MULTICRITERIA TECHNIQUE FOR PROJECT SELECTION UNDER RISK

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Profitable investments lead to the growth and prosperity of each corporation. Various objectives are usually taken into account when an engineering, construction or R&D projects are analysed, including economic desirability, technical issues, and environmental and social factors. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a multicriteria decision problem arises. Criteria, according to which projects are compared, are usually of different nature. While some of them are quantitative ones, others are of qualitative type. When faced with the decision of selecting a project, the decision maker has also to face uncertainty.
The paper proposes a comprehensive methodology for project selection problem, that enables handling both quantitative and qualitative criteria, and takes into account risk associated with each objective. Monte Carlo simulation is used for generating alternatives' evaluations with respect to quantitative measures. Experts' assessments are taken into account when projects are appraised in relation to qualitative criteria. A multicriteria procedure presented in the paper is based on two concepts: stochastic dominance and interactive approach. The first is employed for comparing projects with respect to each criterion separately, the latter in used for generating final solution of the problem. A numerical example is presented to illustrate the applicability of the proposed technique.

Keywords: *project selection, Monte Carlo simulation, stochastic dominance, multicriteria analysis*

1. INTRODUCTION

Selection of a project or a portfolio of projects constitutes one of the main problems that managers are faced with. Decision of selecting an engineering, construction or R&D project is often fundamental for business survival. Such decisions usually involve prediction of future outcomes considering different alternatives. As these predictions are not known with certainty, so project managers often have to face some degree of uncertainty. The fact of matter is that modern businesses face a more severe and challenging environment than ever before. The increasing volatility in interest and exchange rates, lifting trade barriers and development of new technologies in electronics, nanotechnology, biotechnology result in a high level of uncertainty in managerial decision-making.

Various objectives are usually considered for when projects are evaluated, including economic desirability, technical, environmental, social and/or political factors. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a multiple criteria decision-making problem arises. It should be noticed that evaluation criteria could be of various nature. While financial measures (Net Present Value, Internal Rate of Return, Profitability Index) are of quantitative type, the ones that reflect technical, environmental or social objectives are usually of qualitative nature.

Numerous techniques have been proposed in recent years for project selection problems. Heidenberger and Stummer [2] give a survey of quantitative techniques for R&D project selection and resource allocation problems. Most of procedures listed in that paper can be applied for evaluating construction and engineering projects as well. Utility function approach is often employed for solving such a problem. E.g., Moselhi and Deb [3], Wong et al. [4] use this methodology. They propose methods for estimating single-criteria utility functions and aggregating them into a multi-attribute utility function. Thus, both multiple criteria and risk can be considered. The main assumption of this approach is that it is possible determine decision maker's utility functions with respect to criteria. In fact, however, such analysis is usually inconvenient and time consuming. It requires asking the decision maker to make a lot of hypothetical choices between alternatives that often have no practical reality. As a result, such techniques are often recognized as exacting and demanding by decision makers.

Analytic Hierarchy Procedure ([5], [6]), outranking relation ([7], [8]), or goal programming approach ([9], [10]) is also proposed for project selection problems. As AHP technique is based on exploiting decision maker's subjective evaluations formulated for each pair of projects and for each criterion, so its applications are restricted to problems with relatively small number of alternative projects. In order to apply techniques based on outranking relation, thorough analysis of decision maker's preferences have to be conducted. Such study precedes the final analysis and, like in approaches based on utility function, is very absorbing for the decision maker. Finally, goal-programming techniques attempt to find a solution that is as close as possible to goals specified by the decision maker. Unfortunately, it is usually not easy to consider risk using this approach.

In this paper an interactive multiple criteria decision-making technique is applied for a project selection problem. The methodology exploits the STEM method approach ([1]) and uses stochastic dominance rules for comparing uncertain outcomes. Thus, both multiple criteria and risk are considered while alternate projects are analysed. The procedure exploits interactive approach that is widely used in decision problems under certainty, but is rarely used in problems involving risk. Such approach is much less demanding for the decision makers than approaches based on an a priori basis (e.g. techniques based of utility function or outranking relation) and is usually accepted by them.

