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Considering Bipolarity of Attributes With Regards to Objectives in Decisions Evaluation

Ayeley P. Tchangani[1,2]

[1]*IUT de Tarbes - Université de Toulouse.*
1, rue Lautréamont, 65016 Tarbes Cedex, France
e-mail: ayeley.tchangani@iut-tarbes.fr

[2]*Laboratoire Génie de Production - Université de Toulouse.*
47 Avenue d'Azereix, BP 1629, 65016 Tarbes Cedex, France
e-mail : Ayeley.Tchangani@enit.fr

Many decision problems in engineering, economics, and management consist of selecting and/or ranking alternatives that are characterized by multiple attributes in order to satisfy multiple and possible antagonist objectives. Besides this double multiplicity aspect, decision making mainly in engineering economics (decision problems where potential solutions of a problem must be economically viable along with some technical aspects) generally necessitate to cope with many stakeholders opinion regarding the importance to assign to each attribute and/or each objective as well as uncertainty that can impact any of these components (attributes values, objectives measurement and stakeholders statements). Decision processes in this context go through some steps such as 1) definition of the overall decision goal (find the best sustainable site to build a waste management facility for instance), this goal can further be split into many objectives to satisfy; 2) identification of potential alternatives; 3) elicitation and evaluation of attributes that characterize alternatives; 4) and finally evaluate alternatives to recommend the "good enough" alternative to implement. The aim of the research undertaken in this paper is to address the question raised in the third and fourth points by exploiting the bipolar nature of attributes with regards to objective to elicit and assess attributes and to build a final recommendation procedure. Indeed, we will highlight the *bipolar* nature of attributes with regards to pursued objectives (given an objective, there will be attributes that act in the sense of realization of this objective, that we refer to as *supporting attributes* and those working against the achievement of this objective, referred to as *rejecting attributes*) to derive a framework for elicitation and assessment of attributes values. Finally, relying on the bipolar nature of obtained attributes, satisficing game approach is used as a tool to support the evaluation and final recommendation process. The approach is applied to a real world problem which aim is to select the best sustainable site to build a waste management facility.

Keywords: *Selecting and Ranking Alternatives, Multiple Attributes, Bipolarity, Multiple Objectives, Multiple Actors, Satisficing Games.*

Introduction

Introduction and statement of the problem

Sustainable development concerns, needs for more democracy and transparency in public decisions, needs for more efficiency and effectiveness of public infrastructures render decision making in engineering economics (selecting a site to build an infrastructure, strategic infrastructure management policy selection, selecting projects to fund, selecting a design for a facility, ...) more and more complex. This complexity is manifested through the following features that characterize any decision making problem in engineering economics: multiplicity of attributes (alternative solutions of a problem are characterized by many attributes that we consider here to be either numeric or have been assigned as numerical values by experts or stakeholders by applying existing procedures such as the well known analytic hierarchy process, see Saaty (2005)); multiplicity of objectives (decisions are made when seeking to satisfy many objectives); multiplicity of actors or stakeholders (possible antagonist opinions of many actors must be taken into account); uncertainty (uncertainty is inherent to decision making in engineering economics, be it with regards to the formulation of objectives by decision makers, to the evaluation of attributes or because of antagonist opinion of stakeholders).

The revealed complexity of decision making in engineering economics along with computing possibility of our nowadays information society suggests to establish a framework to support the analysis and recommendations of the most efficient and effective solution.

In this paper we will concentrate on the last step of a decision making problem, namely the evaluation and recommendation step where a procedure must be derived in order to evaluate all potential alternatives when taking into account different components of the decision making problem we evoked so far. By so doing we consider that a universe U of potential alternatives has been identified and each element of this universe is characterized by a certain number of attributes that are not necessary the same from an alternative to another. The problem to be solved then is to derive a procedure in order to select a subset Σ of alternatives from U and then to rank them that is to assign a relative weight x_u to a selected alternative $u \in \Sigma$ when seeking to satisfy *m* identified objectives functions f_j, j = *1, 2, .., m* and taking into account the opinion of some stakeholders and/or experts through their preferences regarding objectives and/or attributes.

Decision making problems that fall in the subset of problems consisting of a single stakeholder known in general as decision maker and considering either multiplicity of attributes or multiplicity of objectives and almost never both is typically what is known in the literature as multi-attributes, multi-objectives, multi-criteria decision making or shortly as decision analysis, see for instance (Roy and Bouyssou, 1993), Steuer (1986), Vincke (1989). Decision analysis has been used in economics and management science for years to solve problems such as public and private infrastructures building and management (Brauers et *al.*, 2008; Salminen et *al*., 1996; Roy and Bouyssou, 1993; Turskis *et al.*, 2009; Zavadskas *et al.*, 2009), evaluation of construction process safety solution (Liaudanskiene *et al.,* 2009), activities of buildings maintenance (Vilutiene and Zavadskas, 2003), enterprises classification by using their whole activities is analyzed in (Boguslauskas and Adlyte, 2010), production units efficiency evaluation and benchmarking (Tchangani, 2006a, 2006b; Tchangani, 2010), or sustainable programs development through many indicators (Ciegis and Streimikiene, 2005) to name few. Multi-criteria approach, seen as a classification or pattern recognition problem is being used in business and banking for credit risk evaluation for instance (Danenas & Gintautas, 2009). Multiplicity of objectives is recognized in location problems; see (Brauers & Zavadskas, 2008).

