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MULTI-CRITERIA DECISION AIDING IN PROJECT PLANNING USING DECISION TREES AND SIMULATION

Abstract

A good plan is fundamental for a project's success. Inaccuracies in planning are reported to be among the main reasons of a project's fiasco. Planning means making a variety of decisions. As these decisions refer to the future, so when faced with them, the decision maker has also to face uncertainty. The selection of a new project or a group of projects, as well as decisions how to implement them, involve prediction and comparison of future outcomes. In real world, not every possible future outcome is known with certainty. Thus, decisions made during the project planning process are usually based on past experience, either rationally or intuitively with some degree of uncertainty, and thus are made under risk.

The aim of the paper is to present a simple, yet comprehensive, methodology for project planning that permits the consideration of both multiple criteria and risk. Our approach combines decision trees, simulation modelling and stochastic dominance rules. An example is presented to show the applicability of the procedure. It is based on the experiences of a company providing solutions for the railway industry.

Keywords

Project planning, decision tree, simulation, multiple criteria decision making.

Introduction

A good plan is fundamental for a project's success. Inaccuracies in planning are reported to be among the main reasons of a project's fiasco. The term "project planning" is not uniformly defined. Some authors suggest that planning is just scheduling – determining the dates for performing schedule activities and meeting schedule milestones. However, project planning is also more broadly understood, as a process that includes a number of phases and starts shortly after a business need, contract request, or request for proposal has been received [Nicholas and Steyn, 2008]. A Guide to the Project Management Body of Knowledge [PMBOK, Guide, 2004] defines a project management plan as follows: "A formal, approved document that defines how the project is executed, monitored and controlled". In this paper we focus on the initial phase of the planning process, when basic assumptions defining the project are made.

Planning means making a variety of decisions. As these decisions refer to the future, so when faced with them, the decision maker (DM) has also to face uncertainty. The selection of a new project or a group of projects, as well as decisions how to implement them, involve prediction and comparison of future outcomes. In real world, all possible future outcomes are not known with certainty. Project planning is usually based on past experience. Decisions within this phase of project life cycle are made either rationally or intuitively with some degree of uncertainty, and thus are made under risk.

Although financial analysis plays the key role in project planning, other criteria are also important. It is usually assumed that the purpose for project is to achieve an objective, that cannot be attained by standard operational work. However, the overall goal of the project is often expressed in general terms. A widely used statement says that the goal of a project is to hit a three-dimensional target: to complete the work in accordance with budget, schedule, and performance. As a result, project management problems can be considered as decision problems with multiple criteria. It should be also mentioned that projects are tools for achieving the organization's strategic plan. As profitability is not the only goal considered when the strategy is formulated, various criteria should be taken into account when various ways of project completion are compared.

The aim of this paper is to present a simple, yet comprehensive, methodology for project planning that permits the consideration of both multiple criteria and risk. Our approach combines decision trees, simulation modelling and stochastic dominance rules. The paper is organized as follows. Section 1 describes the project planning process and defines problems considered in this paper. Next section gives a literature overview. In section 3 new methodology for project planning decisions is introduced. Section 4 presents a numerical example. We finish with some conclusions and suggestions for future research in the last section.

1. Decision problems within planning phase of the project's life cycle

In this paper we focus on projects realized by manufacturing organizations by applying the so-called Project Management style of business management. In such companies, most business activity is focused on implementation projects with clearly defined goals and precisely specified due dates. A rough taxonomy of projects implemented by them involves: research and development, engineering, and service. The first group involves projects aimed at developing new products. The main feature of such projects is the lack of direct profit. Their implementation involves significant costs, resulting mainly from the salaries of engineers, designers and constructors.

The next group includes a wide rage of undertakings, from small modernization projects to large-scale ones with budgets of hundreds of millions of euro. The realization of such projects is often the main source of company's revenue and involves all the departments and divisions. Due to their complexity, projects of this type are often subdivided into three stages: the preliminary stage, a middle stage involving preparing and negotiating tenders, and a final implementation stage. Each phase, while significantly distinctive in scope from the others, is a part of the project as a whole. Engineering projects implementation is based on widely used project management methodologies and techniques.

The last group consists of service projects. As with engineering projects, their realization is based on classical project management approaches. They can be divided in two main groups:

- modernization projects involving replacement and upgrades of existing contractor's infrastructure,
- repair projects implemented mainly in manufacturing companies and involving the removal of defects in products delivered to customers.

Although repair projects are a small percentage of all projects, their implementation has a significant contribution to the overall company image. Time and resource availability play an important role in such projects. Since for the company a repair project represents only costs, shortening the completion time is crucial.

Going back to engineering projects we should point out that various teams are usually responsible for the implementation of various project phases. The initial phase of the project focuses on the analysis of business opportunities for planned activities from the perspective of the company itself and its business partners (investor, suppliers). This stage begins from the receipt of the first information about the customer plans of the future investment. At this stage the tender conditions are not yet known, so the analysis is based only on the experience with similar projects completed previously. The bid team has to decide whether the company will be able to accomplish the project, and to specify the project configuration optimal both from financial and scheduling point of view. Various solutions are considered, taking into account production capacity of sub-contractors and suppliers. Inspections in the area, where investment is to be implemented, are often necessary to propose a spectrum of alternatives to the person (or the team) responsible for deciding whether to continue the project.

The next phase of project planning starts with obtaining detailed information about the investment or purchasing tender conditions and continues until the final tender is submitted. At this stage the organization focuses on gatheri ng offers from suppliers and analyzing availability of resources: project manager and team members, equipment, financing, etc. Before preparing a final offer, a preliminary schedule should be prepared. Project planning is completed as soon as the contract is signed. At this stage a detailed project schedule is prepared, taking into account the availability of resources.

