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Decision support for preference elicitation in multi-attribute electronic procurement auctions through an agent-based intermediary

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ABSTRACT

Multi-attribute auctions have become increasingly popular in enterprise procurement. In the auctions, the elicitation of the preference of an auctioneer concerning multiple attributes is a central task in determining the winner(s). Considering the difficulty of explicit elicitation, a preference elicitation framework is proposed to assist the auctioneer in inferring his/her underlying preference model(s). The auctioneer is expected to provide the information of attribute weights, the holistic preference relations concerning a set of reference bids and the comparison information of intensities of preferences between some pairs of bids on all attributes and/or a particular attribute. Based on this information, a linear programming model is constructed to infer the preference model(s) of the auctioneer so that the estimations are as consistent as possible with the given preference statements. Furthermore, a method is also given to select a representative preference model from the set of compatible ones. The framework is implemented by an intelligent buyer agent called e-buyer which has five main components, i.e., a semantic analyzer, a preference elicitation module, a bid evaluation module, a model base, and a database. The e-buyer is embedded into an auction intermediary, and the proposed preference elicitation models are stored in the model base. Several graphical user interfaces are also presented to visualize the future trading intermediaries. Finally, a numerical example is given to illustrate the framework and show the effectiveness of the preference elicitation models.

1. Introduction

Given the remarkably rapid progress of internet technology and electronic commerce over the past decade, online auctions have become very popular venues for conducting business transactions [2,32]. In the business-to-business (B2B) domain in particular, the utilization of information technologies enables firms to employ a new tool, i.e., electronic procurement (e-procurement) auctions (also referred to as electronic reverse auctions) to increase the efficiency of their procurement. For example, Procter & Gamble employed this new tool to conduct auctions for its suppliers. By March 2005, over a period of two and a half years, the company sourced over $3 billion worth of supplies, with up to $294.8 million (9.6%) saved because of advanced technologies [35]. Similarly, Motorola implemented an end-to-end internet sourcing platform by Emptoris in 2002. Motorola's sourcing of materials and services had reached $16 billion by 2005, and savings amounted to $600 million [29].

As extensively reported in the literature (e.g., [19,34,44,45]), cost savings always accompany the employment of e-procurement auctions. Generally, 10% to 40% of the negotiation and contracting costs could be saved through online bidding [19]. The reduction in cycle time that can be attributed to e-procurement auctions is another benefit that enables industrial buyers to improve their sourcing efficiency. The entire negotiation process may last for several months in a traditional procurement event. By contrast, the duration of e-sourcing can be shortened to several weeks or even a couple of hours [35,45]. Moreover, suppliers can also benefit from the new mechanism in terms of an alternative distribution channel. A number of large industrial firms, such as Hewlett-Packard, Dell, General Electric, etc., have recently employed e-procurement auctions to purchase direct and indirect materials. With billions of dollars of transaction contracts being awarded every year, this field continues to flourish.

In a Web-based procurement auction, a single buyer (auctioneer) procures items (goods or services) from numerous potential sellers (bidders), and the transaction usually occurs through an electronic auction (e-auction) intermediary operated by a third-party organization or by the buyer himself/herself. Each participator has to register with the intermediary and then apply for customer identification to gain access to the system. Auctions are then conducted by software agents that negotiate on behalf of the buyer and the suppliers. The entire procedure can be briefly described as follows: First, the buyer, as the leader in the procurement auction, specifies the requirements for the item to be purchased and the qualification for the suppliers. Second, the trading intermediary generates the Request for Quotes

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and sends it to a number of qualified suppliers. Third, seller agents help compose bids, and each bidder then submits a bid through the graphical user interface (GUI) before the deadline. Fourth, the trading intermediary determines a winning bid (or several winning bids) according to the pre-defined scoring rule of the buyer and then prepares the corresponding procurement contract(s). Finally, the winning supplier(s) makes the actual delivery.

In the early development stages, almost all the procurement auctions were conducted in a simple descending price format. However, the price-only focus significantly limited the potential use of procurement auctions in practical applications, particularly in industries where suppliers varied considerably in terms of non-price dimensions, such as quality, brand, terms of warranty, etc. Consequently, a number of researchers began to consider auction mechanisms that would enable a buyer to negotiate with multiple suppliers over heterogeneous goods or services. In the literature, several terminologies have been used to describe such a procurement auction format, i.e., multi-dimensional [7,9,10,12], multi-issue [40,42], multi-criteria [5,17], and multi-attribute auctions [6,36], where the most commonly used is "multi-attribute auctions." Che first proposed a two-dimensional (i.e., price and quality) auction for government procurement [12]. Branco extended the previous model by considering the correlation among the cost functions of sellers [10]. Subsequently, the domain was extensively studied by numerous scholars from different disciplines, such as economics [16,30,33], information systems [1,14,28,38], operation research, computer science, etc.

