

Maciej Nowak

AN INTERACTIVE PROCEDURE FOR PROJECT SELECTION

INTRODUCTION

Profitable investments lead to the growth and prosperity of an economic organization. Various objectives are usually taken into account when an investment project is analyzed. Economic desirability is undoubtedly of primary importance. Various methods and techniques are used for evaluating investment projects [20; 21]. Net present value (NPV), internal rate of return (IRR), profitability index (PI), payback period (PP) and other measures are usually employed when financial analysis of a project is performed. In many cases, however, investor's considerations are not limited to economic desirability. Usually objectives reflecting technical, environmental, social, and/or political factors are also taken into account. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, a multiple criteria decision making problem arises.

Criteria for project comparison are often of different nature. While financial criteria are quantitative, others are often of qualitative nature. If, for example, an engineering project is considered, various technical factors of qualitative kind, including the level of technological novelty, compatibility with existing facilities, reliability and technical service, are taken into account. A similar situation takes place when social and environmental consequences are examined. While some criteria are quantitative (the volume of pollutants, the area of degraded land etc.), others are qualitative (changes in landscape, changes in the way of life of the neighboring population etc.).

When faced with the decision of selecting an engineering, construction or R&D project, the decision maker has also to face uncertainty. Project evaluation involves prediction of future outcomes. In the real world, however, not all predictions are known with certainty. Even experts are sometimes wrong in their assessments. In addition, various experts often differ in their opinions on the same project. Thus, risk associated with at least some objectives has to be considered when projects are evaluated.

A number of procedures for evaluating engineering, construction, and R&D projects have been proposed in recent years. A wide survey of quantitative techniques for R&D project selection and resource allocation is given by Heidenberger and Stummer [7]. Most procedures listed in their paper can be applied for evaluation of construction and engineering projects as well. Analytical Hierarchy Process (AHP), proposed by Saaty [22], is one of the most widely employed techniques. The main idea of AHP is to exploit the results of the decision maker's subjective evaluations formulated for each pair of projects and for each criterion. Lootsma et al. [12] use a procedure similar to AHP for ranking non-nuclear energy research programs. Ferrari [4] presents a choice method, which accounts for the different nature of the two types of agents involved in the decision-making process: technicians and politicians. The method enables calculating the weights of the elements in each hierarchy level with respect to the elements in the next upper level through procedures different from those of traditional analytic hierarchy process, in that it accounts for the dependence of the weights of the viewpoints on the project attributes. Kearns [9] uses AHP approach for economic evaluation of information technology investments. In his work multi-objective technique is used to reflect both tangible and intangible benefits, link the investment to business strategies, increase management participation in the evaluation process, and provide important features of portfolio selection.

Techniques based on the utility function constitute another group of multi-criteria methods employed in project selection problems. This approach is based on the assumption that each decision maker attempts to maximize some utility function aggregating evaluation criteria. In this case the main problem is to estimate the utility function. Multi-attribute utility analysis is used, for example, by Moselhi and Deb [15], who treat uncertainty in a similar way to that used in the PERT technique. In this procedure the total expected utility is calculated by multiplying three matrices: utility matrix, objective matrix, and scaling matrix. Wong et al. [25] incorporate fuzzy analysis into multi-attribute utility theory. Their procedure uses stochastic dominance rules for ordering projects.

Numerous techniques based on the outranking relation have been also proposed. Martel and D'Avignon [13] 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 every project is as good as another. Multiple-criteria decision-aiding procedures ELECTRE and PROMETHEE are used in project evaluation problems by Pin-Yu et al. [19], Costa et al. [2], Mavrotas et al. [14], Al-Rashdan et al. [1], and Goumas et al. [5].

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. The goal programming concept is used, for example, by Santhanam and Kyprasis [23], Lee and Kim [11], de Oliveira et al. [3].

The solution of a multiple criteria decision making problem is possible if the decision maker is able to provide information about his or her preferences with respect to the set of objectives under consideration. Procedures listed above assume that preference information is collected prior to calculating the final solution. The analysis is therefore based on an a priori basis. In many situations, however, the decision maker is unable or unwilling to provide all required information at the same time. A methodology known as interactive approach is very useful in such cases. This technique assumes that the decision maker is able to provide preference information with respect to a given solution or a given set of solutions (local preference information). Two main advantages are usually mentioned for employing interactive techniques. First, such methods need much less information on the decision maker's preferences. Second, since the decision maker is closely involved in all phases of the problem solving process, he or she puts much reliance in the generated solution, and as a result, the final solution has a better chance of being implemented. Numerous interactive techniques have been proposed in recent years. Most of them are applicable in circumstances of certainty, although methods devised for the case of risk are also proposed. The INSDECM technique presented in [16], combines interactive approach and risk analysis based on stochastic dominance and mean-risk analysis.

