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Winner determination for risk aversion buyers in multi-attribute reverse auction ☆

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ABSTRACT

Multiattribute reverse auction has become prevalent for the procurement of goods and services in recent days. In such an auction, a group of potential suppliers bid to win the contract that has been defined in multiple attributes by the buyer for providing goods or services. A corresponding winner determination problem provides important decisions for the buyer to select its best supplier. Considering the buyer with risk aversion behavior and suppliers with positive and negative attributes described by a combination of crisp data, interval numbers and linguistic variables in a multiattribute reverse auction setting, we incorporate the prospect theory (PT) into the "benefits, opportunities, costs and risks" (BOCR) framework to propose a novel PT-BOCR solution method. The effectiveness and distinct advantage of our method on dealing with the buyer's risk averse attitude are demonstrated in comparison with other known methods. Computational results indicate that the PT-BOCR method is robust with respect to the variance of suppliers' attributes and the level of reference points. An interesting result reveals that when suppliers' attributes vary a lot, the degree of risk aversion increases or decreases depending on the reference point is low or high. The PT-BOCR method could be a useful tool for risk aversion buyers to avoid losses and for suppliers to win the bids by improving their attributes.

1. Introduction

With the development of internet technologies, reverse auction has become an important arsenal for buyers to purchase goods or services in recent days [1]. As implied by its name, *reverse auctions* are based on the traditional auctions in a reverse format where one buyer solicits bids from a group of potential suppliers, and then selects a winning supplier by solving a corresponding *winner determination problem* (WDP)[1] [2,3]. Since reverse auctions usually consider price as the key factor and overlook other important attributes like quality, lead time and supplier reputation [3,4], the use of reverse auction may result in nonperformance and serious losses [2,5]. For example, Menu Foods Corp. has suffered serious consequences due to the noxious chemicals contained in the pet food provided by suppliers [5]. To screen suppliers by a variety of attributes and thereby reduce the likelihood of nonperformance, the buyer may have to use *multi-attribute reverse auctions* (MARAs) to determine a winner based on price and non-price attributes [6,7]. In contrast to the price-oriented reverse auctions, MARAs lead to a more satisfying outcome through effective information exchange between buyer's preferences and suppliers' offerings. As the trend of using MARAs for procurement moves up, a buyer faces two critical issues for selecting suppliers.

First, the buyer may become more risk averse when the quality of goods or services provided by potential suppliers varies more. The variability in quality can be attributed to many causes. For example, in the procurement of complex services (e.g., General Electric's legal services procurement), the quality of services each company offers is often more subjective than that for standardized goods [8]. Another example is that the supplier of Foreign Tire Sales neglects the design of gum strips, which results in unqualified products [5]. In circumstances like these, to ensure the quality of goods or services provided by potential suppliers, a buyer may exhibit some behavior of bounded rationality by overestimating the effect in *loss attributes* and underestimating the effect in *gain attributes* for selecting suppliers.

Second, accurate assessment of the performance of individual alternatives with multiattributes becomes more difficult since they may involve two types of attributes: the *quantitative attributes*

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[1] Appendix A contains a list of all the acronyms used in the paper.

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described by crisp data or interval numbers, and the *qualitative attributes* described by fuzzy linguistic variables. Moreover, since the attributes can be conflicting (such as the attributes of price and quality), the buyer essentially needs to balance the *positive attributes* against the *negative attributes*, which reflect the positive or negative impact of selecting a particular supplier. Therefore, a new challenge for the buyer is to assess the conflicting attributes of different types.

In this paper, we consider these new issues from the buyer's point and model a reverse auction in which the buyer is risk averse with bounded rationality, and the attributes of potential suppliers are conflicting and in different types. In other words, our main goal is to design an evaluation mechanism based on the concept of multi-attribute decision making (MADM) to solve the corresponding WDP that incorporates the boundedly rational behavior of the buyer and the conflicting attributes of potential suppliers.

To deal with the risk averse behavior of buyers, we propose using the *prospect theory* (PT) to describe the risk attitude. PT presents a fact that people often interpret outcomes as gains and losses relative to a reference point and are more sensitive to losses than to absolutely commensurate gains [9]. In recent years, PT has been successfully applied as a behavioral model to economics and finance for decision making under risk [10]. It is shown with strong evidence that loss aversion exists at both of the aggregate and individual levels [11]. Adopting PT to characterize the buyer's risk aversion decision behavior becomes a new trend.

To assess different types of conflicting attributes, we adopt triangular fuzzy numbers mixed with crisp data and interval numbers (see [3]), and use the “benefits, opportunities, costs and risks (BOCR)” framework to balance the conflicts among positive and negative attributes (see [12,13]). The BOCR framework contains a control hierarchy, in which the *overall attributes* are used to balance the conflicting attributes of potential suppliers, and a separate hierarchy, in which the *detailed attributes* are used to evaluate potential suppliers.