In this study we focus only on the initial phase of the project planning process. Highly skilled staff is required to complete it successfully. To make good decisions, both experience from the previous contracts and the knowledge of customers needs and local conditions must be exploited. A knowledge base containing all the experience gathered by the organization while executing previous projects could be an advantage. Such information can be used for estimating probabilities of various states of nature taken into account in the analysis. Otherwise, the decision process must be based on experience and intuition of the project team members only.

In general, the problems analyzed within the first stage can be divided into three categories: strategic, technical, and organizational. Strategic perspective requires, for example, the decision whether the project should be implemented and if so, whether the organization should play the role of a general contractor, realize it in cooperation or be only a supplier of products.

Taking into account technical issues, a preliminary analysis should be carried out to answer the question whether the organization provides products that meet customer expectations. A positive answer to this question implies the need for further analysis in order to determine whether the products offered will be capable of working with the customer's existing infrastructure, or will require additional adaptation. At this phase the organization's production capacity should also be analyzed. The team preparing the offer must make sure that the organization will be able to produce and adapt all products on time. Otherwise, other options, such as the use of products offered by subcontractors have to be considered.

The last group of issues includes organizational problems. This refers primarily to the availability of organization's own staff, as well as the possibility of hiring external cooperators, such as legal support, consulting, design offices, etc.

Since such analysis takes time, it is necessary to permanently "keep track of the market" in order to identify opportunities for future projects as soon as possible. The effort in this phase of the project planning process often determines the success of the entire project.

2. Related work

Although the nature of problems that the DM faces in the initial phase of project planning differs from what he/she has to do while selecting a project, both issues considered and methods used to solve them are largely similar. In fact, by making preliminary decisions on the way in which the project should be executed, the DM refines the project and thus, to some extent, selects the project to be implemented. However, if the project selection process is essentially static, the decision-making process during the project planning phase is dynamic. An initial decision determines the alternatives, that can be taken into account in subsequent phases of the process.

Various techniques have been proposed for project planning and estimation. Considering research and development projects Doctor et al. (2001) point out that two approaches have been particularly useful in practice: decision tree and Option Pricing Theory. While the former has been around for a long time, the latter has only become of interest in the last two decades.

Decision trees have found wide use both in literature and also in industry [Magee, 1964; Raiffa, 1968; Thomas, 1972]. Hespos and Strassmann [1965] proposed stochastic decision-tree concept that permits the use of continuous probability density functions instead of the usual discrete ones. Heidenberger [1996] uses decision trees in a mixed integer linear programming model for dynamic project selection and funding problems. He extends a classical approach by adding a new node type that allows for continuous control of discrete branching probability distributions. Examples for the use of decision trees for project selection and resource allocation were also presented by Chiu and Gear [1979], Gear and Lockett [1973], Granot and Zuckerman [1991], Hess [1993], Stonebraker and Kirkwood [1997], Thomas [1985].

Risk environments often require better understanding of the possible range of outcomes. Simulation models try to solve this problem. They allow representation of real-world systems in greater detail than optimization models, at the expense of answering only what-if questions per simulation run. Various simulation approaches are proposed for project selection, resource allocation and other project planning problems. Two main approaches are used in simulation modeling: Monte Carlo simulation and systems simulation. The former uses probability distributions of all stochastic elements to calculate probability distribution of objective values. Such approach is used by Martino [1995], Souder and Mandakovic [1986]. Systems simulation models analyze sequences of events that occur over time. Thus, it is possible, for example, to study results and reactions in certain markets after a new product has been launched [Milling, 1996]. Fox and Baker [1985] combine both approaches and propose a model consisting of three components: a net-present value profitability module, a project generation module and a project portfolio selection submodel based on zero-one programming.

A variety of multi-criteria approaches are also proposed for project selection and planning, including techniques based on the utility function, methods based on the outranking relation, goal programming approaches and algorithms using stochastic dominance relation. Multiattribute utility analysis is used, for example, by Moselhi and Deb [1993], who treat uncertainty in a similar way to that used in PERT technique. In this procedure the total expected utility is calculated as the product of three matrices: utility matrix, objective matrix and scaling matrix. Wong et al. [2000] incorporate fuzzy analysis into multi-attribute utility theory. Their procedure uses stochastic dominance rules for ordering projects.

Outranking relation is used by Martel and D'Avignon [1982]. They consider a case study, where each project is evaluated by experts according to a set of criteria. These evaluations lead to distributive evaluation, i.e. to the calculation of the distribution of the anticipated performance of each project with respect to each attribute. The problem is solved by establishing a confidence index, which is based on probabilities that one project is as good as another.

A goal programming approach is also successively employed in project selection. This technique attempts to find a solution that is as close as possible to the goals specified by the decision maker. A goal programming concept is used, for example, by Santhanam and Kyprasis [1995], Lee and Kim [2000], de Oliveira et al. [2003].

When faced with the project selection and planning problems the decision maker has also to face uncertainty. Stochastic dominance rules are an efficient and flexible tool for comparing alternative solutions under uncertainty. Multicriteria techniques based on this approach are proposed by Nowak [2005, 2006].

3. Methodology

The methodology proposed here combines the decision tree, simulation, lexicographic approach and stochastic dominance rules. Nearly all decisions made during the planning phase of the project's life cycle are made sequentially. The choices made at the initial phase of the process determine the set of alternatives that can be considered at subsequent steps. The decision tree is an efficient tool to analyze such problems, as it makes possible to decompose the whole process into separate stages and analyze them sequentially. However, some disadvantages of this technique are mentioned. It is usually supposed that a crisp value representing the profit, loss or score is assigned to each end node. In many complex decision problems we are not able to quantify evaluations in such a form, unless the decision tree is significantly enlarged. The usefulness of the decision tree lies in its simple form, which is lost if the tree is increased. Instead of enlarging the tree, one can try to decompose the problem into sub-problems analyzed separately. In such a case, a probability distribution is assigned to each end node in the "master" decision tree. Such a distribution can be obtained by a detailed model constructed for the scenario represented by a particular end node. In our procedure we employ such approach. We use a simulation model to analyse each scenario. The results obtained from simulation runs are used for constructing probability distributions, which are assigned to end nodes of the decision tree.

