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THE REFERENCE POINT METHOD APPLIED TO DECISION SELECTION IN THE PROCESS OF BILATERAL NEGOTIATIONS

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Abstract: The paper presents a method of supporting the decision selection in the process of bilateral negotiations. The negotiation process is modeled as using a multi-criteria optimization. The method of finding solutions is the interactive selection process of some proposals. The parties shall submit their proposals to the subjects of the negotiations. These proposals are parameters of the multi-criteria optimization tasks. Selection of solutions is accomplished by solving the optimization task with parameters that define the aspirations of each party involved in the negotiations. Finally, evaluation of the solutions obtained by the parties is done.

Keywords: negotiation process, multi-criteria optimization, equitably effective decision, scalar function, method of the reference point

INTRODUCTION

The paper presents a method of supporting the decision selection in the process of bilateral negotiations. Negotiations serve to agree the decisions when different interests of participants occur. Negotiations are carried out to reach a more favorable result than that which can be achieved without negotiation. Negotiating parties could benefit, coming to the agreement with each other, in comparison to the situation when they act separately. Well arranged agreement is better for the parties than no agreement at all, and some agreements are more favorable for both parties than others. In the complex negotiations, the parties not only want to reach an agreement, but they are looking for the optimal agreement – i.e. the agreement that would be the best for both parties.

Negotiations are characterized by a lack of clear solutions and the necessity of taking into account the preferences of all parties. The process of bilateral negotiations can be modeled using game theory. The solution is then the Nash cooperative solution or Raiffy-Kalai-Smorodinsky solution [Luce, Raiffa 1966], [Malawski i in. 1997], [Raiffa 1998], [Straffin 2004].

The work is devoted to apply a multicriteria optimization to support decision making in negotiation process. The process of bilateral negotiations is modeled as a multi-criteria optimization tasks. The method of decision selection is based on an interactive selection of some proposals of solutions, i.e. the algorithm requires the reaction of parties during this process. The parties submit their proposals for the subjects of negotiations; these proposals are parameters of the multi-criteria optimization task; this way the task is solved. Then, the parties evaluate the solution: they accept it or reject it. In the second case, the parties shall submit new proposals - the new values of parameters and the problem is solved again for these new parameters. The process of selection of solution is not a one-time process, but an iterative process of learning by parties about the negotiated problem.

MODELING OF THE NEGOTIATION PROCESS

The negotiation process is modeled as an interactive decision-making process. Each party presents its proposals of solutions. The negotiation process is then the process of seeking a common decision, which reconciles the interests of both parties. The parties are trying to find a common compromise solution. Decisions require voluntary consent of both parties and are taken together, not unilaterally. Both parties have to accept those decisions.

During the negotiation process, there are many different purposes, which are implemented using the same set of feasible solutions. The negotiation process is modeled by introducing a decision variable that describes the solution as well as two evaluation functions evaluating the solution from the point of view of each party. During the negotiations, each proposal is evaluated by either party by its evaluation function. Such a function is a measure of satisfaction of a party with a given solution. It evaluates the degree of realization of each subject of negotiations by each party. Higher value of the function means higher satisfaction of a party, so each function is maximized. The basis for evaluation and solution selection are two functions of evaluation - the criteria for both parties.

We assume the following terms:

party 1 and party 2 - parties in negotiations,
n - the number of subjects for negotiation,
$x \in X_0$ – solution - a decision, the parties of which are to agree, belonging to a set of feasible decisions

$X_0 \subset R^n$, $x = (x_1, x_2, ..., x_n)$ - each coordinate $x_i, i = 1,...,n$ defines $i-th$ subject of negotiations,

$f1: X_0 \to R^{m1}$ – the evaluation function of decision x by party 1,

$f1 = (f1_1, f1_2, ..., f1_{m1})$ - vector function ,

which determines the degree of realization of solution by party 1,

$f2: X_0 \to R^{m2}$ – the evaluation function of decision x by party 2,

$f2 = (f2_1, f2_2, ..., f2_{m2})$ vector function ,

which determines the degree of realization of solution by party 2.