The following subsection will review classical approaches used to deal with decision analysis problems.

Background: classical approaches for decision analysis

Classical approaches for solving multiple objectives decision problems rely on the notion of the so-called Pareto dominance (Pareto, 1896; Zitzler, 1999) and Pareto-optimal set and the resolution is organized around two processes: search and decision making. Depending on how search (finding a sample of Pareto-optimal set) and decision process are combined, Zitzler (1999) classifies multiple objectives optimization methods in three categories: decision making before search (the objective functions are aggregated into a single objective by using some preference of the decision maker); search before decision making (a sample or the totality of Pareto-optimal set is obtained first and then a choice is made by a decision maker; decision making during search (an interactive optimization is performed where after each search step, the decision maker is presented with a number of alternatives). The first approach to deal with multiple objectives decision making problems has been the aggregation of objectives into a single objective in different ways leading to weighting methods and constraint methods (Steuer, 1986) and goal programming methods, see for instance **(**Steuer, 1986; Ignizio, 1976). The advantage of these methods is that efficient and broad algorithms developed for single objective optimization problems, see Luenberger (1984) and references therein, can be used to solve the resulting problems. The drawback of these techniques is that the subjective intervention of the user is needed to fix weighting factors and it is known that these methods are most of the time not able to finding Pareto-optimal solutions in the case of non convex feasible space (Zitzler, 1999). To overcome these drawbacks, new methods have been designed based on evolutionary algorithms, mainly genetic algorithms that are able to generating efficiently Pareto-optimal solutions (Zitzler, 1999). An additive ratio assessment approach has been used (Zavadskas and Turskis, 2010) to tackle the problem of evaluation of alternatives characterized by multiple criteria. In Shevchenko *et al*, 2008, a method of multi-attribute comparative analysis (CLARA and SAW methods) of variants of investment classified risks in construction is considered. Zavadskas *et al*, 2008 analyze contractors selection process through multi-attributes techniques, namely a metric scores model. The analytic hierarchy process (AHP, see Saaty, 2005; Podvezko, 2009) is widely used in decision analysis and falls into this value like an evaluation scheme.

Approaches for multiple attributes decision making are dominated by so called outranking approaches where a partial order of alternatives is derived by an interactive procedure between the analyst and the decision maker (Brans *et al.*, 1986; Roy and Bouyssou, 1993; Vincke, 1989) with the well known techniques such as ELECTRE and/or PROMETHEE.

Soft computing techniques in terms of evolutionary algorithms that are a class of stochastic optimization methods that attempt to simulate the process of natural evolution are more and more used to tackle the complexity of multiple objectives/attributes decision problems (Coello, 1998; Zitzler, 1999). They have been proved useful in optimizing difficult functions that might mean: non-differentiable objective functions, many local optima, a large number of parameters, or a large number of configurations of parameters, (see Zitzler, 1999).

In this paper we consider a novel evaluation approach that relies on the bipolarity of attributes with regard to an objective that leads to the concept of supporting/rejecting attributes in the framework of satisficing game theory so that each alternative will be evaluated through two measures: selectability measure (related to positive attributes) and rejectability one (related to negative attributes). Similar procedures have been derived by the author for efficiency evaluation and benchmarking (see Tchangani, 2006a, 2006b, 2009, 2010).

Organization of the paper

The remainder of the paper is organized in the following manner. In the second section we will introduce and state the main objective of the paper that is evaluation process in decision analysis and then present the background in terms of approaches that are classically used to deal with this problem. The third section known as developed methodology that represents the main contribution of the paper is organized around three subsections: the first subsection presents relevant features of satisficing game theory that are necessary to develop our evaluation procedure using bipolar nature of attributes; the second subsection shows how to formulate the evaluation problem introduced previously as a satisficing game; evaluation process is carried up in the third subsection in terms of selecting and ranking of alternative decisions on one hand and sensitivity analysis on the other hand. In the fourth section, the developed procedure of section three is applied to a real world problem to show its effectiveness and finally the fitth section concludes the paper.

Developped methodology

The main idea of this paper relies on the fact that bipolarity is pervasive in human behavior. This has been noticed long ago by cognitive psychologists who observed that humans in general evaluate alternatives by considering separately their positive and negative aspect; that is on bipolar basis (see, for instance, Osgood *et al*, 1957; Caciopo and Berntson, 1994). Bipolarity notion has also retained computer scientists' attention for information representation and fusion (Dubois and Fargier, 2006).

Bipolar nature of attributes suggests evaluating options or decisions in two directions, one corresponding to positive behavior and another to negative behavior. To this end, one interesting mathematical tool to carry up this process is satisficing game. This section is then organized in the following way: the next subsection will presents relevant features of a satisficing game that are necessary for the approach developed in this paper; the second subsection will shows how the decision analysis problem presented in the first section can be formulated as a satisficing game and how the evaluation process can be done in terms of selecting and ranking of alternatives as well as sensitivity analysis process.

