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Mechanisms of multicriteria auctions, some remarks

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MECHANISMS OF MULTICRITERIA AUCTIONS, SOME REMARKS*

Abstract

In this paper mechanisms of multicriteria auctions are discussed including elements of decision support of the auction organizer as well as bidders. The mechanisms are considered in the context of incentive compatible decisions. Using domination relations formulated in the space of criteria, different rules describing improvement of offers in successive rounds of an auction process are analyzed. The general discussion is illustrated by an example of an iterative multicriteria closed-bidding auction conducted with the use of a multi-agent computer-based system. The system supports submission of offers, multicriteria analysis made by an organizer of the bidding auction, simulation and analysis of competing bidders' behavior. Experimental results of sessions conducted with use of the system are presented and analyzed.

Keywords

Multicriteria auctions, incentive compatible decision mechanisms, multiagent systems, multicriteria optimization.

1. Introduction

There exists a rich bibliography dealing with auction theory in the case of scalar valuation of offers, including among others papers by Klemperer (2004), Milgrom, Weber (1982), Vickrey (1961). In the case of

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the multicriteria auctions, in each round we have to deal with not only one offer with a better price, but with a set of offers valuated by an auction organizer with the help of a vector of criteria. It is reasonable to support multicriteria analysis made by the auction organizer and to construct an auction mechanism leading to the final offer according to his preferences. In most papers dealing with the multicriteria auctions, aggregation models are applied, by aggregating multiple criteria to a scalar value using a vector of wages, see (De Smet 2007), (Teich et al. 2006), (Bichler Kalagnanam 2005). In this case, the auction organizer has to reveal his model of preferences. Interesting are papers using the reference point approach of multicriteria optimization (Ogryczak, Kozłowski 2011), (Bellosta at al. 2004). This paper belongs to the last class.

The research presented is a part of a wider research direction dealing with analysis of incentive compatible multicriteria decision mechanisms. Within this research, decision situations are analyzed where there is a number of independent agents that have private information and act according to their own interests. Each agent tries to achieve his own multiple egoistic goals, but the results depend on actions of other agents. Our subject of the research includes investigation of the multicriteria decision mechanisms that could lead to incentive compatibility by revealing true multiobjective preferences and by appropriate harmonization of agents activities, so that efficiency of the whole system could be assured. The incentive compatibility in the market mechanisms were analyzed previously by Toczyłowski (2003, 2009). The ideas developed in the papers have inspired the presented research. Analysis of the incentive compatible multicriteria decisions has been presented in (Kruś, Skorupiński, Toczyłowski, 2012a) for a particular case of the producer and buyers problem.

This paper deals with a multicriteria closed bidding-auction for procuring an object, realized in one, or in many rounds. Different forms and rules of the auction are analyzed, not limited to the current rules of the public auctions defined by law. The auction organizer (buyer) and bidders make multicriteria decisions. The organizer and bidders have private knowledge about their own possibilities. The information is confidential. The organizer minimizes criteria (such as cost, time of the object realization). Bidders know these criteria, but the organizer does not inform them about his preferences.

In the classic English type auction, we have a sequence of offers proposed by bidders, with decreasing prices. Each bidder has his reservation price (see figure 1, part a.). It is obvious that any possible contract below his reservation price is not profitable for him. The organizer has also his reservation price. It defines the upper limit of prices he can accept. Information about the reservation prices is private and confidential. In the multicriteria auction, we must deal with the sets of offers in consecutive rounds.

Possibilities of each bidder define his profitability limits that can be presented in the space of criteria formulated by the organizer. They limit possible offers of the bidder. The organizer has also his profitability limit of acceptable offers. Information about the profitability limits is private and confidential. Examples of profitability limits in the buyer's space of criteria: time and cost are presented in part b. of figure 1.

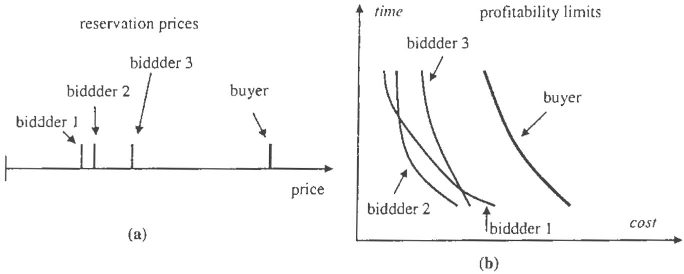

Figure 1. Examples of private information in auctions, a. reservation prices in classic auction, b. profitability limits in multicriteria auctions.

