A Multiattribute Auction Procedure and Its Implementation

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Abstract

A multiattribute auction procedure that allows bidders to make informed bids without knowledge of the bid-taker’s preferences is presented. The procedure can be extended to allow the bid-taker to differentiate among the bidders, place them into categories, and formulate different requirements for each category. The procedure is adapted to reverse auctions and it is illustrated with a simple procurement case. The implementation of the procedure in the IMARAS system and the initial results from the system use in experimental settings are discussed.

1. Introduction

E-procurement is a key area of e-business and supply chain management in which catalogs and reverse auctions have been widely used [1, 2]. On average, about 70% of corporate revenue is spent on purchasing; savings of 5% translate into hundreds of millions of dollars [3, 4]. Reverse auctions have been shown to achieve average gross savings of 15-20 per cent [5].

Most auctions are single attribute, i.e., price. A bid-taker sets up an auction in which bidders engage in a bidding process to buy from the buyer a product or service. In single-attribute reverse auctions (SARAs), the bidders want to sell the buyer a product or service.

The use of SARAs requires that two types of requirements be met:
1. Auctioned goods have to be completely specified, with the exception of one attribute (price). The purpose of the bidding process is the specification of this attribute’s value; and
2. For the bid-taker, the bidders do not differ in terms of their characteristics, i.e., there are no bidders who are more desirable than others.

The first requirement allows for the complete description of the auction with the use of one variable. This variable and its preferential direction are known to all participants; the direction is the same for the bidders and opposite for the bid-taker. In effect both the bid-taker and the bidders know what is better for them and that their interests are strictly opposite [6].

The second requirement complements the first: bidder information needs not to be included in the auction description. The interest of the bid-taker is to obtain the best price for a given item, irrespective of who the seller is. The result is that every bidder may bid anonymously and does not need any information except for the bids.

In many real-life situations, either one or both requirements are not met. A survey by Ferrin and Plank [7] found that over 90% of purchasing managers based their decisions on both price and non-price variables (e.g., durability, service, lead-time, and trust).

The consideration of other attributes than price, describing the item and/or the bidders, violates at least one of the above mentioned requirements. This necessitates the modification of the auction selection, the auction itself, and/or winner determination.

The modifications include: (1) pre-selection of bidders so that only bidders who are known to meet the additional criteria are included; (2) giving incumbents an advantage because their qualifications are known; and (3) the use of disclaimers such as “the lowest bid may not be awarded the contract” [8-10].

The results of such auction modifications are mixed because of collusion and selection of inferior offers [11, 12]. In some situations the process becomes an auction in name only, as is the case with an auction in which neither the winner nor any other bidder is awarded the contract.

Rather than aggregating multiple attributes into one so that a single attribute auction can be used, it is possible to design a multiattribute auction. There have been several multiattribute reverse auctions (MARAs) mod-
els formulated, including models which give bidders all information that the buyer uses in order to analyze and compare bids [13]. This approach is unacceptable when buyers do not want to disclose their preferences for strategic, competitive, or other reasons [14, 15].

Another option rests on the assumption that all attributes can be expressed in monetary terms so that only two items need to be considered: (1) price, and (2) monetized attributes, which typically represent costs—for the sellers and value (income)—for the buyer. When an assumption is added that these two terms are monotonic and the buyer compares bids using the difference between value and price, then the sellers can determine the buyer’s preferential order of the alternatives.

The attribute monetization methods have been widely implemented and tested [e.g., 8, 16, 17], and they are considered a standard in the auction literature [15].

The limitation of this method is the underlying assumption that: (1) the preferential direction of the monetized attributes is the same for all bidders and opposite for the bid-taker, and (2) there is a single function which transforms all attributes into money. The assumption deals with the attributes of the item but not the bidders, hence it cannot be used when the bid-taker wants to treat the bidders differently. It is also problematic if preferentially non-monotonic attributes, such as brand, shape and color are considered. It allowed, however, considering multi-attribute auctions as a subset of combinatorial auctions and transposing the problem of subjectivity and measurement into construction of bundles which can be compared using price [18].

