vol. 41, pp. 1860-1881.

Cox J.C., Ross S.A., Rubinstein M. (1979), *Option Pricing: A Simplified Approach*, "Journal of Financial Economics", Vol. 7, pp. 229-263.

Frini A., Guitouni A., Martel J.M. (2012), *A General Decomposition Approach for Multicriteria Decision Trees*, "European Journal of Operational Research", Vol. 220, pp. 452-460.

Frohwein H.I., Haimes Y.Y., Lambert J.H. (2000), *Risk of Extreme Events in Multiobjective Decision Trees. Part 2: Rare Events*, "Risk Analysis", Vol. 20, pp. 125-134.

Frohwein H.I., Lambert J.H. (2000), *Risk of Extreme Events in Multiobjective Decision Trees. Part 1: Severe Events*, "Risk Analysis", Vol. 20, pp. 113-123.

Granot D., Zuckerman D. (1991), *Optimal Sequencing and Resource Allocation in Research and Development Projects*, "Management Science", Vol. 37, pp. 140-156.

Guthrie G. (2009), *Real Options in Theory and Practice*, Oxford University Press, Oxford.

Hess S.W. (1993), *Swinging on the Branch of a Tree: Project Selection Applications*, "Interfaces", Vol. 23, pp. 5-12.

Haimes Y., Li D., Tulsiani V. (1990), *Multiobjective Decision Tree Method*, "Risk Analysis", Vol. 10, pp. 111-129.

Heidkamp C.P. (2008), *A Theoretical Framework for a 'Spatially Conscious' Economic Analysis of Environmental Issues*, "Geoforum", Vol. 39, No. 1, pp. 62-75.

Keeney R.L., Raiffa H. (1976), *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, Wiley, New York.

Kirkwood C.W. (1993), *An Algebraic Approach to Formulating and Solving Large Models for Sequential Decisions under Uncertainty*, "Management Science", Vol. 39, pp. 900-913.

Lootsma F.A. (1997), *Multicriteria Decision Analysis in a Decision Tree*, "European Journal of Operational Research", Vol. 101, pp. 442-451.

Nowak M. (2006), *INSDECM – an Interactive Procedure for Discrete Stochastic Multicriteria Decision Making Problems*, "European Journal of Operational Research", Vol. 175, pp. 1413-1430.

Nowak M. (2013), *An Interactive Procedure for Multiple Criteria Decision Tree* [in:] A. Skulimowski (ed.), *Looking into the Future of Creativity and Decision Support Systems*, Proceedings of the 8th International Conference on Knowledge, Information and Creativity Support Systems, Progress and Business Publishers, Kraków, pp. 461-472.

Nowak M. (2016), *Solving a Multicriteria Decision Tree Problem Using Interactive Approach* [in:] A.M.J. Skulimowski, J. Kacprzyk (eds.), *Knowledge, Information and Creativity Support Systems: Recent Trends*, "Advances and Solutions. Advances in Intelligent Systems and Computing", No. 364, pp. 301-314.

Plottu E., Plottu B. (2012), *Total Landscape Values: A Multi-Dimensional Approach*, "Journal of Environmental Planning and Management", Vol. 55, No. 6, pp. 797-811.

Skulimowski A. (2014), *Anticipatory Network Models of Multicriteria Decision-Making Processes*, "International Journal of Systems Science", Vol. 45, pp. 39-59.

Targiel K.S. (2013a), *Valuation of Investment Projects in the Context of Sustainable Development: Real Option Approach*, 2013 World Congress on Sustainable Technologies (WCST) Proceedings, London, pp. 90-94.

Targiel K.S. (2013b), *Multiple Criteria Decision Making in the Valuation of Real Options*, "Multiple Criteria Decision Making", Vol. 8, pp. 129-142.

Targiel K.S. (2015), *Real Options in a Systemic Approach to the Timing Problem in Development Projects*, "Operations Research and Decisions", Vol. 25, pp. 73-85.

Winterfeld D. von, Edwards W. (1986), *Decision Analysis and Behavioral Research*, Cambridge University Press, Cambridge.

WIELOKRYTERIALNE DECYZJE W PROJEKTOWANIU ŚRODOWISKOWYM WYKORZYSTUJĄCE DRZEWA DECYZYJNE I OPCJE REALNE – PORÓWNANIE METOD

Streszczenie: Złożoność nowoczesnych projektów sprawia, że zarządzanie ma kluczowe znaczenie. Niestabilne środowisko XXI w. oznacza, że ważne jest, aby podjąć właściwą decyzję w odpowiednim momencie. W trakcie realizacji projektu konieczne jest podjęcie wielu decyzji osadzonych w czasie. Ponadto często ocena tych decyzji zależy od wielu kryteriów. W celu rozwiązania takich sytuacji pojawiają się dwa podejścia: wielokryterialne drzewo decyzyjne i wielostanowe opcje realne (MSRO). W pracy porównano obszary zastosowań, ograniczenia i zalety tych metod. W rezultacie stwierdzono, że metoda MSRO jest bardziej specyficzna i może być stosowana tylko w sytuacjach, w których istnieją opcje realne.

Słowa kluczowe: drzewo decyzyjne, opcja realna, podejmowanie decyzji wielokryterialnych.