Control and Cybernetics

vol. **33** (2004) No. 3

A multicriteria approach to cooperation in the case of innovative activity

by

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Abstract: The paper deals with ideas of multicriteria decision support with the use of computer based systems. A negotiation problem is considered related to joint realization of a risky innovative project by two parties. It is considered as a multicriteria bargaining problem. A procedure enabling interactive multicriteria analysis and derivation of mediation proposals is proposed. Some results of experimental calculations are included.

Keywords: multicriteria decision support, negotiations, innovations, financial analysis.

1. Introduction

A cooperation problem is discussed related to joint realization of a research project aimed to construct a new innovative product or to introduce a new technology. Let two parties, for example a research institute and a firm interested in the product, negotiate conditions of project realization. The project is realized in the presence of risk. It can give high rate of return on the invested capital if it will succeed, but there is also a risk that it can fail. The negotiation problem relates to participation of the parties in investment cost of the project as well as in expected benefits and in risk. The parties have also to fix jointly the planned time of project realization, overall stream of expenditures and other conditions of project realization. Each party has own preferences regarding the financial reward from the project and the risk.

Using this example some problems of multicriteria analysis are considered in this work. The cooperation problem is discussed in relation to the bargaining problem considered in the theory of cooperative games. The classical bargaining problem is generalized to the multicriteria case. Decision support for negotiations is proposed in the form of an interactive procedure enabling derivation of mediation proposals. The procedure includes elements of interactive multicriteria analysis carried out by each party with the use of reference point approach (Wierzbicki, 1986; Wierzbicki, Makowski, Wessels, 2001). To derive the mediation proposals the ideas of cooperative solution concepts for the bargaining games are applied. In Kruś, Bronisz (1993), Kruś (1996, 2002b) iterative mediation procedures have been proposed and analyzed utilizing Raiffa-Kalai-Smorodinsky and Imai solution concepts generalized to multicriteria games. In the cooperation problem considered in the present paper these procedures can hardly be applied. A new procedure is proposed utilizing the idea of Nash cooperative solution concept. The mediation proposals are calculated with the use of an achievement function, and depend on preferences indicated by the parties in an iterative process. The procedure, implemented in a computer-based system, can be considered as a tool supporting the parties in cost-benefit-risk analysis of the project.

Attached references relate to investment analysis: Francis (1991), Sharpe et al. (1995), risk measures: Ogryczak, Ruszczynski (1999), Ogryczak (2002), utility function approach: von Neuman, Morgenstern (1947), Coombs et al. (1970), Tversky (1967), Kulikowski (2003), modeling of innovation projects: Kulikowski (2002), Kruś (2002a), multicriteria decision support: Wierzbicki (1986), Wierzbicki, Makowski, Wessels (2001), cooperative solution concepts: Nash (1950), Raiffa (1953), ideas of decision support in negotiations: Wierzbicki (1983), Kersten (1988), Lewandowski (1989), Vetchera (1990), Wierzbicki, Kruś, Makowski (1993), Kruś (1996), Ehtamo, Hamalainen (2001), Kruś (2002b).

2. A model for financial analysis of innovative activity

Two parties discuss joint realization of a research project aimed to construct a new innovative product. The project requires resources concentrated within the time period $[0, T]$ to accomplish the research activity and implement production of the product. After that a harvesting period $[T, T_1]$ is considered, when the product will be sold on the market and when a cash flow is expected. The parties are partners in the joint venture and jointly participate in the investment expenditures. Let $q_i(t)$, $i = 1, 2$, denote streams of expenditures per time unit covered by the party 1 and 2 respectively. Then, the present discounted value of investment cost can be calculated respectively for each party i by:

$$I_i(T) = \int_0^T q_i(t)e^{-rt}dt, \qquad i = 1, 2,$$

where r is a discount rate.

The costs are compared to the present value of revenue flows in the harvesting period:

$$P(T) = \int_T^{T_1} p_f e^{-(r_a+r)t}dt.$$

It is assumed for simplicity that the revenue flow in the harvesting period $(T, T_1]$, when the new product will be sold on the market, will decrease exponentially in time. The quantities: p_f - denoting the revenue flow which could be obtained in the initial time unit, r_a - representing "aging" of innovative product and T_1 are evaluated by experts.