The purpose of this paper is to present a MARA procedure which allows bidders to make informed bids with no explicit knowledge of the bid-taker’s preferences. The procedure can be extended to allow the bid-taker to differentiate among the bidders, classify them into categories, and formulate different requirements to each category.

Our focus is on designing a feasible auction mechanism which allows for the achievement of efficient winning bids. Given our focus, we are not concerned here with the complete set of auction design rules, which assures that given outcomes are met. Instead, we are concerned with rules which assure that no alternative is removed which could yield the desired outcome. Whether such an outcome is achieved depends on the sellers’ behavior, which is not discussed here.

The procedure allows for trading off the efficiency of the outcome with the efficiency of the process. The former is measured with the distance from the winning bid to the Pareto-optimality frontier and the latter is measured by the process resource requirement. For simplicity, we assume here that process efficiency is measured by the number of rounds required to complete an auction.

Note that, although the procedure is described and illustrated for MARAs, it can easily be modified for standard multiattribute auctions.

The paper has five more sections. In Section 2, the multiattribute auction process is introduced through an illustrative example. In Sections 3 and 4, the proposed procedure and its extensions are described. First, the concept of bid limits based on the reservation levels is introduced, then the limit-sets are described and their use in MARA explained. The InterNeg MARA system (IMARAS), in which the procedure is implemented, and the comments of its users are given in Section 5. Concluding comments and discussion are given in Section 6.

2. Multiattribute auctions

Single-attribute auctions rely on the fact that the bidders know what is better for them and for the bid-taker, and that their interests are strictly opposite. In the case of SARA this means that every bidder knows that any other bidder prefers a higher price and the buyer prefers a lower price and the buyer knows that every seller prefers a higher price.

2.1 Attribute aggregation

We consider the situation in which the buyer does not provide the bidders with information that would allow them to compare different alternatives and evaluate bids made by other bidders. Every bidder can compare bids using her own individual measure (e.g., utility, value, and revenue) but is not able to use the measure that the buyer and the other bidders use. This complicates the process because bidders do not know if a new bid is better for the buyer than an earlier bid.

Let’s consider a very simple case in which the revenues (or profits) are functions of two attributes: price \( p \) measured in millions of dollars and lead time \( l \) measured in weeks. Let’s assume that:

- Buyer’s \((B)\) profit depends on these two attributes and her revenue function is: \( b = 30 – p – 0.4l \).
- Seller’s 1 \((S_1)\) revenue function depends on these two attributes: \( s_1 = 1.2p + 4.2l – 4 \).
- Seller’s 2 \((S_2)\) revenue function is: \( s_2 = 2.3p + 2.3l – 5 \).

Figure 1 illustrates selected revenue functions of the buyer and of the two sellers in the bid space.

Every combination of price and lead time which corresponds to a point lying on the same revenue curve (line) yields the same revenue (e.g., points \( a \) and \( b \) yield the same profit of 20 for \( B \)). Alternatives yielding the same revenue for one participant (buyer and/or sel-
2.2 Bidders’ dilemma

The difficulties of making bids in multiattribute auctions are illustrated in Figure 2. Let’s assume that seller $S_1$ made bid $b_1 = (p=8; t=5)$ with revenue $s_1 = 26.6$. For the buyer $B$ this offer yields revenue $b_1 = 12$ and for $S_2$ the revenue is $s_2 = 24.9$.

Bid $b_1$ may be shown to seller $S_2$ but he may have difficulties in making a bid that is better for $B$ than $b_1$. For $S_2$ to be sure that his bid is better than the previous bid, he has to decrease the value of both attributes. (Note that this requires an assumption that the buyer’s preferences on the attributes are opposite, albeit not necessarily strictly opposite, to the seller’s preferences.)

Decreasing both attribute values may be a move that is certainly better for the buyer than $b_1$, but it may be a strategically ineffective one. This is because such moves do not allow for making trade-offs, hence they may result in a winning bid that is inefficient, i.e., there is a bidder who would make a bid that is better for the buyer but could not because the bid was not admissible.

