Expert Systems with Applications 38 (2011) 4169–4180

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Multi-objective optimization matching for one-shot multi-attribute exchanges with quantity discounts in E-brokerage

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ARTICLE INFO

Keywords:
E-brokerage
Multi-attribute exchanges
Multi-objective optimization
Quantity discounts
Genetic algorithm
Simulated annealing

ABSTRACT

Electronic brokerages (E-brokerages) are Internet-based organizations that enable buyers and sellers to do business with each other. While E-brokerages have become a significant sector of E-commerce, theory and guidelines for matching the multi-attribute exchange in E-brokerage are sparse. This paper presents an approach to optimize the matching of one-shot multi-attribute exchanges with quantity discounts. Firstly, based on the conception and definition of matching degree and quantity discount, a multi-objective optimization model is proposed to maximize the matching degree and trade volume. This model belongs to a class of multi-objective nonlinear transportation problems and cannot be solved effectively by conventional methods, especially when large-scale problems are involved. Hence, secondly, a novel hybrid multi-objective meta-heuristic algorithm named multi-objective simulated annealing genetic algorithm (MOSAGA) has been developed to solve the proposed model. Finally, the computational results and analyses of some numerical problems are given to illustrate the application and performance of the proposed model and algorithm.

1. Introduction

The information revolution is dramatically reshaping the business model and pushing traditional commerce toward electronic commerce (E-commerce). More and more people are getting involved in business activities based on Internet (or electronic) markets. This not only promotes the rapid development of E-commerce, but also brings about new challenges for E-commerce (Albers & Clement, 2007; Lee & Park, 2009; Wang, Nuttle, & Fang, 2005).

For example, due to the vast amount of information on the Internet, it is not easy for a buyer or seller to locate and process relevant information, and to distinguish between useful and not useful material for a specific market transaction, even with the help of the search engines on the Web (such as Google, Yahoo, etc.). This has created the opportunity for new Internet intermediaries to enter the electronic marketplace (Blinov & Patel, 2003; Hands, Bessonov, Blinov, Patel & Smith, 2000). These new Internet intermediaries are called *electronic brokerages* (E-brokerages), also named *electronic intermediaries* (McIvor & Humphreys, 2004) or *cybermediaries* (Caillaud & Jullien, 2001; Sarkar, Butler, & Steinfield, 1998). With the use of information communication technology (ICT), E-brokerages can facilitate exchanges between buyers (consumers) and sellers (producers) by meeting the needs of both buyers and sellers (Datta & Chatterjee, 2008; Giaglis, Stefan, & OKeefe, 2002; Sarkar, Butler, & Steinfield, 1995). Compared with traditional brokerages, E-brokerages have the advantage of not being bound by time and space constraints and the advantage of being able to provide more real-time and effective information for commodity exchanges. As a result, E-brokerages are very popular on the Internet; for instance, a not-for-profit project funded by the trade promotion organizations of various countries, provides a non-exhaustive directory of over 628 active electronic marketplaces around the world (http://www.emarketservices.com, August 2009), which includes various brokerage patterns, such as real estate E-brokerages, automotive E-brokerages, IT product E-brokerages, etc.

However, as a significant sector of E-commerce, E-brokerages are still a relative new and poorly understood type of business (Muylle & Basu, 2008). There is little theory and few guidelines to help E-brokerages optimize the matching of the commodity exchange between buyers and sellers, although there is a growing literature on E-brokerage that is helping to fill the gap. Most current E-brokerages only provide the commodity trade information on the Internet, but do not really serve the function of matching buyers with sellers. Especially in a one-shot multi-attribute exchange where commodities use multiple attributes, such as *price*, *quantity*,

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doi:10.1016/j.eswa.2010.09.079

and *delivery time* in specifications of buy and sell orders (bids) collected over a given time interval. Therefore, in the absence of a comprehensive optimization matching theory for one-shot multi-attribute exchanges, E-brokerages have no solid foundation for improving exchange efficiency and trading profits.

The goal of this paper is to present an approach to optimize the matching of one-shot multi-attribute exchanges with quantity discounts in E-brokerage. Based on the conception and definition of matching degree and quantity discount, a multi-objective optimization model is proposed. Then, in order to solve this model, a multi-objective simulated annealing genetic algorithm (MOSAGA) is developed. Finally, extensive computational experiments on some numerical problems are conducted to illustrate the application and performance of the proposed model and algorithm.

The remainder of this paper is organized as follows: Section 2 reviews some relevant literature. In Section 3, the conception and definition of matching degree and quantity discount are given. In Section 4, a multi-objective optimization model to match the one-shot multi-attribute exchange with quantity discounts in E-brokerage is proposed. Then, a novel hybrid multi-objective meta-heuristic algorithm, i.e. MOSAGA, which has been developed to solve the model, is described in Section 5. Section 6 provides the computational results and analyses of some numerical problems to illustrate the application and performance of the proposed model and algorithm. Finally, some conclusions and further research issues are summarized in Section 7.