The problem of a decision selection has the multi-criteria character. The decision is characterized by a complex evaluation function, wherein the first component is a function of evaluation of the decision by the first party and the second component is a function of evaluation of the decision by the other party. Each party wants to maximize its evaluation function, but it must take into account the existence of the other party. The selection of solution is done by using both evaluation functions.

The negotiation process is considered as a task of multi-criteria optimization with the function of purpose $f = (f1, f2)$:

$$\max_x \{(f1(x), f2(x)): \quad x \in X_0\} \tag{1}$$

where:

$x \in X$ – vector of decision variables

$f = (f1, f2)$ – the vector function which maps the decision space X into evaluation space $Y_0 \subseteq R^{m1+m2}$,

X_0 – the set of feasible decisions.

Task (1) is to find such feasible decision $\hat{x} \in X_0$, for which $m1 + m2$ evaluations takes the best values.

Task (1) is considered in the evaluation space, i.e., the following task is considered:

$$\max_x \{y = (y1, y2): \quad y \in Y_0\} \tag{2}$$

where:

$x \in X$ – vector of decision variables,

$y = (y1, y2) = (y_1, ... y_{m1}, y_{m1+1}, ..., y_{m1+m2})$ – vector quality indicator;

individual coordinates $y_i = f_i(x), \quad i = 1,2,..,m1 + m2$ represent single scalar criteria, first $m1$ coordinates are evaluation criteria of a solution by party 1, the next coordinates are evaluation criteria of a solution by party 2,

$m = m1 + m2$ - dimension of the criteria space,
$Y_0 = (f1, f2)(X_0)$ – a set of achievable vectors of evaluation.

The set of achievable results Y_0 is given in the implicit form - through a set of feasible decisions X_0 and mapping of a model $f = (f1, f2)$. To determine the value y, the simulation of the model is needed: $y = (f1, f2)(x) \;\; for \quad x \in X_0$.

The purpose of task (1) is to help in the selection of such a decision, which takes into account the best interests of both parties [Lewandowski and Wierzbicki 1989], [Ogryczak 2002], [Wierzbicki 1984].

EQUITABLY EFFICIENT SOLUTION

The solution in the negotiation process should satisfy certain properties that the parties accept as reasonable. The solution should be:

- optimal solution in the sense of Pareto – i.e. such that you can not improve the solution for one party without worsening the solution for the other party,
- symmetric solution – i.e. that it should not depend on the way the parties are numbered, no one is more important, the parties are treated in the same way in the sense that the solution does not depend on the names of the party or other factors specific to a given party,
- equalizing solution - that is, a vector that has less variation of coordinates of evaluation is preferred in comparison to the vector with the same sum of coordinates, but with a greater diversity of coordinates,
- the solution should take into account the strength of the parties in the negotiations.

A decision, which satisfies these conditions is an equitably efficient decision. This is Pareto-optimal decision which satisfies additional conditions – anonymity and the axiom of equalizing solution.

Not dominated results (Pareto - optimal) are defined as follows:

$$\hat{Y}_0 = \{\hat{y} \in Y_0 : (\hat{y} + \tilde{D}) \cap Y_0 = \varnothing\} \tag{3}$$

where:

$\tilde{D} = D \setminus \{0\}$ – positive cone without the top. As a positive cone, it can be adopted $\tilde{D} = R_+^m$ [Górecki 2000], [Lewandowski and Wierzbicki 1989].

In the decision space, the appropriate feasible decisions are specified. The decision $\hat{x} \in X_0$ is called effective decision (Pareto - optimal), if the corresponding vector of evaluation $\hat{y} = f(\hat{x})$ is a not dominated vector.

In the multi-criteria problem (1), which is used to select a decision in the negotiation process, the relation of preferences should satisfy additional properties: anonymity property and property of equalizing solution.

This preference relation is called an anonymous relation if, for every assessments $y = (y_1, y_2, ..., y_m) \in R^m$ and for any permutation P of the set $\{1, ..., m\}$, the following property holds:

$$(y_{P(1)}, y_{P(2)}, ..., y_{P(m)}) \approx (y_1, y_2, ..., y_m) \quad (4)$$

No distinction is made between the results that differ in their arrangement. Evaluation vectors having the same coordinates, but in a different manner are identified.