After $S_1$ made bid $b_1 = (8; 5)$, $S_2$ may consider selecting from among the following three potential bids: $b_2 = (7; 4); b_3 = (6.5; 4.5)$ and $b_4 = (8; 4)$. The revenue of the buyer is greater for each one of these bids than the revenue that $b_1$ yields.

Seller $S_2$ is indifferent between $b_2, b_3$, and $b_4$ but the buyer and $S_1$ are not. If $S_1$ knew about the buyer’s revenue function, then he should bid $b_2$. This bid may allow $S_2$ to bid later with $b_3$ or $b_4$, depending on what $S_1$ bids.

The problem arises when the sellers do not know what the buyer’s revenue function is. Every seller has to rely solely on the knowledge of his own revenue function and the bids made by other sellers. In such a situation the bidders may not only be unable to optimize their strategies, but even make bids that are worse for the buyer than their earlier bids. Such bids are inadmissible and they would be rejected by the buyer; the problem is that the sellers have no ability to distinguish between admissible and inadmissible bids.

The proposed procedure addresses the admissibility dilemma through bid limit-sets introduced in Section 3. A separate but associated bidder dilemma pertains to bidding strategy.

Let’s again consider the three bids ($b_2, b_3$ and $b_4$) from the seller $S_2$ perspective. If $S_2$ knew or could approximate the revenue function of $S_1$ and the function was monotonic, then $S_2$ could “push” $S_1$ to either make large concessions or quit the auction. Bid $b_3$ is, from the perspective of $S_1$ very good because it leaves her with much larger interval for the reduction of revenue than bid $b_4$ ($22.7$ vs. $18.2$). Therefore, $S_2$ can make bid $b_4$ thus forcing $S_1$ to make subsequent bids yielding her revenue lower than $18.2$.

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1 This takes place when the bidder trades off value of one or more attributes with values of other attribute(s). It may also occur if the buyer has a satiation point beyond which her utility (revenue) decreases.
3. Bid limits

We describe the proposed MARA procedure using the example introduced above. The issue of inadmissible bids like bid \( b_5 \) is addressed by the introduction of limits. Limits are bounds set up for the attribute values and they help sellers to make only progressive bids, that is, bids which are better for the buyer. In this way we give the bidders information which makes bidding in multiattribute auction similar to bidding in the single-attribute auction.

At each point in time (or round) there may be one or more sets of limits. One set defines limits on every attribute. In Figure 3, three rounds are indicated. In Round 1 the best bid is \( b_1 \); in Round 2 it is \( b_2 \); and in Round 3 the best bid is \( b_3 \).

The limits for each round are determined based on the best bid in the previous round and additional parameters set up by the buyer (e.g., the number of limit sets calculated for each round). This means that there may be more than one set of limits in each round.

For Rounds 2 and 3, two sets per round are shown in Figure 3; they are indicated by rectangles bounded by arrows; every bid in the rectangle is admissible. Three limit sets are determined for bidding in Round 4.

Bids outside the limit-sets are inadmissible. Observe that the limits assure that, after \( S_2 \) made the winning bid \( b_3 \) in Round 3, \( S_1 \) cannot make \( b_6 \) because this bid is outside of the limits. Bid \( b_7 \), however, can be made.

The buyer’s revenue function is shown in Figure 3 with dotted lines to indicate that the bidders do not know it; for them it is sufficient to know the limits given in Table 2.

In each round, every bidder may choose the set of limits that best suits his interests. Every bidder, however, has to observe at least one set of limits. This means that at the beginning of Round 2, the sellers obtain two limit sets (see Table 2) which they have to follow. Their bids have to be such that: (1) either the price is not greater than 8 and the lead time not greater than 5; or (2) the price must be not greater than 10.3 and the lead time not greater than 3.8.