A typical project consists of a number of tasks and operations realized in parallel or in a sequence. It is assumed that the project is represented by a complex of such operations. The project can succeed, but there is also a risk that it can fail. In the case of innovative activity there is no historical data. To evaluate the risk, the use of experts' opinions is proposed and a simple two-scenario model is assumed. The first scenario assumes that the project will be accomplished with success in the given time T. This can occur with probability $p(T)$. The second scenario, assuming failure, can occur with probability $1-p(T)$. The probabilities depend on the planned time of project realization. In Krus (2003) an algorithm is presented enabling calculation of the probability as a function of the accomplishment time for complex projects consisting of some number of risky operation and stages. In the algorithm experts' opinions are used concerning the values of basic probabilities of realization of particular operations in a given time and the Bernoulli scheme is applied. Financial quantities like the rate of return on the capital invested or profit obtained from the project are random variables. Having the probability $p(T)$, the expected rate of return and the expected profit obtained from the project realization can be calculated for given streams of investment expenditures. Let $I(T)$ denote the present value of total investment cost, $I(T) = I_1(T) + I_2(T)$, then the rate of return is $R^u(T) = [P(T) - I(T)]/I(T)$ in the case of success, and $R^d(T) = -1$ in the case of failure. Let the respective profit be denoted by $B^u(T) = P(T) - I(T)$ and $B^d(T) = -I(T)$. The risk can be evaluated with the use of measures like semideviations, conditional value of risk, average lost. In the following example standard semideviation is considered as a risk measure. It has been shown (Ogryczak, Ruszczyński, 1999) that the standard semideviation as a risk measure in mean-risk analysis is consistent with second-degree stochastic dominance rules.

Each partner invests in the project only part of his capital and carries out in the time period $[0, T]$ also other activities. The decision making problem deals with a joint selection of the planned time T and agreement about distribution of the profit among partners. Denote the profit division strategy by $l, 0 \leq l \leq 1$. It defines the part of the profit directed to Party 1. The other part $(1-l)$ is directed to Party 2. The expected rates of return and standard semideviations can be calculated as functions of decision variables, denoted, respectively, by $R_i(T, l)$ and $\delta_i(T, l)$ in the case of Parties $i = 1, 2$.

Summarizing the model:

There are two parties - partners jointly investing in an innovative project.

The decision variables are the streams of expenditures that define the cost of the project, the participation of the parties in the cost, the planned time of the project realization, the strategy of the expected profit division.

For given values of the decision variables the model enables calculation of output quantities like invested capital, expected rates of return on capital invested, expected incomes, expected profit, risk measures and other quantities required in financial analysis, relating to the overall project and to each party separately. Each party selects from the outputs the quantities treated as criteria which should be maximized, minimized or stabilized according to the party preferences.

3. Cooperation problem

Representatives of the parties negotiate contract related to joint project realization. Each has own criteria measuring payoffs from the project and own preferences among the criteria. Each tries to select values of decision variables according to the preferences, which are in general contradictory.

Let x denote a vector of the decision variables, which belongs to a space $I\!R^k$, q_i denote a vector of the criteria of the party $i = 1, 2$, which belongs to m-dimensional criteria space $Y_i = I\!R^m_i$. The model relations define a set, denoted by X_0, of admissible values of decision variables $x \in X_0 \subset I\!R^k$, a transformation $\mathrm{T} : \mathrm{X} \to (Y_1 \times Y_2)$, and a set of attainable payoffs $Y_0 \subset (Y_1 \times Y_2)$, where $Y_1 \times Y_2$ is the cartesian product of the multicriteria spaces of both parties. Each payoff is defined by a pair of vectors (q_1, q_2). The cooperation problem consists in looking for consensus regarding a payoff $(\hat{q}_1, \hat{q}_2) \in Y_0$ and the respective decision variables vector $\hat{x} \in X_0$. Each party can continue an alternative traditional activity, or can invest the capital elsewhere and will not accept the payoff from the innovative activity, which is dominated in the sense of preferences by the payoff obtained from the alternative investment. We assume that each party has given evaluated payoff called the Best Alternative for Negotiating Agreement (according to the Roger Fisher's BATNA concept).