Satisficing game theory

Superlative rationality that is looking for the best has been the underlying philosophy of most techniques used in the literature to construct selecting and ranking model with the consequences that all the alternatives must be compared against each other. But the superlative rationality paradigm is not necessarily the way humans evaluate alternative. Most of the time humans content themselves with alternatives that are just "*good enough*" because their cognitive capacities are limited and information in their possession is almost always imperfect; this is the fundamental idea behind the theory of bounded rationality that has its roots in the work by Simon (1997); the concept of being good enough allows a certain flexibility because one can always adjust its aspiration level. On the other hand, cognitive psychologists have proved, (see, for instance Caciopo and Berntson, 1994; Osgood et *al*, 1984) that humans evaluate alternatives by considering separately their positive aspect and their negative aspect; that is on a bipolar basis with regard to the decision goal instead of ranking units with regard to each other. For instance, to evaluate things such cars to buy, customers often make a list of positive attributes (driving comfort, speed, robustness, etc.) and a list of negative attributes (price, consumption per kilometer, maintainability, etc.) of each car and then make a list of cars for which positive attributes "exceed" negative attributes in some sense. This way of evaluation falls into the framework of praxeology or the study of theory of practical activity (the science of efficient actions, Stirling, 2003). Let us consider a universe U of alternatives; then for each alternative $u \in U$, a *selectability function* $\mu_S(u)$ and a *rejectability function* $\mu_R(u)$ are defined to measure the degree to which u works towards success in achieving the decision maker's goal and costs associated with this alternative respectively. This pair of measures called *satisfiability functions or measures* are mass functions (they have the mathematical structure of the probabilities, see Stirling (2003)): they are non negative and sum to one on U. The following definition then gives the set of options arguable to be "good enough" because for these options, the "benefit" expressed by the function μ_S exceeds the cost expressed by the function μ_R with regard to the index of boldness q.

Definition 1. *The satisficing set $\Sigma_q \subseteq U$ with the index of boldness q is the set of alternatives defined by equation (1)*

$$\Sigma_q = \{u \in U : \mu_S(u) \geq q\mu_R(u)\} \quad (1)$$

The boldness index q can be used to adjust the aspiration level: increase q if Σ_q is too large or on the contrary decrease q if Σ_q is empty for instance.

Applying the satisficing game theory to the selecting and ranking problem defined previously return then to determining satisfiability measures $\mu_S(u)$ and $\mu_R(u)$ for each alternative u; the process of determining these measures for our decision problem will be considered in the following section.

Satisficing game formulation of evaluation problem

The approach considered in this paper is based on the idea of bipolarity of attributes that is, given an objective as defined in the introduction section, there are those attributes which variations are positively correlated to that objective (larger is better) and those for which variations are negatively correlated (smaller is better). The former are supporting attributes and the later rejecting ones for the considered objective. So one can establish a selecting and ranking model based on two measures: selectability measure $\mu_S(u)$ that aggregate supporting contributions and the rejectability measure $\mu_R(u)$ that aggregate rejecting contributions in the framework of satisficing game theory for the alternative u.

In the following paragraph we will show how to compute these parameters from specification materials (objectives, attributes, stakeholders preferences).

Satisfiability measures derivation

The procedure for determining selectability and rejectability measures begins with the normalization of attributes to obtain a normalized value $a^n(u)$ for each alternative u, see (Brauers *et al.*, 2008; Turkis *et al.*, 2009) for some normalizations schemes. As we stated previously, given an objective function f_j we divide the set of attributes of a given alternative u into two sets $A_j^S(u)$ and $A_j^R(u)$ containing supporting attributes and rejecting attributes respectively (see the following definition) with regard to that objective function.

Definition 2. *An objective function f_j is said to be supported (respect. rejected) by an attribute a if and only if $a^n(u) \geq a^n(v) \Rightarrow u$ is preferred to v for that objective (respect. $a^n(u) \geq a^n(v) \Rightarrow v$ is preferred to u for that objective). In order words an objective is said to be supported (respect. rejected) by an attribute a if and only if its variation is positively (respect. negatively) correlated with the variations of that attribute as shown by the following Figure 1. Otherwise this attribute is said to be neutral with regard to that objective.*

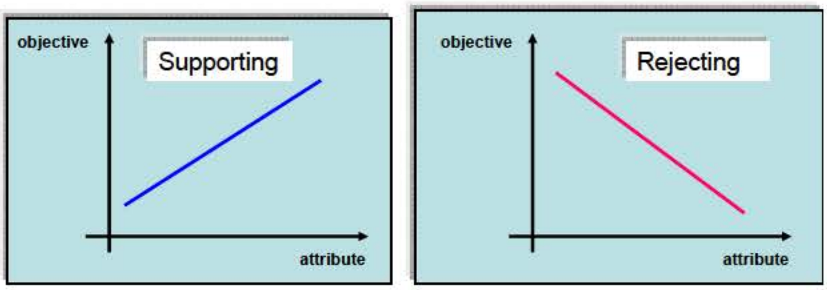

Figure 1. Illustration of supporting/rejecting relationship between attribute and objective

