EMERGING MULTIPLE ISSUE e-AUCTIONS

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Abstract

We review the emerging field of multiple issue e-auctions and discuss their design features and performance criteria. We primarily consider B2B transactions in a reverse auction, that is, a procurement setting. In traditional auctions, the matching of buyers and sellers is typically based just on price. However, when there are quality and other differences in the merchandize and differences in the terms of the transaction, which are common in Request for Quotes (RFQs), additional issues besides price should be considered. Such multiple issue, multiple unit e-auctions/ negotiations, and their characteristics are the focus of our paper. We also discuss the role that OR has played and undoubtedly will play in the design and implementation of such e-auctions.

1 Introduction

As pointed out by Geoffrion and Krishnan (2001), the Internet-driven networked economy is creating ample opportunities for operations research (OR) practitioners and theoreticians to work together with information systems and computer science specialists on WWW-based applications in many areas of business. Notable advances have already been made in financial services, electronic markets, supply-chain management, and travel-related services, among others.

The following quote from Bapna, Goes and Gupta's article (2001) provides the basis for our paper:

> *"The Internet-driven networked economy is evolving to the point where firms are beginning to realize the enormous business value possible from a richly connected, global network of consumers and producers. However, full exploitation of these seemingly limitless opportunities will depend largely on the design of efficient mercantile processes that facilitate a wide variety of mechanisms for the exchange of assets, goods, and services. … Online auctions, brought about by the synergetic combination of Internet technology and traditional auction mechanisms, present a significant new dimension for mercantile processes, many of which are not yet fully understood." (Bapna, Goes, and Gupta, Communications of the ACM 44, 11, 2001)*

One such synergetic combination is the implementation of various auction types for procurement purposes in the supply chain. The procurement function is of great significance for many industrial corporations and public sector organizations, not to mention retail and wholesale businesses. Corporations and public sector organizations routinely arrange **RFQ**s[1]. In an RFQ the buyer normally specifies the merchandize, including desired quality, the quantity demanded, terms and time of delivery, terms of payment, and so forth, and requests the bidders to specify the price and quantity supplied if less than quantity demanded. If the buyer is willing to consider different

[1] Definitions for bolded terms have been provided in a glossary at the end of our paper.

quality levels and standards, and different terms of delivery and payment, she can indicate that in the RFQ. Once bids have been delivered, the buyer must make an intelligent decision about whom to award the contract. If the buyer knows precisely what she wants, including all terms of delivery and payment, and fully trusts the suppliers, the comparison boils down to comparing costs and choosing the supplier(s) offering best prices. Such an ideal situation rarely exists in the real world and the buyer has to make complex tradeoffs between price, different quality levels, and different terms of delivery and payment. Obviously, arranging RFQs is costly and time-consuming. Furthermore, the buyer may not be aware of all potential suppliers. In short, there are a number of potential complications and inefficiencies in the procurement process, some of which may be alleviated by the use of web-based electronic markets. In particular, electronic markets are expected to reach more qualified bidders, generate cost savings for buyers, create new means to increase sales for suppliers, and lower transaction costs for both, to name a few (Kambil and van Heck, 2002).

The earliest WWW-based trading sites date back to 1995, although the history of electronic markets/auctions is older. Lucking-Reiley (1999) provides an interesting discussion of the earliest WWW-based trading sites. Kambil and van Heck (2002) go further back in time and provide an insightful discussion of the history of electronic markets and the role that information and communication technologies have played in this process. They also describe how firms can design and profit from online auctions, particularly by placing auctions properly in their broader context of exchange processes and taking all stakeholders in a market into account. Today, WWW-based trading sites are plentiful. The largest B2C sites list hundreds of thousands of goods/services for sale. As pointed out by Bapna, Goes and Gupta (2001) and Gupta and Bapna (2001), until recently the electronic trading sites have been simple, concentrating on the price of the merchandize. The Internet, however, has allowed the inclusion of many novel and useful features into trading sites. We will discuss several such features below.

The roots of electronic auction and negotiation mechanisms are in the auction and negotiation theory. See, for instance, Raiffa (1982), Teich, Wallenius, Wallenius (1994) (negotiations); or Kagel and Roth (1995), Milgrom (1989), and Rothkopf and Harstad (1994a) (auctions). Economists have in-depth investigated, isolated, single good auctions. The ascending price **English auction**, the descending price **Dutch auction**, and the **Vickrey second-price sealed bid auction** have been the most commonly studied auction mechanisms. The theoretical properties, particularly their revenue-generating properties, of the various auction mechanisms have been the subject of intense research,. However, as pointed out by Rothkopf and Harstad (1994a) in their critical essay, it would be useful to expand the focus, because isolated, single-good auctions are not the most common and interesting ones from the practical perspective. Hence, there have been several extensions to the traditional auction paradigm in recent years. One active field of research has been **multiple unit auctions**. In the simplest case, the bidders are allowed to buy only one unit of the merchandise. In the more realistic case, such restrictions are not imposed. As Bapna et al. (2001), Rothkopf and Harstad (1994a), and Tenorio (1999), among others, have pointed out, the strong theoretical results obtained for isolated single good auctions, are not necessarily transferable to the more complicated multiple unit situation. Another extension is the development of **combinatorial auctions**, in which bidders desire to buy or sell bundles of goods rather than one single good (Rothkopf et al., 1998). Such combinatorial auctions have been of considerable interest to operations researchers and computer scientists, especially the computational issues associated with determining the winner and the final allocation (Kelly and Steinberg, 2000; Sandholm, 2002; Jones and Koehler, 2002).

In this paper, we focus on another extension to the traditional auction paradigm, one that is particularly relevant for the RFQ-setting, namely the **multidimensional auction**[2] (Che, 1993; Branco, 1997; Koppius and van Heck, 2003; DeSmet, 2003; note that some authors refer to this auction as a **multi-attribute auction**, e.g. Bichler, 2000; Beil and Wein, 2001). In such a setting, there are multiple dimensions to a transaction, such as quality, delivery time and warranty terms that all need to be incorporated through the auction mechanism. If we have a multidimensional auction where quantity is also a relevant variable, we refer to it as a **multiple issue auction**. Perhaps since multidimensional/ multiple issue auctions hold great promise for the improvement of B2B transactions, their development has largely been practice driven.

We review the state-of-the-art of multiple issue auctions, designed primarily for B2B procurement situations. We provide a classification of auctions based on their characteristics, and present a generic description of multiple issue e-auction mechanisms. We also discuss the role that OR has played in their design and implementation. The emphasis is on academic research, although we devote one section to overviewing relevant commercial auction sites. We also discuss what criteria one should use in judging the performance of auctions in the WWW environment.[3] In an appendix we provide a glossary of terms and definitions for readers not intimately familiar with auction research.