Once the decision tree is constructed and scores are assigned to each end node, it is possible to identify the optimal solution. Two main principles are usually used for comparing alternative solutions in the decision tree: expected value maximization and expected utility maximization. The former is easy to employ, but ignores risk. The latter takes risk into consideration, but is difficult to implement because of the problems with the utility function estimation. In our approach we propose to apply a combined approach that uses the expected utility maximization principle and employs simulation modelling for analysing the risk. Thus, simulation is used twice in our procedure: first, to evaluate scores in end nodes, second, to evaluate risk associated with the implementation of a particular solution.

As already mentioned, various criteria are usually considered during the project planning process. In this paper we analyze a two-criteria problem, taking into account profit margin and completion time. However, our procedure can also be used for more complex problems. We employ a lexicographic approach. First, the most important criterion (profit margin) is optimized. The best solutions with respect to this criterion are identified. In the second phase, the less important goal (completion time minimization) is taken into account.

The procedure consists of five main steps:
1. Defining the decision problem and constructing the decision tree.
2. Performing simulations to assess distributional evaluations of criteria assigned to decision tree end nodes.
3. Identifying decision strategies to be considered.
4. Performing simulations on the decision tree.
5. Solving the multi-criteria problem using lexicographic approach and stochastic dominance rules.

Details for each step of the procedure are provided below.

Step 1: Defining the decision problem and constructing the decision tree.

The initial phase of the procedure focuses on problem definition. In order to describe the DM's situation properly, we should specify decision points: the choices that should be made and the decision alternatives that can be selected. These decision points should be arranged in a logical sequence, as choices made in the initial phase of the decision process determine alternatives that can be considered at subsequent steps. The events that are not under the DM's control (states of nature) should also be identified. Finally, probabilities should be assigned to each state of nature.

The estimation of these probabilities is probably the most difficult part of the work. Usually two sources of data are suggested: historical and experts' assessments. Real-world organizations usually do not collect a sufficient amount of data required by formal probability estimation techniques. Moreover, the DM often has to solve a problem for which historical data are not available. As a result, subjective feelings have to be translated into quantitative estimates. The shortcomings of subjective assessments are often pointed out. People usually overestimate the probability of a rare event, while underestimating the probability of a frequent one [Fischhoff, De Bruin, 1999]. Nevertheless, Teale et al. [2003] argue that „[…] it is better to have imperfect information than perfect 'misinformation' because a fateful event with severe consequences is one in which we may be particularly reluctant to commit ourselves to a value". In order to assess the probability of a particular state of nature, it can be helpful to use a probability scale from 0 to 100. Obviously, if the problem is important enough the organization may try to assess additional information in order to gain more precise estimations of probabilities. In this paper, however, we do not consider this issue.

Step 2: Performing simulations to assess the distributional evaluations of criteria assigned to end nodes of the decision tree.

Once the decision tree is constructed, payoffs or losses should be assigned to end nodes. In classical approach results are represented by crisp values. It is assumed, that all risks are represented by state-of-nature nodes. Real problems, however, are usually much more complex. As a variety of risks has to be taken into account, it is not convenient to present all of them on the decision tree. Moreover, in the decision tree we are able to present only those risks for which a finite and relatively small number of possible states of nature are identified.

In this paper we assume that the decision tree represents only the general scheme of the problem. Each end node corresponds to one possible scenario, which should be analyzed in details. Here we assume that simulation modeling is used to analyze such scenarios. Another possibility is to construct additional decision subtrees for each end node.

To estimate distributional evaluations with respect to the criteria the following steps should be performed:

a) analyzing sources of risks,
b) identifying appropriate probability distributions for input data,
c) constructing simulation models,
d) performing simulation runs.

A spreadsheet model can be used for evaluating a particular scenario with respect to the criterion "profit margin". In such a case additional tools, like CrystalBall or @Risk, can be used to perform simulations. As with the construction of the decision tree, also in this case, estimating probability distributions is the most difficult step. Three types of data can be used for this task [Robinson, 2004]:

– category A: data that are available because they are known or they have been collected earlier,
– category B: data that need to be collected,
– category C: data that are not available and cannot be collected.

In the absence of data, approximate distributions not based on strong theoretical underpinnings are used. Among them the uniform distribution and triangle distributions are used most often.

Once the simulation model is built, verified, and validated, simulation runs can be performed. The results are used for constructing the distributional evaluation assigned to a particular end node.

Step 3: Identifying decision strategies to be considered.

In this step we focus on identifying the decision strategies that can be implemented by the DM. By a strategy we mean a rule that is followed by the decision maker, when he/she has to make a decision at any stage of the decision process. As in this study we analyze only small-scale problems with up to ten decision nodes, the identification of all possible strategies is quite easy. However, if the decision tree is large, it would not be feasible to analyze all of them. In such a case we suggest identifying the subset of the strategies that provide the best evaluations with respect to the most important criterion. They can be identified using the expected value optimization rule. If, for example, profit margin is considered to be the most important criterion, strategies with the highest expected profit should be identified. While finding the strategy that optimizes this value is quite easy, the identification of sub-optimal solutions is not trivial and requires a special procedure. However, we do not analyze that problem in this study.

Step 4: Performing simulations on the decision tree.