In the multicriteria auction there are some open questions regarding rules for improvement of offers in consecutive rounds, range of information accessible to bidders, form of multicriteria decision support, and others. Regarding the incentive compatibility of multicriteria decisions, a question arises how much the auction mechanism can lead to reveal the private information of bidders.

In this paper a general scheme of multicriteria auctions mechanism is discussed including elements of decision support of the auction organizer as well as bidders. Using domination relations formulated in the space of criteria, different rules describing improvement of offers in successive rounds of an auction process are analyzed. The general discussion is illustrated by an example of iterative multicriteria closed-bidding auction conducted with the use of a multi-agent computer-based system. The system (Skorupiński 2010, Kruś, Skorupiński, Toczyłowski 2012b) supports submission of offers, multicriteria analysis made by an organizer of the bidding auction, simulation and analysis of competing bidders' behavior. Experimental results of sessions conducted with use of the system are presented and analyzed.

2. Problem formulation

Let a decision making authority, organizes an English-type auction for construction of an object. We assume that there is a set of n bidders competing to obtain the order for the construction. Let $O=\{o^1, o^2,\dots,o^n\}$ be the set of bidders accessing in the auction. Offers $x\in X$, where X is a set of admissible offers, are valuated by a vector of m criteria $y=\{y_1,\ y_2,\ y_m\}\in \boldsymbol{R}^m$ defined by the auction organizer, called also buyer. Let W: $X\rightarrow \boldsymbol{R}^m$ be mapping assigning a vector of the criteria to each offer. The buyer would like to obtain the offer with the minimal values of the criteria.

We define relations in $\boldsymbol{R}^m$:

weak domination: $y^1 \succeq y^2 \Leftrightarrow y_i^1 \le y_i^2$, for each $i= 1, 2, \dots, m$, and

domination: $y^1 \succ y^2 \Leftrightarrow y_i^1 \le y_i^2$, for each $i= 1, 2, \dots, m$, where

$y^1, y^2\in \boldsymbol{R}^m$.

The buyer has given profitability limits defined as a set of acceptable offers X^0 and related to them a set of acceptable multicriteria valuations $Y^0=W(X^0)$. The offers not belonging to set X^0 are not accepted by the buyer.

The auction is conducted in some number of rounds t=1, 2,.... In each round t the bidders present their offers $x^i(t)$, where i=1, 2,...n is index of a bidder. Each bidder i has also his own profitability limits, defined by a set of admissible offers X^i and related set of multicriteria valuations $Y^i = W(X^i)$. If the bidder cannot find an offer in the set, which beats the offers of competitors, he will waive and can not continue the bidding.

A general scheme of the auction carried on with use of a computer-based system is presented in figure 2.