2 A Classification of Auction Situations Based on Their Characteristics

At the DEXA Conference in London, September 2000, the participants drafted a classification of negotiation protocols[4]. Many of the elements in our classification can be found in this 'London Classification' as well. However, in the 'London Classification' negotiations and auctions were both included and treated alike. We find this confusing. Historically both fields have developed separately and have their own identity. Many computer science researchers refer to 'negotiations' when we think they actually mean auctions (see, for example, Beam and Segev, 1997). If an auction mechanism is used in a one-to-many situation (with bidding), we prefer to use the term 'auction'. We use the term 'negotiation', when there are only two parties involved. If an auction mechanism is used in a multi-party group decision situation to resolve a conflict (as Raiffa, 1982 suggests), then the situation may be regarded as a negotiation as well. A 'Montreal Classification' seeks to clarify the terminology (Stroebel and Weinhardt, 2003; Neumann and Weinhardt, 2001; see also Bichler et al. (2003).

In Table 1 we have listed 18 important characteristics of practical auction situations. Certainly one could extend the list with additional characteristics. We, however, feel

[2] Thiel (1988) appears to have been the first to discuss multidimensional auctions.
[3] We do not discuss bidder behavior, or bidding strategies available to them.
[4] One of the authors of this paper participated in the London DEXA conference, but did not take part in the compilation of the 'London classification'.

that our list is comprehensive enough to demonstrate the richness of auction situations in practice (for an alternative classification from a game-theoretic perspective, see Wurman et al., 2001).

In Table 1, the first four characteristics concern the number and nature of the good(s) to be auctioned. Characteristics 5-14 concern the auction rules and format. Characteristics 15-18 concern the nature and composition of bids. As stated, in this paper our focus is on multiple unit, multiple attribute auctions, the combination of which we define as 'multiple issue' auctions. The presented systems can deal with many of the auction situations listed.

Characteristics 5 and 7 seem to conflict. However, when combined, they result in four cells: 1) Forward Dutch (or just Dutch), 2) **Forward English** (just English), 3) Reverse Dutch (prices rise until the first suppliers offer to supply at that price), and 4) Reverse English (or just Reverse). The Reverse Dutch is apparently the least common of the four.

In case of a progressive multi-stage auction event, the different stages could consist of the same auction type, or a different auction type, or perhaps conclude in two-party negotiations (characteristics 6 & 13). If negotiations follow an auction event, the negotiation could be only with the winner(s) of the auction event(s), or, it could be with the winners and near winner(s). These two-party negotiations may run sequentially or concurrently. If run concurrently, they are sometimes known as 'combined negotiations' (Benyoucef et al., 2001).

The use of a primitive type of agent (characteristic 9) in commercial sites is quite common. These consist of auto bidding procedures, which act on behalf of the bidders. More advanced intelligent agents are in development.

Because second price auctions (characteristic 10) are rare, first price auctions are predominant in e-auctions.[5] Neutrality of and trust in a system is obviously important with both first and second price auctions[6]**. Price discrimination** refers to the phenomenon that the buyer pays different prices for different suppliers for the same good/service (characteristic 11). Price discrimination increases the monopoly power (in our case, monopsony power), leading to potentially higher profits than uniform pricing.

Referring to characteristic 15, the bid becomes 'semi-sealed' if, for instance, only the rank of the bid (in the bid-stream) is reported to the bidder, but not to rivals. In other words, each bidder knows the current rank of their own bid in the bid-stream, but not the contents of rival bids. Another example is the case where the bidder is supplied with price information that will make her bid active in the event, but no listing of the bids themselves is provided. See Koppius (2002a & b) for more on issues related to the **information architecture** of the auction.

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[5] Interestingly, Lucking-Reiley (2000) claims that the use of a proxy (auto) bidding system in e-auctions is equivalent to a second price auction.

[6] Internet fraud is more of a problem in C2C rather than B2B (or B2C) auctions. We assume that most B2B sites are neutral and can be trusted. However if proxy bidding were used, we would caution the bidders to be aware of the ownership of the software and location of the servers, especially in a private marketplace.

The bid vector may be a scalar (price only), 2-dimensional (price & quantity), or of higher dimension, incorporating quality aspects, terms of delivery, payment, warranty, etc. (characteristic16). Interestingly, Jones and Koehler (2002) define bids implicitly using a set of rules/constraints that they must fulfill. Particularly in multiple unit auctions, a relevant consideration is whether bids are allowed to be **divisible** or not. For example, assume there is a bid for 1000 units of a certain commodity. If bids are allowed to be divisible, the solution of the '**Winner Determination Problem'** may be that this bidder is only allocated half of the desired units.

In a multi-item auction, different products/services are auctioned simultaneously. In such a case, complementarities may exist between different goods either from the buyer's or supplier's perspective. Examples are FCC spectrum licenses, airport time slots, and delivery routes (deVries and Vohra, 2003). In such combinatorial auctions, bids for bundles of goods are allowed (characteristic 18). Combinatorial auctions have attracted considerable attention in the auction literature (Rothkopf, Pekec and Harstad, 1998; deVries and Vohra, 2003). Of particular focus have been their computational aspects. See, for example, Rothkopf et al. (1998), who discuss the computational complexity of solving different types of combinatorial auctions. In fact, much of the combinatorial auction literature, with ties to the set packing/knapsack problem in operations research (see, for example, Vemuganti, 1998), has dealt with computational aspects and heuristics for solving what is known as the 'Winner Determination Problem' of an auction (Gonen and Lehmann, 2000; Sandholm, 2000; 2002). The computational problems may be avoided by using Linear Programming for solving the 'Winner Determination Problem' and assuming goods to be divisible (Gonen and Lehmann, 2001). This appears to be a good strategy particularly when large numbers of the same good(s) are auctioned. Another alternative is to use rule-based bids (Jones and Koehler, 2002).