3.1. Utility function approach

Following the results of utility theory of von Neuman, Morgenstern, Savage, Tversky, Kulikowski, it is assumed that functions are given aggregating vectors of criteria into one dimensional utility of each party, and that each party tries to select the decision variables maximizing his utility. The model relations define a set of attainable utilities - payoffs of the parties in the space of utilities. Each party i has the Best Alternative for Negotiating Agreement represented by the utility $U_{imin}, i = 1, 2$. Using this concept one can formulate acceptability conditions for each party: $U_1(x) \geq U_{1min}$ and $U_2(x) \geq U_{2min}$, where $U_1(x)$ and $U_2(x)$ are the utilities of the parties, which are the functions of decisions x. The utilities U_{1min} and U_{2min} define the so called disagreement (or status quo) point in the space of utilities. The set of attainable utilities dominating the disagreement point describes the benefits, expressed in terms of utilities, the parties can obtain by realizing jointly the project. This set, denoted by A, is presented in Fig. 1. In the theory of bargaining games it is called the agreement set. Any point from the set A, different than (U_{1min}, U_{2min}), defines the payoff that can be obtained by the parties under their unanimous agreement. If they do not reach the agreement then they will obtain the payoffs on the level (U_{1min}, U_{2min}). The parties have to decide how to divide the benefits resulting from cooperation i.e. which point from the set A to select.

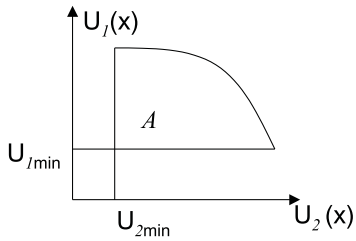

Figure 1. The classical bargaining problem

The utility function approach with utilization of solution concepts from the classical theory of bargaining games in application to computer-based decision support in the case of joint innovative projects has been presented in Kruś (2002a, 2003).

3.2. Multicriteria approach

In contrast to the utility function approach, in which the problem is considered in the space of utilities, in multicriteria approach the problem is considered directly in the space of all criteria considered by the negotiating parties. Each party has his own criteria space. Utility functions are not assumed to be given. We formulate the cooperation problem as a multicriteria barganing problem (Krus 1996). It is represented by a pair (A_m, q_d), where an agreement set A_m and a disagreement point $q_d = (q_{d1}, q_{d2})$ are defined in the Cartesian product $Y_1 \times Y_2$ of the multicriteria spaces of the parties. The problem consists in finding an agreement point $q^0 \in A_m$, dominating q_d with respect to the preferences of the parties. It is obvious that it should be looked for on the Pareto frontier of the set A_m.

The multicriteria bargaining problem is illustrated in Fig. 2. Two parties: a research institute (denoted in the figure by RI) and an investor (IN) negotiating joint project are considered. The horizontal axes relate to two criteria of the investor. Both are maximized. The first is the expected rate of return. The second is calculated as a given value Z minus the standard semideviation. The vertical axis relates to the expected rate of return of the institute. The solid figure represents the set of attainable payoffs. The best alternative to the negotiated agreement (BATNA) of the investor is presented by a vertical bolded line.