The aim of this paper is to propose a comprehensive methodology for project selection problems that enables handling both quantitative and qualitative criteria and takes into account risk associated with each objective. While simulation technique is used for generating distributional evaluations with respect to quantitative measures, expert assessments are taken into account when projects are appraised in relation to qualitative criteria. The interactive procedure INSDECM is employed for generating the final solution. In previous work this technique was applied for cardinal data only. This study presents the way in which INSDECM can be utilized when both cardinal and ordinal variables are considered. The methodology, which essentially combines stochastic dominance technique and interactive approach, is described first, followed by an illustrative example.

1. METHODOLOGY

The decision situation considered in this paper may be conceived as a problem (A, X, E) where A is a finite set of alternative projects a_i , $i = 1, 2, \dots, m$; X is a finite set of criteria X_k , $k = 1, 2, \dots, n$; and E is a set of evaluations of projects with respect to criteria:

$$E = \begin{bmatrix} X_{11} & \cdots & X_{1k} & \cdots & X_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ X_{i1} & \cdots & X_{ik} & \cdots & X_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ X_{m1} & \cdots & X_{mk} & \cdots & X_{mn} \end{bmatrix}$$

In this paper the author assumes that two techniques are used for generating project evaluations: simulation and expert assessments. The former is employed when projects are evaluated with respect to financial measures, while the latter is used for obtaining evaluations related to qualitative criteria. In both cases the results can be transformed into probability distributions.

The procedure consists of four major steps. First, the set of criteria is defined. Next, evaluations of projects with respect to the criteria are generated. In the third step project evaluations are compared with respect to the criteria. Finally, interactive technique is employed for selection of the most desirable project. The steps required to perform the analysis are described below.

Step 1. Identification of criteria

The selection of the criteria is of crucial importance. According to Keeney and Raiffa [10] the set of criteria should be complete, operational, decomposable, non-redundant, and minimal. Completeness means that all important aspects of the problem are covered. The set of criteria is operational if it can be meaningfully used in the analysis. When the set of criteria is decomposable, the evaluation process can be simplified by breaking it down into parts. Non-redundancy means that duplicate counting of impacts is avoided. Finally, when the set of criteria is minimal, the solution of the problem is easier as its dimension is as small as possible. It is quite clear that criterion with respect to which all project outcomes are the same can be discarded, as it does not influence the decision maker's choice.

Step 2. Generation of project evaluations

Economic desirability analysis of a project involves prediction of future outcomes. In the real world, however, predictions are not known with certainty. Thus, risk associated with each project has to be taken into account. Simulation technique is an efficient and flexible tool for doing this. Various risk factors can be taken into account in a simulation model. For example, when a construction or manufacturing project is analyzed, uncertainties related to availability of resources, market prices, or demand can be considered. On the other hand, in projects with R&D elements activity durations are much more sensitive

to incorrect evaluation. In such cases simulation may provide the dates of the milestones of the project, which determine the set of cash-flows during the life cycle of the project. One of the most important elements of simulation modeling is identifying appropriate probability distributions for input data. Usually, this requires analyzing empirical or historical data and fitting these data to distributions. Sometimes, however, such data are not available and an appropriate distribution has to be selected according to the decision maker's judgment. Once the simulation model is built, verified, and validated, it can be used for generating probability distributions of output variables.

If experts are asked to assess projects with respect to qualitative criteria, distributional evaluations can be constructed in a similar way. Let's assume that each project a_i is evaluated by l experts with respect to criterion X_k on a specified scale. Such scale can be defined, for example, as a 10-point one, with 1 assigned to the least desirable and 10 to the most desirable output. As a result, l evaluations are obtained for each project. Assuming equal probabilities of each assessment, a distribution evaluation is achieved. Such distribution, however, differs from the one obtained in simulation, as qualitative criteria are measured on ordinal scale. As a result, the rules for comparing such distributions are different from the ones used for real-value outcomes, i.e. outcomes measured on cardinal scale, such as return, net profit, or volume of pollutions.

Step 3. Comparing projects with respect to criteria

Once evaluations of the projects are obtained, relations between projects with respect to criteria can be analyzed. Two methods are usually used for comparing uncertain outcomes: mean-risk analysis and stochastic dominance. The former is based on two criteria: one measuring expected outcome and another representing variability of outcomes. In stochastic dominance approach random variables are compared by pointwise comparison of their distribution functions. In this paper both techniques are used. While stochastic dominance is employed for constructing rankings of projects with respect to each criterion, mean-risk technique is used when a final solution is chosen.