<table>
<thead>
<tr>
<th>Table 2. Limit-sets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Round no.</strong></td>
</tr>
<tr>
<td>Round 2</td>
</tr>
<tr>
<td>Set 2</td>
</tr>
<tr>
<td>Round 3</td>
</tr>
<tr>
<td>Set 2</td>
</tr>
<tr>
<td>Set 1</td>
</tr>
<tr>
<td>Round 4</td>
</tr>
<tr>
<td>Set 3</td>
</tr>
</tbody>
</table>

4. Procedure

The proposed MARA procedure builds on the one proposed by Bellosta et al. [19, 20], [21], and Teich et al. [22]. Bellosta, et al. (2008) and Brigui-Chtioui et al. (2010) auction design for multiattribute reverse auctions relies on the notion of reservation levels for which constructing the preference aggregation method is used.

In this paper, we also use the buyer’s reservation levels for auction design. The key difference is the space in which these levels are constructed. While in both procedures the levels originate in the utility space, we transform the reservation from the utility space to the space of alternatives. This has an important and desirable impact on the information feedback: similarly to Teich et al. [22], any information conveyed to the sellers refers to the space of alternatives.

4.1 Problem representation

There are \( l \) sellers \((S_l, l=1, ..., L)\) interested in selling an item \( x = [x_n, n=1, ..., N] \) characterized by \( N \) attributes which need to be determined in an auction.

We assume that the buyer is interested in all \( N \) attributes and that she has constructed a utility function \( u_B(x) \), (or any measure defined on the attributes and preferences). Without loss of generality, we assume that: (1) the buyer prefers smaller attribute values over greater ones (e.g., lower price and shorter lead time); and (2) the bidding space is represented by a closed set \( X \). This means that every attribute has its upper limit (e.g., market price) and lower limit (e.g., zero or some minimum possible value). The upper limits thus represent the maximum values \([x_n^u]\) acceptable for the buyer and they correspond to the minimum acceptable utility \( u_B(x^u) \).
In what follow we also assume that set $X$ is discrete, i.e., the number of feasible bids is finite. The procedure can be applied to continuous variables but its introduction is simpler for discrete ones which are typical for real-life situations.

In the example (Fig. 3), we constructed two sets for $R_2$ and $R_3$ and three sets for $R_4$. The number of sets that is constructed depends on three aspects:

1. The shape of the utility function (i.e., linear, convex, non-convex). In general, more complex functions suggest constructing more limit-sets;
2. The number of admissible alternative bids that are removed from the admissible bidding space. The fewer alternative bids that the buyer agrees to be removed, the more sets are needed; and
3. The acceptable degree of auction process difficulty; more limit-sets increase the difficulty.

The number of sets may be fixed for the auction or it can be controlled and depend on, e.g., time and distance from the best possible alternative. For simplicity, we assume here that the number ($K$) is fixed. Hence, in every round $t$ ($t = 1, \ldots, T$), $X_{ti}$ ($k = 1, \ldots K$) sets are constructed.

The auction begins with the bidders being given the highest reservation values of the attributes, i.e., the admissible bids are $x: x \in X$. After the initial bids are submitted, the subsequent activities are the same for every round.

### 4.2 Limit-set construction

Let $x_t^*$ be the bid which yields the highest value of the buyer’s utility, i.e., $u_t^* = u(x_t^*)$. Point $x_t^*$ is the first one to be used to determine the limit-set for the next round, i.e., $X_{t1} = \{x_{t+1,1} \geq x_t^*\}$. The remaining $k-1$ points are selected in the way which assures that the distribution of the points covers the widest possible range of the feasible alternatives in this round [23].

The limit-set construction process for $K = 2$ is illustrated in Figure 4. Three bids were made at round $t$ (shown as stars). The best bid $x_t^*$ yields utility $u_t^*$. The search for a distinct alternative which yields the same utility results in $x_t$.

The two alternatives $x_t^*$ and $x_t$ can be used to generate limit-sets. The effect of selecting alternatives yielding the same utility may allow the bidders’ to approximate the bid-taker’s utility.