During the next phase of our procedure simulations are performed to analyze how risky the strategies identified at the previous step are. For each strategy a series of simulation runs is performed. In each run sampling methods are used to determine the path through the tree and to generate the values of the criteria at the end node taking into account distributions generated in step 2. The simulation procedure is presented in Figure 1.

As a result, for each strategy and for each criterion a series of observations is obtained. These data are used to generate probability distributions expressing how good the strategy with respect to each criterion is.

Step 5: Solving the multi-criteria problem.

In our approach stochastic dominance rules are used for comparing uncertain outcomes. This concept is based on the axioms of the utility theory, but does not require estimating the utility function. Instead, probability distributions are compared by pointwise comparison of some performance functions. In this study we assume that the DM is risk-averse. In such a case two types of stochastic dominance relations can be used for modeling DM's preferences: First Stochastic Dominance (FSD) and Second Stochastic Dominance (SSD).

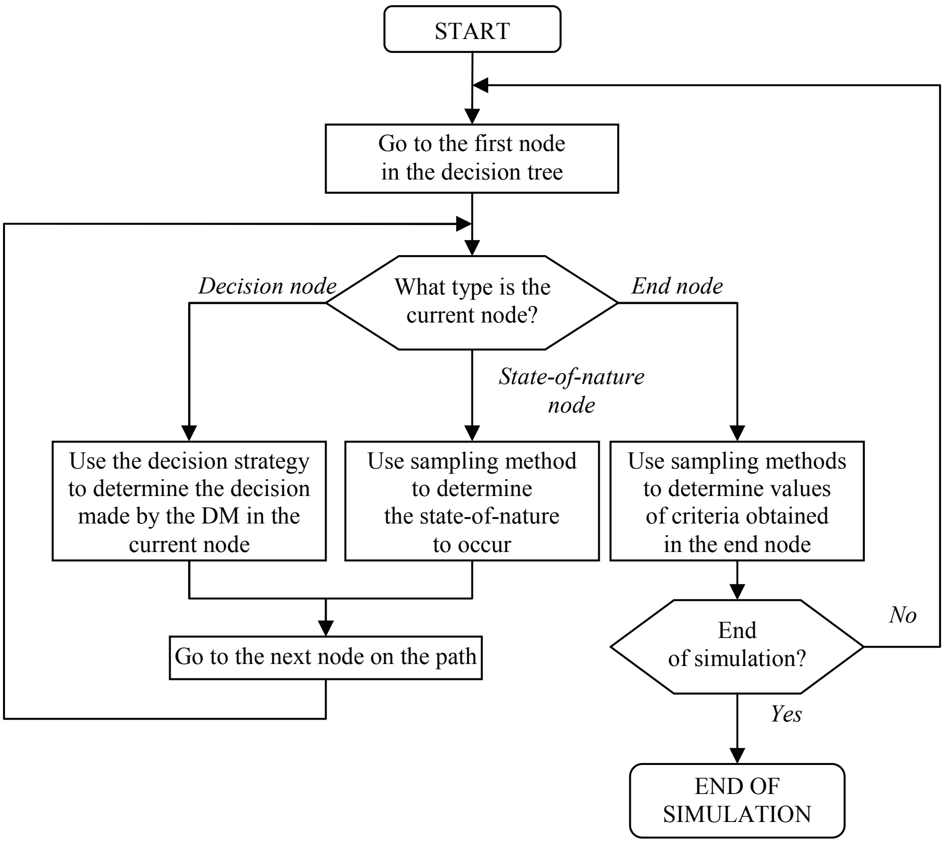

Figure 1. Simulation procedure

Let us assume the following notation:

$\mathbf{A} = \{a_1, a_2, \dots, a_m\}$ – the set of strategies under consideration,

m – number of strategies,

n – number of criteria,

X_{ik} – evaluation of strategy a_i with respect to k-th criterion,

$\mathbf{A}^{(l)}$ – the set of strategies considered at the l-th step of the multi-criteria procedure.

We will assume that criteria are defined so that larger values are preferred to smaller ones. Let $F_{ik}(x)$ and $F_{jk}(x)$ be right-continuous cumulative distribution functions representing evaluations of ai and aj respectively over criterion X_k:

$$F_{i\,k}(x) = \Pr(X_{i\,k} \le x),$$
$$F_{j\,k}(x) = \Pr(X_{j\,k} \le x).$$

The definitions of the first and second degree stochastic dominance relations are as follows:

Definition 1. (FSD – First Degree Stochastic Dominance)

$X_{i\,k}$ dominates $X_{j\,k}$ by FSD rule ($X_{i\,k} \succ_{\text{FSD}} X_{j\,k}$) if and only if $F_{i\,k}(x) \neq F_{j\,k}(x)$ and $H_1(x) = F_{i\,k}(x) - F_{j\,k}(x) \le 0$ for $x \in R$.

Definition 2. (SSD – Second Degree Stochastic Dominance)

$F_{i\,k}$ dominates $F_{j\,k}$ by SSD rule ($F_{i\,k}$ SSD $F_{j\,k}$) if and only if

$F_{i\,k}(x) \neq F_{j\,k}(x)$ and $H_2(x) = \int_{-\infty}^{x} H_1(y)dy \le 0$ for $x \in R$.

Hadar and Russel [1969] show that the FSD rule is equivalent to the expected utility maximization rule for all decision makers preferring larger outcomes, while the SSD rule is equivalent to the expected utility maximization rule for risk-averse decision makers preferring larger outcomes.