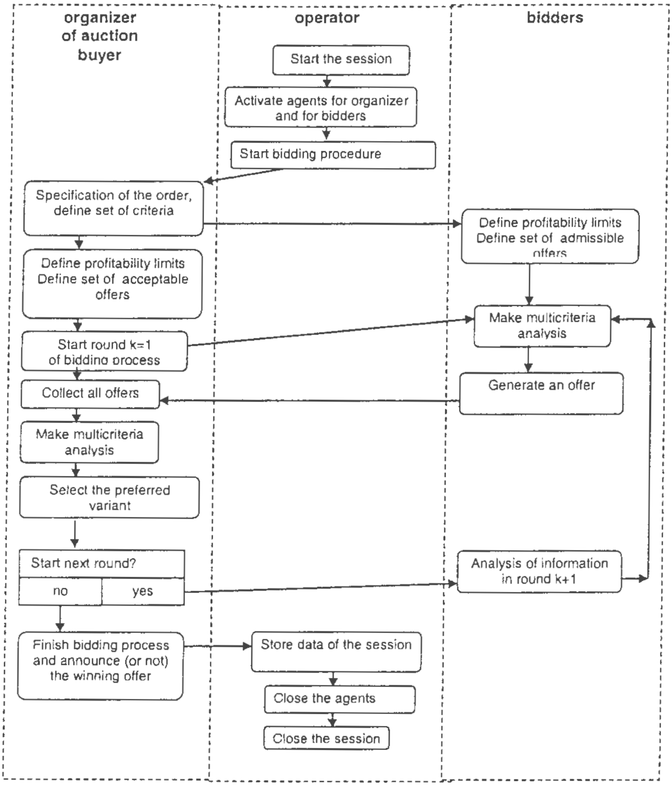

Figure 2. General scheme of decision making processes in a multicriteria auction

Actions of a system operator and decision-making processes of the auction organizer (buyer) and of bidders are taken into account. The system operator starts the session and activates computer agents supporting the organizer and bidders. Before the real bidding auction process starts, the organizer and bidders should define their profitability limits and the respective sets: the set of offers acceptable by the organizer and the sets of offers admissible for the bidders. Information about the profitability limits and about the sets is private and strictly confidential.

The auction organizer – buyer would like to obtain the offer that is the best with respect to his preferences. On the other hand each bidder would like obtain the contract which fulfills his profitability limits and is the best according to his preferences.

In the case of the classic English auction, bidders propose offers with decreasing prices in successive rounds. In the case of multicriteria auction, in each round, there can be a set of offers proposed by bidders and the offers can be noncomparable in the sense of the mentioned domination relations. Therefore the buyer should make multicriteria analysis in each round, so the support of the analysis is required.

An example of a set of offers analyzed by the buyer is presented in figure 3, as a set of black points in the space of two criteria y_1, y_2. In the set there are nondominated (Pareto-optimal) points, from the point of view of the buyer, denoted by y^1, y^2, y^3, y^4, y^5, y^6 in part (c) of the figure.

Multicriteria analysis of the set of offers and selection of the offer according to preferences of the buyer can be done with use of the reference point approach (Wierzbicki, 1986), (Wierzbicki, Makowski, Wessels, 2000). The method has been used and implemented in the computer based system constructed for experimental studies on a multicriteria bidding auction (Kruś, Skorupiński, Toczyłowski, 2012).

The reference point method has been originally developed for analysis of offers in multicriteria auction by Ogryczak & Kozłowski (2011).

3. Remarks on multicriteria auction mechanisms

Some questions arise regarding rules of the auction and the range of information accessible to bidders in particular rounds. The rules defining improvement of offers can be formulated in different ways. Let us consider three variants:

a. the offer proposed can not be dominated by any of offers given in previous rounds,

b. the offer proposed should dominate any of offers given in previous rounds,

c. the offer proposed should dominate the offer selected by the buyer in the previous round.

Figure 3 presents the sets of possible improved offers in variants **a**, **b**, **c**, as shadowed areas.

Variant **a**. defines the weakest requirements to the offers that can be submitted in the successive round. Each bidder can propose an offer which dominates any of the offers nondominanted in the previous round, but also can propose an offer noncomparable to the offers nondominated in the previous round. The set to which the improved offers should belong is constructed as the sum of the shifted domination cons without their borders.

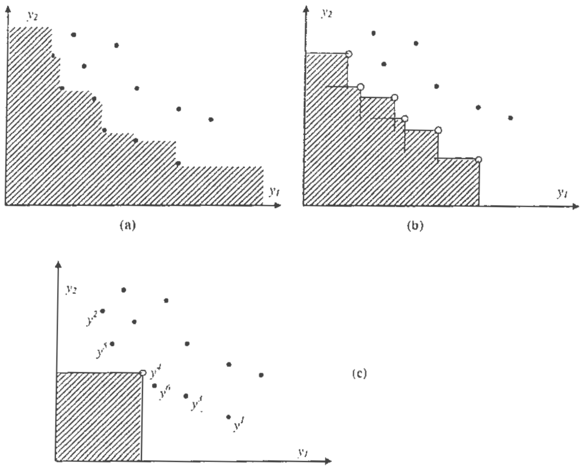

Figure 3. Sets of possible offers according to rules (a), (b), (c).