It is also possible that the number of such alternatives is smaller than the number of limit-set required for the particular auction. Therefore, the procedure searches for alternatives that are within a certain distance from the alternatives yielding $u_t^*$. In Figure 4 this search results in the selection of $x_t$. Alternatives $x_t^*$ and $x_t$ are used to construct $X_{t1,1} = \{x_1 \geq x_t^*, x_2 \geq x_t^*\}$ and $X_{t1,2} = \{x_1 \geq x_t, x_2 \geq x_t\}$, respectively.

Sets $X_{t1,1}$ and $X_{t1,2}$ are presented to the bidders who are asked to make admissible bids. If bids are submitted, then the best bid is selected, its utility calculated and the process continues as shown in Figure 4.

The distance ($d$) used for the modification of the alternatives used to construct the limit-sets is one of the auction design parameters. The greater the distance, the fewer rounds are required but the greater the possibility that the winning bid being inefficient. The use of $k$ limit-sets typically will result in some alternatives being inadmissible, despite the fact that they yield utility greater than $u_t^*$. Among these alternatives (shown in yellow in Fig. 4) there is (diamond). If in round $t+1$ no bids are made, then $x_t^*$ becomes the winning bid. It is possible, however, that a bidder would offer, if was admissible. If that were the case, then the procedure causes the auction to end with an inefficient alternative.

### 4.3 Bidder differentiations

We have mentioned that one reason for using multiattribute auctions is the differences among the bidders which are important for the bid-taker. This means that bidders have different characteristics and some of them are preferred over the others.

The proposed procedure allows for the distinction among bidders when the following two conditions are met:

1. The bid-taker can partition all suppliers into exclusive groups comprising suppliers with the same or very similar characteristics so there are no differences among suppliers from the same group; and
2. The bid-taker can measure the differences between each supplier group in terms of the utility; the bid-taker is indifferent between members coming from different groups if the bid utility from a less desirable member is greater than the bid from a more
Let \( H \) denote the number of groups; \( h = 1, \ldots, H \) and let’s assume that the lower the group index the lower the utility assigned to this group. That is, the members from group \( h \) are less desirable than the members from group \( h+1 \).

Let \( w_h, \ldots, w_H \) \((w_h > w_{h+1})\) be the utility values required for making tradeoffs between bidders. Condition (2) states that the desirability can be measured with utility, so that bidders \( S_h \) (from group \( h \)) and \( S_{h+1} \) (from group \( h+1 \)) are equally desirable if the utility of the bid made by \( B_h \) is equal to the utility of \( S_{h+1} \) bid adjusted by \( w_h \).

In the procedure with \( H \) different types of bidders, the process of the limit-set construction is divided into \( H \) sub-processes. In each sub-process, the steps are essentially the same; the only difference is in the computation of the utility value of the best bid in round \( t \) \((t = 2, \ldots, T)\). For a uniform group of bidders (discussed in Section 3.2) the utility value that is used as the basis for the limit-set construction is the actual bid utility, i.e.,

\[
u^*_t = u(x^*_t);
\]

If there are \( H \) types of bidders, we need to construct \( H \times K \) of limit-sets. Instead of the above formula, we use the following formula:

\[
u^*_{h,k} = u(x^*_{h,k}) = \max_{b=1,\ldots,H} \{ u(x_{b,k}) / w_b \},
\]

where \( x^*_{h,k} \) is the bid yielding the highest utility value after the adjustment made that account for the group differences.

If the coefficients \( w_h \) \((h=1, \ldots, H)\) are normalized so that \( \sum w_h = 1 \), then the less desirable sellers have to make better bids in order to be considered as good as the bids made by the more desirable sellers (i.e., \( u_h < 1 \), \( h < H \)).

An example for two types of bidders \((H=2)\) is shown in Figure 5.

A seller of the best type \((h=2)\) made a bid \( x^*_1 \) which utility is \( u^*_{1,2} = u(x^*_1,2) \). The best bid by a seller from group 1 is \( x^*_1 \). The utility of this bid \( u(x^*_1,1) \) is greater than \( u(x^*_1,2) \), but it is lower than \( u(x^*_1,2) / w_1 \). Therefore, \( x^*_1 = x^*_1,2 \) and \( u^*_{1,2} \) is used as the basis for the construction of the limit sets for the next round.