Characteristic:	Range:
1. Number of Items of a Certain Good	One to Many
2. Number of Goods Auctioned	One to Many
3. Nature of Goods	Homogeneous to Heterogeneous
4. Attributes	One to Many
5. Type of Auction	Reverse Vs. Forward
6. Nature of Auction	One-Round Vs. Progressive
7. English Vs. Dutch Auction	Ascending, Descending Price
8. Participation	By Invitation Vs. Open
9. Use of Agents	Agent Mediated Vs. Manual Mode
10. Price Paid by Winner	First Price vs. Second Price vs. n-th Price
11. Price Discrimination	Yes, No
12. Constraints Exist	Implicitly, Explicitly
13. Follow-up Negotiation	Yes, No
14. Value Function Elicitation	Yes, No
15. Nature of Bids	Open-Cry Vs. Semi-Sealed Vs. Sealed
16. Bid Vector	1, 2, or n-dimensional
17. Bids divisible	Yes, No
18. Bundle Bids Allowed	Yes, No

Table 1**:** Classification of Auction Situations Based on Their Characteristics

3 A Generic Description of Multiple Issue e-Auction Mechanisms

For simplicity, we consider auctions of one commodity (good/service) and assume that the buyer demands *k* units (positive real number) of it. With *n* attributes besides price and quantity, the bids become (*n+2*)-dimensional vectors, where the *n* dimensions represent quality, terms of warranty, delivery, payment, etc. If all issues and attributes, besides price and quantity, have been 'priced out' prior to actual bidding, each bid is simply a two-dimensional vector: (q, p), where $q = k$ is a real positive number (quantity) and *p* (price) is also a real positive number. In other words, a bid is an offer to deliver *q* units of the good/service for a price of *p*.

Multiple issue e-auction mechanisms have been investigated by Bichler (2000), Bichler, Lee, Lee, and Chung (2001), Koppius, Kumar and van Heck (2000), Beil and Wein (2001), Teich, Wallenius, Wallenius (1999) and Teich, Wallenius, Wallenius, and Zaitsev (2001, 2002), among others. Rather than describing the existing mechanisms separately, we seek to provide a generic description of such mechanisms.

(1) Auction Rules

The **auction owner** sets the auction rules and communicates them to the bidders. In addition, the auction owner must make public the starting and closing dates & times of the auction. Potential bidders should be informed, whether the auction is by invitation only, whether anyone can participate, or whether there are special bidder qualification criteria that they must meet. Furthermore, the auction must be defined either as a one-round or progressive auction, where bids can be improved (the usual case in the Internet), as an English or a Dutch auction (descending or ascending price). The most common format in procurement situations is an English, descending price auction. The bidders should also be informed, whether the auction is discriminatory or not. In other words, do 'winners' pay their own bid price or does a uniform price apply to all winning bids. Multiple unit, multiple issue auctions are normally discriminatory, i.e. each bidder pays their own bid price. Furthermore, the bid withdrawal policy must be defined, in other words, under which circumstances, if any, can bids be withdrawn.

(2) Product and Issue/Attribute Description, Specification of Quantity Demanded, Reservation Price(s), and Bid Decrement

The auction owner provides the product description and usually specifies the desired quantity demanded.[7] To protect herself, the buyer usually specifies a **reservation price**, above which she is not willing to pay. In multiple unit auctions, she has the option of specifying one reservation price for all quantities or different reservation prices for different quantities, and perhaps, a quantity discount once reservation price levels have been met. Next, the auction owner must specify the relevant issues/attributes of the auction. Researchers do not always make a distinction between issues and attributes and, e.g., Bichler et al. (2001) refer to them as attributes. Teich et al. (2001, 2002) make a distinction between Negotiable Bid Issues (NBI) and Bidder Attributes (BA). NBIs are characteristics of the merchandize or the supply

[7] One can, however, argue whether it is optimal for the buyer to fully reveal her actual demand, particularly if demand is large relative to supply.

chain, such as the quality rating of the good, terms of delivery, warranty, etc. BAs are characteristics pertaining to the bidders, such as the buyer's historical business relationship with the bidders, subjective bidder ratings, whether they are ISO certified or not, etc. Furthermore, the auction owner has the option to specify constraints limiting the quantities accepted from certain bidders or groups of bidders, etc.

The auction owner must also specify the size of the **bid decrement** (increment in a forward auction). She should also decide whether one bid decrement is used throughout the auction or whether its size is decreased as a function of the progression of the auction (such as a percentage of the price level). The bid decrement may be specified in terms of average unit price or total cost. Only a few researchers have explicitly discussed the role of the bid increment/decrement, but those who have, found it to be of significant influence on the auction outcome (Rothkopf and Harstad, 1994b; Avery, 1998; Bapna, Goes and Gupta, 2000).

(3) Representing Buyer's Preferences over Multiple Issues/Attributes

In a multiple issue auction, a central task is to represent the buyer's preferences over the multiple issues/attributes deemed relevant. The following four approaches are currently available for this task:

(1) Explicitly eliciting the buyer's **value function** over multiple attributes (Bichler, 2001)
(2) '**Pricing out**' all attributes besides price and quantity (Teich et al., 2001, 2002)
(3) Using a progressive, interactive scheme, to learn of the buyer's and sellers' preference functions to solve the problem (Beil and Wein, 2001)
(4) Using an auction owner specified bid path (Teich, Wallenius, and Wallenius, 1999)

Since preference modeling in the context of auctions is a very relevant and complex problem, we devote Section 4 to further investigating this problem. We feel that the OR/MCDM community can make significant contributions to solving it.

(4) Winner Determination

The 'Winner Determination Problem' is to find the winning set of bids from the existing bids. Several authors, e.g. Che (1993), Branco (1997), Bichler (2000) and Koppius and van Heck (2003), suggest formulating this problem as maximizing the buyer's **utility function**, or rather the value function $V(\boldsymbol{x}_i) = \sum_{j=1}^{n} v_j(x_i^j)$, where v_j are single dimensional value functions defined over the set of bidder attributes $\boldsymbol{x}_i$. The value function may be kept private or made public. Once assessed, it is optimized subject to constraints. In practice, the elicitation of the buyer's value function may be difficult. Simplifying assumptions are normally made. As a proxy to maximizing the buyer's multi-attribute value function, Teich et al. (2001, 2002) 'price out' Negotiable Bid Issues/Bidder Attributes and use Linear Programming or Integer Programming to minimize the cost to the buyer subject to the quantity (demand) constraint and other constraints. Teich et al. (2001, 2002) provide an empirical validation of their scheme.

Beil and Wein (2001) propose a scheme that bears resemblance to early work in interactive multi-criterion optimization. They seek to identify an optimal supplier by maximizing the difference between the buyer's value function and an estimate of the supplier's cost function defined over the attributes. They assume that the value and cost functions are additive separable. The buyer is assumed to know the parametric form of the bidders' cost functions, but is assumed to possess no knowledge of the precise values of its parameters. The buyer uses the bids to learn the suppliers' cost functions progressively. The scheme is theoretically appealing, but the authors do not provide empirical support to validate it in practice.

In the "auction owner specified path" approach (Teich, Wallenius and Wallenius, 1999), the 'Winner Determination Problem' is fairly straightforward. However, there are a variety of ways it could be implemented, depending on whether the auction owner desires price discrimination or not. Graphically, the winning bidders are those who lie in the northeast direction in Figure 1 and fulfill the total quantity demanded. The scheme has not yet been tested in practice.