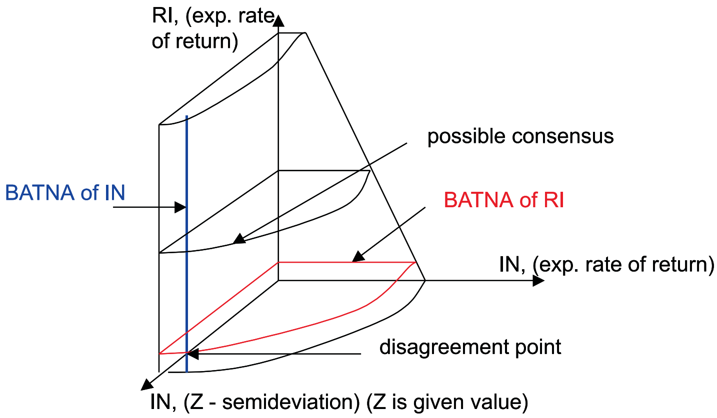

Figure 2. Example of multicriteria bargaining problem

The best alternative to the negotiated agreement (BATNA) of the research institute is drawn as a surface at the bottom of the figure. A possible consensus is on a surface lying higher, such that both the research institute and the investor improve payoffs (in the sense of preferences) in comparison to the disagreement point. Let observe that in general, as shown in Fig. 2, the disagreement point can be Pareto optimal.

A multicriteria approach to decision support in negotiations has been developed as the so-called multicriteria bargaining (Kruś, Bronisz, 1993; Kruś, 1996, 2002b). The results obtained include the generalization of classical solution concepts like Raiffa-Kalai-Smorodinsky and Imai solutions to the multicriteria case. An iterative solution concept has been proposed in the form of an iterative, progressive process starting from the disagreement point and converging to a Pareto optimal outcome. An idea of iterative mediation support has been elaborated with application of the reference point (Wierzbicki, 1986) approach and the above iterative solution concept. The support is made in the form of an iterative procedure in which a sequence of mediation proposals (payoffs) is generated. The proposals are calculated on the basis of the preferences of players. The sequence starts from the disagreement point, which is inside the agreement set, not on the Pareto frontier. Successive mediation proposals are also inside the set, but the sequence converges to a Pareto point.

Let us consider the investor who compares an investment in a research project and in governmental bonds. He can decide to invest in the risky project if the expected rate of return is relatively high. In this case the disagreement point, defined by the rate of return and the risk of governmental bonds, can be on the Pareto frontier. An iterative process, which would be progressive with respect to all the criteria, cannot be constructed. To cover such cases, there is a need for a modified procedure.

3.3. An idea of new iterative procedure supporting multicriteria bargaining

Motivations and general assumptions

In multicriteria approach, according to Simon's view, we assume that preferences of decision makers are not given explicitly and the decisions are not made by maximizing a given utility function. A good decision is the result of a learning mechanism, in which the decision maker can change his preference upon having compared different options and obtained more information about the decision situation.

Supporting of the learning process is the main objective of the procedure and it is implemented with the use of the reference point approach. The procedure combines the learning mechanism in which each party can generate some number of payoffs, which can be obtained from the project, can analyze and compare them independently (can make unilateral analysis), with the multilateral analysis for which the mediation proposals are generated.

The procedure consists of some number of rounds. Each round starts from the unilateral analysis, in which each party, looking for the best, preferred payoff, expresses his preferences. Information about the preferences is used for derivation of the mediation proposal. According to the general idea of the Nash solution to the bargaining problem, each mediation proposal is calculated as a payoff maximizing the product of the possible payoff improvements in comparison with the disagreement point. We assume that a scalarizing achievement function can be used to measure the improvements of payoffs obtained by the parties from cooperation. It can be shown that the generated mediation proposals are Pareto optimal in the set of attainable payoffs.

At the beginning of the procedure the parties are asked to introduce the data describing their BATNA payoffs and the disagreement point is derived, after which the ideal point and the so called utopia point relative to the parties' aspirations are calculated. Assuming that all criteria are maximized, the ideal point is a combination of the maximal values the particular criteria can reach. The notion of utopia point relative to the parties' (players in the baraganing problem) has been introduced first in Kruś, Bronisz (1993), where a detailed formulation can be found. It is derived after multicriteria analysis made independently by each party, under the assumption that the party could obtain all the benefits from cooperation. It is the combination of the best preferred payoffs the parties can obtain.

All the information introduced by each party is assumed to be strictly confidential. In particular, the information regarding BATNA and the selected preferred payoffs (expressing preferences) is not accessible to the counterparty.