The winner determination problem (WDP) is a major concern in multi-attribute procurement auctions. Many scholars used scoring functions in their study to evaluate the bids submitted by bidders. However, it is usually difficult for an auctioneer to give precisely all parameter values of the scoring function in practical implementation because of his/her cognitive limitation. Therefore, we propose a new preference elicitation framework, which is based on the aggregation-disaggregation paradigm [37], to assist the auctioneer in inferring his/her underlying preference model(s) from the preference information provided by himself/herself. The preference information can be either direct or indirect, depending whether the auctioneer specifies directly values of some parameters used in the preference model or whether he/she specifies some examples of holistic judgments from which compatible values of the parameters are induced [21]. Four types of information are expected to provide in the proposed framework, namely the information of attribute weights, the holistic preference relations concerning a set of reference bids and the comparison information of intensities of preferences between some pairs of reference bids on all attributes and/or a particular attribute. The information of weights is direct, whereas the others are indirect. The reference bids can generally be derived from several sources as follows: (a) A set of fictitious actions, which should be easily judged by the auctioneer to express his/her preference [23]; (b) A subset of real commodities available in the current trading market. The items with different specifications are actually potential choices for procurement in auctions; (c) The tentative bids from a pre-bidding stage. A pre-bidding stage can be designed before the formal negotiation process, and some tentative bids from potential suppliers then can be collected and utilized as reference bids; (d) Some historical bids stored in e-auction intermediaries. In the B2B domain, the industrial buyer always purchases the same item repetitively. Thus, a large amount of historical transaction data may help determine preference. The last of the abovementioned sources is quite suitable for Web-based transactions; therefore, the historical data are considered the primary source of reference bids in this study. Based on the information provided by the auctioneer, a linear programming model is constructed to infer the preference model(s) of the auctioneer so that the estimations are as consistent as possible with the given preference statements. Furthermore, a method is also given to select a representative preference model from the set of compatibles ones. An intelligent buyer agent is designed to implement the framework. It is comprised of five functional components, i.e., a semantic analyzer, a preference elicitation module, a bid evaluation module, a model base, and a database. The buyer agent is embedded into an auction intermediary.

Some contributions of this paper are summarized as follows. (1) To the best of our knowledge, only Karakaya and Köksalan have studied the indirect preference elicitation in the field of auctions [25]. In their setting an auctioneer is required to choose the most preferred bid(s) in each round so that his/her nonlinear utility function can be estimated from the information, while our framework uses the additive value function and requests an auctioneer to provide the four types of information mentioned above for inferring such a function. Moreover, we also give a reference ranking of the bids in each round to assist the auctioneer in submitting new preference information, which is not mentioned in [25]. (2) Like the traditional UTA method, our preference elicitation method also adopts the aggregation–disaggregation paradigm, and uses linear programming techniques to infer preference models which are as consistent as possible with the given information. It estimates the parameters by minimizing the maximum error, not the total error as in UTA. In case of a non-empty set of compatible value functions, traditional UTA method and one of its variants UTASTAR select a mean value function by conducting so-called post-optimality analysis [37], whereas our method aims at determining a representative function which emphasizes the advantages of some bids over the others if the auctioneer prefers the former ones, highlights the differences of intensities of preference among pairs of bids if the auctioneer assigns them with different degrees, and reduces the differences among pairs of bids with the same degree. (3) Prior research on solving WDPs or on eliciting preference of an auctioneer has seldom addressed the implementations of the proposed methods. In this article, an intelligent buyer agent is designed to implement the framework, and thus promotes the practical use of the proposed framework in real-world commerce.

The remainder of this paper is organized as follows. In Section 2, we discuss the related literature. In Section 3, we propose a preference elicitation framework for multi-round, multi-attribute e-procurement auctions, and devise the architecture of an intelligent buyer agent to implement the framework. Section 4 is devoted to the underlying decision-making approach, including the required preference information and the models used to estimate the preference. Several GUIs are presented to depict our vision of how the preference information is obtained in an e-auction intermediary. We then exemplify the use of the framework and present the theoretical comparisons in Section 5. Finally, in Section 6, we conclude with the contributions of the paper and give some suggestions for future research.

2. Literature review

Two streams of literature are closely related to this work. The first stream is the study of winner determination problems in multi-attribute auctions. There is a large body of literature devoted to this field [3,8,13,15,24,39]. The WDPs have been studied under various situations. Cheng presents a multi-attribute decision-making model for solving the WDP in sealed-bid reverse auction setting [15]. Beil and Wein study the determination of winner(s) in a multiround open-ascending auction mechanism [4]. They use an inverse optimization technique to learn the suppliers' cost functions from their bids, and then optimize the scoring rule which maximizes the auctioneer's utility to determine the winner. Bichler and Kalagnanam focus on the case that the total demand can be purchased from multiple suppliers (i.e., multiple sourcing) and the suppliers are allowed to submit configurable offers [8]. Kameshwaran et al. analyze the WDPs in case of large-volume procurements with quantity discounts and business constraints [24]. Chen et al. consider the situation that the chosen supplier fails to accomplish the project, and they take into