(5) Information Architecture

Auction mechanisms differ regarding what feedback information is provided to bidders during and after the auction, i.e. the information architecture of the auction (Koppius, 2002a). In the past, the choice has essentially been between progressive, open-cry and one-round, sealed-bid auctions. In the latter case no feedback information is provided to bidders during the auction. In a progressive, open-cry auction, there are several options. The bid-taker's preferences may be made known via the value function. In an extreme case, the value function is made public and all bidders are informed of the contents of each new bid and its relative standing with respect to rival bids. There are many intermediate situations though. For instance, only parts of the buyer's value function may be made known to bidders. It is also an option that no information about the value function is revealed to bidders. Instead the bidders have to rely on information contained in the highest bid(s) or the bid scores, but not the bids themselves. Alternatively, they may be informed of the ranking of the bids, but not the exact scores. It has been shown that such seemingly small changes to the information architecture of the auction can have a significant impact on the auction outcome and performance (Koppius, 2002a, 2002b; Koppius and van Heck, 2003).

In Teich et al. (2001, 2002), the buyer has access to complete bid stream information (order book), but bidders know only whether their bid is '**active**', '**semi-active**', or '**inactive**'. They do not know, how many bidders are out there, nor how many bids are 'active'. But bidders have the option of requesting a 'Suggested Price', which would make their (full-lot) bid 'active'. Naturally, the bidders need not accept the 'Suggested Price'. If partial lots are acceptable to bidders, the authors suggest using LP; if not, Integer Programming should be used to find the optimal solution to the winning bid problem. See also Teich, Wallenius, Wallenius, and Zaitsev (1999).

We believe that it is important to support bidders in making 'good' bids, although we realize that this has not been a mainstream concern in auction literature. See Gallien and Wein (2000), who discuss a scheme called 'Myopic Best Response' that bears resemblance to our 'Suggested Price'. Again, such issues all revolve around which information is (made) available to bidders, i.e. the information architecture of the auction.

(6) Closing Rules

Normally e-auctions specify a closing date and time, such as at noon, July 10^{th}, 2003. In practice, a strictly enforced closing time may create problems, with several bids submitted during the last few minutes. The auction owner is better off by extending the deadline in such an event. In commercial systems it is not uncommon that deadlines are extended in case active bidding continues, say by five minutes after each new bid.

4 Incorporating Preferences Over Multiple Issues in Auctions

A central issue underlying multiple-issue auctions is eliciting the bid taker's preferences over the issues involved. This problem is far from trivial and of great practical importance.

In the economics and management science literature the decision-maker's preferences over multiple issues, attributes, or criteria are often (at least conceptually) represented in terms of a multi-attribute **value function** when no uncertainty regarding the consequences of outcomes is present. Elaborate schemes have been presented for eliciting such value functions (Keeney and Raiffa, 1976; Borcherding, Eppel, VonWinterfeldt, 1991). If mutual *preferential independence*[8] can be assumed, the task becomes simpler. It can be shown that value functions in such a case are additive (Keeney and Raiffa, 1976; p. 104).

The use of value functions has been adopted by several auction researchers (Bichler, 2000, 2001; Beil and Wein, 2001, among others), who have proposed the idea of eliciting a simplified value function for the buyer (in case of a **reverse auction**). Normally the value function is assumed to be additive and it is referred to as a 'scoring function'. More specifically, the overall value for bid i can be defined as follows:

$$V(\mathbf{x}_i) = \sum_{j=1}^{n} v_j(x_i^j),$$

where x^j_i is the level of attribute j in bid i ($\mathbf{x}_i = (x^j_i, \ldots, x^n_i)$) and v_j are single dimensional value functions defined over the levels of attributes. Bichler, Lee, Lee, and Chung (2001) argue that the explicit elicitation of buyer's value functions may be difficult. They introduce a 'new' technique called WORA (**W**eight Determination Based on **O**rdinal **R**anking of **A**lternatives), based on generating weights from a partial ranking of bids. The authors do not reveal details, how this is accomplished, but generating bounds on weights from a partial ranking of alternatives is an old problem studied by Zionts and Wallenius (1976) and Zionts (1981). Beil and Wein (2001) suggest the use of interactive techniques for eliciting the scoring and cost functions. In the spirit of interactive multi-criteria optimization algorithms, they assume the form of the function known but not the values of its parameters.

[8] The pair $\{X,Y\}$ is preferentially independent of Z, if the indifference curves (or conditional preferences) in the (x,y) space do not depend on the value of Z.

Many MCDM scholars are critical of explicit assessment of value functions (Larichev, 1984; Simon, 1955; Korhonen and Wallenius, 1996; H. Wallenius, 1991; and Zeleny, 1989, among others) even in a paper-and-pencil context. Unfortunately, the task does not become any easier in a WWW environment. In fact, the criticism of explicit assessment of value functions served as a motivation for the development of dozens of interactive programming procedures during 1970s and 1980s, based on the assumption of an implicitly (not explicitly) known value function.

As a response to the difficulty of explicitly assessing value functions in practice, Teich, Wallenius, and Wallenius (1999) suggested the use of an 'auction owner specified path' method for the case of a multi-attribute single unit auction. In Figure 1 we extend this idea to the multi-unit, multiple issue case, where price and quantity are also issues. The auction owner first specifies the reservation price on each issue and the desired quantity. Bidders are provided with this information and, if desired, insert the quantity they are willing to supply at that price and those attribute levels. Once the maximum quantity is filled (100 units in our example), the bidders are encouraged to bid at the next point along the path that the auction owner has defined previously. The process repeats until the close of the auction. This process does not guarantee Pareto optimality to the bidder/auction owner dyads.

FIGURE 1 ABOUT HERE

To attempt to improve the chances of achieving Pareto optimal solutions to the bidder/auction owner dyads, Teich, Wallenius, Wallenius and Zaitsev (2001, 2002) adopt the 'pricing out' technique from decision analysis to deal with multiple issues in procurement auctions. Practicing decision analysts, in fact, fairly commonly use this approach, particularly in situations where there is a natural monetary attribute (price or cost). Keeney and Raiffa (1976) describe 'pricing out' as follows.[9]

Assume that there is a monetary attribute M, measured in monetary units m, and a set of other attributes $X_1, X_2, \ldots, X_n$. Attribute values are represented by lower case letters (vectors). In 'pricing out' we ask the decision-maker to compare vectors of attributes and identify the monetary value (m^*) that would make her indifferent between two bundles, such as (m^*, $\boldsymbol{x}^*$) and (m^o, $\boldsymbol{x}^o$). The interpretation is that she is willing to pay $m^*–m^o$ to transform $\boldsymbol{x}^o$ into $\boldsymbol{x}^*$. If the number of alternative vectors that we ask the decision-maker to compare is small, this procedure would work. If the number of comparisons is large, it is often assumed that the willingness to pay for transforming $\boldsymbol{x}^o$ into $\boldsymbol{x}^*$ does not functionally depend on the level of the monetary attribute; and the monetary attribute and X_j (as a pair) are *preferentially independent* of the complementary set of attributes.

