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SUSTAINABILITY PROJECT: RISK ANALYSIS BASED ON DECISION TREES UNDER CONDITIONS OF TOTAL AND PARTIAL IGNORANCE

Karel Doubravský[1], Radek Doskočil[2], Mirko Dohnal[3]

[1,2] Brno University of Technology, Faculty of Business and Management, Institute of informatics, Kolejní 2906/4, CZ-61200, Brno, Czech Republic
[3]Brno University of Technology, Faculty of Business and Management, Institute of economics, Kolejní 2906/4, CZ-61200, Brno, Czech Republic

E-mails: [1] doubravsky@fbm.vutbr.cz; [2] doskocil@fbm.vutbr.cz; [3]dohnal@fbm.vutbr.cz

Abstract. Sustainability project is an important part of project management and depends on many factors, such as financial resources, human resources, scheduling operations and especially potential risks. This paper presents a way to work with uncertain information processing project risk analysis with regard to its sustainability. Risk management is an important part of various disciplines, e.g. Project management, Crisis management, Change management, Information Security Management System, etc. Risk analysis is mostly based on expert estimates. However, this may be a problem with brand new tasks as identification of different threats and their numerical evaluations can be interpreted as a decision-making task which can be formalised as a decision tree. A decision-making task solution requires knowledge of all relevant input information items (III), such as probabilities, penalties and profits. If all those numerical values are known then the well-known methods of decision trees evaluations can be used. However, if complex project management problems are solved then a substantial set of relevant data items is missing or its accuracies are prohibitively low. The aim of this paper is to present easy approach how missing elements of the III set can be obtained and integrated into incomplete data sets. The paper contributes a common sense heuristics to obtain missing elements of the III set which can generate all numerical values, i.e. a problem under complete ignorance is solve, and a reconciliation mechanism based on linear programming which allows results of common sense heuristics simply integrate into incomplete data set, i.e. a problem under partial ignorance is solved. The results are therefore divided into two parts. In the first part solves a problem under total ignorance. The second part of the case study evaluates some unknown probabilities, therefore solves a problem under partial ignorance. Both tasks, i.e. partial and total ignorance are demonstrated using a quasi-realistic decision tree. The decision tree has one root node, 6 lotteries and 15 terminals; the total number of unknown probabilities is 21 under total ignorance and 18 probabilities are evaluated under partial ignorance.

Keywords: project risks, sustainability projects, decision tree, total ignorance, partial ignorance, reconciliation.

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JEL classifications: Q01, O22, D81

1. Introduction

Project management is a widely used discipline whose spectrum of different applications is very broad, e.g. politics, economics, sociology, ecology, see e.g. (Chan et al. 2011; Hwang et al. 2014; Kuo & Lu 2013; Čirjevskis 2015; Tvaronavičienė et al. 2015; Lace et al. 2015; Oganisjana et al. 2015; Vaško, Abrhám 2015; Laužikas et al. 2015; Dobele et al. 2015; Prause 2015; Beifert 2015; Schröder, Prause 2015; Pelše et al. 2015; Ignatavičius et al.; Endrijaitis, Alonderis 2015). From the perspective of project management is important to realize that the management of the project does not end with the termination of its implementation (investment) phase, but continues operating phase. In both phases of the project is necessary to assess and manage its sustainability. Project sustainability is the set of characteristics that affect performance, outcomes, and achieving objectives. Project sustainability is generally a time for which must be project outputs unchanged retained (Chuanmin et al., 2012; Shen et al., 2011). Usually it is a period of 5 years from the date of completion of the physical implementation of the project, see e.g. (Khan, 2015, 1995).

