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An iterative auction for carrier collaboration in truckload pickup and delivery

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ABSTRACT

While carriers can collaborate to reduce empty traveling miles in truckload shipping, this is difficult to realize because each party is self-interested who may not share his private information that is necessary for the cooperation. In this paper, we propose an iterative auction scheme, which enables carriers to collaborate by exchanging their shipping requests iteratively. The auction is shown to be incentive-compatible, individually rational, budget balanced, monotonic, and convergent. Computational experiments indicate that it has small efficiency loss and can significantly improve carriers' profits. We also develop two acceleration methods and extend the auction to more general problems.

1. Introduction

Collaboration is increasingly popular in logistics industry. Through asset sharing, carriers can collaborate to reduce overall operating expenses and carbon emissions, improve asset utilization levels, and create a win-win solution for the industry and the society (U-TURN Project, 2015; World Economic Forum, 2016). In the highly competitive full truckload (TL) shipping industry, traditionally carriers operate independently without cooperation, and receive only very low profit margins. The profits of carriers are further eroded by costs on the empty traveling miles because of the imbalance of freight requests from different shippers. The Economist (2016) reports that truck drivers in the United States log about 50 billion empty miles each year, which is approximately 28% of the total traveling miles; in Europe, 25% of the containers on the road are empty. In China, the empty traveling rate of road freight transport even reaches the level of 40–50% (Qianzhan.com, 2015).

This paper considers carrier collaboration in truckload shipping, where the transport of goods takes up the space or weight limit of an entire truck. Specifically, a TL carrier operates a fleet of trucks to pick up and deliver customers' TL freight requests. A TL request consists of picking up a full truckload at one location and delivering it to another location. After completing the delivery, a truck typically runs empty on the way to pick up the next request or backhaul. Fulfilling a request generates a revenue but traveling empty with no freight incurs only costs. To reduce deadhead empty traveling miles, carriers can strategically collaborate with each other by jointly creating a freight movement solution that reduces one-way movements and empty traveling miles (Barbara et al., 2012). Request exchange in the collaboration allows carriers to sell or buy requests so that each carrier can strategically optimize his pickup and delivery routes to improve profit.

Our study is motivated from the increasingly popular industry practice in collaborative pickup-and-delivery among carriers. The importance of this problem is widely recognized in the literature; See, e.g., Liu et al. (2010a),Adenso-Díaz et al. (2014), Li et al.

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(2015),Hezarkhani et al. (2016). U-TURN Project (2015) reports that TL carrier collaboration is typically facilitated by a collaborative logistics network platform, e.g., LeanLogistics, Transplace, and Hitachi Transport System. Through sharing their transport resources, carriers can utilize the synergies among freight requests and thus gain more profits. For example, the GreenLanes platform of LeanLogistics creates continuous movement of assets and optimizes the routes for the carriers and shippers participating in the network. Currently, GreenLanes optimizes over 25 million annual loads across U.S (The LeanLogistics, 2014). PR Newswire (2009) reports that GreenLanes can achieve a reduction of empty miles from 15% to 20% down to 3% to 5% in most cases.

Realizing the full benefits of carrier collaboration is, nevertheless, very challenging. It is generally difficult to find the routes that minimize the empty traveling miles even in the centralized setting (Ropke and Pisinger, 2006). Furthermore, as pointed out by Agarwal et al. (2009), the effective collaboration requires the carriers to share their private and sensitive information, e.g., operational cost efficiency and request revenues, which would not be practicable. It is of necessity to design a proper mechanism that facilitates the successful collaboration among carriers who are self-interested and aim to maximize their own profits.