In variant **b**. each proposed offer should dominate at least one of the offers nondominated in the previous round. The set defining possible improved offers is constructed as the sum of the domination cons shifted to the points representing offers nondominated in the previous round. Some offers which could be proposed in the case of variant **a**., can not be proposed in this variant though could be interesting to the buyer. In variants **a**. and **b**., bidders should have information about all nondominated offers proposed in the previous round. The buyer can not inform which of the nondominanted offer is preferred to him, however the information could speed up auction process.

In variant **c**. the buyer, after each round, informs bidders about his preferred offer and expects that at least one of his criteria will be improved. The variant defines the strongest requirements to the offers proposed in successive rounds. The auction process is speeding up in comparison to variants **a**. and **b**. On the other hand, some offers, which are nondominated and interesting to the buyer, can be omitted. It is important especially at the end of the auction process, when bidders are close to their profitability limits.

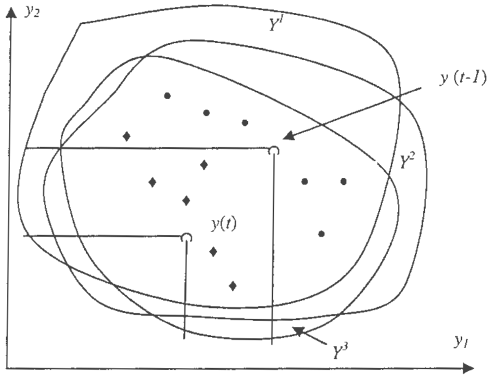

Figure 4. Sets of admissible offers. Examples.

Figure 4 presents sets Y^1, Y^2, Y^3 of admissible offers of three bidders in the space of criteria y_1, y_2 of the buyer. The sets correspond to profitability limits of the bidders. Black points represent offers given in round t-1. Offer $y(t$-1) denoted by the small empty circle has been selected by the buyer as the preferred one in round t-1. At this place starts the set of offers that can be proposed by bidders in round t according to variant **c**. It is domination cone shifted to point $y(t\text{-}1)$. Black rhombs represent offers given in round t. Offer $y(t)$ denoted by the small empty circle has been selected by the buyer as his preferred one in round t. At the point the set of possible offers in the next round starts. Sets of offers that can be proposed by bidders are limited by their profitability limits and decreased in successive rounds. Finally, particular bidders have to waive the auction in sequence and some offers that could be interesting to the buyer can be omitted. It is result of the rule defining improvement of offers assumed in variant **c**.

Different rules can be assumed on different stages of the auction process when the auction mechanism is constructed. For example, **c.** variant can be assumed as the basic one. At the beginning and in final rounds, variant **a**. or **b**. can be applied. At the beginning of the auction the buyer is not fully conscious of his preferences, therefore bidders should have possibility to present a wide portfolio of offers, what variant **a.** and **b.** enables. Similarly - in the final rounds it would be a pity to miss some offers, which are nondominated and lie near the border of the domination cone, excluded from consideration by variant **c.**

The questions discussed above have been solved in a specific way in the case of a closed bidding-auction analyzed during the research. Let us assume that a decision making authority organizes auction bidding for construction of a public object, for example a bridge. The authority is interested in construction of the object in possibly short time and bearing possibly low cost. The authority - called further - the auction organizer and buyer, defines a discrete set T of several times variants in which the object will be constructed, with realization times $tr \in T$. We assume that the organizer and each bidder has his own profitability limit for each variant of time. In the case of the organizer, it is the maximal accepted cost of realization of the object. In the case of bidders, it is assumed that each of them has made multicriteria analysis of possible realization of the object. On this basis, he has defined values of minimal payments for the object realization for the time variants. Below the values, realization of the object is not profitable for him. Confidentiality of information is approved. Bidders do not know which time variant will be finally accepted by the organizer. Any bidder does not know profitability limit of the organizer nor profitability limits of competitors. The organizer does no know profitability limits of bidders. The auction mechanism should lead to finding the contractor and the best variant of project realization according to the preferences of the organizer.