The multi-criteria procedure is based on lexicographic approach. First, the DM is asked to define a strict hierarchy of criteria according to their importance. Next, strategies are compared using stochastic dominance rules starting from the most important criterion. For each criterion, strategies dominated according to FSD/SSD rules are identified and removed. Finally, when all criteria have been considered (or there is only one strategy to be taken into account), the results are presented to the DM. He/she is asked to make a final choice. However, if the DM is not able to do this, some additional procedure must be employed. An interactive procedure for discrete multi--criteria decision making problems under risk proposed in Nowak [2006] can be used to complete the analysis.

Let us assume that the criteria are numbered according to their importance: the most important is criterion no. 1, while the least important in criterion no. n. The procedure operates as follows:

1. Assume: l := 1, $\mathbf{A}^{(l)} := \mathbf{A}$.
2. For each pair (a_i, a_j), such that $a_i, a_j \in \mathbf{A}^{(l)}$, $a_i \neq a_j$ identify FSD/SSD relation with respect to l-th criterion.

3. Identify the set of nondominated strategies with respect to l-th criterion:

$$\mathbf{A}^{(l+1)} = \mathbf{A}^{(l)} \setminus \{a_j : a_j \in \mathbf{A}^{(l)} \wedge \underset{i}{\exists}(X_{ik} \succ_{\mathrm{FSD}} X_{jk} \vee X_{ik} \succ_{\mathrm{SSD}} X_{jk})\}$$

4. If $l < n$, assume $l := l + 1$, go to 2, otherwise go to 5.
5. Present the results to the DM and ask him/her to make a final choice.

The procedure presented here differs from the ones that are usually used for project planning problems. In previous studies a decision tree was used mainly for single criterion problems. Simulation techniques were also popular. However, these approaches were usually used for comparing no more than two or three alternatives. In a multi-criteria framework goal programming was often employed. In such approaches, however, the risk was either ignored, or included in the model using some risk measures. In our approach we take into account both multiple criteria and risk. By using stochastic dominance rules we are able to take into account the DM's attitude to risk.

4. Illustrative example

The example presented in this section is based on the experience of the employees of the company providing solutions for the railway industry. The company is famous for the exceptional care it takes with regard to the safety of equipment and the range of services offered. Due to the specialised nature of its business, the execution of each project requires particular attention to detail and care both in preparation and implementation phase.

As a part of a global corporation, the company adopted standards according to which each project is divided into a number of crucial steps. This study focuses only on the first stage, i.e. project planning. Besides this stage, the company breaks down the project life cycle into 3 additional steps: tender preparation, project's implementation, and warranty coverage. The project life cycle is presented in Figure 2.

For each project project groups are formed responsible for preparing the documents required. At the end of each phase the documentation of project implementation strategy – white book, blue book, orange book, or red book – is presented to the management body responsible for deciding whether the project should be continued. Although the preparation of this data is time consuming and laborious, it makes possible to rationalize the decision process, as well as eliminate various weaknesses in the offer.

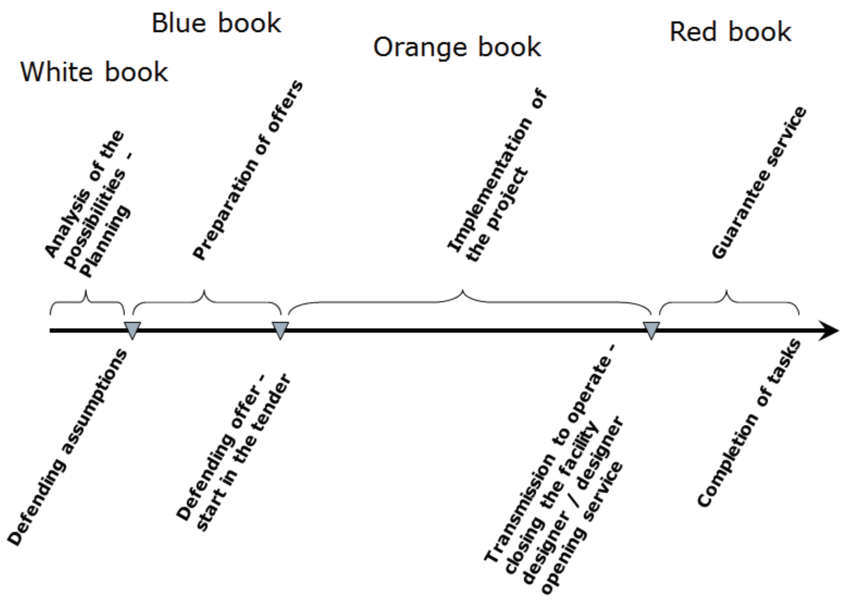

Figure 2. Project life cycle phases

In this study we consider both technical and organizational problems that have to be solved within the project planning phase. They consist mainly in assessing the potential use of company resources and experience to estimate the number of essential project elements. At this stage the team should verify that the company will be able to implement the project having won the tender. The most important factors determining the implementation of the planned tasks include: accessibility of the resources required for effective project management (project and construction managers, experienced contract engineers and contractors), production capacity adequate to produce the equipment required, the availability of the technology suitable for satisfying investor's needs. Knowledge of the local market and local circumstances is also very important. Combined, all these factors affect the decision regarding preparation and submitting a bid for the investor.

This example describes how the procedure proposed in the paper can be used when the decision on the tender preparation is made. The company considers entering a new market. It is possible to operate as a general contractor or to cooperate with a local company. Two criteria are considered: profit margin and project completion time. The final decision should specify whether the company should prepare and submit the tender or give up the contract.

Step 1: Defining the decision problem and constructing the decision tree.

The decision process involves several steps. Initially, the DM is faced with the choice between executing the project as a general contractor, or collaborating with a local company. The latter option leads to the necessity to search for a cooperator. Such a search, however, may be unsuccessful. In this case the company can either try to carry out the contract alone or to abandon it. On the other hand, if the cooperator is found, it can be employed as a supplier of some part of equipment, or hired for completing the installation work only. Figure 3 exemplifies this decision making process in the form of a decision tree.