The paper is organized as follows. Section 2 formulates the decision problem and presents the proposed methodology. Next section presents a numerical example. Last section gives conclusions.

2. METHODOLOGY

Let us consider a project selection problem in which A is the set of alternate projects: $a_1, \ldots, a_m$, X is the set of decision criteria: $X_1, \ldots, X_n$, and E is the set of evaluations of projects with respect to criteria: $X_{11}, \ldots, X_{mn}$. The decision maker has to choose only one project. It is assumed that each criterion is defined in such a way, that larger values are preferred to smaller ones.

Following procedure can be used for solving problem formulated above:

1. Generation of projects' evaluations.
2. Comparing projects with respect to criteria.
3. Selection of a final solution employing interactive approach.

Various techniques can be used for generating evaluations of projects with respect to criteria. Simulation is an efficient and powerful tool for analysing economic desirability of alternate projects, as it makes possible to consider uncertainties relative to various aspects of the problem. If, for example, a construction or manufacturing project is analysed, uncertainties relative to availability of resources, market prices, demand can be considered. On the other hand, in projects with R&D elements activity durations are much more sensitive to misevaluation. In such cases simulation may provide the dates of the project's milestone occurrences, which determine the set of cash flows during project's life cycle. As simulation experiments are performed, series of observations is obtained for a considered criterion. These observations can be easily transformed to a probability distribution.

In order to analyse projects' performances with respect to criteria that are qualitative or subjective in nature, experts' assessments may be analysed. A 10-point scale may be utilized with 10 assigned to the maximum value that is desirable, and 1 to the least desirable one. If l experts are asked for assessing projects then l evaluations are obtained for each project. Assuming equal probabilities for each assessment, probability distribution is obtained for each project. Such distributions, however, are different in nature to the previous ones, as they are defined on ordinal scale.

Once projects' evaluations are generated, relations between alternative projects with respect to criteria can be analysed. In this study stochastic dominance rules are employed for comparing uncertain outcomes. It is assumed that the decision maker is risk averse. Such supposition is usually taken in finance and corresponds to the results of experiments of Kahneman and Tversky [11] showing that decision makers are usually risk averse in relation to criteria defined in the domain of gains. Two groups of stochastic dominance rules can be considered. The first one groups First Degree Stochastic Dominance (FSD) and Second Degree Stochastic Dominance (SSD) rules. These rules can be applied for providing ranking of preferences among real-valued outcomes, such as income, wealth or rates of return. Ordinal First Degree Stochastic Dominance (OFSD) and Ordinal Second Degree Stochastic Dominance (OSSD) rules compose the second group. These rules can be applied for providing ranking of preferences among variables of ordinal nature.

Let us start with real-valued outcomes. Assume $F_{ik}(x)$ and $F_{jk}(x)$ are right-continuous cumulative distribution functions representing evaluations of a_i and a_j respectively over criterion X_k:

$F_{ik}(x) = \Pr\{X_{ik} \le x\}$ $\qquad$ $F_{jk}(x) = \Pr\{X_{jk} \le x\}$

First-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) relations are defined as follows:

X_{ik} dominates X_{jk} by FSD rule ($X_{ik} \succ_{\mathrm{FSD}} X_{jk}$) if and only if

$F_{ik}(x) \ne F_{jk}(x)$ and $H_1(x) = F_{ik}(x) - F_{jk}(x) \le 0$ for all $x \in \mathrm{R}$

X_{ik} dominates X_{jk} by SSD rule ($X_{ik} \succ_{\mathrm{SSD}} X_{jk}$) if and only if

$F_{ik}(x) \ne F_{jk}(x)$ and $H_2(x) = \int_{-\infty}^{x} H_1(y)dy \le 0$ for all $x \in \mathrm{R}$