The authors Poveda and Lipsett present the Wa-Pa-Su project sustainability rating system presents an integrated approach to sustainability assessment by integrating three distinctive areas of knowledge: 1) sustainable development theory and fundamentals supports the ultimate goal of the rating system, which is to contribute to sustainability, with the aim of finding a path to balance social, economic, and environmental needs; 2) continual performance improvement becomes essential due to the duration of the projects, as it is critical to allow organizations or projects to improve performance over time; and 3) multi-criteria decision analysis assists with the assessment process through stakeholder engagement and participation, and the design and implementation of a criteria weighting system (Poveda and Lipsett, 2014). The research by the authors Pereira et al. presented a methodology that uses the Monte Carlo Method to estimate the behavior of economic parameters which may help decision, considering the risk in project sustainability. This methodology was used on a Grid-Connected Photovoltaic System (GCPVS) of 1.575 kWp (da Silva Pereira et al., 2014). In the case study authors Zhang et al present an improved SDA (Sustainable Development Ability) prototype model that incorporates the effects of dynamical factors on project sustainability. This involves the introduction of two major factors concerning technological advancement and changes in people’s perceptions (Zhang et al., 2014).

From the nature of the concept of project sustainability indicate that directly relate mainly to the project risk management (MacAskill and Guthrie, 2013), but also with financial planning, human resource planning and scheduling operations. Risk analysis is among the basic processes of project management and with projects sustainability directly related. The need to manage the risk of projects is included in the international standards *ISO 31000 Risk Management - Principles and guidelines* and *IEC 62198 Managing risk in projects - Application guidelines* (Cooper et al., 2014).

This paper presents a way to work with uncertain information processing project risk analysis with regard to its sustainability. Risks evaluations are essential activities of management process of project risk and directly determines the success or failure of a project under study (Czech Standards Institute 2002) and are often based on vague, inconsistent, partially subjective data / knowledge items of interdisciplinary nature (Chen et al. 2009). The importance of the risk management and its complexity is reflected by a broad spectrum of formal tools, such as cause and effect diagrams, risk tree, risk maps, brainstorming, simulation, see e.g. (Bergantiños & Vidal-Puga 2009; Hwang et al. 2014; Relich 2012, 2010), expert estimates, see e.g. (Chan et al. 2011), and widely used fuzzy sets, e.g. methods of fuzzy logic, fuzzy numbers, etc.(Peker et al. 2014).

The method of fuzzy logic applied to the risk management process is described in (Nasirzadeh et al. 2014). The authors present an integrated fuzzy system dynamic modelling for quantitative risk assessment. The values of the various factors, which are characterized by the nature of uncertainty, are defined by fuzzy numbers. The proposed model was simulated at different levels of risk; the optimum level of risk is determined by the point at which the minimum cost of the project, see e.g. (Nasirzadeh et al. 2014).

The same risk issues of construction projects are presented by authors Yao-Chen Kuo and Shih-Lu Tong. This study deals with a fuzzy multiple criteria decision making approach to systematically assess risk for a metropolitan construction project where twenty risk factors were identified. Triangular fuzzy sets are used for describing of identified factors. The overall risk level of the project depends on the individual impact of individual risk factors; the scheme was evaluated based on the relative impact and likelihood. They note that the suggested model for risk assessment is more reliable, more convenient than traditional statistical methods, and that this model can be used to efficiently identify risks metropolitan construction projects, see (Kuo & Lu 2013).

An article by Nieto Morote-and-Ruz Vila is a methodology for risk assessment based on fuzzy set theory, which is an effective tool for dealing with subjective assessments. The proposed methodology is based on the knowledge and experience gained from many experts. Risk factors are evaluated by qualitative criteria in the form of trapezoidal fuzzy numbers. Fuzzy numbers describe the uncertainty variables at the language level, see .e.g. (Nieto-Morote & Ruz-Vilas 2011).

Application of fuzzy logic in project risk management of Czech authors is also engaged by Peták. The author informs about the appropriateness of using fuzzy methodology in project risk management. For a description of risks uses ordinal scale: small, medium, large risk, which is 'sharp' description of dynamic phenomenon. Subsequently author recommends the scale transform on fuzzy concepts using fuzzy sets of the complete system, see e.g. (Peták 2011).

In the study 'The Moderating effect of risk on the Relationship between planning and success' authors Zwikael, Pathak, Singh, Ahmed deal with examination the relationship between the project planning process and its success. They show the level of success (measured in the form of risk) associated with the project plan. They conclude the high risk projects must be carefully planned, see e.g. (Zwikael et al. 2014).