The process of eliciting and dividing attributes into supporting attributes and rejecting ones can be carried out by using a BOCR (Benefit, Opportunity, Cost, and Risk) analysis, see (Tchangani and Pérès, 2010); benefit and opportunity attributes will constitute the supporting attributes and cost and risk the rejecting ones. At the end of normalization and supporting/rejecting repartition processes, for each alternative $u \in U$ and each objective function f_j we determine the measures $\Psi_S^{f_j}(u)$ and $\Psi_R^{f_j}(u)$ as given by equations (2).

$$\Psi_S^{f_j}(u) = \sum_{a \in A_j^S(u)} \alpha_a^{f_j} a^n(u) \quad and \quad \Psi_R^{f_j}(u) = \sum_{a \in A_j^R(u)} \beta_a^{f_j} a^n(u) \qquad (2)$$

where $\alpha_a^{f_j}$ and $\beta_a^{f_j}$ are the relative supportability and rejectability importance assigned to attribute a (by stakeholders and/or experts) with regard to the objective function f_j. These measures represent supporting and rejecting weight of objective f_j for the alternative u.

The aggregated selectability and rejectability measures for the alternative u are then given by equation (3)

$$\Psi_S(u) = \sum_{j=1}^{m} \omega_j \Psi_S^{f_j}(u) \quad and \quad \Psi_R(u) = \sum_{j=1}^{m} \omega_j \Psi_R^{f_j}(u) \qquad (3)$$

where ω_j is the relative importance of the objective function f_j with regard to selecting and ranking goal assigned by stakeholders.

Determination of weights $\alpha_a^{f_j}$, $\beta_a^{f_j}$ and ω_j can be done using an AHP approach, see for instance (Tchangani, 2009) where a similar procedure for weights elicitation have been proposed. Experts and/or stakeholders that will determine these weights are not necessarily the same.

The selectability and rejectability measures $\mu_S(u)$ and $\mu_R(u)$ are then given by the following definition.

Definition 3. *The selectability measure $\mu_S(u)$ and the rejectability measure $\mu_R(u)$ for the alternative u are given by equation (4)*

$$\mu_S(u) = \frac{\Psi_S(u)}{\sum_{v \in U} \Psi_S(v)} \quad and \quad \mu_R(u) = \frac{\Psi_R(u)}{\sum_{v \in U} \Psi_R(v)} \qquad (4)$$

Notice that these measures define probability tables over the set U and so fulfill the requirements of satisficing game theory. The following paragraph presents the procedures to select and to rank alternatives arguable to be satisficing or good enough.

Selecting and ranking procedure

The selected subset is constituted by the alternatives for which the selectability measure exceeds the rejectability measure as given by the following definition.

Definition 4. *The selected subset Σ_q at the index of boldness q is given by equation (5)*

$$\Sigma_q = \{u \in U : \mu_S(u) \geq q\mu_R(u)\} \quad (5)$$

The caution index q can be used to adjust the number of alternatives one want to include in the selected subset Σ_q : small values of this index will lead to a lot of alternatives being declared satisficing whereas large values of q will reduce the number of satisficing alternatives. This index will be selected in the interval $[q_{\min} \quad q_{\max}]$ where $q_{\min}$ and $q_{\max}$ are given by the following equation (6), see (Tchangani, 2009).

$$q_{\min} = \min_{u \in U}\left(\frac{\mu_S(u)}{\mu_R(u)}\right) \quad and \quad q_{\max} = \max_{u \in U}\left(\frac{\mu_S(u)}{\mu_R(u)}\right) \quad (6)$$

Once the desired selected subset Σ_q is obtained, one will consider ranking its alternatives. The ranking process consist in assigning a weight $x_u > 0$ to each alternative $u \in \Sigma_q$ so that the overall satisficing condition of equation (7) is satisfied

$$\sum_{u \in \Sigma_q} \mu_S(u)x_u \geq q \sum_{u \in \Sigma_q} \mu_R(u)x_u \Leftrightarrow \sum_{u \in \Sigma_q} (\mu_S(u) - q\mu_R(u))x_u \geq 0 \quad (7)$$

subjected to conditions of equation (8)

$$\sum_{u \in \Sigma_q} x_u = 1, \quad x_u \geq \varepsilon \quad (8)$$

where ε is a very small real number to ensure that each alternative receives a non zero weight. These weights can be determined by solving the following linear programming problem (9)

$$\min_x \{0\} \; s.t. \sum_{u \in \Sigma_q} (\mu_S(u) - q\mu_R(u))x_u \geq 0, \sum_{u \in \Sigma_q} x_u = 1, x_u \geq \varepsilon. \quad (9)$$

where *s.t.* stands for subjected to and x is a real vector of dimension Σ_q which entries correspond to x_u respectively.

In the following paragraph, a sensitivity analysis procedure will be established to cope with possible uncertainty that may affect attributes values.