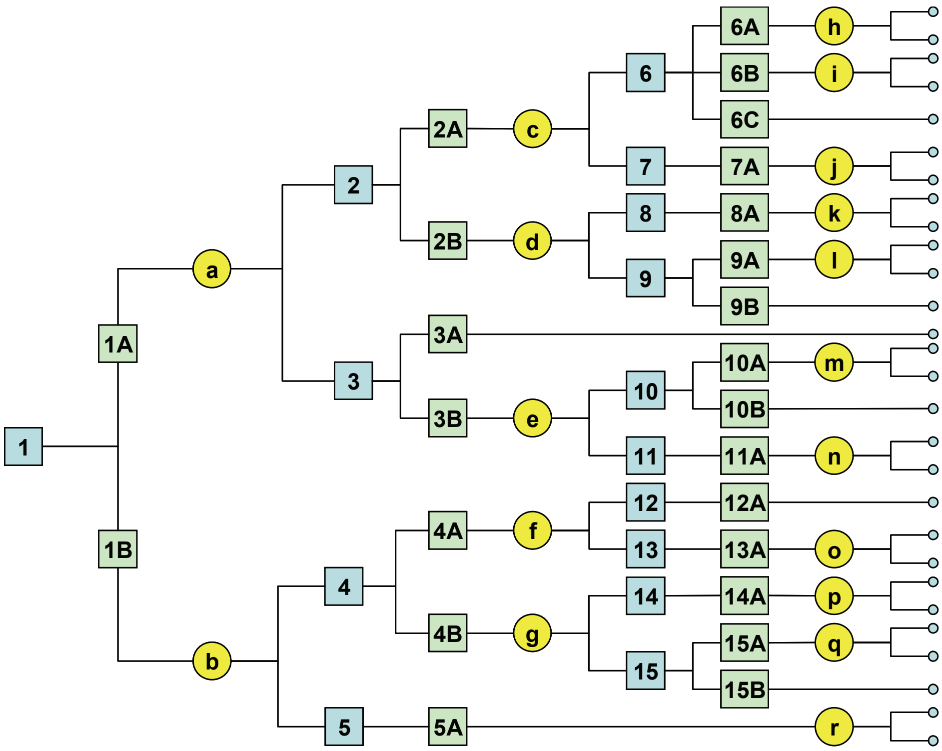

Figure 3. The decision tree describing the decision-making process

The details of the decision-making process under consideration are given below. At the first stage (decision node 1) the choice between two options must be made:

- implementation of the project in collaboration with a local company (decision 1A),
- implementation of the project as a general contractor (decision 1B).

The first option leads to the state-of-nature node a, in which two states of nature can arise:

- the company finds a local representative for cooperation (state a1),
- the company is not able to find a cooperator (state a2).

If a1 arises, the decision process proceeds to the decision node 2, otherwise it proceeds to the decision node 3. The decision 1B leads to the state-of-nature node b, in which the following states of nature are considered:

- the company is facing technical and organizational problems during the tender preparation (state b1),
- the company is able to prepare the tender without too much trouble (state b2).

While the occurrence of b1 moves the decision-making process to the decision node 4, the occurrence of b2 moves it to node 5.

The decisions considered in node 2 are as follows:

- the collaborating company is employed as the supplier of some part of equipment (decision 2A),
- the collaborating company is employed for completing a part of installation work only (decision 2B).

If decision 2A is made, the process proceeds to state-of-nature node c, otherwise it proceeds to the node d. The following states of nature are considered in node c:

- problems with adaptation of devices supplied by the local cooperator occurred (state c1),
- no problems with adaptation are identified (state c2).

The occurrence of these states moves the decision-making process to decision nodes 6 and 7, respectively. The states of nature taken into account in node d are as follows:

- an agreement concerning the distribution of responsibilities has been reached, no problems arise from the implementation of the assigned tasks (state d1),
- an agreement concerning the distribution of responsibilities has been reached, there are problems arising from implementation of the assigned tasks (state d2).

If d1 occurs, the decision-making process goes to the node 8, otherwise to the node 9.

In the decision node 3 the DM can choose between two alternatives:

- to give up tender submission (decision 3A),
- to turn back to the original concept – the completion of the task as general contractor (decision 3B).

If the first option is chosen, the decision-making process is finished, otherwise it goes to the state-of-nature e, where two states are considered:

- the company is facing problems with the organisation of the project (state e1),
- the company is not facing any problems with the organisation of the project (state e2).

The occurrence of these two states leads to nodes 10 and 11, respectively.

The decision node 4 represents the situation when the DM has to choose between two alternatives:

- to hire a consulting firm to support project implementation (decision 4A),
- to turn back to the original concept – to establish cooperation with a local company (decision 4B).

If the first option is chosen, the process goes to state-of-nature node f, otherwise it is moved to node g. The former represents the possibility of the occurrence of two states:

- problems with implementation are not solved (state f1),
- with the help of the consulting firm problems are solved (state f2).

The occurrence of these states moves the decision-making process to nodes 12 and 13, respectively. In node g two possibilities are considered:

- cooperation with a local company makes it possible to solve problems (state g1),
- problems identified during tender preparation are not solved (state g2).

State g1 leads to node 14, while state g2 to node 15.

The last decision node that has to be considered at the second stage of the process is node 5. It represents the situation in which the company is able to prepare the tender without too much trouble. In such a case the decision to submit the tender is made.

The decisions made at the third stage are as follows:

1. Decision node 6:
   - deciding to complete the contract by using only devices produced by the company itself and submitting the tender (decision 6A),
   - deciding to propose adaptation works and submitting the tender (decision 6B),
   - giving up tender submission (decision 6C).