Let us now consider a random variable X_{iq} is defined by $(e_{q1}, \ldots, e_{qz}, p_{iq1}, \ldots, p_{iqz})$, where $e_{q1}, \ldots, e_{qz}$ are z real numbers, such that $e_{ql} < e_{ql+1}$ for all $l = 1, \ldots, z-1$, and $p_{iq1}, \ldots, p_{iqz}$ are the probability measures. The variable X_{jq} is defined similarly with $p_{jq1}, \ldots, p_{jqz}$ replacing $p_{iq1}, \ldots, p_{iqz}$. If the outcomes can be ranked in order of preferences, i.e. the decision maker prefers $e_{q\,l+1}$ over $e_{q\,l}$ for all $l = 1, \ldots, z-1$ then Ordinal First Degree Stochastic Dominance (OFSD) rule can be used:

X_{iq} dominates X_{jq} by OFSD rule ($X_{iq} \succ_{\mathrm{OFSD}} X_{jq}$) if and only if

$$\sum_{l=1}^{s} p_{iql} \le \sum_{l=1}^{s} p_{jql} \quad \text{for all } s = 1, \ldots, z$$

Let us assume that the decision maker adds additional information and indicates that the outcome is improved more by switching from $e_{q\,l}$ to $e_{q\,l+1}$ than from $e_{q\,l+1}$ to $e_{q\,l+2}$ for all $l = 1, \ldots, z-2$. In such case Ordinal Second Degree Stochastic Dominance (OSSD) rule can be employed:

X_{iq} dominates X_{jq} by OSSD rule ($X_{iq} \succ_{\mathrm{OSSD}} X_{jq}$) if and only if

$$\sum_{r=1}^{s}\sum_{l=1}^{r} p_{iql} \le \sum_{r=1}^{s}\sum_{l=1}^{r} p_{jql} \quad \text{for all } s = 1, \ldots, z$$

FSD and OFSD rules are equivalent to the expected utility maximization rule for all decision makers preferring larger outcomes, while SSD and OSSD rules are equivalent to the expected utility maximization rule for all risk-averse decision makers preferring larger outcomes ([11], [12]).

The procedure presented here uses interactive technique for solving project selection problem. The method is based on the approach proposed in the STEM technique [1], which uses the ideal solution concept. Such solution is composed of maximum values of all criteria that are individually attainable within the set of decision alternatives. In the STEM method candidate alternative is generated and presented to the decision maker in each step. It is the one that is closest to the ideal solution according to the mini-max rule. If the decision maker accepts the proposal, then the procedure ends, otherwise the decision maker is asked to define the margins of relaxation for these criteria, whose values are already satisfactory. Then the decision maker generates new set of alternatives taking into account the restrictions defined. The procedure continues until an alternative with satisfactory criteria evaluations is found. The technique employed in this study adopts similar approach for solving decision-making problems under risk. The number of alternatives measures the distance from the ideal solution with evaluations dominating the evaluation of the considered alternative according to stochastic dominance relations.

Let μ_{ik} be average evaluation of alternative a_i with respect to X_k. The operation of the proposed procedure is as follows:

1. $l := 1, A_1 := A, K := \{ 1, ..., m \}$;
2. Identify candidate alternative a_i:

   $$a_i := \arg \min_{a_j \in A_l} \max_{k \in K} \{d^l_{jk}\}$$

   where d^l_{jk} is the number of alternatives $a_i \in A_l$ such that the evaluation of a_i dominate the evaluation of a_j with respect to criterion X_k according to stochastic dominance rules:

   $$d^l_{jk} = \operatorname{card} D^l_{jk}$$

   $$D^l_{jk} = \{a_i : a_i \in A_l; F_{ik} \succ_{SD} F_{jk}\}$$

   where $\succ_{\mathrm{SD}}$ means FSD/SSD or OFSD/OSSD relation.