Sensitivity analysis

As we mentioned it in introduction section, uncertainty affects almost all components of an engineering economics decision problem and particularly the values of attributes. It is then necessary to do a sensitivity analysis in order to have an idea of how the solution structure may change if the value of attributes of a given alternative do change mainly for non satisficing alternatives. So, given a non satisficing alternative u, one may wonder how should its attributes values be improved in order to render it satisficing if other alternatives remain unchanged; this process can be carried up hierarchically by determining first the variation to be done by its aggregated supporting measures $\Psi_S^{f_j}(u)$ and its aggregated rejecting measures $\Psi_R^{f_j}(u)$ with regard to each objective function f_j and then inject these values into equations (2) and (3) to determine how much its attributes values must change. To do so, let us derive how the variations $d\mu_S(u)$ and $d\mu_R(u)$ of the selectability measure do depend on the variations $d\Psi_S^{f_j}(u)$ and $d\Psi_R^{f_j}(u)$, *j=1, 2, ..., m* of the aggregated supporting and rejecting measures values respectively; these dependencies are given by equation (10).

$$d\mu_S(u) = \left(\frac{\mu_S(u)(1-\mu_S(u))}{\Psi_S(u)}\right)\sum_{j=1}^{m}\omega_j d\Psi_S^{f_i}(u) \quad and \quad d\mu_R(u) = \left(\frac{\mu_R(u)(1-\mu_R(u))}{\Psi_R(u)}\right)\sum_{j=1}^{m}\omega_j d\Psi_R^{f_i}(u) \quad (10)$$

see (Tchangani, 2009) for derivation of these relationships.

So, for a non satisficing alternative u to become a satisficing one when other alternatives remain unchanged the inequality of equation (11) must be satisfied.

$$\mu_S(u) + d\mu_S(u) \geq q(\mu_R(u) + d\mu_R(u)) \quad (11)$$

which is equivalent to the linear inequality given by equation (12) in variation values $d\Psi_S^{f_j}(u)$ and $d\Psi_R^{f_j}(u)$, *j=1, 2, ..., m,* to be determined,

$$\left(\frac{\mu_S(u)(1-\mu_S(u))}{\Psi_S(u)}\right)\left\{\sum_{j=1}^{m}\omega_j d\Psi_S^{f_j}(u)\right\} - q\left(\frac{\mu_R(u)(1-\mu_R(u))}{\Psi_R(u)}\right)\left\{\sum_{j=1}^{m}\omega_j d\Psi_R^{f_j}(u)\right\} \geq q\mu_R(u) - \mu_S(u) \quad (12)$$

Furthermore for these variations to be feasible the inequalities of equation (13),

$$0 \leq d\Psi_S^{f_i}(u) \leq \sum_{a \in A_j^S(u)} \alpha_a^{f_j} - \Psi_S^{f_i}(u), \quad -\Psi_R^{f_i}(u) \leq d\Psi_R^{f_i}(u) \leq \min\left(0, \sum_{a \in A_j^R(u)} \beta_a^{f_j}\right) \quad (13)$$

see (Tchangani, 2009) for their derivation, must be verified; so that these variations can be determined by solving a linear programming problem given by equation (14)

$$\min_{d\Psi_S^{f_j}, d\Psi_R^{f_j}, j=1,2,\ldots,m} \{0\} \quad s.t. \quad (12)-(13) \quad (14)$$

which is a mathematically ill-defined problem that can be rendered well defined by adding constraints and/or changing the function to be optimized in order to take into account practical concerns for instance. Once these values are determined, they will be injected into the equation (2) and one will solve the linear programs of equation (15)

$$\min_{da^n(u)} \{0\}\, s.t. \begin{cases} d\Psi_S^{f_j}(u) = \sum_{a \in A_j^S(u)} \alpha_a^{f_j} da^n(u) \\ d\Psi_R^{f_j}(u) = \sum_{a \in A_j^R(u)} \beta_a^{f_j} da^n(u) \end{cases} \quad \forall\ f_j \qquad 0 \le a^n(u) + da^n(u) \le 1 \ \ \forall\ a^n(u) \tag{15}$$

to finally determine the amount $da^n(u)$ by which the attributes of the non satisficing alternative *u* must vary in order to become satisficing. Notice that for a practical case one may consider adding other constraints in equation (14); for instance if a given attributes participate only in supporting (respectively rejecting) some objectives it is obvious that one will constrain its variation to be non negative (respectively non positive).

Remark 1. *A similar sensitivity analysis can be carried out with regard to almost all materials defining the parameters of the established model and mainly with regard to objectives weighting parameters* ω_j *as they will be a atter of stakeholders preferences* .

In the following section a real world application will be considered to show how the approach established in this paper does operate in practical situation.

Illustrative application

To illustrate the potentiality of the established method, let us consider a real-world example in the domain of waste management facility location. This application is adapted from (Salminen et *al.*, 1976) where the objective was to find the most plausible solution to a municipal solid waste management problem in a region of Central Finland. The intention here is to test how well our approach would have worked in real situation; so we will reformulate decision making goal to fit our approach.