The limit-set for members of group 2 are the same as in the example shown in Figure 4. For group 1 the required value of utility is calculated so that it is equivalent to utility of group 1, i.e., \( u^*_1 = u^*_2 / w_1 \). Selecting two points yielding this utility value and distorting one of them allows for the construction of limit-sets containing admissible bids for members of group 1. The admissible area is shown in Figure 5.

The shaded area contains the bids which are admissible to group 2 members but inadmissible to group 1 members. The latter need to make bids which yield higher utility.

5. Implementation

The proposed procedure has been implemented on the Invite platform, which is a software platform for the development of multiattribute negotiation and auction systems. In this section the IMARAS system and the preliminary results from its use are discussed.

5.1 System features

IMARAS adopts the model-view-controller design pattern, which allows separating the different auction procedures and the user interface. It supports several types of auction settings, including:

- Disclosure of bids to bidders: only the bidder’s own bid is displayed, both own and winning bids are displayed, or all bids are displayed;
- Bidding process: continuous (asynchronous bidding) or round-based (synchronous bidding); with rounds being defined by time (e.g., number of minutes or hours) or defined by a rule (e.g., number of submitted bids).

The design pattern used in IMARAS allows for decoupling of the interface from the engine. This helps in conducting experiments with different mechanisms that have very similar user interface.
IMARAS main screen is shown in Figure 6; it is the bidding screen of a round-based auction in which the bidder can see her own bids and the winning bids.

The interface has four main components. The auction clock (A) shows time from the beginning of the auction and the time left to the deadline.

The system navigation is located on the right-hand side (B) where links to active pages are listed. In this bar the round number and clock are also given. The clock is reset at the beginning of every round.

Section C of the bidding screen contains the most recent bids shown in both tabular and graphical forms. The complete list of bids is shown on the Auction history page (see Section B).

Bids are generated and submitted in Section D. This contains information about the limit sets: shown in the table on the left-hand side. In our example three limit sets are shown. In order to construct a bid, the bidder may choose any one of the three limit sets. Once the limit set is selected (using the radio button on the left-hand side), the user chooses values for every one of the three attributes; the available values meet the constraints of the limit set. The rating is automatically calculated and the bid appears in the table located at the bottom of the screen.

The users have an alternative method of constructing bids. Rather than selecting bids as mentioned above, they can generate a list of bids with ratings equal to or close to the rating they wish to have. They enter the preferred rating in the small box on the right-hand side and press the button “Generate bids”. A list of possible bids then appears in the table from which one bid may be selected and submitted. Note that in our example, the user has already submitted one bid in this round and is not allowed to submit more bids. This is one of the types of protocols implemented in IMARAS.

5.2 Procedure illustration

The key elements of the procedure are illustrated with a transportation service procurement scenario.

A milk producer (the buyer) sets up an auction to outsource the transportation service described by three attributes: (1) standard rate (SR), (2) rush rate (RR) for rush orders; and (3) penalty for delay (PD) for late deliveries. The importance (rating) of each attribute and its value are private. The attribute value range and the buyers’ reservation levels are public to all bidders (see Table 3). The reservation levels are used to determine the initial limit-set (see Fig. 3).
Table 3. Attributes, weights and reservation levels

<table>
<thead>
<tr>
<th>Attribute</th>
<th>SR</th>
<th>RR</th>
<th>PD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating (weight)</td>
<td>0.45</td>
<td>0.15</td>
<td>0.40</td>
</tr>
<tr>
<td>Value range</td>
<td>$20 ~ 40/kl</td>
<td>$50 ~ 70/kl</td>
<td>30 ~ 50%</td>
</tr>
<tr>
<td>Reservation levels</td>
<td>$40/kl</td>
<td>$70/kl</td>
<td>30%</td>
</tr>
</tbody>
</table>

The auction is round-based with the disclosure of bidder’s own bids and the winning bids in previous rounds. The system calculates limit-sets at the beginning of each round based on the winning bid made in the previous round and the parameters set up by the buyer. In two experiments, discussed in Section 5.3, we use the following parameters:

- Reservation levels on each attribute (see Table 3);
- Increment: $4/kl for SR and RR, 4% for PD;
- Maximum number of limit-sets provided to the bidders: 3 (if they all yield the same utility for the buyer, one of them will be modified); and
- Round duration and auction length: 5 minutes per round and 50 minutes per auction.