3. Present the data to the decision maker:
   – the average evaluations of the candidate alternative a_i with respect to all criteria μ_{ik}, $k = 1, ..., m$,
   – the values of d^l_{ik} for $k = 1, ..., m$,
   – the maximal average evaluations μ_k^* for $k = 1, ..., m$:

   $$\mu_k^* = \max_{i: a_i \in A_l} \{\mu_{ik}\}$$

4. Ask the decision maker whether he/she is satisfied with the candidate alternative. If the answer is YES – the final solution is alternative a_i – go to 8, else – go to 5.
5. Ask the decision maker whether the candidate alternative is satisfactory with respect to at least one criterion. If the answer is YES – go to 6, else – it is impossible to find an alternative with satisfactory evaluations by the procedure – go to 8.
6. Ask the decision maker to select criterion with respect to which the candidate alternative is satisfactory for him/her, say criterion X_k and to define δ_k – the limit of concessions, which can be made on average evaluations of the X_k.
7. Generate the set $A_{l+1} := \{a_j: a_j \in A_l, \mu_{jk} \geq \delta_k \}$, assume $l := l + 1$, $K := K \setminus \{ k \}$, if $K = \varnothing$ then $K = \{ 1, ..., m \}$, go to 3.
8. The end of procedure.

More detailed description of the procedure is presented in [14].

3. NUMERICAL EXAMPLE

To illustrate the proposed technique let us consider a manufacturing company operating on a growth market. Management board decided to purchase a new production facility to increase production capacity. Ten alternate projects are considered. All proposals are viable from a standpoint that output from any of these alternatives meets product specification. A decision for selecting a project has to be made based on the following criteria:

- X_1 – net present value,
- X_2 – reliability and technical service,
- X_3 – technical novelty,
- X_4 – compatibility with existing facilities.

Simulation technique is applied for generating distributional evaluations of projects with respect to criterion X_1. The economic life for all projects is assumed to be 5 years. Based on past experience and data provided by facilities' manufacturers, analysts has determined probability distributions for:

- initial investments,
- salvage values,
- production costs per unit,
- fixed costs,
- demand,
- market prices.

Next, a series of experiments has been performed and probability distributions describing NPV for all projects have been obtained. Table 1 presents results of simulation experiments.

Criteria X_2, X_3 and X_4 are of qualitative nature. Ten experts have been asked for evaluating projects in relation to these criteria on the scale form 1 to 10. As a result, series of assessments for each project and for each criterion has been obtained. These assessments have been transformed to probability distributions. Table 2 presents experts assessments obtained for project a_1 and criterion X_2, while table 3 shows the corresponding probability distribution.

Next, stochastic dominance rules have been applied for comparing projects with respect to criteria. FSD/SSD rules have been used for criterion X_1, while OFSD/OSSD rules have been employed for criteria X_2, X_3 and X_4. Results are shown in tables 4, 5, 6 and 7.

Table 1. Results of simulation experiments

Project	NPV (mean)
1	1413.84
2	1183.06
3	1139.12
4	1244.56
5	979.66
6	1137.93
7	1208.61
8	1432.72
9	1211.81
10	1226.72

Table 2. Experts assessments of project a_1 on criterion X_2

Evaluation	Number of experts
1	
2	
3	
4	
5	1
6	2
7	2
8	3
9	2
10	

Table 3. Distributional evaluation of project a_1 on criterion X_2

Evaluation	Probability
1	0,0
2	0,0
3	0,0
4	0,0
5	0,1
6	0,2
7	0,2
8	0,3
9	0,2
10	0,0

Table 4. FSD/SSD relations between projects' evaluations with respect to criterion X_1