Analysis

A preliminary study has identified 11 alternatives (see Salminen et *al.*, 1976) for the meaning of each alternative) and 8 attributes meanings of which are described in the following points:

- **a_1**: net cost per ton,
- **a_2**: global effects,
- **a_3**: local and regional health effects,
- **a_4**: acidificative releases,
- **a_5**: surface water dispersed releases,
- **a_6**: technical reliability,
- **a_7**: number of employees,
- **a_8**: amount of recovered waste.

The evaluation of alternatives with regard to these attributes is well defined and row data (indicating units is not relevant here, interested readers for that can consult (see Salminen et *al.*, 1976)) are given on Table I.

To fit our approach we consider that the principal goal is to select the most sustainable site. The concept of sustainability relies on three pillars for evaluation, namely social, economic and environmental. Thus, the principal goal can be divided into three objectives, economical objective, social objective, and environmental objective. But here we merge economical and social objectives into one objective known as socioeconomic objective so that in the spirit of the approach established in this paper two objectives functions f_1 and f_2 that are described below must be satisfied.

- f_1: enhance the socioeconomic situation of the considered region;
- f_2: respect the environment.

From the definition of attributes we consider supporting/rejecting attributes sets $A_{f_1}^S / A_{f_1}^R$ and $A_{f_2}^S / A_{f_2}^R$ (that are common to all alternatives) for these objectives to be given by equation (16).

$$A_{f_1}^S = \{a_6, a_7, a_8\},\ \ A_{f_1}^R = \{a_1, a_2, a_3, a_4, a_5\},\ \ A_{f_2}^S = \{a_6, a_8\},\ \ A_{f_2}^R = \{a_2, a_3, a_4, a_5\} \tag{16}$$

which means that we consider for instance technical reliability (attribute, **a_6**), number of employees (attribute, **a_7**) and the amount of recovered waste (attribute, **a_8**) to support socioeconomic enhancement of the region and so fourth. One shall notice that this repartition is done by the author applying a common sense so it is not an output of an expert analysis; but we do think that it reflects some reality. These materials have been used by the procedure established in this paper to obtain the subsequent results.

Table 1

Row data of the illustrative example

Alternatives								
	a_1	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**a_7**	**a_8**
IA	787	155714560	148	364	505	9	20	4330
IB1	828	154887200	148	364	390	6	28	4080
IB2	837	154889339	148	364	390	6	24	5340
IC1	1062	139621200	201	377	370	7	35	11470
IC2	1050	139623330	201	377	370	7	28	12700
IIA	769	155061660	150	364	520	9	26	4330
IIB	861	154228170	138	364	310	6	32	5340
IIC	1048	138952170	203	377	300	7	36	12700
IIIA	894	154342000	137	364	470	5	25	3260
IIIB	997	153762000	137	364	300	5	32	4080
IIIC	1231	140035000	205	375	220	5	38	10600

Results

If we consider attributes as well as objectives to have the same importance, we obtain satisfiability results of the following Table II that are also depicted on Figure 2 that also shows satisficing alternatives for different values of the index of boldness q. The normalization procedure used is that of linear Weitendorf, see (Brauers *et al.*, 2008; Turkis *et al.*, 2009).

Table 2

Results in the case of equal importance assumption

Alternatives	$\Psi_S^{f_1}(u)$	$\Psi_R^{f_1}(u)$	$\Psi_S^{f_2}(u)$	$\Psi_R^{f_2}(u)$	$\mu_S(u)$	$\mu_R(u)$
IA	1.1133	2.1507	1 1133	2.1118	0.0958	0.0930
IB1	0.7813	1.8068	0 3369	1.6791	0.0481	0.0760
IB2	0.6926	1.8264	0.4703	1.6792	0.0500	0.0765
IC1	2.2030	3.1153	1 3697	2.4811	0.1536	0.1221
IC2	1.9444	3.0894	1 5000	2.4812	0.1481	0.1215
IIA	1.4467	2.1522	1 1133	2.1522	0.1101	0.0939
IIB	1.1370	1.4252	0.4703	1.2260	0.0691	0.0578
IIC	2.3889	2.8412	1 5000	2.2373	0.1672	0.1108
IIIA	0.2778	2.0220	0	1.7515	0.0119	0.0823
IIIB	0.7535	1.6437	0.0869	1.1502	0.0361	0.0609
IIIC	1.7775	2.9108	0.7775	1.9108	0.1099	0.1052