Most of above noted decision tasks (Relich et al., 2014) can be represented by single root trees, i.e. decision trees, and sets of available III (input information items), such as probabilities, penalties, plausibility etc., see e.g. (Thipwiwatpotjana & Lodwick 2014). In the practice, the complete III set is usually not available. The above noted literature review revealed there is main problem, such as lack information and information uncertainty. Problem of information uncertainty is usually solved using fuzzy sets. Problem of lack information is usually based on usage metaheuristics, see e.g. (Bradshaw 2000; Jegadeesh et al. 2004). Decisions are made under information shortage; therefore classical statistical methods are not applicable, see .e.g. (Spanos 2010). When the information about uncertainty cannot be quantified in a simple probabilistic way, the topic of possibility decision theory is often a natural one to consider, see e.g. (Dubois 2014; Fargier et al. 2012). However, if the probabilities interpretation is not used then it is difficult for a decision maker from such branches as economics and engineering who has no relevant knowledge of the relevant methods of Artificial Intelligence to understand how the reconciliation results are achieved, see e.g. (Danielson et al. 2007; Nie et al. 2009). These studies focus on description of second-order representation which may significantly increase a decision-maker's understanding of a decision situation. Relations of a complex set of pairs of Causes – Consequences can be formalized by a decision tree. A sophisticated set of knowledge items generates such decision tree which has many branches as a specific Cause has several Consequences. Therefore a methodology is needed to quantify the missing elements of the III set in the decision tree. This is a serious problem as experts of practice are often not willing to accept results based on algorithms which are not clearly understood or computationally demanding for them, such as Monte Carlo method, a discriminant analysis, logistic regression, artificial neural networks (multilayer perceptron), fuzzy logic, see .e.g. (Jaskowski et al. 2014; Mileris & Boguslauskas 2011; Zhang 2012). Moreover majority of these methods cannot feasibly absorb additional information which is usually not fully consistent with relevant sets of available III (input information items). Moreover above noted studies are based either on very sophisticated algorithms of reconciliation or free description of reconciliation. The studied models of reconciliation were created for specific situations. This is a serious problem as experts of practice, e.g. project management, often have a problem with the implementation of such models.

Therefore the aim of paper is to present new easy approach how missing elements of the III set can be obtained and integrated into incomplete data sets. The paper's original contributions are the following. First, it provides common sense heuristics to obtain missing elements of the III set which can generate all numerical values, i.e. a problem under complete ignorance is solved. Second, it provides a reconciliation mechanism which allows results of common sense heuristics simply integrate into incomplete data set, i.e. a problem under partial ignorance is solved.

The rest of the paper is organized as follows. The next section discusses the relevant theory and methods about common sense heuristics and reconciliation algorithm. This section is followed by results. The results are demonstrated using a quasi-realistic decision tree. The decision tree has one root node, 6 lotteries and 15 terminals; the total number of unknown probabilities is 21 under total ignorance and 18 probabilities are evaluated under partial ignorance. The final section presents a discussion of findings and implications for future research.

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2. Materials and Methods

2.1. Heuristics

Missing quantitative items of III must be evaluated in order to solve the risk tasks under study. Decision-makers are therefore often / sometimes ready to accept some general heuristics as the only way to compensate the missing numerical values. There are several possible common sense heuristics. The heuristic used in this paper is, see (Kubíčková et al. 2013):

The longer sequence of events is more probable (1)

The heuristic (1) is based on a common sense assumption that if we know more about an event then this event is more probable. A broader spectrum of knowledge item related to an event is an indication that this event is studied for a longer time and consequently its behaviour can be more precisely predicted. However, if a user is not willing to accept the heuristic (1) then he/she can choose any other heuristic, e.g.

The longer sequence of event is less probable

2.2. Total ignorance

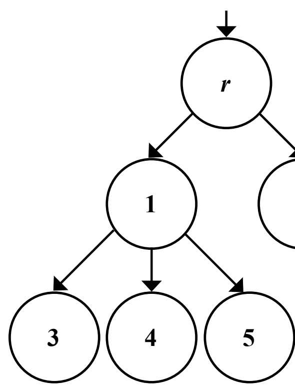

Figure 1. Decision Tree

Source: own processing

A decision tree has one root node *r*, see e.g. Figure 1. The following definitions are used:

T Set of terminals, see e.g. nodes 2, 3, 4 and 5; see e.g. Figure 1.