	$\mu_{i\,1}$	$X_{1\,1}$	$X_{2\,1}$	$X_{3\,1}$	$X_{4\,1}$	$X_{5\,1}$	$X_{6\,1}$	$X_{7\,1}$	$X_{8\,1}$	$X_{9\,1}$	$X_{10\,1}$
$X_{1\,1}$	1226.72		FSD		FSD		FSD	SSD	FSD		FSD
$X_{2\,1}$	979.66										
$X_{3\,1}$	1432.72	SSD	FSD		FSD		FSD	FSD	FSD		FSD
$X_{4\,1}$	1208.61		FSD				FSD				FSD
$X_{5\,1}$	1244.56	SSD	FSD		FSD		FSD	FSD	SSD		FSD
$X_{6\,1}$	1137.93		FSD								
$X_{7\,1}$	1211.81		FSD		SSD		FSD		FSD		
$X_{8\,1}$	1183.06		FSD								
$X_{9\,1}$	1413.84	FSD	FSD		FSD		FSD	FSD	FSD		FSD
$X_{10\,1}$	1139.12		FSD				SSD				

Table 5. OFSD/OSSD relations between projects' evaluations with respect to criterion X_2

	$\mu_{i\,2}$	$X_{1\,2}$	$X_{2\,2}$	$X_{3\,2}$	$X_{4\,2}$	$X_{5\,2}$	$X_{6\,2}$	$X_{7\,2}$	$X_{8\,2}$	$X_{9\,2}$	$X_{10\,2}$
$X_{1\,2}$	7.3		OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	
$X_{2\,2}$	3.0			OFSD		OSSD					
$X_{3\,2}$	2.8										
$X_{4\,2}$	5.3		OFSD	OFSD		OFSD		OFSD			
$X_{5\,2}$	2.9										
$X_{6\,2}$	7.9	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	OSSD
$X_{7\,2}$	4.5		OFSD	OFSD		OFSD					
$X_{8\,2}$	6.8		OFSD	OFSD	OFSD	OFSD		OFSD			
$X_{9\,2}$	6.9		OFSD	OFSD	OFSD	OFSD		OFSD			
$X_{10\,2}$	7.8	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	

Table 6. OFSD/OSSD relations between projects' evaluations with respect to criterion X_3

	$\mu_{i\,3}$	$X_{1\,3}$	$X_{2\,3}$	$X_{3\,3}$	$X_{4\,3}$	$X_{5\,3}$	$X_{6\,3}$	$X_{7\,3}$	$X_{8\,3}$	$X_{9\,3}$	$X_{10\,3}$
$X_{1\,3}$	3.4										
$X_{2\,3}$	4.9	OFSD			OSSD						OFSD
$X_{3\,3}$	7.0	OFSD	OFSD		OFSD	OSSD	OSSD			OFSD	OFSD
$X_{4\,3}$	4.6	OFSD									OFSD
$X_{5\,3}$	6.4	OFSD	OFSD		OFSD		OFSD			OFSD	OFSD
$X_{6\,3}$	5.9	OFSD	OFSD		OFSD					OFSD	OFSD
$X_{7\,3}$	7.5	OFSD	OFSD		OFSD	OFSD	OFSD		OSSD	OFSD	OFSD
$X_{8\,3}$	7.2	OFSD	OFSD		OFSD						OFSD
$X_{9\,3}$	5.4	OFSD	OSSD		OFSD						OFSD
$X_{10\,3}$	4.1	OFSD									

Table 7. OFSD/OSSD relations between projects' evaluations with respect to criterion X_4

	$\mu_{i\,4}$	$X_{1\,4}$	$X_{2\,4}$	$X_{3\,4}$	$X_{4\,4}$	$X_{5\,4}$	$X_{6\,4}$	$X_{7\,4}$	$X_{8\,4}$	$X_{9\,4}$	$X_{10\,4}$
$X_{1\,4}$	8.2		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
$X_{2\,4}$	2.6										
$X_{3\,4}$	5.3		OFSD			OFSD		OFSD		OSSD	
$X_{4\,4}$	8.0		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
$X_{5\,4}$	4.3		OFSD					OSSD			
$X_{6\,4}$	6.6		OFSD	OFSD		OFSD		OFSD	OFSD	OFSD	
$X_{7\,4}$	3.9		OFSD								
$X_{8\,4}$	5.7		OFSD			OFSD		OFSD		OFSD	
$X_{9\,4}$	4.7		OFSD					OSSD			
$X_{10\,4}$	7.2		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	