Teich et al. (2001, 2002) make these simplifying assumptions in their 'pricing out' implementation (Figure 2). Accordingly, the 'pricing out' can be done for each issue/attribute separately. The buyer will simply state upfront, how much she would be willing to pay extra for higher quality merchandise, for faster deliver times, etc., and what discount (if any) she would like to give to trusted suppliers. The system will automatically revise the bid prices accordingly.

[9] 'Pricing out' can be used to elicit a value function, although this is not necessary. Teich et al. (2001, 2002) use 'pricing out' in their *NegotiAuction*™, but do not seek to provide an explicit representation of the buyer's value function.

FIGURE 2 ABOUT HERE

5 Multiple Issue Auction Mechanisms in Practice

Searching the WWW[10] we have found many more than a dozen companies that offer multi-dimensional RFQ, auction or negotiation software applications. We briefly characterize some of them. See Table 2. They all incorporate multiple attributes or issues into the bidding or negotiation process. Some of the sites are pure reverse auction or auction sites; some contain features of both auctions and negotiations. Because mathematical details are seldom disclosed, it is often not clear how the different systems handle the matching of suppliers and buyers, scoring, rating and ranking of bidders, elicitation of the users' value functions, and solving the 'Winner Determination Problem'.

Most implemented auction sites use standard web technologies and open architecture standards. Additionally, many systems use a multi-tier approach with presentation, application and data components. Further technical details can be found on the various commercial web-sites. It is difficult to provide a uniform description of the technical aspects because of the variety of hardware and software solutions adopted and the fast pace of technological change. One of the differentiating features is whether the system is intended to be integrated with other internal enterprise systems, such as ERP (Enterprise Resource Planning) or SRM (Supplier Relationship Management). If a system is of a standalone type, Application Service Provider (ASP), like freemarkets.com, integration is less important. Some solutions, such as CommerceOne, are intended for both markets. No matter what the intention, the latest security technology is important to ensure trust in the system.

Frictionless and Perfect were among the earliest companies who incorporated multiple issues into e-auctions. In fact, they are so named because their processes were intended to radically change trade. Frictionless was originally a B2C company, utilizing additive value functions for consumers to rate products. However, they quickly morphed into a B2B company, once they realized that there were better business opportunities in the B2B market. Perfect used a similar elicitation procedure to construct additive value functions in a B2B e-procurement environment. The majority of companies, which allow some form of multi-attribute bidding, utilize a similar procedure. Some of the companies show the bidders the scoring rule itself, some just the score of the bid, and some the scores of all bids. In most cases, the auction owner will determine the winner manually after the event.

[10] The listing provided was accurate as of July, 2003, but it is possible that by the time of publication new sites have appeared or old ones disappeared.

Company, Site	**Type**	**Main Functional Features**	**Comments**
Perfect	RFQs, One-shot sealed bids	Multi-attribute bids, elicits a fuzzy utility function from bidder	Matches buyers and sellers based on one sealed bid, not an iterative negotiation
Ariba	RFQs, Auctions, Negotiations	Multi-attribute bids	Online negotiation mode outside of auctions
CommerceOne	RFQs, RFPs (Request for Proposal), Auctions	Multi-attribute bids, multi-line bids	Iterative online bidding
Ebreviate	RFQs, RFPs, Auctions	Multi-attribute bids Total cost approach	Automated customer surveys, online communication and negotiation facilities
Emptoris	RFQs, Negotiations, auctions	Multi-attribute bids, constraints, combinatorial bids	No actual negotiation of non-price attributes
Frictionless	RFQs	Multi-attribute bids, simple constraints, elicits a fuzzy utility function from bidder	Rates and ranks bidders
FreeMarkets	RFQs, Sourcing, Auction, Asset management	Multi-attribute bids	Many large clients; technology not discussed (black box)
Combinenet	Combinatorial Auctions	Multi-attribute RFQs, multi-items	Advanced combinatorial optimization
B2eMarkets	RFQs, Sourcing, Negotiation, eLearning	Multiple issues	Collaborative online negotiations

TABLE 2: Commercial WWW Auction and Negotiation Sites

Ebreviate is an early player who used the 'total cost approach'. Instead of utilizing an additive value function, the auction owner inserts cost formulas for each attribute, and when the bids arrive, the total cost is calculated and shown to the bidder. They also report the 'best bid' level for each attribute separately. See Figure 3.

FIGURE 3 ABOUT HERE

Emptoris offers one of the most elegant solutions to e-auctioning. They were recently selected by Motorola to handle their billion dollar annual procurement budgets. They are one of the few software providers with an underlying optimization algorithm that can also handle both combinatorial and multi-attribute bids. The auction owner inserts weights and scores on non-price attributes. The algorithm handles volume discounts, bundled bids, constraints, and non-price attributes. Winner determination is conducted manually, after the close, while making tradeoffs across attributes.

Ariba, CommerceOne, FreeMarkets, and B2eMarkets (B2eMarkets recently acquired the assets of Diligent-systems) offer other interesting sites. Ariba offers customers, in addition to standard multi-attribute bidding, online negotiations outside auctions. CommerceOne allows iterative online bidding for multi-attribute and multi-item bids. FreeMarkets is also an early player. They have many large clients, but unfortunately the technology is not discussed on their web-site. B2eMarkets allows collaborative online negotiations. Diligent offered simple decision support options, including a negotiation and contract management tool. For further details, please visit the company websites.

It is difficult to predict what the future of e-auctions will entail. But we foresee the further development of multiple item bundle (combinatorial) auctions (for example CombineNet), the incorporation of enhanced audio-visual capabilities, and further integration into enterprise and supply chain management systems. The burst of the Internet bubble has had the impact of reducing the number of companies providing e-auction solutions, for example Clarus, Purchasepro, Materialnet, Dealigence and Diligent-systems. The industry has seen much consolidation and standardization due to an active merger and acquisition market.