By incorporating PT with the BOCR framework, we propose a novel approach called PT-BOCR method to deal with the buyer's risk averse attitude and suppliers' conflicting attributes with different types simultaneously. The effectiveness and distinct advantage of our method are demonstrated in comparison with other known methods. We find that the PT-BOCR method indeed performs better, and is more effective for risk aversion buyers to avoid potential losses.

Our work contributes to the MARA literature by incorporating the buyer's risk attitude and suppliers' conflicting attributes with different types into the conventional WDP. In particular, we provide a novel PT-BOCR method for risk aversion buyers to select their suppliers in contrast to existing decision methods, where the decision makers are assumed to be risk neutral and the attributes are non-conflicting. Numerical experiments show that the proposed method is robust with respect to the variance of suppliers' attributes and the level of reference points of PT. Through the risk averse behavior analysis, we find an interesting result that when suppliers' attributes are not similar to each other in the supply market, the degree of risk aversion increases for the case with a low reference point and decreases for the case with a high reference point. We also provide some suggestions for suppliers to improve their attributes in order to be favorably considered by risk aversion buyers.

The rest of this paper is organized as follows. A brief literature review is provided in Section 2. The background knowledge of interval numbers, fuzzy logic, PT and BOCR is presented in Section 3. Our problem description and PT-BOCR framework are provided in Section 4. In Section 5, the PT-BOCR method for risk aversion buyers is presented. To illustrate the effectiveness of the proposed methodology and provide useful insights for buyers and suppliers, we conduct numerical experiments, behavior parameters analysis, comparison analysis with other MADM methods, and risk averse behavior analysis in Section 6. Section 7 concludes the paper with some managerial implications.

2. Literature review

In this paper, we consider the multiattribute reverse auction setting where the buyer employs the multiattribute decision making concepts to select a winner from a group of potential suppliers. The literature relevant to our work mainly comes from two separate streams, namely, MARA and MADM.

In the MARA literature, Che's work [14] is seminal. He embeds two attributes of price and quality into the government procurement process by using the first and second scoring rules. Beil and Wein [15] extend Che's work for MARAs in which an inverse optimization method is introduced to learn the suppliers' cost functions under the assumption that suppliers submit their myopic best-response bids. In parallel, David et al. [16] focus on a specific model for three different protocols, i.e., first-score sealed-bid, second-score sealed-bid and sequential full information revelation, and show that the three protocols are approximately equivalent. On a different line, Teich et al. [1] propose a decision method based on mathematical programming for the buyer to evaluate potential suppliers. In contrast, Cheng [2] studies a particular MARA where the “Technique for Order Preference by Similarity to Ideal Solution” (TOPSIS) method is used to select the best supplier. However, only quantitative attributes are considered in the aforementioned works. To release the full potential of MARAs, Singh and Benyoucef [3] focus on the evaluation mechanism with both quantitative and qualitative attributes. They assume that the buyer is risk neutral and propose a fuzzy logic and interval arithmetic based TOPSIS (F-TOPSIS) method to evaluate potential suppliers in MARAs. They show that F-TOPSIS works for risk neutral buyers to determine the winner. Yet, as pointed out in Section 1, buyers may become more risk averse (by overestimating the effect of loss attributes and underestimating the effect of gain attributes) in an environment with high variability in quality of goods or services, and actually need to balance the conflicting attributes (such as price and quality).

In the MADM literature, the two most commonly studied methods are the Analytic Hierarchy Process (AHP) [12,17–19] and TOPSIS [2,3,20,21]. Reviews of this research area are made available by Ho et al. [22] and Wallenius et al. [23]. Also, data envelopment analysis has been extensively studied in recent years (see [24–26]). To the best of our knowledge, the existing literature considers the conflicting attributes and the decision behavior separately. For example, the BOCR concept that balances the positive and negative attributes (see [13]) has been widely applied to supplier selection [12,27], project selection [28], and wind farm selection [29]. In parallel, the PT concept has been applied to traditional MADM to capture the psychological behavior of decision makers (e.g., [10,30]). Integrating PT into BOCR may lead to a novel approach.

In this paper, we model a setting of MARA where the buyer is risk averse and the attributes are conflicting and in different types. The proposed model is more general than that of Singh and Benyoucef [3], in which they overlook the buyer's risk averse attitude and potential suppliers' conflicting attributes. To solve the WDP from the buyer's point, we integrate PT and BOCR together to propose a novel PT-BOCR method for MADM. Since the problem considered in [3] can be viewed as a special case of our problem, and the TOPSIS methodology has been successfully applied to a wide range of areas [31], the proposed PT-BOCR method is evaluated by comparing it with the F-TOPSIS method in [3]. We