Let's assume that criteria are defined so that larger values are preferred to smaller ones. Let $F_{i k}(x)$ and $F_{j k}(x)$ be right-continuous cumulative distribution functions representing evaluations of a_i and a_j respectively over criterion X_k :

$$F_{i k}(x) = \Pr(X_{i k} \leq x)$$

$$F_{j k}(x) = \Pr(X_{j k} \leq x)$$

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

Definition 1 (FSD – *First Degree Stochastic Dominance*)

X_{ik} dominates X_{jk} by FSD rule ($X_{ik} \succ_{\text{FSD}} X_{jk}$) if and only if :
 $F_{ik}(x) \neq F_{jk}(x)$ and $H_1(x) = F_{ik}(x) - F_{jk}(x) \leq 0$ for $x \in R$

Definition 2 (SSD – *Second Degree Stochastic Dominance*)

F_{ik} dominates F_{jk} by SSD rule ($F_{ik} \text{SSD } F_{jk}$) if and only if :

$$F_{ik}(x) \neq F_{jk}(x) \text{ and } H_2(x) = \int_{-\infty}^x H_1(y) dy \leq 0 \text{ for } x \in R$$

Hadar and Russel [6] have shown 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 rules defined above can be applied to real-value outcomes, such as income, wealth, or rates of return, but fail to provide ranking of preferences among variables of ordinal nature. Stochastic dominance rules that can be applied in such situations were proposed by Spector et al. [24]. They distinguish between two separate ordinal measurements:

1. The alternative outcomes can only be ranked in order of preference.
2. In addition to ranking, it is also possible to rank the differences between alternative outcomes.

Let's assume that a random variable X_{ik} is defined by $(e_{k1}, \dots, e_{kz}, p_{ik1}, \dots, p_{ikz})$, where e_{k1}, \dots, e_{kz} are z real numbers, such that $e_{kl} < e_{k,l+1}$ for all $l = 1, \dots, z-1$, and p_{ik1}, \dots, p_{ikz} are the probability measures. The variable X_{jk} is defined analogously with p_{jk1}, \dots, p_{jkz} replacing p_{ik1}, \dots, p_{ikz} .

If the outcomes can be ranked in order of preferences, i.e. the decision maker prefers $e_{k,l+1}$ over e_{kl} for all $l = 1, \dots, z-1$ then Ordinal First Degree Stochastic Dominance (OFSD) rule can be used:

Definition 3 (OFSD – *Ordinal First Degree Stochastic Dominance*)

X_{ik} dominates X_{jk} by OFSD rule ($X_{ik} \succ_{\text{OFSD}} X_{jk}$) if and only if :

$$\sum_{l=1}^s p_{ikl} \leq \sum_{l=1}^s p_{jkl} \text{ for all } s = 1, \dots, z$$

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

Definition 4 (OSSD – Ordinal Second Degree Stochastic Dominance)

X_{ik} dominates X_{jk} by OSSD rule ($X_{ik} \succ_{\text{OSSD}} X_{jk}$) if and only if :

$$\sum_{r=1}^s \sum_{l=1}^r p_{ikl} \leq \sum_{r=1}^s \sum_{l=1}^r p_{jkl} \text{ for all } s = 1, \dots, z$$

Spector et al. [24] have shown that the OFSD rule is equivalent to the expected utility rule for all decision makers preferring larger outcomes, while the OSSD rule, to the expected utility rule for risk-averse decision makers preferring larger outcomes.

The procedure proposed in this paper assumes that the decision maker is risk averse. Such assumption is usually made in finance and corresponds to the results of experiments of Kahneman and Tversky [8] showing that decision makers are usually risk averse in relation to criteria defined in the domain of gains. As a result, FSD / SSD rules are used for modeling decision maker’s preferences with respect to real-valued criteria, while OFSD / OSSD rules, in the case of qualitative variables measured on ordinal scale. Thus, the third step of the procedure involves determination of stochastic dominance relation for each pair of projects and for each criterion.

Step 4. Final solution selection

The last step of the procedure involves final selection and is realized in two steps. First, efficient projects are identified; then the final solution is selected in a dialog procedure. We assume that project a_i is efficient if and only if for no other project a_j the following condition is fulfilled:

$$\forall k = 1, \dots, n \quad X_{jk} \succ_{\text{SD}} X_{ik}$$

where \succ_{SD} stands for a stochastic dominance relation (FSD/SSD/OFSD/OSSD). Thus we assume that project a_i is efficient if there is no other project that dominates a_i according to stochastic dominance rules with respect to all criteria.