2. Literature review

Exchanges (also called double auctions) are double-sided marketplaces where both buyers and sellers submit their requirements (bids) for trading (Fink, Johnson, & Hu, 2004; Pinker, Seidmann, & Vakrat, 2003; Simchi-Levi, Wu, & Shen, 2004) The exchanges differ in functionality with respect to timing of clearing, number of bid submissions, pricing, aggregation and the varieties of commodities traded (Kameshwaran & Narahari, 2003). In this paper, our interest is to determine trade matching for one-shot exchanges in E-brokerage, because they often enjoy liquidity and efficiency advantages over other exchanges (Economides & Schwartz, 1995). In one-shot exchanges, buyers and sellers submit their bids once during the specified bidding interval and the market is cleared by the broker (i.e. the E-brokerage firm or the decision maker) after the termination of the bidding time. This is similar to call markets or clearing house (Kameshwaran & Narahari, 2002), but the bids may have multiple attributes, in this case, the exchange is a one-shot multi-attribute exchange. Therefore, in this section, we mainly review the literature on one-shot multi-attribute exchanges (also called multi-attribute call double auctions).

Only a small but steadily growing number of academic papers have considered one-shot multi-attribute exchanges so far. Ryu (1997) proposes a computable mechanism of trading intermediaries for commodity auction markets, supporting not only ordinary trading constraints of prices and quantities but also other qualitative and quantitative constraints on the commodity properties and trading conditions. Jung and Jo (2000) introduce *constraint satisfaction problems* (CSP) to find an optimal solution by the brokerage to satisfy various preferential requirements for buyers and sellers, and build a prototype of a brokerage system for dealing in real estate. Kameshwaran and Narahari (2003) address the trade determination issue for one-shot multi-attribute exchanges that trade multiple units of the same good. They model trade determination as mixed integer programming problems for different possible bid structures and show that even in two-attribute exchanges, trade determination is NP-hard for certain bid structures. Wang, Wang, and Xie (2003) investigate the trade matching problem in the electronic market based on a brokerage agent, but the proposed model and algorithm are only suitable in the view of either buyers or sellers, not both of them. Zhang (2005) presents the model and algorithm for a single unit of multi-attribute commodity trade matching, and which are applied in second-hand real estate and car E-brokerages. Dani, Pujari, and Gulati (2005) and Engel, Wellman, and Lochner (2006) discuss the optimal matching problem in two-sided multi-attribute auctions that involve multiple buyers and sellers. Some exact algorithms or CPLEX software techniques are proposed to solve the matching problem. Kim, Chung, Hwang, and Ko (2005), Placek and Buyya (2006) and Schnizler, Neumann, Veit, and Weinhardt (2008) study multi-attribute trade matching models in goods distribution brokerage, storage services brokerage and grid services brokerage, respectively. They also use heuristic algorithms and CPLEX software techniques to solve the models. Gujo (2008) introduces an approach for multi-attribute inter-enterprise exchange of logistics services, which based on combinatorial auction and multi-attribute bid formation.

Nevertheless, most of the existing literature related to one-shot multi-attribute exchange is based on optimization models that assume the objective function is only relative to the price, such as maximizing the trading surplus or profits, and other non-price attributes are regarded as the constraints. In fact, other non-price attributes, such as "*quality*, *delivery time*, *after-sale service* ", should not only satisfy the constraints, but also be considered in the objective function. Another widely used assumption is to have a linear or piecewise linear relationship between price and quantity. However, this assumption is quite unrealistic because most sellers have nonlinear quantity discounts for multiple units of the same commodity. Thus, our work differs from these contributions in that we propose a multi-objective model to optimize trade matching in one-shot multi-attribute exchanges with quantity discounts. One objective is to maximize the matching degree from both the buyer's and the seller's points of view, and the other is to maximize the trade volume (profits) from the broker's point of view. Furthermore, a novel hybrid multi-objective meta-heuristic algorithm named MOSAGA is developed in order to solve the model.

3. Matching degree and quantity discount

3.1. Definition of matching degree

There are three principal roles played by actors in a one-shot multi-attribute exchange based on E-brokerage, that is, buyer, seller, and broker. The broker is often called the facilitator, who acts as an intermediary in the commodity exchange between the buyer and the seller. In this paper, we consider the broker is to match m ($m \geqslant 1$) buyers and n ($n \geqslant 1$) sellers for the same multi-attribute commodity in order to satisfy their requirements. Moreover, buyer b_i ($i \in I = \{i|i = 1, \ldots, m\}$) and seller s_j ($j \in J = \{j|j = 1, \ldots, n\}$) have e_i and f_j units of the commodity with l attributes to buy or sell.

From the buyer's point of view, buyer b_i can represent his requirements for the kth attribute of the commodity, where $k \in K_b = \{k|k = 1, \ldots, l_b\}$ and $l_b \leqslant l$. We can define the buyer's requirements as the constraints. These constraints are divided into two kinds of constraints: *hard constraints* and *soft constraints*. Hard constraints are represented in the form of an "equal to" notation. Soft constraints are represented in the form of inequality and the constraints can be relaxed within the given scope of values. There are also three kinds of soft constraints as follows:

(1) *Benefit soft constraints*, such as the quality of the commodity. The higher its value, the keener a buyer would be to buy it. Correspondingly, the quality is regarded as the benefit soft attribute.