Let $PP(q_1^0, q_2^0, q_{r1}, q_{r2})$ denote the parametric optimization problem:

$$\max_{x \in X_0} [s(q_1(x), q_{r1}) - s(q_{d1}, q_{r1})] \cdot [s(q_2(x), q_{r2}) - s(q_{d2}, q_{r2})]$$

where
x is the vector of decision variables,
X_0 is the set of admissible decisions,
$q_1(x), q_2(x)$ are the vectors of criteria of the party 1 and 2, depending upon on the decision variables vector x,
q_{r1}, q_{r2} are the reference points of the parties, respectively,
q_1^0, q_2^0 denote the obtained solutions in the multicriteria space, $(q_1^0, q_2^0) \in (Y_1 \times Y_2)$,
$s(.,.)$ is an achievement function (compare Wierzbicki, 1996) approximating preference ordering of the respective party.

Let $PP1(q_1^0, q_{r1})$ denote the optimization problem $\max_{x \in X_0}[s(q_1(x), q_{r1})]$, and $PP2(q_2^0, q_{r2})$ denote the problem $\max_{x \in X_0}[s(q_2(x), q_{r2})]$.

General scheme of the procedure

Step 1 Fix the disagreement point d
Each party assumes his BATNA and the respective values of criteria q_{d1} and q_{d2} are calculated.

Step 2 Calculate the ideal point
Maximum attainable values of criteria are derived. Therefore the ideal point $q_1^I \in Y_1$ in the criteria space of the first party, $q_2^I \in Y_2$ in the criteria space of the second party and $q^I = (q_1^I, q_2^I) \in Y_1 \times Y_2$ in the multicriteria space are derived.

Step 3 Calculate the relative utopia point
The parties, each assuming full control on decision variables, carry out independently the multicriteria analysis of their attainable payoffs. The analysis is made in some number of iterations. At each iteration the representative of the party 1 assumes a reference point $q_{r1} \in Y_1$. The maximization problem $PP1(q_1^0, q_{r1})$ is solved. The solutions q_1^0 obtained are collected in a data base. The party representative compares and analyzes the solutions and is asked to select the best preferred q_1^R point.
The second party carries out the multicriteria analysis in the same way assuming the different reference points $q_{r2} \in Y_2$, solving the optimization problems $PP2(q_2^0, q_{r2})$ and selecting the best preferred q_2^R from the obtained q_2^0 points. The relative utopia point is fixed $q^R = (q_1^R, q_2^R)$.

Step 4 Calculate an initial cooperative outcome
The optimization problem $PP(q_1^0, q_1^0, q_2^R, q_2^R)$ is solved. The obtained values q_1^0, q_2^0 define the initial cooperative outcome $q^1 = (q_1^1, q_2^1) \in Y_1 \times Y_2$, where$(q_1^1 = q_1^0), (q_2^1 = q_2^0)$.
Set the number of the round $i = 1$.

Step 5 Multicriteria analysis of cooperative outcomes
Each party analyzes the obtained cooperative outcome and the values of decision variables.
The first party defines his reference point $q_{r1} \in Y_1$. The reference point of the counter party is assumed to be $q_{r2} = q_2^i$. The optimization problem $PP(q_1^0, q_2^0, q_1^R, q_2^R)$ is solved and the results obtained are analyzed. The analysis is repeated, so that some number of solutions for different reference points can be collected in a data base and the party can decide and select the best preferred $q_1^a \in Y_1$.
The second party performs the analysis in an analogous way, selecting at the end his best preferred $q_2^a \in Y_2$ point.

Step 6 Calculate a successive cooperative outcome. Set $i = i + 1$
The optimization problem $PP(q_1^0, q_2^0, q_1^a, q_1^a)$ is solved. The obtained values q_1^0, q_2^0 define the successive cooperative outcome $q^i = (q_1^i, q_2^i) \in Y_1 \times Y_2$, where$(q_1^i = q_1^0), (q_2^i = q_2^0)$.
Go to Step 5.