2. Decision node 7:
   – tender submission (decision 7A).
3. Decision node 8:
   – tender submission (decision 8A).
4. Decision node 9:
   – organizing additional training for the employees of the cooperator and submitting the tender (decision 9A),
   – giving up tender submission (decision 9B).
5. Decision node 10:
   – hiring a consulting company and submitting the tender (decision 10A),
   – giving up tender submission (decision 10B).
6. Decision node 11:
   – tender submission (decision 11A).
7. Decision node 12:
   – giving up tender submisision (decision 12A).
8. Decision node 13:
   – tender submission (decision 13A).
9. Decision node 14:
   – tender submission (decision 14A).
10. Decision node 15:
   – organizing additional training for the employees of the cooperator and submitting the tender (decision 15A).
   giving up tender submission (decision 15B).

The decision to submit the tender in each case leads to a state-of-nature node in which two states are considered: the company's offer is accepted or rejected. Finally, probabilities are assigned to each state of nature (Table 1).

Table 1

Probabilities assigned to each state of nature

State of nature node	State of nature	Probability	State of nature node	State of nature	Probability
a	a1	0.7	e	e1	0.4
	a2	0.3		e2	0.6
b	b1	0.6	f	f1	0.6
	b2	0.4		f2	0.4
c	c1	0.6	g	g1	0.3
	c2	0.4		g2	0.7
d	d1	0.6	h-r	h1 … r1	0.6
	d2	0.4		h2 … r2	0.4

Step 2: Performing simulations to assess distributional evaluations of criteria assigned to end nodes of the decision tree.

For each end node a calculation sheet and project network describing tasks required for completing the project are developed. At this stage precise data are not available. However, the expertise of team members and data contained in company's knowledge base can be used to estimate probability distributions of uncertain variables. To analyze the profit margin made on contract, not only project implementation cost, but also tender preparation cost are taken into account.

Spreadsheet models are constructed for performing simulations. The simulation results – means of distributions obtained for criteria – are presented in Table 2. Each scenario is defined by a sequence of decisions and states of nature. The completion time equal to 0 means that either the company decides to give up submitting the tender, or the offer is not accepted.

Table 2

Results of simulations performed for scenarios represented by end nodes

Scenario	Values of criteria (means)		Scenario	Values of criteria (means)	
	profit margin (PLN)	completion time (days)		profit margin (PLN)	completion time (days)
1A-a1-2A-c1-6A-h1	634.733	80	1A-a2-3B-e1-10A-m2	–46.400	0
1A-a1-2A-c1-6A-h2	–46.233	0	1A-a2-3B-e1-10B	–34.333	0
1A-a1-2A-c1-6B-i1	800.867	80	1A-a2-3B-e2-11A-n1	744.667	65
1A-a1-2A-c1-6B-i2	–34.500	0	1A-a2-3B-e2-11A-n2	–46.750	0
1A-a1-2A-c1-6C	–27.867	0	1B-b1-4A-f1-12A	–39.220	0
1A-a1-2A-c2-7A-j1	870.333	75	1B-b1-4A-f2-13A-o1	694.340	70
1A-a1-2A-c2-7A-j2	–34.783	0	1B-b1-4A-f2-13A-o2	–46.700	0
1A-a1-2B-d1-8A-k1	819.467	75	1B-b1-4B-g1-14A-p1	750.467	75
1A-a1-2B-d1-8A-k2	–34.730	0	1B-b1-4B-g1-14A-p2	–46.733	0
1A-a1-2B-d2-9A-l1	760.567	85	1B-b1-4B-g2-15A-q1	710.833	85
1A-a1-2B-d2-9A-l2	–46.467	0	1B-b1-4B-g2-15A-q2	–46.033	0
1A-a1-2B-d2-9B	–39.333	0	1B-b1-4B-g2-15B	–39.167	0
1A-a2-3A	–27.200	0	1B-b2-5A-r1	756.000	65
1A-a2-3B-e1-10A-m1	694.167	70	1B-b2-5A-r2	–34.221	0

Step 3: Identifying decision strategies to be considered.

At this step decision strategies are identified. As the example considered here is not very large, it is quite easy to list all decision strategies (Table 3).

Table 3

Decision strategies under consideration

Decision strategy		Decision strategy	
a_1	1A – 2A – 3A – 6A – 7A	a_{10}	1A – 2B – 3A – 8A – 9A
a_2	1A – 2A – 3A – 6B – 7A	a_{11}	1A – 2B – 3A – 8A – 9B
a_3	1A – 2A – 3A – 6C – 7A	a_{12}	1A – 2B – 3B – 8A – 9A – 10A – 11A
a_4	1A – 2A – 3B – 6A – 7A – 10A – 11A	a_{13}	1A – 2B – 3B – 8A – 9A – 10B – 11A
a_5	1A – 2A – 3B – 6A – 7A – 10B – 11A	a_{14}	1A – 2B – 3B – 8A – 9B – 10A – 11A
a_6	1A – 2A – 3B – 6B – 7A – 10A – 11A	a_{15}	1A – 2B – 3B – 8A – 9B – 10B – 11A
a_7	1A – 2A – 3B – 6B – 7A – 10B – 11A	a_{16}	1B – 4A – 5A – 12A – 13A
a_8	1A – 2A – 3B – 6C – 7A – 10A – 11A	a_{17}	1B – 4B – 5A – 14A – 15A
a_9	1A – 2A – 3B – 6C – 7A – 10B – 11A	a_{18}	1B – 4B – 5A – 14A – 15B

Step 4: Performing simulations on the decision tree.