A special multiagent system has been constructed to simulate different variants of bidding auction process. The system has been made in AIMMS (see Bisschop, Roelofs 2009) environment. Users of the system play roles of an organizer of the auction and of bidding competitors respectively. The system is started by an operator who starts actions of a computer agent for the organizer and required number of agents for the competitors. The system supports confidentiality of information of the users. The auction is carried on according to the general scheme presented in figure 2. In each round, bidders can present their offers with prices for each time variant. The organizer makes multicriteria analysis of the offers submitted. He does not inform bidders about his preferences. They obtain information about the best offers for each time variant, but do not know who has proposed each of the offers.

Multicritera analysis is made by the organizer in an interactive way with use of the reference point method developed by A. P. Wierzbicki (Wierzbicki 1986, Wierzbicki, Makowski, Wessels 2000). According to the method, the organizer can find and analyze nondominated offers in the space of his criteria, assuming respectively reservation points r and aspiration points a in this space. Subscripts i of components r_i, a_i of vectors r and a, refer respectively to the cost and the time of the project realization. A set of the indexes will be denoted by I. The following optimization tasks are solved:

$$\max z + \varepsilon \sum_{i \in I} z_i$$

subject to constraints of the reference point method:

$$\begin{aligned}
& z \le z_i, \forall i \in Y, \\
& z_i \le \gamma(x_i - r_i)/(a_i - r_i), \forall i \in I, \\
& z_i \le (x_i - r_i)/(a_i - r_i), \forall i \in I, \\
& z_i \le \beta(x_i - a_i)/(a_i - r_i) + 1, \forall i \in I,
\end{aligned}$$

limits for minimized values for the time and the cost:

$$\begin{aligned}
& x_{cost} \ge p_{o,tr} - (p_{\max} - \mathrm{p}_{\min})(1 - w_{o,tr}), \forall o \in O, tr \in T, \\
& x_{time} \ge d_{tr} - (d_{\max} - d_{\min})(1 - q_{tr}), \forall tr \in T,
\end{aligned}$$

and constraints related to discrete form of set T:

$$\begin{aligned}
& \sum_{o \in O, t \in T} w_{o,tr} = 1, \\
& \sum_{o \in O} w_{o,tr} = q_{tr} \forall tr \in T.
\end{aligned}$$

It is a mixed integer-programming problem. With use of the problem the reference point method is implemented for the considered multicriteria optimization problem of the organizer of the auction. The problem is solved by the system for points r and a, assumed by the organizer. The solution of the problem - a point x in the criteria space - is nondominated in the set of variants proposed by bidders, due to properties of the reference point method. The organizer by changing the reference points can obtain a representation of the set of the nondomineted offers. In this formulation there are additional variables z, z_{cost}, $z_{time} \in \mathbf{R}^1$, coefficients of the reference point method ε, β, γ, where ε is respectively small positive number, $0<\beta<1<\gamma$, p_{max} and p_{min} denote respectively the most costly and the cheapest offer for the given variants of time, d_{max} and d_{min} denote respectively the shortest and the longest realization time, $w_{o,tr}$ for $o \in O$ and $tr \in T$, q_{tr} for $tr \in T$ denote additional binary variables.

The organizer finishes multicriteria analysis when he has valuated and compared all nondominated points interesting for him. Then he selects the best solution, according to his preferences and announces the selected offer, finishing the bidding auction, or decides to continue the auction for the next round.

If he decides to continue the auction, the bidders obtain information about the cheapest offers for the indicated time variants. However they do no know who of the bidders has presented the given offer, and they do not know preferences of the organizer. Each bidder can update his offers by decreasing costs. He can not however recede from the previous offer if he does not like to correct it. Moreover, he does not know whether the auction will be continued in the next round or not. The organizer opens the new offers and repeats multicriteria analysis for the new set of offers. He can continue the process in the next round; he can stop the process at any round and cancel the auction if he has found all the offers unsatisfactory, or can finish the auction announcing the selected offer.

A number of simulated interactive auction sessions has been made with the use of the computer-based system. Human users of the system played roles of an auction organizer and of bidders. We were interested in possible behaviors of the organizer and of the bidders. An important question can be posed, whether a multiround and multicriteria auction mechanism enhances to reveal some confidential information of the bidders about their true cost of realization of the public object.