The above procedure has no formal stopping condition. The negotiating parties can obtain a sequence of mediation proposals and analyze them. The proposals are generated on the base of preferred outcomes selected by each of the parties at the individual multicriteria analysis included in the step 5. The proposals can be useful in the negotiation process, enabling the parties to understand better the nature of decision problem they have to solve. The parties should decide what cooperative outcome to assume as a consensus and when to stop the procedure. They can also decide not to participate in the project if the obtained outcomes are unsatisfactory.

4. Experimental calculations

A simple mathematical model has been constructed for the case of a research project carried out in the Systems Research Institute. On the basis of experts opinions, the probability of success was calculated as a function of the time of project accomplishment. The institute and a firm (called investor) participating in the project were considered as negotiating parties. The streams of expenditures covered by the institute and by the investor were assumed to be given. (In fact three scenarios of the streams were assumed and the probability of success were derived for all the three scenarios). Decision variables are the time T of project realization and the division l of profit. The project requiring an innovative activity, was compared to alternative traditional activities carried out independently in the institute and in the firm. The traditional activities define the BATNA of the institute and of the investor, respectively. The above model was used to test the procedure. Selected results are presented in the following figures, obtained with the use of computer simulations

Figures 3 and 4 relate to the analysis preformed by a representative of the research institute. These figures include information about the expected rate of

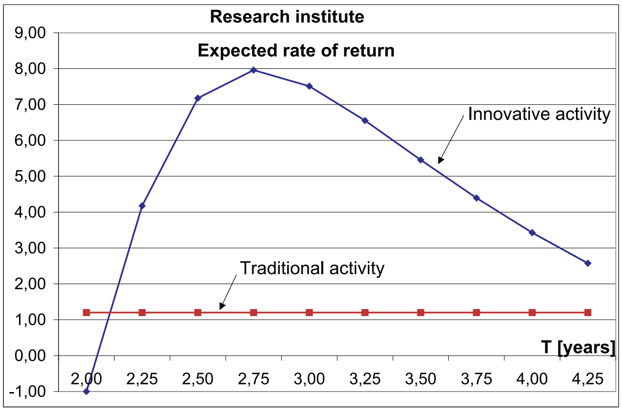

Figure 3. Rate of return obtained by the research institute

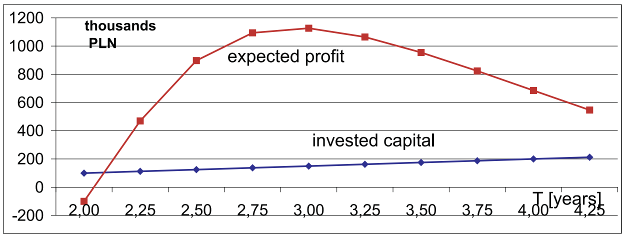

Figure 4. Profit obtained by the research institute

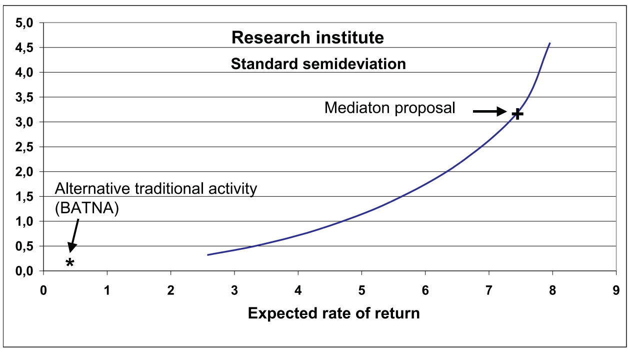

Figure 5. Pareto frontier of the agreement set in the criteria space of the research institute

return on the capital invested in the project in comparison with the traditional activity, as well as the expected profit and the invested capital. All the quantities are presented as depending on the planned time of project accomplishment. There is an optimal time, which maximizies the expected rate of return. Increasing the time results in lower rate of return but in greater probability of success and lower value of standard semideviation. Fig. 5 presents an approximation of the Pareto frontier of the agreement set in the criteria space of the research institute. The expected rate of return and the standard semideviation are treated as criteria in the decision analysis. The star sign (*) relates to the traditional activity. The plus sign (+) marks the derived mediation proposals.