N Set of all nodes.

s_{ij} Number of edges of the sub-tree where *i* is the root of the sub-tree and *j* is the node next to the sub-root, see e.g. $s_{r1} = 4$ namely the edges r-1, 1-3, 1-4, 1-5. (2)

S_i Number of all edges of the sub-tree where *i* is the sub-root (resistance of *i*th node).

$$S_i = \sum_j s_{ij} \text{, see e.g. } S_r = s_{r1} + s_{r2} = 4 + 1 = 5 \quad (3)$$

where *j* represents nearest downstream node of the sub-tree next to the *i*th node.

$\alpha_{i,j}$ is splitting ratio from *i*th node to *j*th node:

$$\alpha_{i,j} = s_{ij}/S_i \text{, for all } j \in N - T \text{, see e.g. } \alpha_{r,1} = s_{r1}/S_r = 4/5 \quad (4)$$

P_j of *j*th terminal for $j \in N$ is a probability of *j*th node. The value P_r of a root node is always equal one.

$$P_r = 1 \tag{5}$$

Non-root node probability is

$$P_j = P_i \cdot \alpha_{i,j},\ j = 1,2,\ldots,K \tag{6}$$

where *i* represents nearest forgoing node (the sub-root node of the sub-tree) and $K = (N - T)$ is number of non-terminal nodes. The set of K linear equations (6), where the set **P** is a vector of unknown variables and the splitting ratios *α* (4) are numerical constants, is denote as a set of balance equation which can be easily solved as system of linear equations **A · P = B**; see e.g. (Meluzín et al. 2012).

Solving system of equations (6) gives the probabilities of the terminals under total ignorance (only topology of decision tree is known).

2.3. Partial ignorance

A typical feature of all realistic decision tasks is a shortage of information. Isolated information items, e.g. probabilities of certain events, are known. The concept of the total ignorance represented by e.g. the heuristics (1) helps to incorporate a set of isolated specific information items within a general framework of metaheuristics; see e.g. (Kubíčková et al. 2013). An incomplete set (7) of isolated specific probabilities

$$R \equiv (R_1, R_2, \ldots, R_h) \tag{7}$$

has *h* elements. Each element of the set R can be formally interpreted as an equation.

The answer to the question how to incorporate additional information into total ignorance gives reconciliation, see e.g. (Doubravsky and Dohnal, 2015).

Reconciliation is a solution of an over-specified set of linear equations (6) and trivial equations (7):

$$\mathbf{E} = \mathbf{A} \cdot \mathbf{P} = \mathbf{B} \cup \mathbf{P} = \mathbf{R} \tag{8}$$

The set of equations E has $n + h$ equations and *n* variables P (see (6)). The set of equations (9) has nearly always no solution. An objective function *F*

$$F = \sum_{j=1}^{h} d_j \tag{9}$$

is chosen which is minimized. This function (9) is usually a sum of deviations *d* (10)

$$d_j = P_j - R_j \tag{10}$$

where $j = 1,\ldots, h$. A methods of linear programming is used to solve the following problems (11)

$$\begin{aligned} &\min F \\ &\text{s.t.}\ a_1 P_1 = b_1 \\ &\quad\vdots \\ &\quad a_n P_n = b_n \\ &\quad P_{n+1} = R_{n+1} \\ &\quad\vdots \\ &\quad P_{n+h} = R_{n+h} \end{aligned} \tag{11}$$

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The reconciliation can be solved by a well-known algorithms of linear programming; see e.g. (Buckley 1988; Huang & Dan Moore 1993; Tan et al. 2007).

3. Results and Discussion

A medium-sized decision-making tree was chosen as a case study. A simplified version of this decision-making tree is seen on Figure 2. The nodes represent „Lotteries“, for details, see e.g. (Rose 1976), where the decision-maker is not in control.

The tree, Figure 2, has four levels. The nodes are described according the levels in Table 1.