Knowledge of the current limit-sets is sufficient to make bids. An allowable bid is one that conforms to at least one of the limit-sets. The auction will close if one of the following conditions is met:

- No more than one bidder's bid in a round; or
- The closing time is reached.

Table 4 shows four rounds of the auction from one bidder’s viewpoint (the best bid in a round is italicized).

Table 4. Auction process from one bidder’s viewpoint

<table>
<thead>
<tr>
<th>Round</th>
<th>SR</th>
<th>RR</th>
<th>PD</th>
<th>Revenue</th>
<th>Bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>36</td>
<td>66</td>
<td>38%</td>
<td>78</td>
<td>Own</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>66</td>
<td>38%</td>
<td>68</td>
<td>Other</td>
</tr>
<tr>
<td>R2</td>
<td>32</td>
<td>62</td>
<td>46%</td>
<td>57</td>
<td>Own</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>54</td>
<td>34%</td>
<td>44</td>
<td>Other</td>
</tr>
<tr>
<td>R3</td>
<td>32</td>
<td>58</td>
<td>50%</td>
<td>45</td>
<td>Own</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>54</td>
<td>38%</td>
<td>38</td>
<td>Own</td>
</tr>
<tr>
<td>R4</td>
<td>20</td>
<td>62</td>
<td>42%</td>
<td>24</td>
<td>Other</td>
</tr>
</tbody>
</table>

The process demonstrates how the bidder was making trade-offers among the three attributes. For example, in R3 she bid with a lower RR than her own bid but higher than the winning bid in R2, raised PD and maintained SR (higher than winning bid). As the buyer weighted SR and PD much higher than RR, the bidder won in R3.

An example of the auction process with four bidders and eight rounds is shown in Figure 7. This type of chart can be shown to buyers. The sellers’ view may be different; this depends on the design parameters. The possibilities include the representation of only own bids, own and winning bids, and all bids.

The bids are depicted on the chart in which one dimension describes the buyer’s revenue (from 0 to 100) and the second dimension shows the round number. The step line indicates the utility of lower-bound limits in each round, and thus the bids should not be lower than it. The highest value represents the winning bid in the round.

5.3 Two experiments

The IMARAS system is being used to test the users’ behavior under different conditions controlled by the above mentioned design parameters. We have conducted auctions with 2, 3 and 5 attributes and between 3 and 5 bidders. The reason for a relatively small number of bidders is that we are also interested in comparison of multilateral negotiations and auctions.

To date, we have conducted experiments involving undergraduate students from Canada, undergraduate students from Italy and groups of undergraduate and graduate students from Poland and Taiwan. In all experiments we used the same case briefly discussed above.

The first experiment involved Canadian students. We organized 21 auctions in a lab which lasted 1.5 hrs. and 15 online auctions which lasted one week. Some information about the results is given in Table 5. The average number of bids is significantly higher in the lab than online.

Bidders obtained information about the breakeven value and were told that they should not bid below this value because it would result in losses for their company. This was stated both in the case and again in the quiz administered to the participants. Nonetheless many winners bid below their break even values, on average.

To provide a comparable values for the winning bids we calculated profit (profit = revenue – break-
even). In the lab condition, the winning bids were significantly below the breakeven values which were between 16 and 25 (on the scale 0-100). In contrast, the online winning bids were profitable—16.3 on average. The effect was that buyers’ profit dropped from 96.5 in lab experiments to 69.3 in online experiments. A possible explanation of this difference is the time pressure in the lab condition.