Relation of preferences satisfies the axiom of equalizing transfer if the following condition is satisfied:

for the evaluation vector $y = (y_1, y_2, ..., y_m) \in R^m$:

$$y_{i'} > y_{i''} \Rightarrow y - \varepsilon \cdot e_{i'} + \varepsilon \cdot e_{i''} \succ y \text{ for } 0 < y_{i'} - y_{i''} < \varepsilon \quad (5)$$

Equalizing transfer is a slight deterioration of a better coordinate of the evaluation vector and simultaneously improvement of a poorer coordinate, giving the evaluation vector strictly preferred in comparison to the initial evaluation vector. This is a structure of equalizing – the evaluation vector with less diversity of coordinates is preferred in relation to the vector with the same sum of coordinates, but with a greater diversity of coordinates.

Not dominated vector satisfying the anonymity property and the axiom of equalizing transfer is called a equitably not-dominated vector. The set of equitably not dominated vectors is denoted by $\hat{Y}_{0w}$. In a decision space, the equitably efficient decisions are specified. The decision $\hat{x} \in X_0$ is called the equitably efficient decision, if the corresponding evaluation vector $\hat{y} = f(\hat{x})$ is an equitably not dominated vector. The set of equitably efficient decisions is denoted by $\hat{X}_{0w}$ [Ogryczak 2002].

The relation of equitable domination can be expressed as the relation of inequality for cumulative, ordered evaluation vectors. This relation can be determined with the use of transformation $\overline{T} : R^m \rightarrow R^m$ that accumulates coordinates of decreasing order in the evaluation vector.

The transformation $\overline{T} : R^m \rightarrow R^m$ is defined as follows :

$$\overline{T}_i(y) = \sum_{l=1}^{i} T_l(y) \quad \text{for } i = 1, 2, ..., m \quad (6)$$

where:

$T(y)$ is the vector with decreasing ordered coordinates of the vector y, i.e. $T(y) = (T_1(y), T_2(y), ..., T_m(y))$, where $T_1(y) \leq T_2(y) \leq ... \leq T_m(y)$ and

there is a permutation P of the set $\{1,...,m\}$, such that $T_i(y) = y_{P(i)}$ for $i = 1,..,m$.

The relation of equitable domination $\geq_w$ is a simple vector domination for the evaluation vectors with coordinates which are accumulated values of ordered evaluation vector [Ogryczak 2002].

The evaluation vector y^1 dominates in equitable way the vector y^2 if the following condition is satisfied:

$$y^1 \geq_w y^2 \Leftrightarrow \overline{T}(y^1) \geq \overline{T}(y^2) \tag{7}$$

Solving the problem of decision selection in the negotiations process consists in determination of equitably efficient decision that satisfies the preferences of parties.

SCALARING THE PROBLEM

For determination of equitably efficient solutions of multi-criteria task (1) a specific multi-criteria task is solved. It is the task with the vector function of the cumulative, ordered evaluation vectors, i.e. the following task:

$$\max_y \{(\overline{T}_1(y), \overline{T}_2(y), ..., \overline{T}_m(y)) : \quad y \in Y_0\} \tag{8}$$

where:

$y = (y_1, y_2, ..., y_m)$ – evaluation vector,

$\overline{T}(y) = (\overline{T}_1(y), \overline{T}_2(y), ..., \overline{T}_m(y))$ cumulative, ordered evaluation vector,

Y_0 – set of achievable evaluation vectors.

An efficient solution of multi-criteria optimization tasks (8) is an equitably efficient solution of the multi-criteria task (1).

To determine the solution of a multi-criteria task (8) the scalaring of this task with the scalaring function $s : Y \times \Omega \rightarrow R^1$ is introduced:

$$\max_x \{s(y, \overline{y}) : x \in X_o\} \tag{9}$$

where:

$y = (y_1, y_2, ..., y_m)$ – evaluation vector,

$\overline{y} = (\overline{y}_1, \overline{y}_2, ..., \overline{y}_m)$ – control parameters for individual evaluations.