Efficient projects can be identified by pairwise comparisons. Let A' be the set of efficient projects. The generation of A' proceeds as follows:

1. Let $A' = A$.
2. Let $i = 2$.
3. Let $j = 1$.
4. If $a_j \notin A'$ then go to 7.
5. If $X_{jk} \succ_{\text{SD}} X_{ik}$ for all $k = 1, 2, \dots, n$, $A' = A' \setminus \{a_i\}$, go to 8.
6. If $X_k^i \succ_{\text{SD}} X_k^j$ for all $k = 1, 2, \dots, n$, $A' = A' \setminus \{a_j\}$.
7. If $j < i - 1$, let $j = j + 1$, go to 4.
8. If $i < m$, let $i = i + 1$, go to 3.
9. End of the procedure.

Interactive approach is employed for selection of the most desirable project. The proposed technique is based on the main ideas of the INSDECM procedure [16]. Each iteration includes the following phases:

- presentation of the data,
- asking the decision maker to provide preference information in the form of aspiration levels based on expected outcome measures (mean) or variability of outcomes measures,
- identification of projects satisfying restrictions.

It is assumed that the decision maker is able to specify the method of data presentation. For each criterion he or she may choose one or more scalar measures to be presented to him or her. Both expected outcome measures (mean, median, mode) and variability measures (standard deviation, semi-deviation, probability of getting outcomes not greater or not less than target value) can be chosen. It is also assumed that the decision maker defines additional requirements specifying minimum or maximum acceptable values of those scalar measures. Unfortunately such constraints are in general not consistent with stochastic dominance rules (for details see [17; 18]). Such situation takes place if the following conditions are fulfilled simultaneously:

- the evaluation of a_i with respect to X_k does not satisfy the constraint,
- the evaluation of a_j with respect to X_k satisfies the constraint,
- $X_{i k} \succ_{SD} X_{j k}$.

We propose to verify whether a constraint defined by the decision maker is consistent with stochastic dominance rules and to suggest methods of re-defining constraint if inconsistency is found for any pair of projects. Let's assume that inconsistency has been verified for projects a_i and a_j . Inconsistent constraint should be redefined in a way that results in accepting or rejecting both a_i and a_j . The former can be achieved by making the constraint less restricted, the latter, by relaxing it.

The procedure operates as follows:

1. Let $l = 1$, $B_l = A'$.
2. Rank projects $a_i \in B_l$ according to stochastic dominance rules with respect to criterion X_k , $k = 1, \dots, n$.
3. If l is equal to 1, go to 6, else go to 4.
4. Present the best and the worst projects with respect to X_k , for $k = 1, \dots, n$ and the values of the corresponding scalar measures to the decision maker.
5. Ask the decision maker whether he or she accepts the move from B_{l-1} to B_l . If the answer is YES, go to 6, else set $l = l - 1$ and go to 3.
6. Present the list of considered projects to the decision maker. If the decision maker is able to choose the final solution then the procedure ends, else go to 7.
7. Present the best and the worst projects with respect to X_k , for $k = 1, \dots, n$ and the values of the corresponding scalar measures to the decision maker.

8. Ask the decision maker to define a new constraint.
9. Verify the consistency of the constraint defined by the decision maker with stochastic dominance rules. If inconsistency is found, go to 10, else go to 11.
10. Present to the decision maker the ways in which the restriction can be redefined and ask him or her to choose one of the suggestions. If he or she does not accept any proposal, go to 8; else replace the restriction by the accepted proposal and go to 11.
11. Generate B_{l+1} – the set of projects $a_i \in B_l$ satisfying the considered restriction. If $B_{l+1} = \emptyset$, notify the decision maker and go to 8, else set $l = l + 1$ and go to 2.

The procedure iterates until the decision maker is able to accept one of the considered projects as the final solution. Although the procedure does not limit the number of scalar measures to be presented, the decision maker is usually not able to analyze too many of them. If the number of criteria is large then it is practical to limit the number of the measures for each criterion to one. Usually, central tendency measures provide beneficial information. Measures based on probability of getting outcomes above or below the specified target value are also interesting, as they are intuitively comprehensible for the decision maker.

2. ILLUSTRATIVE EXAMPLE

To illustrate the procedure let us consider a manufacturing company operating in a growth market. The management board decided to purchase a new production facility to increase production capacity. Ten alternative projects are considered. All proposals are viable: that is, the output from any of these alternatives meets product specification. The decision for selecting a project has to be made based on net present value for each project, in addition to three other objectives identified in Step 1 below. The economic life for all projects is assumed to be 5 years. Based on past experience and data provided by the manufacturers of facilities, analysts have determined the probability distributions for:

- initial investments (triangular distributions),
- salvage values (uniform distributions),
- production costs per unit (triangular distributions),
- fixed costs (triangular distributions),
- demand (normal distributions),
- market prices (triangular distributions).

Production capacities for each project and for each year have also been specified. The data are shown in Tables 1 and 2.