The next step of the procedure involves performing simulation runs for each strategy identified in the decision tree. The procedure used for analyzing the profit margin differs from the one used for analyzing the completion time. When the profit margin is analyzed, all potential states of nature and decisions are taken into account, including the ones which result either in giving up tender submission or having the offer rejected. However, if completion time is analyzed, such procedure does not make sense, as we cannot take into account the scenarios that do not result in project implementation (giving up tender submission or having the offer rejected). Thus, only scenarios resulting in offer acceptation are taken into account while analyzing completion time.

The results of simulation runs were used for generating distributional evaluations of each solution with respect to both criteria. The summary of the results is presented in Table 4.

Table 4

Results of simulations performed on the decision tree

Decision strategy	Means of probability distributions		Decision strategy	Means of probability distributions	
	profit margin (PLN)	completion time (days)		profit margin (PLN)	completion time (days)
a_1	244.158	57.8	a_{10}	265.446	37.2
a_2	203.071	52.4	a_{11}	138.666	42.0
a_3	78.588	35.0	a_{12}	380.129	55.2
a_4	331.328	52.0	a_{13}	310.040	50.4
a_5	268.953	53.7	a_{14}	266.929	44.2
a_6	358.841	51.4	a_{15}	218.128	42.6
a_7	317.754	49.9	a_{16}	240.371	37.0
a_8	193.271	39.3	a_{17}	387.623	53.2
a_9	144.471	37.7	a_{18}	214.224	33.4

Step 5: Solving the multi-criteria problem.

The last step includes multi-criteria analysis of the problem. First, probability distributions of profit margin are compared according to FSD/SSD rules (Table 5).

Table 5

Stochastic dominance relations with respect to criterion "profit margin"

	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}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}
a_1			FSD					FSD	FSD		FSD				FSD	FSD		FSD
a_2	FSD		FSD					FSD	FSD	FSD	FSD			FSD	FSD	FSD		FSD
a_3																		
a_4	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD		FSD	FSD	FSD	FSD		FSD
a_5	FSD	FSD	FSD					FSD	FSD	FSD	FSD			FSD	FSD	FSD		FSD
a_6	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD		FSD	FSD	FSD	FSD		FSD
a_7	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD		SSD	FSD	FSD	FSD		FSD
a_8			FSD						FSD		FSD							SSD
a_9			FSD								FSD							
a_{10}	FSD		FSD					FSD	FSD		FSD				FSD	FSD		FSD
a_{11}			FSD															
a_{12}	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD		FSD	FSD	FSD	FSD		FSD
a_{13}	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD			FSD	FSD	FSD		FSD
a_{14}	FSD		FSD					FSD	FSD		FSD				FSD	FSD		FSD
a_{15}			FSD					FSD	FSD		FSD					SSD		FSD
a_{16}			FSD						FSD		FSD							FSD
a_{17}	FSD	FSD	FSD		FSD			FSD	FSD	FSD	FSD		FSD	FSD	FSD	FSD		FSD
a_{18}			FSD						FSD		FSD							

Five strategies are nondominated according to FSD/SSD rules with respect to profit margin criterion: a_4, a_6, a_7, a_{12}, and a_{17}. Thus, to identify the final solution, relationships between these alternatives with respect to the second criterion "completion time" should be analyzed (Table 6).

Table 6

Stochastic dominance relations with respect to criterion "completion time"

Decision strategy	Decision strategy				
	a_4	a_6	a_7	a_{12}	a_{17}
a_4				FSD	FSD
a_6				FSD	FSD
a_7				FSD	FSD
a_{12}					
a_{17}					

Three strategies are nondominated according to stochastic dominance rules with respect to the criterion "completion time": a_4, a_6, and a_7. These solutions are presented to the DM. The simulation results can be used to provide additional information, such as the probability of making a profit not smaller than a specified value or the probability of meeting the due date. In our case, the probability of making a profit not smaller than 400 000 PLN is equal to 0.63 for a_4, 0.78 for a_6, and 0.56 for a_7, while the probability of meeting the due date (65 days) is equal to 0.81 for both a_4 and a_6, and 0.89 for a_7. Thus, it seems that the DM should choose a_6 as the final solution. According to this, the company should first of all try to find a local partner. If it is successful, it will employ it as a supplier of some part of equipment. Next, if any problems with adaptation of devices supplied by the local cooperator arise, the company will perform adaptation works. However, if the search for a local partner is not successful, the company should return to the original concept – the completion of the task as general contractor.

Conclusions

Project planning involves making a series of decisions. As these decisions are made under risk, the decision tree seems to be an efficient tool. However, the results that are obtained in end nodes often cannot be expressed as crisp values. In such situations, computer simulation can be employed for analyzing results of various strategies.

In the example presented in this paper, a two-criteria problem was analyzed. Obviously profit and completion time are usually taken into account when various project implementation strategies are considered. Nevertheless, other issues are also taken into account, such as resources usage. Our procedure can be successfully used in those cases as well.

The example presented in this paper is relatively simple. The number of end nodes in our tree is not very large. Thus, we were able to analyze all alternative strategies identified in the tree. Such approach is applicable for small problems. In real-life situations the size of the problem is usually much larger. However, some segments of the tree are replicated. Moreover, such fragments can occur in various projects. Thus, when faced with a new problem, the DM can adapt some parts of decision trees constructed previously. Our idea for future work is to construct a "library" or "database" of tree segments which can be used while constructing a decision tree for a new problem. For each problem a "master tree" describing only the main idea of the problem will be constructed, and a subtree will be assigned to each end node. As these subtrees will be considered separately, the problem will become simpler. Additionally, the procedure should approximate the knowledge about results that can be achieved for each scenario. These data can be used at the initial phase of the procedure, for selecting the most promising solutions. Next, simulation should be used for in-depth analysis of selected solutions.

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