It is the task of single objective optimization with specially created scalaring function of two variables - the evaluation vector $y \in Y$ and control parameter $\bar{y} \in \Omega \subset R^m$. It is the function $s : Y \times \Omega \to R^1$. The parameter $\bar{y} = (\bar{y}_1, \bar{y}_2, ..., \bar{y}_m)$ is available to the parties, it allows them to review the set of equitably efficient solutions.

A optimal solution of the task (9) should be a solution to the multiple criteria task (8). A scalaring function should satisfy certain properties - property of completeness and property of sufficiency. The property of sufficiency means that for each control parameter $\bar{y}$ the solution of the scalaring task is the equitably efficient solution, i.e. $\hat{y} \in \hat{Y}_{0w}$. The property of completeness means, that by appropriate changes of the parameter $\bar{y}$ it can be achieved any solution $\hat{y} \in \hat{Y}_{0w}$. Such a function completely characterizes the equitably efficient solutions. Inversely, each maximum of such a function is an equitably efficient solution. Each equitably efficient solution can be achieved with some appropriate values of control parameters $\bar{y}$.

Complete and sufficient parameterization of the set of equitably efficient solutions $\hat{Y}_{0w}$ can be achieved, using the method of reference point for the task (8). This method makes use of aspiration levels as control parameters. Aspiration levels are such values of evaluation function that satisfy the decision owner.

The scalaring function in the method of reference point is as follows:

$$s(y, \bar{y}) = \min_{1 \le i \le m} (\overline{T}_i(y) - \overline{T}_i(\bar{y})) + \varepsilon \cdot \sum_{i=1}^{m} (\overline{T}_i(y) - \overline{T}_i(\bar{y})) \tag{10}$$

where:

$y = (y_1, y_2, ..., y_m)$ – evaluation vector,

$\overline{T}(y) = (\overline{T}_1(y), \overline{T}_2(y), ..., \overline{T}_m(y))$ - cumulative, ordered evaluation vector,

$\bar{y} = (\bar{y}_1, \bar{y}_2, ..., \bar{y}_m)$ – vector of aspiration levels,

$T(\bar{y}) = (T_1(\bar{y}), T_2(\bar{y}), ..., T_m(\bar{y}))$ - cumulative, ordered vector of aspiration levels,

ε – arbitrary small, positive adjustment parameter.

Such scalaring function is called function of achievement. The aim is to find a solution that approaches as close as possible the specific requirements – the aspiration levels.

Maximizing this function with respect to y determines equitably efficient solution $\hat{y}$ and the equitably efficient decision $\hat{x}$. Note, the equitably efficient decision $\hat{x}$ depends on the aspiration levels $\bar{y}$ [Lewandowski and Wierzbicki 1989], [Ogryczak 2002], [Wierzbicki 1984].

SET OF NEGOTIATIONS

The aim of the complex negotiations is not only the achievement of an agreement between the parties, even if it is beneficial for both parties, but finding a solution that meets the expectations of parties as much as possible and, if it is not worse than a solution attainable without negotiations.

Before starting the negotiations, parties should consider what is the result they can achieve if negotiations are not successful - the status quo point. This point is the result which can be achieved by each party without negotiation with the other one. If the parties can achieve the result $ys = (y1s, y2s)$ without negotiations - part 1 can achieve the result $y1s$, part 2 - the result $y2s$, then, no one party will agree to the worse result. During negotiations, parties want to improve the solution in relation to this point. The status quo point determines the strength of the parties in the negotiations and, what is their impact on the result.

The set of negotiations is a collection of equitably dominated evaluation values dominating the status quo point.

The set of negotiation is as follows:

$$B(\hat{Y}_{OW}, ys) = \{\hat{y} = (\hat{y}1, \hat{y}2) \in \hat{Y}_{OW} \wedge \hat{y}1 \geq y1s \wedge \hat{y}2 \geq y2s\} \tag{11}$$

where:

$\hat{y} = (\hat{y}1, \hat{y}2) \in \hat{Y}_{0W}$ – equitably not-dominated vector for the set $\hat{Y}_{0W}$,

$ys = (y1s, y2s)$ – status quo point - the result, which can be achieved by both parties without agreement.