The famous Vickrey-Clarke-Groves (VCG) mechanism requires finding the exact optimum of the centralized problem with all players directly reporting their private sensitive information. This is considered as impractical or inapplicable (Barrera and Garcia, 2015). In a VCG mechanism, a player is awarded with the difference between the welfare of all the players when this player is in the collaborative system and that if he was not. In contrast, iterative auctions are well known for the advantages in solving computationally difficult collaboration problems and preserving sensitive private information (Kalagnanam and Parkes, 2004). In this paper, we develop an iterative auction mechanism with multi-round exchanges of freight requests. At each iteration of the auction, each carrier can sequentially decide on the requests to buy and the requests to sell; the mechanism optimally assigns the role of buyer (*i.e.*, the one that sources requests from other carriers) or seller (*i.e.*, the one that outsources his own requests to others) to each carrier and matches the supply with the demand. The second-price auction is used for the exchange at each iteration, where for each selling request the highest bidder wins and pays the second highest price. During the iterations, a carrier may be rotated to different roles and his profit is monotonically increasing. The auction continues until no exchange is possible.

The iterative auction mechanism we propose for carrier collaboration in truckload pickup-and-delivery has the following features.

(i) First, the auction mechanism is easily computable and introduces flexibility for bidding. The new auction does not require the carriers to evaluate an exponential number of bundles for either selling or buying as in Xu et al. (2016), and hence reduces computational efforts. The auction neither restricts that each carrier can only bid one request at a time, which typically stops too soon and results in high efficiency gap (Li et al., 2015). Instead, each carrier is allowed to bid for multiple requests and propose a bundle for selling. In this way, the rate of matching the demand with the supply can be high while the efficiency gap is small. Furthermore, our auction separates the buying and selling decisions of a carrier, so that there is no competition on the sellers' side but only on the buyers' side. As a result, the bidding process is simplified and guarantees that the supply always has a demand.
(ii) Second, the auction is proven to be incentive compatible, individually rational, and budget balanced. In addition, the auction can monotonically increase the total profit of the carriers and converge in finite steps, as shown by both theoretical proofs and evidence from computational experiments. Computational results on small-scale instances show that the auction reaps most of the potential collaboration benefits, with an efficiency gap 2.93% and an individual profit increase 7.21% on the average.
(iii) Finally, we show that the auction for large-scale problems can be accelerated by two methods based on an insertion heuristic; Moreover, the auction can be extended to more general problem settings (including additional constraints and transaction cost) with minor changes in the model while the theoretical results still hold.

The remainder of the paper is organized as follows. In Section 2, we review the relevant literature on carrier collaborative transportation. In Section 3, we describe the collaborative TL pickup-and-delivery problem and formulate the individual and centralized optimization models. In Section 4, we propose an iterative auction to facilitate the collaboration in the presence of private information. In Section 5, we analyze the properties of the auction mechanism. In Section 6, we conduct computational experiments to analyze the auction and to reveal insights. In Section 7, we extend the auction to more general settings. Finally, in Section 8, we conclude the main results of the paper.

2. Literature review

Collaborative transportation has become increasingly important in logistics and the related literature has dramatically grown during the last decade. Gansterer and Hartl (2017c) and Zhang et al. (2017) present extensive reviews on the state of knowledge in collaborative transportation. The main methodologies include centralized collaborative planning (Liu et al., 2010b; Adenso-Díaz et al., 2014; Wang et al., 2014a; Gansterer et al., 2017a; Kuyzu, 2017; Zhang et al., 2017; etc.), cooperative game theories (Özener and Ergun, 2008; Agarwal et al., 2009; Hezarkhani et al., 2016; Guajardo and Rönnqvist, 2016; etc.), non-auction exchange mechanism (Özener et al., 2011; Houghtalen et al., 2011; Wang and Kopfer, 2015; etc.), and auction-based exchange mechanisms (Berger and Bierwirth, 2010; Li et al., 2015; Xu et al., 2016; etc.), applied to collaboration in varied transportation modes. As our work is to improve profitability for truck freight carriers through collaboration facilitated by an iterative auction, in the following we review the relevant literature on mechanism design for less-than-truckload (LTL) carrier collaboration and truckload (TL) carrier collaboration. For other types of the literature, please refer to the reviews of Gansterer and Hartl (2017c),Lai et al. (2017), and Zhang et al. (2017).

Mechanism design studies for collaborative transportation are mostly based on lane/request or capacity exchanges. Through