Table 5. Results of experiment 1

<table>
<thead>
<tr>
<th></th>
<th>Lab</th>
<th>Online</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of auctions</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>Avg. no. of bids</td>
<td>5.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Profit (buyer)</td>
<td>96.5</td>
<td>69.3</td>
</tr>
<tr>
<td>Profit (winning bidder)</td>
<td>-9.5</td>
<td>16.3</td>
</tr>
<tr>
<td>No. of dominating alternatives</td>
<td>0.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Overall satisfaction (1-7)</td>
<td>4.7</td>
<td>4.8</td>
</tr>
</tbody>
</table>

We calculated the number of alternatives which dominated the winning bid, that is, these alternatives yield a higher profit for the winning bidder, the buyer or both, and for none of them the profit is lower. The winning bids made in the lab were, on average, Pareto optimal (the average no. of dominating alternatives is 0.1). The winning bids made online were not Pareto optimal, because there were 2.9 dominating bids, on average.

There was little difference between lab and online experiments in terms of user satisfaction.

The second experiment was organized in Italy and was conducted in a lab. There were two treatments, differing in the number of attributes. The results of this experiment are shown in Table 6.

Table 6. Results of experiment 2

<table>
<thead>
<tr>
<th>No. of attributes</th>
<th>Two</th>
<th>Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of auctions</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Avg. no. of bids</td>
<td>2.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Profit (buyer)</td>
<td>92.7</td>
<td>93.3</td>
</tr>
<tr>
<td>Profit (winning bidder)</td>
<td>-4.9</td>
<td>-9.2</td>
</tr>
<tr>
<td>No. of dominating alternatives</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Overall satisfaction (1-7)</td>
<td>5.4</td>
<td>5.3</td>
</tr>
</tbody>
</table>

The differences between the two treatments do not appear significant. The exception is the average no. of bids. Perhaps not surprisingly in the simple 2-attribute case only 2.9 bids were made on average as compared to 4.9 bids in the 3-attribute case.

Overall, the winning bids were not better than those achieved in the first experiment for the 3-attribute case. Similarly, there is little difference in both experiments in terms of the number of dominating alternatives for the lab condition.

Italian students reported somewhat higher satisfaction than the Canadian students. This difference may due to the streamlining of the process and improvements in the system interface which we made after the first experiment.

6. Discussion

We designed a multi-attribute auction procedure and implemented it in an online auction system. The key question that now needs to be addressed is the procedure and system’s usefulness for real-life e-procurement auctions. Prior to addressing this question we conducted experiments with business and engineering students. Their purpose included validation of the procedure and system tools, assessment of the system’s ease of use, construction of behavioral model of the bidding process, and observation of bidding strategies. A field study would then follow the experiments.

Observation of the bidding process and comments from the experiment participants led us to treat the experiments as extensive testing rather than a research experiments.

We received both positive comments (“positive overall experience”, “fun to use”, “enjoy the challenge”, and “good learning experience”) and negative ones (“not clear process”, “difficult construction of bids”, “no guidance”). The latter comments and the results of the experiments, in particular the losses that the winners “brought in” to the firms they represented, led us to realize that multi-attribute auctions are difficult and that we need to provide more and better tools for learning about the system, its use and the specifics of the bidding process. To this end, we have prepared several training materials.

Participants in our experiments are students who differ in their motivation and interest to learn the system and the case. In order to provide a more even field so that every participant knows the basics of the system and the bidding process, we are developing a demo followed by a short quiz which will test students’ understanding of the system and its use. Students will watch the demo and pass the quiz about one week before the experiments.

The next step aiming at increasing students’ understanding of the process is breaking up the process into two separate phases. One phase will be preparation which will take between three days during which students will log in to the system and learn about the case. Before moving to the next phase, which involves bidding, students will need to pass a test.
Experiments with these changes will be administered in November 2011. We expect about 300 students to participate in IMARAS auctions. We expect that there will be no technical problems and that the participants’ preparation would allow them to focus on the bidding strategy having sufficient knowledge of the system and the case. The results of these experiments will be compared with the results of multi-bilateral negotiation experiments with the same case and will be conducted in parallel. If the results are encouraging, then we will set experiments for procurement and sales managers.

7. Acknowledgements

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8. References