Table 1

Distributions for project characteristics
(a – minimum, b – maximum, m – most likely)

	Project										
	Year	1	2	3	4	5	6	7	8	9	10
Initial investment EUR · 10 ³ (triangular distr.)	a	480	390	470	370	390	410	380	500	570	360
	m	540	490	550	480	460	490	450	570	490	470
	b	580	580	610	560	510	520	530	650	440	540
Prod. capacity units · 10 ³ (normal distribution)	1	1200	1150	1350	1050	1000	1050	950	1400	1100	1025
	2	1200	1150	1350	1050	1000	1050	950	1400	1100	1025
	3	1200	1150	1350	1050	1000	1050	950	1400	1100	1025
	4	1100	1050	1250	950	900	950	950	1300	1000	950
	5	1000	950	1150	850	800	850	900	1200	900	900
1	a	4.75	4.80	4.81	4.76	4.82	4.79	4.74	4.72	4.78	4.77
	m	5.00	5.05	5.06	5.01	5.07	5.04	4.99	4.97	5.03	5.02
	b	5.38	5.43	5.44	5.39	5.45	5.42	5.36	5.34	5.41	5.40
2	a	4.85	4.89	4.90	4.85	4.91	4.88	4.84	4.82	4.87	4.86
	m	5.10	5.15	5.16	5.11	5.17	5.14	5.09	5.07	5.13	5.12
	b	5.20	5.54	5.55	5.49	5.56	5.53	5.47	5.45	5.51	5.50
3	a	4.94	4.99	5.00	4.95	5.01	4.98	4.93	4.91	4.97	4.96
	m	5.20	5.25	5.26	5.21	5.27	5.24	5.19	5.17	5.23	5.22
	b	5.59	5.64	5.65	5.60	5.67	5.63	5.58	5.56	5.62	5.61
4	a	5.04	5.09	5.10	5.04	5.11	5.07	5.03	5.01	5.06	5.05
	m	5.30	5.36	5.37	5.31	5.38	5.34	5.29	5.27	5.33	5.33
	b	5.70	5.76	5.77	5.71	5.78	5.74	5.69	5.67	5.73	5.72
5	a	5.14	5.20	5.21	5.15	5.22	5.18	5.13	5.11	5.17	5.16
	m	5.41	5.47	5.48	5.42	5.49	5.45	5.40	5.38	5.44	5.43
	b	5.82	5.88	5.89	5.83	5.90	5.86	5.81	5.78	5.85	5.84
Salvage value EUR · 10 ³ (uniform distr.)	a	250	200	225	175	125	175	100	250	175	150
	b	325	275	325	250	200	225	150	350	275	225

Table 2

Fixed costs and market predictions
(a – minimum, b – maximum, m – most likely, μ – mean, σ – standard deviation)

Year	Fixed costs EUR · 10 ³ (triangular distr.)	Demand units · 10 ³ (normal distr.)	Market price EUR (triangular distr.)
1	$a = 270.00$ $m = 300.00$ $b = 322.50$	$\mu = 950.00$ $\sigma = 92.60$	$a = 6.00$ $m = 6.20$ $b = 6.35$
2	$a = 283.50$ $m = 315.00$ $b = 338.63$	$\mu = 976.00$ $\sigma = 104.90$	$a = 5.95$ $m = 6.15$ $b = 6.30$
3	$a = 297.68$ $m = 330.75$ $b = 355.65$	$\mu = 1008.00$ $\sigma = 115.90$	$a = 5.75$ $m = 6.10$ $b = 6.25$
4	$a = 312.56$ $m = 347.29$ $b = 373.34$	$\mu = 1020.00$ $\sigma = 117.40$	$a = 5.75$ $m = 6.05$ $b = 6.20$
5	$a = 328.19$ $m = 364.65$ $b = 392.00$	$\mu = 1023.00$ $\sigma = 117.60$	$a = 5.73$ $m = 6.00$ $b = 6.20$

Step 1. Identification of criteria

The decision maker decided to consider the following criteria:

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

Step 2. Generation of project evaluations

Simulation technique has been applied for generating distributional evaluations of projects with respect to attribute X_1 . Table 3 presents results of simulation experiments.

Table 3

Results of simulation experiments

Project	Mean	Standard deviation
1	1413.84	265.94
2	1183.06	269.73
3	1139.12	277.16
4	1244.56	260.44
5	979.66	237.21
6	1137.93	244.98
7	1208.61	234.54
8	1432.72	283.48
9	1211.81	256.91
10	1226.72	256.32

Expert assessments are used for constructing distributional evaluations of the projects with respect to criteria X_2 , X_3 , X_4 . Ten analysts assessed each proposal on the scale from 1 to 10. Tables 4, 5 and 6 present expert assessments.