2. Experimental results

Selected results of one of the sessions are presented and analyzed below. The session relates to a bidding auction for construction of a public object. Three bidders have participated in it. An organizer of the auction has defined 6 possible time variants for realization of the contract: 30, 33, 36, 39, 42 or 45 months. He has defined also his profitability limit, i.e. maximal cost limit he can pay for the project realization for each of the time variants. We assume that each bidder has also defined his profitability limit i.e. the lower limit of price for which he can construct the object in each given time variant.

The profitability limits of the organizer and of the bidders are presented in figure 5. In the presented example, the profitability limits of bidders are below the profitability limit of the organizer. There exist intervals of costs in which possible solution of the auction can be profitable for the organizer and for a winning bidder as well. Comparison of the profitability limits is presented only for analysis of the bidding process. The organizer does not know profitability limits of bidders, and the bidders do not know the profitability limit of the organizer.

The organizer is interested in realization of the object in possibly short time and for minimal cost. He understands that realization of the object in a shorter time requires a greater cost.

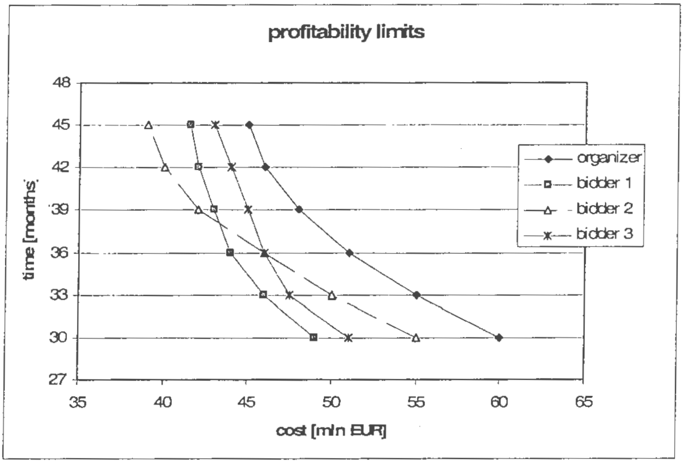

Figure 5. Profitability limits of the organizer and of bidders.

The organizer makes in each round multicriteria analysis when all offers are collected. The analysis is made in some number of iterations according to the reference point method. The organizer assumes in each iteration a reservation and an aspiration point in his criteria space. The computer-based system solves optimization task formulated in the previous section and derives respective nondominated point. The organizer can obtain a representation of the set of nondominated points assuming different aspiration and reservation points, and can then select the point being close to his preferences, but he informs bidders about the decision when he decides to finish the auction.

Figure 6 presents offers in the final fourth round. In the case of times 30, 33, 36 months, the best ones are offers of bidder 1, when in the case of times 39, 42 and 45, the best ones are offers of bidder 2. The organizer has obtained significant improvement of offers in comparison of the best initial offers given in round 1. Concurrent offers have been revealed for each of the time variants.

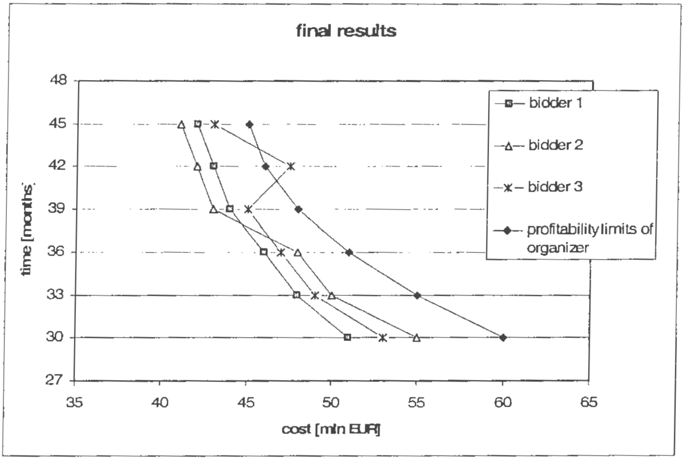

Figure 6. Offers in the final, fourth round.