6 Judging the Performance of Auctions in the WWW Environment

Economics literature discusses a number of criteria for comparing auction mechanisms. They include **allocative efficiency**, revenue to seller (in forward auctions), and cost to buyer (in reverse auctions). Economists have traditionally considered isolated single good, price-only auctions. Our focus is, however, on multiple issue, multiple unit e-auctions. Traditional economists' criteria are not necessarily directly useful in such a complicated environment.[11] We discuss, what criteria are applicable in the multiple issue, multiple unit WWW environment. To be consistent with the rest of our paper, we assume the reverse auction situation with one buyer and many sellers.

Total Cost to Buyer[12]

[11] Interestingly, Schotter (1998) argues that, for practical purposes, economists' criteria are not sufficient for (auction) mechanism design and selection.
[12] This corresponds to (total) revenue for seller in a forward auction.

Total cost as such is not a good measure of auction performance in a situation where there are quality differences in the merchandize and differences in the terms of trade. To be able to use cost as a measure of performance, one would somehow have to eliminate the effect of varying quality and terms of trade. Teich et al. (2001, 2002) resolve this difficulty by 'pricing out' all other attributes besides price (and quantity). Accordingly, their 'Winner Determination Problem' boils down to minimizing total cost to buyer subject to quantity and other constraints.

Revenue/Profit to Sellers

In reverse auctions the bidders (sellers) are concerned of their revenue/profit. If bidders bid too high, they will not be among the winners. If they bid too low, they may end up receiving less revenue than they desired, resulting in **winner's curse**. Given that the sellers know their cost structure (usually assumed to be private information), profit to sellers resulting from each bid can be calculated and optimized (at least in theory).

Allocative Efficiency

Generally speaking, allocative efficiency measures the extent to which the goods/services are allocated to the bidders who value them most. If we knew the individual valuations and the set of bidders, allocative efficiency could be defined. In a multiple issue WWW environment such multi-dimensional valuations are not easily obtainable, nor is the set of potential bidders known except afterwards. Hence the measure of allocative efficiency does not seem operational.

Incentive Compatibility

The economics literature discusses **incentive compatibility** at length. A mechanism is not incentive compatible, if bidders do derive benefits from not truthfully disclosing their valuations. It is incentive compatible in the opposite case. It is often not easy to show mathematically whether an auction mechanism is incentive compatible or not. A thorough discussion of possible incentives to misrepresent one's valuations is, however, deemed useful.

Nash Equilibrium

In contrast to single-unit auctions, in multiple unit auctions there is no unique **Nash equilibrium** (Maskin and Riley, 1989) in general, where bidders have no incentive to unilaterally change their bids. Hence the measure is only of limited relevance to performance of multiple-issue auctions, since the benchmark by which to assess performance is unknown.

Speed of Convergence

The speed of convergence is important in many auctions. A case in point is an auction of perishable products, such as airline tickets for certain flights or flowers in the Dutch flower auction. The one single factor that most clearly impacts the speed of convergence of an auction is the bid decrement (increment in forward auctions).

Careful judgment, possibly some experimentation, must be used to specify a reasonable bid decrement (increment), not too large, not too small (Bapna, Goes and Gupta, 2001).

Computational Efficiency

In combinatorial, bundle auctions computational issues are important. In non-combinatorial single good (multiple unit) auctions computational issues are much less important. If partial quantities of bids are acceptable to bidders, we can work with Linear Programming. Linear Programming is computationally much more efficient than Integer Programming, if its use is justified. The use of Linear Programming also allows the calculation and interpretation of dual variables as shadow prices.

Fairness

Fairness or perhaps we should say perceived fairness is an important criterion for judging the performance of auction mechanisms and for e-auctions to become widely used. It is of great importance that both sellers and buyers perceive to benefit from the use of the trading mechanism. Being subjective, fairness is difficult to measure.

Efficiency of Bids

In a multiple issue environment, an important consideration is whether winning bids are **efficient**. This depends on the winner determination mechanism and has to be proven.

Pareto Optimality of Bids

We can interpret **Pareto Optimality** from the perspective of the auction owner/bidder dyads or from the group as a whole. The approach used to represent buyer's preferences over multiple issues will determine whether the result is Pareto Optimal for the dyads. If all dyads are Pareto optimal, it should follow that the group as a whole is also Pareto optimal (although unproven). However, an implementation to incorporate logrolling possibilities to multilaterally improve the result is difficult because bidders normally are not allowed to collude with each other.

Volume of Trade

From a practical point of view an important question is how much volume of (profitable) trade an auction generates. This is particularly relevant for auction houses, which generate their income via large trade volumes. The trade volume depends among other things on how accessible the auction is and, how easy and costly it is to participate. Generally speaking, Web-based auctions can easily be accessed by a large number of suppliers or buyers and the transaction costs are low. This is likely to increase the volume of trade for certain goods. Especially because of low transaction costs there is great potential for win-win situations where both suppliers and buyers would profit.

7 Conclusion

We have discussed the state-of-the-art of the emerging field of multiple issue, multiple unit online procurement auctions and measures to judge their performance. Published academic research on multiple issue online auctions is relatively scarce, yet commercial online auction sites are plentiful. In more than a few cases, academic auction researchers have been involved or have at least consulted in the development work. Still, it is difficult to escape the feeling that it would be in everybody's interest to forge a stronger link between commercial site developers and auction researchers. Many of the commercially available systems appear to lack the scientific theory base and rigorous testing. At least such information is not normally disclosed. The other side of the coin is that many of the interesting academic prototype auction systems lack the real-world usage that commercial companies could provide.

The problems in electronic market mechanism design are interdisciplinary. We hope that our article has convinced the reader that the field is very exciting and that the OR and Decision Analysis community has played a role in this development work. They have contributed to various mathematical formulations of the 'Winner Determination Problem' and its computational solution. They have contributed with their conceptual and practical ideas of how to represent preferences over multiple issues and attributes. Together with information systems scholars, they have contributed to the design of user-friendly interfaces for online auction mechanisms. There is evidence that they can contribute to the analysis of desired feedback information and decision support to bidders. With their skills and know-how, the OR and Decision Analysis community can also contribute to conducting behavioral experiments and field studies of the pros and cons of different online auction mechanisms in different settings, if they seize the opportunity.

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Glossary: Definitions and Terminology

Allocative Efficiency: The sum of the producer and consumer surplus resulting from the auction, divided by the sum of the producer and consumer surplus, which would be realized if the bidders with the highest valuations received the contract.

Auction Owner: The initiator of an auction; the buyer in a reverse auction and the seller in a forward auction.

Bid Decrement: (In a reverse auction) the desired reduction in price (or total cost) from one bid to the next.