Table 4

Analysts' evaluations with respect to X_2 (reliability and technical service)
(number of experts assigning the specified criteria value for a project)

Evaluation	Project									
	1	2	3	4	5	6	7	8	9	10
1			2		3					
2		4	2		1		1			
3		3	3	1	2		3		1	
4		2	2	2	2		1	1		
5	1	1	1	3	2		1	1	1	
6	2			2		1	3	2	1	2
7	2			1		4	1	2	3	2
8	3			1		2		3	2	3
9	2					1		1	2	2
10						2				1

Table 5

Analysts' evaluations with respect to X_3 (technical novelty)
(number of experts assigning the specified criteria value for a project)

Evaluation	Project									
	1	2	3	4	5	6	7	8	9	10
1										1
2	2			1						2
3	4	2		2				1	2	3
4	2	2		3	1	1		1	4	3
5	2	1			2	4	1	1	2	1
6		5	4	2	2	2	3	2	2	
7			2	2	3	2	1			
8			4		1		2			
9					1	1	1	2		
10							2	3		

Table 6

Analysts' evaluations with respect to X_4 (compatibility with existing facilities)
(number of experts assigning the specified criteria value for a project)

Evaluation	Project									
	1	2	3	4	5	6	7	8	9	10
1		3								
2		3			1		3			
3		1			2		1	1	4	
4		1	4		3	1	1	2	3	
5		2			1	2	4	3		1
6	1		5		3	2	1	1		3
7	2		1	3		2			1	1
8	3			5		1		2	2	3
9	2			1		2		1		2
10	2			1						

Step 3. Comparing projects with respect to criteria

FSD/SSD rules are applied for comparing projects with respect to criterion X_1 , while OFSD/OSSD rules are employed when projects are analyzed with respect to criteria X_2, X_3 , and X_4 . Tables 7, 8, 9 and 10 show relations between projects.

Table 7

FSD/SSD relations between project evaluations with respect to criterion X_1

	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}	X_{61}	X_{71}	X_{81}	X_{91}	X_{101}
X_{11}		FSD	FSD	FSD	FSD	FSD	FSD		FSD	FSD
X_{21}			SSD		FSD					
X_{31}										
X_{41}		SSD	SSD		FSD					
X_{51}										
X_{61}					FSD					
X_{71}		SSD	SSD		FSD	SSD				
X_{81}		FSD	FSD	FSD	FSD	FSD	FSD		FSD	FSD
X_{91}		SSD	FSD		FSD					
X_{101}		SSD	SSD		FSD					

Table 8

OFSD/OSSD relations between project evaluations with respect to criterion X_2

	X_{12}	X_{22}	X_{32}	X_{42}	X_{52}	X_{62}	X_{72}	X_{82}	X_{92}	X_{102}
X_{12}		OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	
X_{22}			OFSD		OSSD					
X_{32}										
X_{42}		OFSD	OFSD		OFSD		OFSD			
X_{52}										
X_{62}	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	OSSD
X_{72}		OFSD	OFSD		OFSD					
X_{82}		OFSD	OFSD	OFSD	OFSD		OFSD			
X_{92}		OFSD	OFSD	OFSD	OFSD		OFSD			
X_{102}	OFSD	OFSD	OFSD	OFSD	OFSD		OFSD	OFSD	OFSD	

Table 9

OFSD/OSSD relations between project evaluations with respect to criterion X_3

	X_{13}	X_{23}	X_{33}	X_{43}	X_{53}	X_{63}	X_{73}	X_{83}	X_{93}	X_{103}
X_{13}										
X_{23}	OFSD			OSSD						OFSD
X_{33}	OFSD	OFSD		OFSD	OSSD	OSSD			OFSD	OFSD
X_{43}	OFSD									OFSD
X_{53}	OFSD	OFSD		OFSD		OFSD			OFSD	OFSD
X_{63}	OFSD	OFSD		OFSD					OFSD	OFSD
X_{73}	OFSD	OFSD		OFSD	OFSD	OFSD		OSSD	OFSD	OFSD
X_{83}	OFSD	OFSD		OFSD						OFSD
X_{93}	OFSD	OSSD		OFSD						OFSD
X_{103}	OFSD									

Table 10

OFSD/OSSD relations between project evaluations with respect to criterion X_4

	X_{14}	X_{24}	X_{34}	X_{44}	X_{54}	X_{64}	X_{74}	X_{84}	X_{94}	X_{104}
X_{14}		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
X_{24}										
X_{34}		OFSD			OFSD		OFSD		OSSD	
X_{44}		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	OFSD
X_{54}		OFSD					OSSD			
X_{64}		OFSD	OFSD		OFSD		OFSD	OFSD	OFSD	
X_{74}		OFSD								
X_{84}		OFSD			OFSD		OFSD		OFSD	
X_{94}		OFSD					OSSD			
X_{104}		OFSD	OFSD		OFSD	OFSD	OFSD	OFSD	OFSD	

