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Efficient intermodal transportation auctions for B2B e-commerce logistics with transaction costs

Su Xiu Xu, Meng Cheng, George Q. Huang *

HKU-ZIRI Lab for Physical Internet, Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Hong Kong

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ABSTRACT

We propose efficient intermodal transportation auctions for the *B2B e-commerce logistics problem* (ELP). This paper is among the first to consider transaction costs into auctions. In the ELP, the shipper is a B2B e-commerce platform by which a number of online orders between goods sellers and buyers are generated, and 3PLs (third-party logistics providers) can fulfill these online orders. The shipper bears transaction costs while goods sellers or buyers eventually pay intermodal services. We extend both *Vickrey–Clarke–Groves* (VCG) auction and *primal–dual Vickrey* (PDV) auction to the ELP where total logistics chain cost is minimized. The VCG-like auction realizes incentive compatibility, allocative efficiency, individual rationality, and budget balance for general valuations; while the PDV-like auction need presume the condition of *seller-submodularity*, which implies that the effect of each 3PL is decreasing when coalition increases. Computational results show that incorporating transaction costs leads to considerable cost saving for the shipper, shipper's group (that consists of the shipper herself, good sellers and buyers), and the logistics chain, as well as higher profitability for the group of 3PLs. As the variance of transaction costs increases, incorporating transaction costs leads to higher cost saving for the entities that matter to the shipper (i.e., herself, her group, and the logistics chain), and higher profitability for the group of 3PLs, regardless of valuation distribution type. Finally, we investigate the impact of self-interested shipper and the impact of the gap between intermodal service costs and transaction costs.

1. Introduction

The proliferation of e-commerce marketplaces and economic globalization have created enormous needs for intermodal transportation and opportunities for new means of logistics service procurement. According to a recent report of Frost & Sullivan (Vidyasekar, 2014), the global online B2B market is expected to reach $6.7 trillion in gross merchandise value by 2020, two times larger than the B2C market potential ($3.2 trillion). Online retailing is one thing but delivery is another. The effectiveness and efficiency of logistics systems is a critical success factor for e-commerce (Ricker and Kalakota, 1999; Ramanathan, 2010). A big challenge faced by B2B e-commerce companies like Alibaba (www.alibaba.com) is how to get the large number of online orders delivered quickly, safely and cheaply. It is no surprise that research and practice in B2B e-commerce logistics has emphasized the integrated logistics chains, where long-term relationships between B2B e-commerce platforms and third-party logistics providers (3PLs) facilitate optimization of *logistics chain cost*.

* Corresponding author.
E-mail address: gqhuang@hku.hk (G.Q. Huang).

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In general, the *B2B e-commerce logistics problem* (ELP) involves setting logistics service prices, determining transportation and inventory decisions, integrating B2B e-commerce and logistics trading, as well as utilizing common protocols and shared logistics assets to improve profitability and market efficiency. In the ELP, the shipper is a B2B e-commerce platform (e.g., Alibaba) by which a number of online orders between goods sellers and buyers are created and released to fulfillment. 3PLs can fulfill these online orders. The shipper is indeed the agent of goods sellers and buyers who eventually pay the 3PL services, and purchases logistics services on behalf of them.

This paper focuses on the ELP in the context of intermodal transportation. Typically, *intermodal transportation* can be defined as the delivery of containerized cargo from its origin to its destination by at least two transportation modes, the transfer from one mode to the next being executed at an intermodal terminal (Crainic and Kim, 2007). Besides the "pure" sea and inland transportation, *intermodal services* contain the supporting services like pick-up, storage, customs clearance, import–export documentation, and exception handling. We only consider the *door-to-door* services; that is, each container (1 TEU or 2 TEUs) links the initial goods seller to the final consignee (without consolidation). The shipper announces the set of requests, each of which is specified by one lane (origin–destination pair), a delivery schedule, intermodal service type, and minimal normalized quantity. Each request is indivisible, called *atomic request*. One trade order may be associated with multiple atomic requests. The set of atomic requests are assigned among 3PLs via a reverse combinatorial auction. The shipper is the auctioneer while 3PLs are bidders.