A set of negotiations embraces the points from the set of equitably not-dominated results, which give each party at least as much as it can achieve individually (without negotiation).

The parties wish to find such a decision, $\hat{x} \in X_0$, that the corresponding evaluation vector $\hat{y} = (\hat{y}1, \hat{y}2) = (f1(\hat{x}), f2(\hat{x}))$ belongs to the set of negotiations $B(\hat{Y}_{0W}, ys)$ [Luce, Raiffa 1966], [Raiffa 1998].

METHOD OF SOLUTION SELECTION

The solution to multi-criteria optimization task (8) is the set of equitably efficient decisions. In order to resolve the problem there should be selected one solution that will be evaluated by both parties. Since the solution is a whole set, the parties shall select the solution with the help of an interactive computer system. Such a system allows us a controlled overview of the whole set. Each party attending the negotiation determines its proposed solutions as aspiration levels. These are the values of evaluation of individual negotiation issues, that each party would like to achieve. These values are control parameters of the scalaring function. For these values the system indicates different equitably efficient solutions for analysis; they correspond to current values of the control parameters. The aim is to find solutions which meet, as close as possible, the specific requirements – aspiration levels.

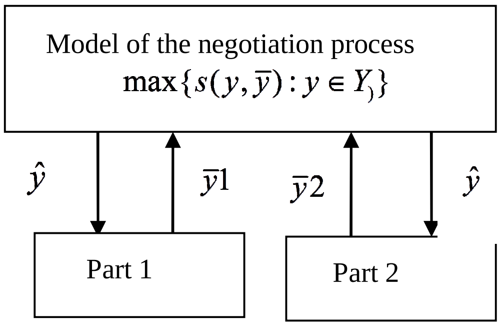
The method of decision selection is as follows:

1. The initial arrangements.
2. Iterative algorithm - proposals for further decisions.
   2.1. The interaction with the system - parties define their proposals for individual subjects of negotiations, as aspirations levels $\bar{y}1$ and $\bar{y}2$.
   2.2. Calculations - giving another solution from the set of negotiations, $\hat{y} = (\hat{y}1, \hat{y}2) \in B(\hat{Y}_{0W}, ys)$.
   2.3. Evaluation of the obtained solutions $\hat{y} = (\hat{y}1, \hat{y}2)$ – the parties may accept the solution or not. In the latter case, the parties shall submit new proposals – they provide new values of their aspiration levels $\bar{y}1$ and $\bar{y}2$ and a new solution is determined (see sec. 2.2).
3. Determination of the decision that meets the requirements of both parties.

A choice is not a single act of optimization, but a dynamic process of searching solutions. That means the parties learn and can change their preferences during the process. Comparing the results of the evaluation $\hat{y}1$ and $\hat{y}2$ to their aspiration points $\bar{y}1$ and $\bar{y}2$, we see that each party has information about what is and what is not achievable, and how far the parties` proposals $\bar{y}1$ and $\bar{y}2$ are from the possible solutions $\hat{y}1$ and $\hat{y}2$. This allows the parties to do appropriate modifications of their proposals: to provide their new aspiration points. These levels of aspiration are determined adaptively during the learning process. The process ends when the parties find such a decision, which allows them to achieve results that meet their aspirations or, in a sense, are as close as possible to these aspirations.

The method of finding a solution is show at Figure 1.

Figure 1. The method of decision selection



Source: own work

This method of decision selection does not impose any rigid scenario on parties and allows them to change their preferences while solving the problem. As we see, parties are learning about the problem during the negotiation. The computer does not replace the parties in selection of solution. It should be witnessed that the entire process of solution selection is controlled by both parties.