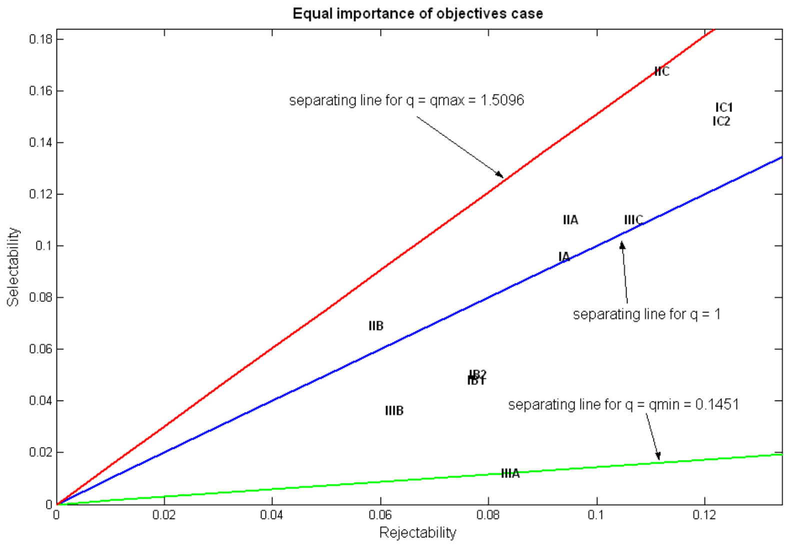

Figure 2. Results in the case of equal importance assumption:

So the satisficing alternatives subset Σ_1, with the index of boldness $q=1$, are given by equation (17)

$$\Sigma_1 = \{IA, IC1, IC2, IIA, IIB, IIC, IIIC\} \quad (17)$$

and the solution of linear program (11) is given by equation (18)

$$x = [0.1336 \quad 0.1479 \quad 0.1455 \quad 0.1403 \quad 0.1378 \quad 0.1603 \quad 0.1346] \quad (18)$$

that leads to the order of equation (19)

$$IIC \succ IC1 \succ IC2 \succ IIA \succ IIB \succ IIIC \succ IA \quad (19)$$

Non satisficing alternatives set $\overline{\Sigma}_1$ is given by (20)

$$\overline{\Sigma}_1 = U - \Sigma_1 = \{IB1, IB2, IIIA, IIIB\} \quad (20)$$

For these later alternatives a sensitivity analysis to determine how to render each one satisficing if other alternatives remain unchanged has been carried up and the results are summarized in the following Table III that shows how each of the 8 attributes values must change in order to render the corresponding alternative satisficing. Notice that as the first 5 attributes contribute to the rejection of the two objectives and the 3 later ones to supporting them, we constrain the variations of the first ones to be non positive and the later to be non negative.

Table 3

Sensitivity analysis results

	IB1	IB2	IIIA	IIIB
$d\Psi_S^{f_1}(u)$	1.1536	1.1997	1.4181	1.1684
$d\Psi_R^{f_1}(u)$	-0.9210	-0.9311	-1.0309	-0.8380
$d\Psi_S^{f_2}(u)$	0.8645	0.7950	1.0417	0.9949
$d\Psi_R^{f_2}(u)$	-0.8559	-0.8560	-0.8929	-0.5862
da_1^n	-0.0651	-0.0751	-0.1380	-0.2518
da_2^n	-0.4808	-0.4808	-0.4676	-0.4473
da_3^n	-0.0863	-0.0863	0	0
da_4^n	0	0	0	0
da_5^n	-0.2888	-0.2888	-0.4253	-0.1389
da_6^n	0.3507	0.3827	0.5209	0.5409
da_7^n	0.2891	0.4047	0.3764	0.1736
da_8^n	0.5138	0.4123	0.5209	0.4540

Remark 2. *It is interesting to notice that the final accomplished alternative* ***IIC*** *in the original study (Salminen et al., 1976) is the one that is ranked first by the approach established in this paper.*

Conclusions

The bipolar nature of attributes that characterize alternatives of the problem of selecting and ranking (mainly in engineering economics) has been exploited to derive a decision making framework using satisficing game paradigm as the evaluation tool. The main idea of the method established in this paper relies on first determining, for any objective, attributes that support it (larger is better) and attributes that reject it (smaller is better); then considering stakeholders preferences regarding the importance of objectives by weighting them as well as weights that stakeholders and/or experts may assign to each category of attributes, two measures, one known as selectability based on supporting attributes and another one known as rejectability based on rejecting attributes, are derived for each alternatives. Alternatives to be included in the selected subset are those for which the selectability measure exceeds the rejectability measure subjected to an index of caution that permits to adjust the size of this subset. A priority index is then determined to order the selected alternatives in order to optimize the difference between the aggregated selectability and rejectability measures. A sensitivity analysis is proposed to determine changes in attributes of a non satisficing alternative that will allow it to become satisficing; this analysis will permit to integrate attributes values uncertainty in the decision process. Another interesting fact of the procedure established in this paper is that alternatives are not required to be characterized by the same attributes, the important thing is to be able to establish a supporting/rejecting relationship between these attributes and stakeholders objectives. The procedure is applied to a real world problem with interesting results that confirm the potentiality of the approach.