The dialog with the decision maker proceeds as follows:

Iteration 1:

1. $l = 1$, $A_1 = A$, $K = \{1, 2, 3, 4\}$.
2. Alternative a_8 is selected as a candidate alternative.
3. Following data are presented to the decision maker:
   $\mu_{8\,1} = 1183.06$, $\mu_{8\,2} = 6.8$, $\mu_{8\,3} = 7.2$, $\mu_{8\,4} = 5.7$
   $\mu_1^* = 1432.72$, $\mu_2^* = 7.9$, $\mu_3^* = 7.5$, $\mu_4^* = 8.2$
   $d_8{}^1{}_1 = 5$, $d_8{}^1{}_2 = 3$, $d_8{}^1{}_3 = 1$, $d_8{}^1{}_4 = 4$;
4. Let us assume that the candidate alternative is not satisfactory for the decision maker;
5. Let us assume that the candidate alternative is satisfactory for the decision maker with respect to X_3;
6. The decision maker defines $\delta_3 = 4.5$ as the minimum average evaluation with respect to X_3;
7. $A_2 = \{ a_j: a_j \in A_1, \mu_{j3} \geq 4.5 \} = \{ a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9 \}$, $l = 2$, $K = \{1, 2, 4\}$.

Iteration 2

2. Alternative a_4 is selected as a candidate alternative;
3. Following data are presented to the decision maker:

$\mu_{41} = 1208.61$, $\mu_{42} = 5.3$, $\mu_{43} = 4.6$, $\mu_{44} = 8.0$
$\mu_1^* = 1432.72$, $\mu_1^* = 7.9$, $\mu_3^* = 7.5$, $\mu_4^* = 8.0$
$d_4^2{}_1 = 4$, $d_4^2{}_2 = 3$, $d_4^2{}_3 = 7$, $d_4^2{}_4 = 0$;

4. Let us assume that the candidate alternative is not satisfactory for the decision maker;
5. Let us assume that the candidate alternative is satisfactory for the decision maker with respect to X_4;
6. The decision maker defines $\delta_4 = 4.5$ as the minimum average evaluation with respect to X_4;
7. $A_3 = \{ a_j: a_j \in A_2, \mu_{j4} \geq 4{,}5 \} = \{ a_3, a_4, a_6, a_8, a_9 \}$, $l = 3$, $K = \{1, 2\}$.

Iteration 3

2. Alternative a_9 is selected as a candidate alternative;
3. Following data are presented to the decision maker:
   $\mu_{91} = 1413.84$, $\mu_{92} = 6.9$, $\mu_{93} = 5.4$, $\mu_{94} = 4.7$
   $\mu_1^* = 1432.72$, $\mu_1^* = 7.9$, $\mu_3^* = 7.2$, $\mu_4^* = 8.0$
   $d_9^3{}_1 = 0$, $d_9^3{}_2 = 1$, $d_9^3{}_3 = 2$, $d_9^3{}_4 = 4$;
4. Let us assume that the decision maker accepts the candidate alternative as a final solution.
8. End of the procedure.

4. CONCLUSIONS

In this study a new methodology for a project selection problem is proposed. The method combines interactive approach commonly used in multicriteria analysis with stochastic dominance rules that are often employed for comparing uncertain outputs. There are several advantages of the proposed technique. First, the decision maker is able to consider various criteria. Second, both quantitative and qualitative data can be analysed. Finally, the procedure permits the consideration of risk that the decision maker has to face.

Although the example given in this paper illustrates an implementation for selecting production facility, the method can also be used to provide a similar support for selection construction, R&D, social and others projects.

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