Step 4. Generating the final solution

Project a_2 is not efficient – its evaluations are dominated by the corresponding evaluations of $a_7, a_8,$ and a_9 with respect to all attributes:

$$X_{71} \succ_{SSD} X_{21} \text{ and } X_{72} \succ_{OFSD} X_{22} \text{ and } X_{73} \succ_{OFSD} X_{23} \text{ and } X_{74} \succ_{OFSD} X_{24}$$

$$X_{81} \succ_{FSD} X_{21} \text{ and } X_{82} \succ_{OFSD} X_{22} \text{ and } X_{83} \succ_{OFSD} X_{23} \text{ and } X_{84} \succ_{OFSD} X_{24}$$

$$X_{91} \succ_{SSD} X_{21} \text{ and } X_{92} \succ_{OFSD} X_{22} \text{ and } X_{93} \succ_{OSSD} X_{23} \text{ and } X_{94} \succ_{OFSD} X_{24}$$

All other projects are efficient:

$$A' = \{ a_1, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10} \}$$

Let's assume that the decision maker has chosen the mean to be presented during the dialog procedure. The final solution is generated as follows:

Iteration 1

1. $l = 1, B_1 = \{ a_1, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10} \}$.
2. Projects are ranked according to stochastic dominance rules with respect to each criterion (Table 11).

Table 11

Rankings of projects with respect to the criteria

X_1	X_2	X_3	X_4
a_1, a_8	a_6	a_3, a_7	a_1, a_4
a_4, a_7, a_9, a_{10}	a_{10}	a_5, a_8	a_{10}
a_3, a_6	a_1	a_6	a_6
a_5	a_8, a_9	a_9	a_3, a_8
	a_4	a_4	a_5, a_9
	a_7	a_{10}	a_7
	a_3, a_5	a_1	

6. Projects $a_i \in B_1$ are presented to the decision maker. He states that he is not able to select the final solution yet.
7. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 12).

Table 12

Iteration 1 – the best and the worst alternatives with respect to the criteria

	X_1		X_2		X_3		X_4	
	project	mean	project	mean	project	mean	project	mean
best	a_1	1413.84	a_6	7.9	a_3	7.0	a_1	8.2
	a_8	1432.72			a_7	7.5	a_4	8.0
worst	a_5	979.66	a_3	2.8	a_1	3.4	a_7	3.9
			a_5	2.9				

8. The decision maker formulates the following constraint:
The average evaluation with respect to X_1 not less than 1000: $\mu_{i1} \geq 1000$
9. The constraint is consistent with stochastic dominance rules – the only action that does not satisfy it is a_5 ; the evaluation of a_5 with respect to X_1 does not dominate the corresponding evaluation of any other $a_i \in B_1$.
11. $B_2 = \{ a_1, a_3, a_4, a_6, a_7, a_8, a_9, a_{10} \}; l = 2$.

Iteration 2

2. Projects $a_j \in B_2$ are ranked according to stochastic dominance rules with respect to each criterion.
4. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 13).

Table 13

Iteration 2 – the best and the worst alternatives with respect to the criteria

	X_1		X_2		X_3		X_4	
	project	mean	project	mean	project	mean	project	mean
best	a_1	1413.84	a_6	7.9	a_3	7.0	a_1	8.2
	a_8	1432.72			a_7	7.5	a_4	8.0
worst	a_3	1139.12	a_3	2.8	a_1	3.4	a_7	3.9
	a_6	1137.93						

5. The decision maker accepts the move from B_1 to B_2 .
6. Projects $a_i \in B_2$ are presented to the decision maker. He states that he is not able to select the final solution yet.
7. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 13).
8. The decision maker formulates the following constraint:
The probability that the evaluation with respect to X_4 is not less than 7 is at least equal to 0.2: $\Pr(X_{i4} \geq 7) \geq 0.2$
9. The constraint is not consistent with stochastic dominance rules for pair (a_3, a_9) :

$$\Pr(X_{34} \geq 7) = 0.1$$

$$\Pr(X_{94} \geq 7) = 0.3$$

$$X_{34} \text{ OSSD } X_{94}$$

10. The ways in which the restriction can be redefined are presented to the decision maker:
 - (1) $\Pr(X_{i4} \geq 7) \geq 0.1$
 - (2) $\Pr(X_{i4} \geq 6) \geq 0.2$
 - (3) $\Pr(X_{i4} \geq 7) \geq 0.31$
 - (4) $\Pr(X_{i4} \geq 9) \geq 0.2$
 Proposals (1) and (2) accept both a_3 and a_9 , while proposals (3) and (4) eliminate each of them. The decision maker accepts proposal (1).
11. $B_3 = \{ a_1, a_3, a_4, a_6, a_8, a_9, a_{10} \}; l = 3$.