Bid Status: ‘Active’, ‘Inactive’, ‘Semi-Active’: Were the auction to close at this very moment, the ‘active’ bids are the winning bids; the ‘semi-active’ bids are partial winners, receiving a partial quantity desired; ‘inactive’ bids are loosing bids.

Combinatorial (Combinational) Auction: Bidders are allowed to bid simultaneously on a combination of goods. The bid price is a bundle price. Complementarities exist between goods.

Divisibility of Bids: In multiple unit (quantity) auctions, where bidders accept partial quantities (percentages) of their desired quantities.

Dutch Auction: Descending price auction format; the first bidder that indicates willingness to buy at the announced price wins.

Efficiency: A multiple issue/attribute bid vector $\boldsymbol{q}^*$, where each component of the vector is assumed to be maximized, is efficient if and only if there does not exist another bid vector $\boldsymbol{q} \geq \boldsymbol{q}^*$ and $\boldsymbol{q} \neq \boldsymbol{q}^*$. (Note that here $\boldsymbol{q}$ refers to the entire bid vector, not just quantity.)

English Auction: Ascending price auction format. Highest bidder(s) wins.

Forward Auction: An auction format with one seller, many buyers, and ascending price.

Incentive Compatibility: A mechanism where bidders have no incentive to mask their true valuations.

Information Architecture: The set of rules that determines what information is or becomes available to which auction participants during the auction (Koppius, 2002a).

Multidimensional Auction: Often synonymous to multiattribute, multiple unit auction. Sometimes used to refer to combinatorial bundle auctions with multiple heterogeneous goods.

Multiple Issue (Reverse) Auction (Also referred to as multiattribute auction): A procurement auction where (generally) multiple units of merchandize varying in terms of quality, warranty, delivery terms, etc. are demanded.

Multiple Unit (Quantity) Auction: An auction where multiple units of a homogeneous good/service are being auctioned. The bidders may or may not be limited to supplying one unit per bidder. In the latter case bids consist of price and desired quantity.

Nash Equilibrium: (In an auction setting) a situation where no bidder wants to change her bid. Assumes that we can specify the bidder's so called bid function.

Pareto Optimality: The auction outcome is Pareto Optimal if and only if there is no other outcome that is preferred by all parties. This applies both to the case of an auction owner/bidder dyad as well as to the group (buyer and sellers) as a whole.

Price Discrimination: Buyer pays different prices for different suppliers for the same good/service. (Quantity discounts may also be regarded as a form of price discrimination, as would bidder penalties.)

Pricing Out: ('Costing out') Eliminating attributes by expressing them in monetary terms.

Procurement Auction: See reverse auction.

Reservation Price: (In a reverse auction) the maximum a buyer is willing to pay for the merchandize/service.

Reverse Auction: An auction format with one buyer, many sellers (suppliers), and descending prices.

RFQ: Request for Quote.

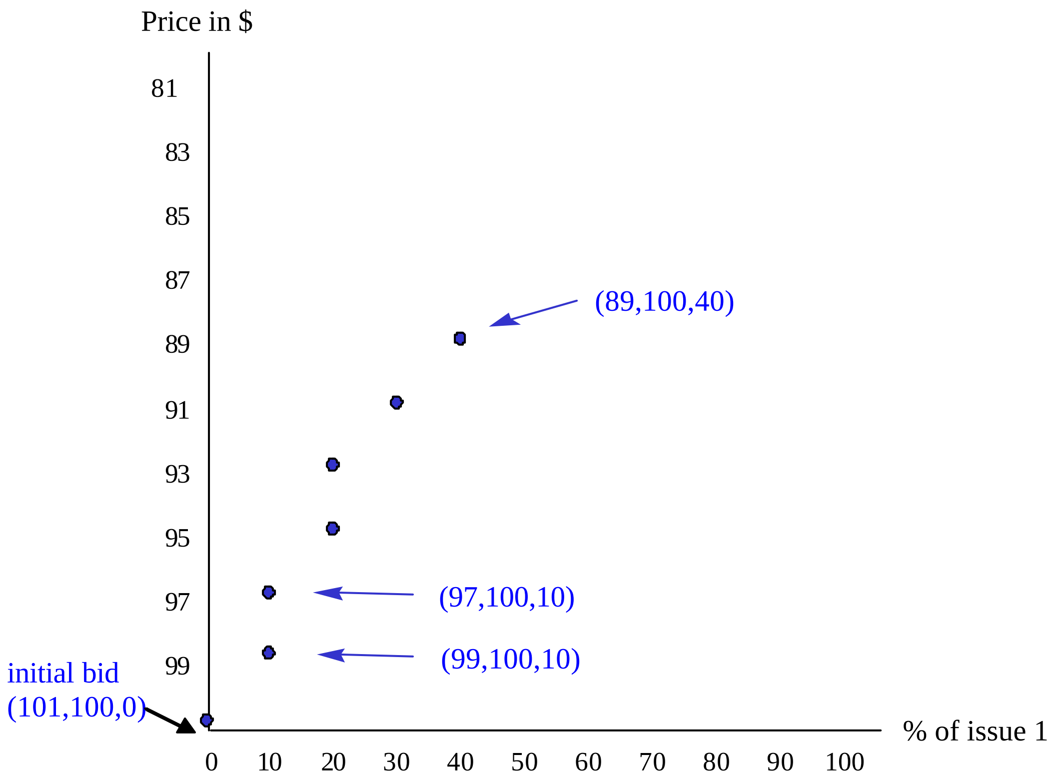
Utility Function: Cardinal utility function for situations where outcomes are probabilistic.

Value Function: Ordinal utility function for situations where no uncertainty regarding outcomes is present.

Vickrey auction: Second-price sealed bid (forward) auction, where the highest bidder wins, but pays the second highest price. Named after William Vickrey, the Nobel-laureate in economics.

Winner's Curse: Highest bidder ends up paying 'too much', that is above her true valuation.

Winner Determination Problem: Determining, given a set of bids, who wins the auction (the goods/services). In a multiple unit auction, there are normally multiple winners.