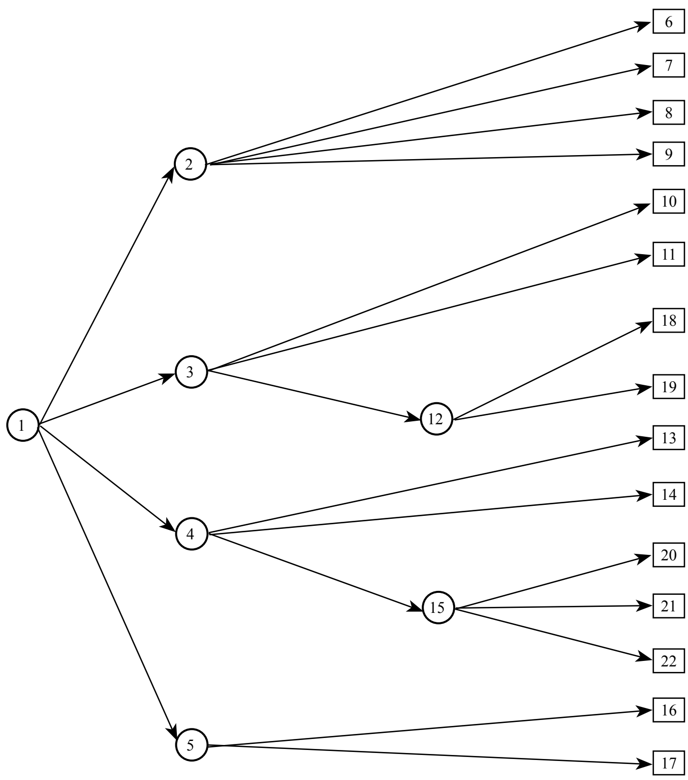

Figure 2. Decision-making tree

Source: own processing

Table 1. Importance of nods

Level	Node	Importance	Level	Node	Importance
I (scenario)	1	Extending the project duration	IV (threat)	10	Resources lack
II (threat)	2	Stakeholders	IV (threat)	11	Resources loss
II (threat)	3	Resources	IV (threat)	13	Exaggeration durations
II (threat)	4	Plan	IV (threat)	14	High criticality tasks
II (threat)	5	Finance	IV (threat)	16	Cash flow loss
III (threat)	12	Poor allocation resources	IV (threat)	17	Cash flow interruption
III (threat)	15	Network graph	IV (threat)	18	Uneven allocation resources
IV (threat)	6	Poor project team management	IV (threat)	19	Resources overload
IV (threat)	7	Suppliers	IV (threat)	20	Incorrect task link
IV (threat)	8	Investor	IV (threat)	21	Incorrect milestones
IV (threat)	9	Others (government, media, citizens)	IV (threat)	22	Incorrect constrain tasks

Source: own processing

Case study is divided into two parts, namely total and partial ignorance.

3.1. Total ignorance

The following table shows the splitting ratios α (4) of each branch of Figure 2.

Table 2. Splitting ratio

Branch	Splitting ratio
1-2	0.238
1-3	0.286
1-4	0.333
1-5	0.143
2-6	0.25
2-7	0.25
2-8	0.25
2-9	0.25
3-10	0.6
3-11	0.2
3-12	0.2
4-13	0.167
4-14	0.167
4-15	0.667
5-16	0.5
5-17	0.5
12-18	0.5
12-19	0.5
15-20	0.333
15-21	0.333
15-22	0.333

Source: own processing

The following table shows the probabilities P of threats (6), which were obtained by solving the problem (11).

Table 3. Probabilities of threats

Node (threat)	Threat Probability
6	0.0595
7	0.0595
8	0.0595
9	0.0595
10	0.0572
11	0.0572
13	0.0556
14	0.0556
16	0.0715
17	0.0715
18	0.0858
19	0.0858
20	0.0739
21	0.0739
22	0.0739

Source: own processing

3.2. Partial ignorance

The topology of the decision tree (see Figure 2) is known and isolated probabilities (7) of some splitting ratios (4) are known as well, see Table 4.