Iteration 3

2. Projects $a_j \in B_3$ are ranked according to stochastic dominance rules with respect to each criterion.
4. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 14).

Table 14

Iteration 3 – the best and the worst alternatives with respect to the criteria

	X_1		X_2		X_3		X_4	
	project	mean	project	mean	project	mean	project	mean
best	a_1	1413.84	a_6	7.9	a_3	7.0	a_1	8.2
	a_8	1432.72			a_8	7.2	a_4	8.0
worst	a_3	1139.12	a_3	2.8	a_1	3.4	a_9	4.7
	a_6	1137.93						

5. The decision maker accepts the move from B_2 to B_3 .
6. Projects $a_i \in B_3$ are presented to the decision maker. He states that he is not able to select the final solution yet.
7. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 14).
8. The decision maker formulates the following constraint:
The average evaluation with respect to X_2 is not less than 6: $\mu_{i2} \geq 6$
9. The constraint is consistent with stochastic dominance rules – actions a_3 and a_4 do not satisfy such restriction; evaluation of a_3 and a_5 with respect to X_2 do not dominate the corresponding evaluations of $a_1, a_6, a_8, a_9, a_{10}$.
11. $B_4 = \{ a_1, a_6, a_8, a_9, a_{10} \}; l = 4$.

Iteration 4

2. Projects $a_j \in B_4$ are ranked according to stochastic dominance rules with respect to each criterion.
4. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 15).

Table 15

Iteration 4 – the best and the worst alternatives with respect to the criteria

	X_1		X_2		X_3		X_4	
	project	mean	project	mean	project	mean	project	mean
best	a_1	1413.84	a_6	7.9	a_6	5.9	a_1	8.2
	a_8	1432.72			a_8	7.2		
worst	a_6	1137.93	a_8	6.8	a_1	3.4	a_9	4.7
	a_9	1211.81	a_9	6.9				
	a_{10}	1226.72						

5. The decision maker accepts the move from B_3 to B_4 .
6. Projects $a_i \in B_4$ are presented to the decision maker. He states that he is not able to select the final solution yet.
7. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 15).
8. The decision maker formulates the following constraint:
The probability that the evaluation with respect to X_3 is not less than 5 is at least equal to 0.5: $\Pr(X_{i_3} \geq 5) \geq 0.5$
9. The constraint is consistent with stochastic dominance rules – actions a_1 and a_{10} do not satisfy such restriction; evaluations of a_1 and a_{10} with respect to X_3 do not dominate corresponding evaluations of a_6, a_8, a_9 .
11. $B_5 = \{ a_6, a_8, a_9 \}; l = 5$.

Iteration 5

2. Projects $a_j \in B_5$ are ranked according to stochastic dominance rules with respect to each criterion.
4. The best and the worst projects with respect to the criteria are presented to the decision maker (Table 16).

Table 16

Iteration 5 – the best and the worst alternatives with respect to the criteria

	X_1		X_2		X_3		X_4	
	project	mean	project	mean	project	mean	project	mean
best	a_8	1432.72	a_6	7.9	a_6	5.9	a_6	6.6
					a_8	7.2		
worst	a_6	1137.93	a_8	6.8	a_9	5.4	a_9	4.7
	a_9	1211.81	a_9	6.9				

5. The decision maker accepts the move from B_4 to B_5 .
6. Projects $a_i \in B_5$ are presented to the decision maker. He select a_8 as the final solution.

CONCLUSIONS

Selection of a new project or a group of projects undoubtedly constitutes one of the main management functions required to ensure business survival. Such decision must usually be made using more than one criterion. Technical factors, environmental effects, social issues, and financial desirability are taken into account in the project evaluation process. Moreover, selection is made

in a risky environment. In this study a new methodology for this problem has been proposed. It uses two approaches: stochastic dominance and interactive approach. The former is widely used for comparing uncertain prospects, the latter is a multiple criteria approach that is probably most often used in real-world applications. These two concepts have been combined in the INSDECM procedure.

The technique presented in this paper uses data of various types. Simulation technique and expert assessments are used for evaluating projects with respect to criteria. Therefore, both quantitative and qualitative criteria can be taken into account. Although our example illustrates an implementation for selecting a production facility, the present method can also be used to provide a similar support for selection of R&D projects, real estate projects, or marketing strategies.

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