Key: Bid vectors represented in price, quantity, and issue 1 space

Figure 1. Auction Owner Specified Bid Path

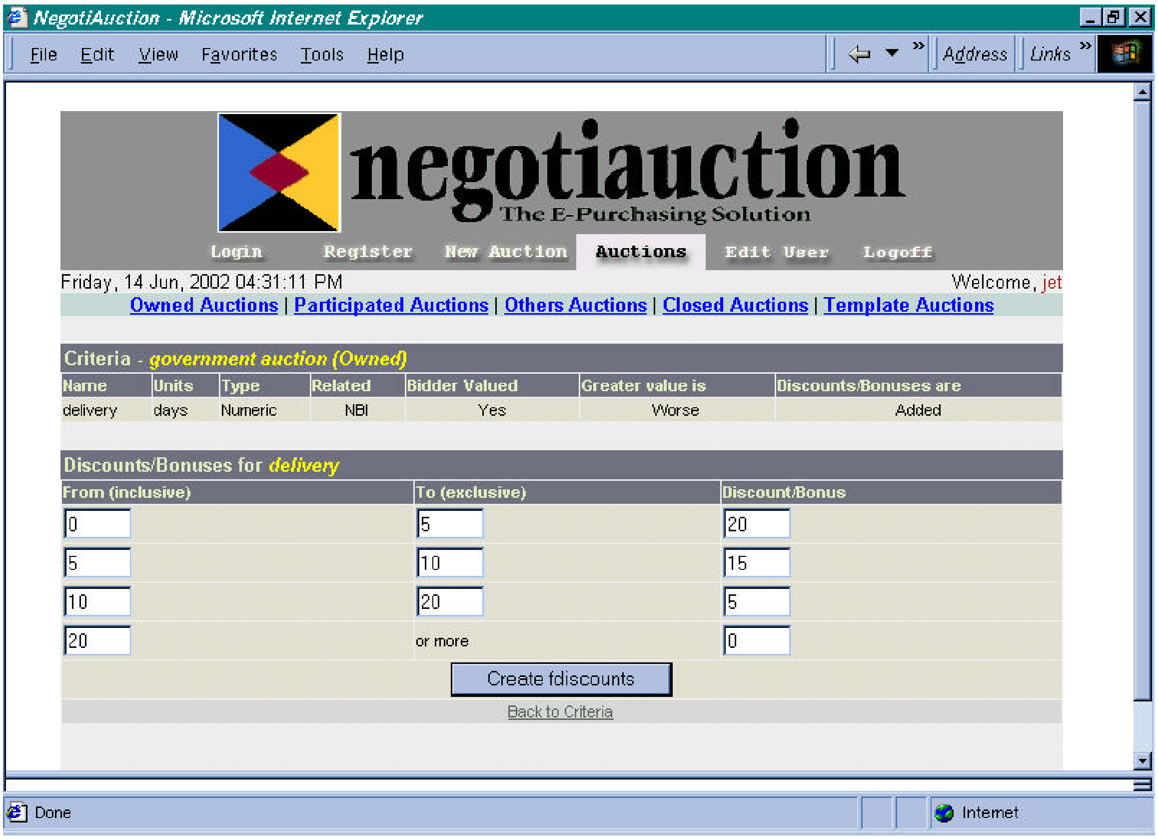


Figure 2. ‘Pricing Out’ in NegotiAuction

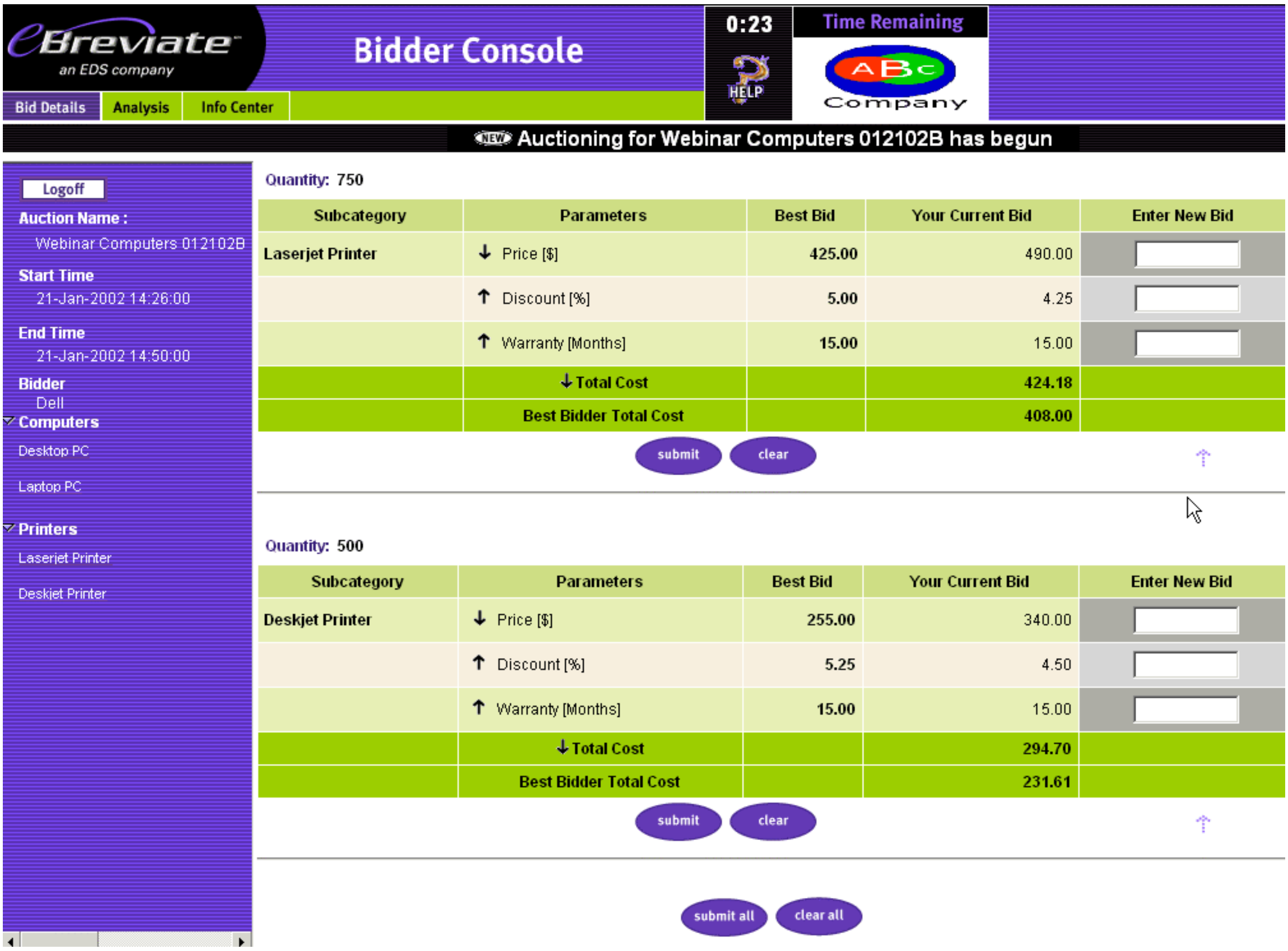


Figure 3. Ebreviate Solution: Multi-attribute Bid Screen

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