In this presented session, as well as in other sessions made, we have observed that final offers converged to the level of second minimal profitability limit of bidders. As we can see in figure 5, the profitability limits of bidder two are the lowest for the time variants 45, 42 and 39 months. Bidder 1 has the second minimal profitability limits for the time variants. The profitability limits of bidder 3 are the second minimal ones for the time variants 36, 33 and 30 months. Let us compare the results of the final session presented in figure 6. The winning offers of bidder 2 are on the level of the profitability limits of bidder 1 for 45, 42 and 39 months, and the winning offers of bidder 1 are on the level of the profitability limits of bidder a 3 for 36, 33 and 30 months. It is understandable, that the bidder having the lowest profitability limit for given time variant has no incentives to decrease such an offer and other bidders can not beat it. In general, a large number of rounds could be required to obtain such result, especially if the bidders are allowed to make only small decrease of offers in the rounds.

4. Final remarks

The paper deals with mechanisms of multicriteria auctions in the context of incentive compatible decisions.

We have done an assessment of the rules for defining improvements of offers in successive rounds, on the basis of the domination relation defined in the criteria space of the organizer. The rules differ with respect to range of possible offers that can be proposed by bidders, and to the progress of the auction process. It seems reasonable to apply different rules at different stages of the auction process. For example at the begining of the auction, the organizer may be not fully conscious of his preferences. Therefore, the rule that enable the bidders to propose a wide range of offers can be applied, though the progress of auction at the rule is rather slow. In furthers stages of the auction another rather narrow rule for giving the quicker progress can be applied, by limiting the range of possible offers.

We have constructed the mathematical model of iterative multicriteria closed-bidding auction. It includes the formulation of the optimization task and implementing reference point approach of multicriteria analysis made by the organizer. The multi-agent computer-based system has been built supporting submission of offers, multicriteria analysis made by an organizer of the bidding auction, simulation and analysis of competing bidders' behavior.

The computer-based system used in the experimental studies assures confidentiality of the private information on profitability limits of bidders and the organizer. We have done the assesment of results of sessions conducted with the use of the system. We have observed that generally bidders are enhanced in the auction to reveal their private information, and that proposed offers tend to converge in the consecutive rounds to the second minimal profitability limits of the bidders. In particular, the noncompetitive bidders that must compete with the others to their limits are motivated in the consecutive rounds to propose the offers that tend to their profitability limits.

Our further research may include development of the model and respective rebuilding of the multi agent computer-based system. Different rules of the multicriteria auction, different strategies of bidders in the auction may be analyzed. Full confidentiality of individual information has been assumed in the model already proposed. The confidentiality relates to cost limits and to preferences of the organizer as well as of the bidders. It is interesting to check how an access of bidders to some selected information, for example the information on preferences of the organizer, may inflow on a behavior of bidders and their strategies during the auction process. Bidders, in the present model, introduce into the system given data about their cost limits as well as proposed offers. Respective multicriteria analysis leading to calculation of the data has to be made outside the system. An additional module supporting such analysis would be useful. The cost limits of the organizer and of bidders state natural reservation points in multicriteria analysis made by them respectively. The cost limits can be calculated with use of the BATNA (Best Alternative to Negotiation Agreement) concept in an analogical way as in papers (Kruś 2002, 2008, 2011). The BATNA concept (see Fisher, Ury 1981) is commonly used in international negotiation processes.

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Wybrane zagadnienia aukcji wielokryterialnych

Dyskutowane są mechanizmy aukcji wielokryterialnych w kontekście decyzji motywacyjnie zgodnych. W szczególności analizowane są różne zasady poprawiania ofert w kolejnych rundach aukcji. Wykorzystuje się przy tym relacje dominacji określone w przestrzeni kryteriów organizatora aukcji. Ogólna dyskusja ilustrowana jest na przykładzie wielokryterialnego przetargu, prowadzonego iteracyjnie z wykorzystaniem wieloagentowego systemu komputerowego. System ten umożliwia składanie ofert, wspomaga analizę wielokryterialną wykonywaną przez organizatora aukcji (kupującego), wykonywanie badań symulacyjnych i analizę możliwych zachowań konkurujących ze sobą oferentów. Przedstawiane są i analizowane wybrane wyniki badań eksperymentalnych przeprowadzonych przy pomocy systemu.

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