Let us suppose that the following splitting ratios are known (may be an expert estimation, data collected on the basis of historical data, etc.), therefore the III set is partially known:

Table 4. Known splitting ratios

Branch	Splitting ratio
1-4	0.5
5-17	0.6
12-19	0.6

Source: own processing

The decision-making problem is solved as a reconciliation problem (8). The following table shows the splitting ratios (4) of each branch of Figure 2.

Table 5. Splitting ratio

Branch	Splitting ratio
1-2	0.238
1-3	0.119
1-4	0.5
1-5	0.143
2-6	0.25
2-7	0.25
2-8	0.25
2-9	0.25
3-10	0.6
3-11	0.2
3-12	0.2
4-13	0.167
4-14	0.167
4-15	0.667
5-16	0.4
5-17	0.6
12-18	0.4
12-19	0.6
15-20	0.333
15-21	0.333
15-22	0.333

Source: own processing

Table 6 shows the probabilities of all threats (6).

Table 6. Probabilities of threats

Node (threat)	Threat Probability
6	0.0595
7	0.0595
8	0.0595
9	0.0595
10	0.0238
11	0.0238
13	0.0835
14	0.0835
16	0.0572
17	0.0858
18	0.02856
19	0.04284
20	0.1110
21	0.1110
22	0.1110

Source: own processing

The probability values, see Table 6, are required with well-known method, such as RIPRAN method, scoring method see e.g. (Doležal et al 2012; Lacko 2014; Chan et al. 2011; Cleland 1998; Chan et al. 2011).

In analysis of risk projects expert estimates of values of probabilities threats are usually obtained using Delphi techniques, such as Team Delphi, see. e.g. (Lester 2014). These techniques are based on a subjective assessment of the probability of threats by each expert. Some modifications of these techniques use the arithmetic means of subjective assessments others use fuzzy numbers, see .e.g. (Kuo & Lu 2013; Nieto-Morote & Ruz-Vila 2011). More often is used a qualitative approach where threats are verbally assessed, e.g. High, Medium, Low, see (Lester 2014). Essential for all these techniques is that experts have given the value of probability to all considered threats.

The proposed approach allows to assessment only some threats (some probabilities are known from previous projects), the remaining threats are assessed on the basis of known topology of the decision / risk tree. This approach can also be used even if the decision tree topology is only available known information.

Conclusion

The importance of identification of risks attracts attention of many researchers. Identification of a complex risk related task involves identifying threats, scenarios and their evaluations. The article shows a possible approach to evaluation of identified threats of a scenario. The proposed approach is based on an easy to understand heuristic that uses the decision tree topology as the only available information. This new approach is shown in a case study. The relevant decision tree has 22 nodes. The case study is divided into two parts which represent the total and partial ignorance.

The problem of reconciliation of probabilities generated by the used heuristic and the available subset of probabilities is solved by using linear programming. The advantage of this approach lies in the fact that the objective function and the equations of the individual constrain are linear, and therefore easily solvable using commonly known simplex method.

Limitation of proposed approach is the need to build decision tree (it can be large for extensive projects). Also it should be noted that the proposed heuristics (1) is not the only one possible and it may not suit all decision-making problems. The choice of suitable heuristics depends on the type of solved decision-making problem.

The proposed approach have broad spectrum of applications, e.g. failure trees evaluations. Moreover it is possible to take into consideration tasks where the probabilities are given vaguely, e.g. using fuzzy numbers, or they are specified from different sources, e.g. from different members of project teams, experts of project management, etc.

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Karel DOUBRAVSKÝ is an Assistant Professor at Brno University of Technology, Department of Informatics. His research and publication activities are focused on problems of data mining, mathematical statistics, decision analysis and qualitative modelling.

Radek DOSKOČIL is an Assistant Professor at Brno University of Technology, Department of Informatics. His research and publication activities are focused on problems of knowledge management, project management and quantitative decision-making methods.

Mirko DOHNAL is a Professor at Brno University of Technology, Knowledge Economics Center. His research is in several areas, e.g., ecology, knowledge engineering, as he cooperates with many departments of the university. Qualitative models and their possible applications are currently the most important task.