EXAMPLE OF BILATERAL NEGOTIATIONS

To illustrate the method of decisions selection in the process of bilateral negotiations the following example is shown [Górecki 2000].
The negotiation problem is as follows:
part 1 and part 2 – the parties attending the negotiations,
$n = 2$ - number of subjects for negotiations,
$x = (x_1, x_2) \in X_0$ - a decision that the parties are to agree and which belongs to set of feasible decisions $X_0 \subset R^2$,
x_1 - the decision concerning the first subject of negotiations,
x_2 - the decision on the second subject of negotiations,
$X_0 = \{(x_1, x_2) \in R^2 : -2 \cdot x_1 + 3 \cdot x_2 \le 27,\ \ 6 \cdot x_1 + 7 \cdot x_2 \le 175,\ \ 0 \le x_1 \le 21,\ \ 0 \le x_2 \le 13\}$ - the set of feasible decisions,
$f1 : X \to R^1\ \ f1(x) = \frac{20}{21}x_1 - \frac{2}{3}x_2$ – evaluation function of decision x by party 1,
$f2 : X \to R^2\ \ f2(x) = -\frac{4}{21}x_1 + \frac{2}{3}x_2$ – evaluation function of decision x by party 2,

$ys = (ys1, ys2) = (10, \quad 1)$ - status quo point.

The resulting task is a typical optimization problem with parameters that every party may dispose. It is solved with the use of a standard optimization software (Solver in Excel).

As a first step of the multi-criteria analysis, a single-criterion optimization of evaluation function of each party is done. The result is a matrix of implementation goals, containing the values of all criteria of each party, received during solving two single-criterion problems. This matrix allows for the estimation of the range of changes of each evaluation function on the feasible set, as well as provides some information about the conflictual nature of evaluation function. The matrix of the implementation of goals generates an utopia vector representing the best value of each separate criterion.

Table 1 The matrix of the implementation of goals with the utopia vector

Optimized criterion	Solution	
	$y1$	$y2$
Evaluation by the party 1 $y1$	20	-4
Evaluation by the party 2 $y2$	-2,85	7,52
Utopia vector	20	7,52

Source: own calculations

The Table 1 shows a clear advantage of party 1 in negotiations.

The multi-criteria analysis is presented in Table 2.

Table 2. Interactive analysis of seeking a solution

Iteration	Evaluation of party 1	Evaluation of party 2
	$y1$	$y2$
1. Aspiration point $\bar{y}$	20	7,52
Solution $\hat{y}$	15,33	0,66
2. Aspiration point $\bar{y}$	15	7
Solution $\hat{y}$	14,99	0,83
3. Aspiration point $\bar{y}$	14	6,5
Solution $\hat{y}$	13,33	1,33
4. Aspiration point $\bar{y}$	13	6,5
Solution $\hat{y}$	12,99	1,83
5. Aspiration point $\bar{y}$	12	5
Solution $\hat{y}$	11,99	2,33

Source: own calculations

At the beginning of the analysis, the parties specify their preferences as an aspiration point equal to the utopia vector. The resulting solution clearly prefers the first party and it is not acceptable to the other party – it is worse than its status quo point. To improve the solution, the first party reduces its requirements in the next iteration. The result is a slight deterioration of solution for the first party and a slight improvement of solution for the other party. The solution still does not exceed the status quo point of the other party. In subsequent iterations, the first party still reduces its requirements and the obtained solutions are now better than the status quo point of the other party. They become more rewarding for it. The analysis shows, that the solution depends in a significant way from the first party, which has a stronger position in negotiations and can impose a solution. For iteration 5 the relevant decisions are as follow $\hat{x}^5 = (18{,}81; 8{,}88)$.

Final selection of a specific solution depends on the parties` preferences. The example shows that this method allows the parties to explore the capabilities of decision-making during the interactive analysis and to search a mutually satisfactory solution.

CONCLUSIONS

The paper presents a method of modeling a process of bilateral negotiations in the form of multi-criteria optimization task. It is used to support the decision selection. The model of the negotiation process as a multi-criteria optimization task allows us to create variants of decision and to track their consequences.

The method of interactive analysis, based on the reference point, is applied for multi-criteria task with a cumulative, ordered evaluation vector. It allows us to determine solutions, well-tailored to the parties preferences. The numerical example shows that the proper computational task efficiently can be solved by the standard optimization software.

This procedure does not determine the final solution, but supports and teaches the parties about the specific negotiation problem. The final decision is to be taken by the parties involved in the negotiations.

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