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Ayeley P. Tchangani

Dvejopą pobūdį savybių, palaikančių sprendimus inžinerinėje ekonomikoje, rodanti sistema

Santrauka

Dauguma problemų sprendimų inžinerinėje ekonomikoje ir vadyboje priklauso nuo alternatyvų pasirinkimo. Suprasti akcininkų nuomones tam, kad efektyviai būtų galima spręsti ar pasirinkti sprendimą tiek viešame, tiek privačiame versle, yra labai sudėtinga. Tai, kad sudėtinga, parodo inžinerinės ekonomikos sprendimai, kurie pasižymi šiomis savybėmis: daugybe požymių, veikėjų arba akcininkų (reikia atsižvelgti į daugelį nuomonių), netikrumu, kuris yra būdingas inžinerinės ekonomikos sprendimams tiek formuluojant tikslus, tiek vertinant sprendimus, kai akcininkų nuomonės yra priešingos. Atsižvelgiant į šį sudėtingumą, sprendimus priimantys inžinieriai ir specialistai turi sukurti sistemą, kuri padėtų analizuoti ir rekomenduoti efektyviausius sprendimus.

Literatūroje yra daugybė požiūrių, kurie susiję su sprendimų problemomis, t. y. atvejų, kai alternatyvas apibūdina arba veikiantieji asmenys, arba jos apibūdinamos akcininkams per daug nesikišant. Šie požiūriai gali būti sugrupuoti į tris kategorijas:

- Požiūriai, kurie priklauso nuo vadinamųjų Pareto optimalių alternatyvų arba procedūrų. Jų rezultatas priklauso nuo dviejų aspektų: paieškos ir sprendimo priėmimo. Atsižvelgiant į tai, kaip paieškos ir sprendimų procesai yra susieti, autoriai klasifikuoja sprendimus arba optimizacijos metodus į tris veiksmus: sprendimas prieš paiešką, paieška prieš sprendimą, sprendimas paieškos metu (kiekvienas sprendimo veiksmas kelia daugybę alternatyvų). Pirmuoju požiūriu, kuris skirtas daugybei objektyvių sprendimų spręsti, tikslai sutelkiami į vieną bendrą kai kuriais atvejais skatinantį apribojimų metodus. Šių metodų pranašumas yra tas, kad efektyvūs algoritmai, skirti atskiroms optimizacijos problemoms analizuoti, gali būti panaudoti iškilusioms problemoms spręsti. Šių metodų trūkumas yra tas, kad reikia vartotojo intervencijos, kad galima būtų nustatyti veiksnius, kurie lemia sprendimus.
- Klasifikuojantysis požiūriai: metodai, skirti daugybės dalyvių sprendimams analizuoti, kai dalinė alternatyvų tvarka yra nustatoma tarp analitiko ir sprendimų pateikėjo bendra procedūra.
- Programinės įrangos metodai pagal algoritmus, kurie siekia stimuliuoti natūralios evoliucijos procesą ir vis plačiau taikomi norint nustatyti sudėtingus daugiatikslius sprendimus. Buvo nustatyta jų nauda optimizuojant sunkias funkcijas, kurios apima daugybę parametrų arba jų konfigūracijų.

Šiame straipsnyje pateiktas naujas požiūris, integruojantis visas sprendimų priėmimo sudedamąsias dalis (daug dalyvių, tikslų, akcininkų bei netikrumą), kurios buvo paaiškintos anksčiau. Pagrindinė šio požiūrio mintis yra savybių poliariškumas, atsižvelgiant į tikslus, kurie yra būdingi realaus pasaulio problemų pasirinkimui. Esant pasirinktam tikslui, egzistuoja tos savybės, kurių variacijos teigiamai koreliuoja su tikslu, ir tos, kurios derinamos neigiamai (mažesnė yra geresnė). Tai pastebėjus sukuriama bendra šio straipsnio idėja. Taigi požymiai, kurie teigiamai dera su tikslu, laikomi remiančiais, palaikančiais, o tie, kurie neigiamai gretinami, laikomi priešingais, atmetamaisiais. Remiantis šia požymių prigimtimi, žaidiminis požiūris yra taikomas kaip priemonė vykdant įvertinimo ir galutinio pasiūlymo procesus. Šis žaidimas yra apibrėžiamas kaip dviejų matmenų derinimas: atrankos matas, kuris išreiškia mastą, iki kurio ši alternatyva pasirenkama siekiant sprendimo tikslo, ir atmetimo matas, apytiksliai parodantis kainą, kurią reikia mokėti siekiant šio tikslo. Alternatyvos, kurioms atrankos matas viršija atmetimo matą, tam tikra prasme bus laikomos kaip tenkinančios. Šiame straipsnyje teigiama, kad esant objektui ir alternatyvai, palaikantys požymiai rodo atrankos matą, o atmetimo požymiais – atmetimo matą. Siūloma jautrumo analizė tam, kad galima būtų nustatyti alternatyvų pakitimus. Dėl to alternatyva taptų tenkinanti.

Kitas svarbus šiame straipsnyje aptartas aspektas – nereikalinga, kad alternatyvas apibūdintų tie patys požymiai. Svarbu, sukurti palaikančią arba atmetančią sąveiką tarp šių požymių ir sprendimų. Ši procedūra naudojama realaus pasaulio problemoms spręsti. Kuriamos specialios grupės tam, kad būtų galima patvirtinti šio požiūrio teisingumą.

Raktažodžiai: *atrankos ir klasifikacijos alternatyvos, sudėtinės savybės, dvipoliariškumas, daugiausia tikslai, vykdytojų gausa, tenkinantys žaidimai*.