To date, little attention has been paid to auction-based intermodal transportation. Regarding recent reviews of intermodal transportation, see Crainic and Kim (2007), Caris et al. (2013), and SteadieSeifi et al. (2014). However, there are three streams of studies upon single-mode transportation procurement auctions: (i) *combinatorial auctions*, in which carriers are allowed to bid on groups of lanes (e.g., Sheffi, 2004; Song and Regan, 2005; Chen et al., 2009; Chang, 2009; Ma et al., 2010; Kuo and Miller-Hooks, 2012; Remli and Rekik, 2013; Xu and Huang, 2014); (ii) *sequential auctions*, in which transportation demands arrive randomly over time and each demand is auctioned sequentially (e.g., Garrido, 2007; Ağrali et al., 2008; Xu and Huang, 2015); and (iii) *double auctions*, in which bilateral bidding is allowed and the transportation market is cleared by the third-party auctioneer (e.g., Huang and Xu, 2013; Xu and Huang, 2013). See Xu (2014) for a detailed review. More recently, Kuyzu et al. (2015) optimize one carrier's bid prices in the *simultaneous* transportation procurement auctions where a (fixed) group of lanes are auctioned independently but simultaneously. In practice, intermodal transportation may be achieved by a single or several 3PLs; for example, Maersk Line (www.maerskline.com) can offer both inland and sea transportation services at a package price. To capture the "economies of scope", we hence use combinatorial auction approaches for intermodal transportation procurement.

Although online auctions are increasingly viewed as a viable mechanism for transportation procurement, the majority of auction models so far have ignored the impact of *transaction costs* on mechanism design. As Lucking-Reiley (2000) pointed out, online auctions lead to lower transaction, participation and information costs, as well as easier access to wider markets, increased geographic and temporal conveniences, and the ability for asynchronous bidding. On the other hand, nearly 30% of transportation e-marketplaces cease operations due to high transportation costs and low revenues (Goldsby and Eckert, 2003).

In fact, in addition to the payments for supporting services, intermodal service procurement via online auctions occurs transaction costs, including costs associated with the potential risk and damage during transportation, service quality, delivery lead time, shipper-3PL relationship, and 3PL reputation. A simple example below demonstrates the benefits of incorporating transaction costs into mechanism design (not merely auctions). Consider a shipper who will choose one winner between 3PL-1 and 3PL-2 for one atomic request. 3PL-1's (real) cost for that request is $55, while 3PL-2's cost is $50. The shipper's transaction cost that is associated with 3PL-1 is $10, and that is associated with 3PL-2 is $20. Clearly, 3PL-2 will be the winner if total 3PLs' cost is minimized ($50); however, 3PL-1 wins if total logistics chain cost is minimized ($65). In this example, incorporating transaction costs leads to cost saving of 50% and 7% for the shipper and logistics chain, respectively.

Our auction model will take into account transaction costs. The problem faced by the shipper is then to design an *efficient* auction mechanism that minimizes the sum of intermodal service costs and transaction costs (i.e., logistics chain cost). Chu and Shen (2006, 2008) are among the first that propose asymptotically efficient double auctions with transaction costs. However, this paper aims to devise allocatively efficient (one-sided) combinatorial auctions where the auctioneer bears transaction costs and investigate the pros and cons of incorporating transaction costs.

From the perspective of auction mechanism design, this paper is most related to Xu and Huang (2014). Specifically, Xu and Huang (2014) propose two allocatively efficient combinatorial auctions for the distributed transportation procurement problem, which is generally the problem of matching demands and supplies over a transportation network. The objective of their auction model is to minimize the total transportation cost. The first mechanism is called *one-sided VCG* (Vickrey, 1961; Clarke, 1971; Groves, 1973) auction, and the other one is called *primal–dual Vickrey* (PDV) auction that is indeed a multi-round descending mechanism. The PDV auction eventually realizes the outcome of (one-sided) VCG auction under the condition of *seller-submodularity*, which implies that the effect of each individual seller (e.g., 3PL) is decreasing when coalition increases. In this paper, we extend both VCG auction and PDV auction (Xu and Huang, 2014) to the ELP where total logistics chain cost is minimized. We further investigate the impact of incorporating transaction costs on logistics chain performance. Our computational results demonstrate that besides cost saving for both the shipper and logistics chain, incorporating transaction costs will lead to higher overall profitability for 3PLs.