The analogous information related to the investor is presented in Figures 6, 7, 8. The optimal time of the project accomplishment from the point of view of the research institute and the optimal time from the point of view of the investor are different. Each party has also different preferences regarding to relation between the rate of return and the standard semideviation, representing the risk. The mediation proposal presented in the figure has been calculated at the step 6 of the procedure after an interactive analysis carried out by the parties at step 5. Each party could in the analysis express their preferences assuming some number of reference points, collecting solutions obtained by solving the problem PP and by selecting the best, preferred solution. On the basis of the preferred solutions selected by both parties the mediation proposal has been derived.

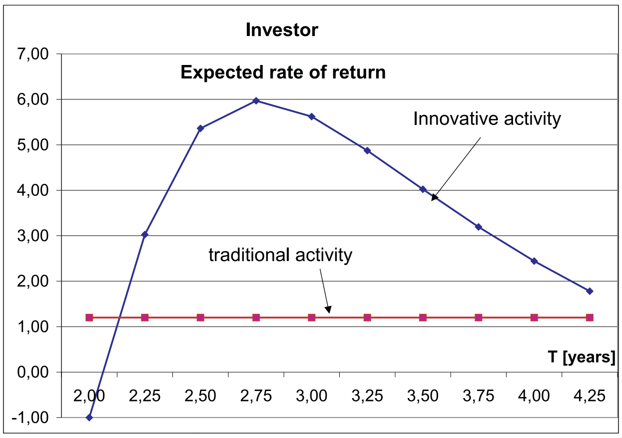

Figure 6. Rate of return obtained by the investor

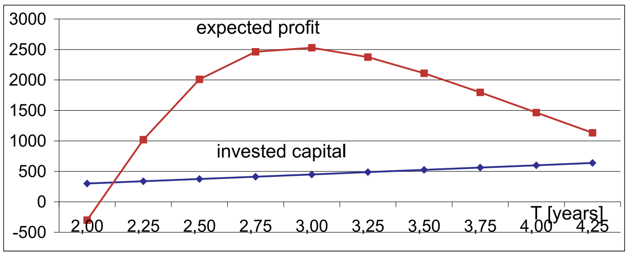

Figure 7. Profit obtained by the investor

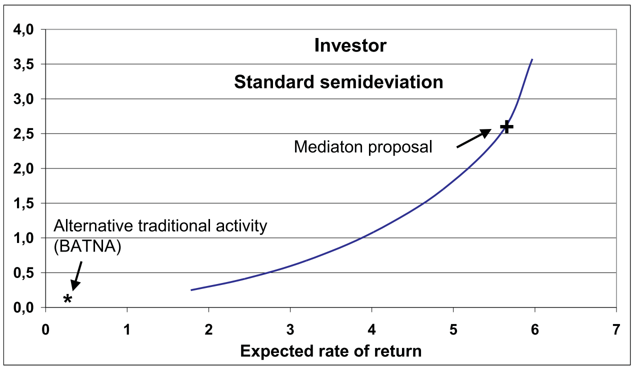

Figure 8. Pareto frontier of the agreement set in the criteria space of the investor

5. Final remarks

In the paper a simple mathematical model is presented describing an innovative research project from the point of view of financial analysis. Two parties realize the project jointly. A cooperation problem is considered in the case of multicriteria payoffs of the parties. It is formulated a multicriteria bargaining problem. The decision support includes multicriteria analysis performed by each of the parties with the use of the reference point approach, and calculation mediation proposals. A new idea of an iterative procedure is proposed utilizing the Nash concept of cooperative solution. The procedure can be applied to the multicriteria bargaining problems in which the disagreement point is situated in the Pareto set of attainable criteria. Initial tests of the procedure have been carried out with promising results. Further research, including theoretical framework, analysis and calculation tests using other examples is planned. In particular, the properties of the mediation proposals calculated with use of the scalarizing achievement function will be analyzed.

Acknowledgement

The author would like to thank the anonymous reviewers for their helpful suggestions and valuable detailed comments.

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