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Benefits of in-vehicle consolidation in less than truckload freight transportation operations ☆

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ABSTRACT

Researchers and public agencies have proposed consolidation policies as an alternative to increase truck payload utilization and mitigate externalities produced by freight transportation. Understanding and enhancing the economic mechanisms that lead to freight consolidation can ease the implementation of these strategies, increase profits for shippers and carriers, and reduce freight-related negative externalities. An important mechanism that has recently been studied for cost reduction in the freight industry is combinatorial auctions. In these auctions, a shipper invites a set of carriers to submit bids for freight lane contracts. Carriers can bid for individual lanes or bundles of them according to their operational characteristics. These bids are constructed considering direct shipments (Truckload operations) and several biding advisory models have been proposed for this purpose. However, there are economies of scale that can be achieved if shipments are consolidated inside vehicles, which have not been explored in the construction of competitive bids. This paper investigates such benefits and provides insights on the competitiveness and challenges associated to the development of consolidated bids (suitable for Less-Than-Truckload operations). Consolidated bids are constructed using a multi-commodity one-to-one pickup-and-delivery vehicle routing problem that is solved using a branch-and-price algorithm. The numerical experiment shows that non-consolidated bids are dominated by consolidated bids, which implies that this type of operation can increase the likelihood of a carrier to win auctioned lanes, while increasing its profits margins over truckload companies (non-consolidated bids), and keeping the reported benefits that combinatorial auctions represent for shippers.

1. Introduction

Freight transportation is an important economic indicator of a nation. In 2010, the demand of transportation related goods and services represent 9.1% ($1,316 billion dollars) of the United States (US) Gross Domestic Product (GDP) ($14,499 billion dollars). In the same year, for-hire transportation services represent 2.8% of the US GDP ($402.5 billion dollars), where trucking contributed to 28.8%, followed by air transportation 15.7%, and rail 8.0%, i.e. $116, $63.3, and $14.7 billion dollars respectively (USDOT, 2012). Despite the economic importance of trucking operations, there are several externalities associated to trucking, e.g., congestion, pollution, noise and accidents. One strategy to mitigate these externalities is to utilize unused capacity inside the trucks (EC-DGET, 2006; OECD, 2003; Sathaye, 2006; TFL, 2007). Understanding

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and promoting economic mechanisms that improve truck utilization while enhancing shippers and carriers profits can accelerate the acceptance and implementation of such strategies.

An evolving market mechanism used to assign freight contracts to carriers is combinatorial auctions, which has shown costs savings for both shippers and carriers. These auctions have been successfully implemented by several firms, e.g., Home Depot Inc., Wal-Mart Stores Inc., Compaq Computer Corporation, Staples Inc., The Limited, K-Mart Corporation, Ford Motor Company, Reynolds Metal Company, Sears Logistics Services, among others (De Vries and Vohra, 2003; Elmaghraby and Keskinocak, 2004; Moore et al., 1991; Porter et al., 2002; Sheffi, 2004).

A freight transportation combinatorial auction is a reverse auction, i.e., auctioneers are buyers and bidders are sellers. Thus, a shipper auctions freight lanes, i.e., shipments to be transported between geographically distributed origins and destinations, and a group of carriers bid for them. The main characteristic of a combinatorial auction is that, rather than bidding for individual lanes, carriers can bid for bundles of lanes. This is attractive to the shippers because the price of a shipment served as part of a bundle is usually lower than or equal to the price of serving it individually. Once all the bids are collected, the shipper solves the Winner Determination Problem (WDP) to match lanes with the most appropriate carriers. Extensive research has been conducted to formulate and solve the WDP in combinatorial auctions (Abrache et al., 2007; Caplice and Sheffi, 2006; Ma et al., 2010; Sandholm, 2002). On the other hand, carriers are responsible for building and submitting bids that are attractive to the shipper. Competitive prices are usually achieved when the quoted lanes are complementary to the routes operated by the carrier. Previous researchers propose bidding advisory models to solve this problem (Chang, 2009; Lee et al., 2007; Song and Regan, 2003, 2005; Wang and Xia, 2005).

Defining appropriate routes is important for the carriers to distribute the variable cost among their clients, achieving different levels of economy, and quoting competitive shipping prices. To understand how this has been done previously, we briefly review the microeconomic operation of trucking firms. The total income perceived by a carrier is the sum of the prices charged to each shipment transported in a time period. Likewise, the total cost is the summation of costs associated with the delivering routes plus fixed costs. The total profit is defined by the difference between these two. For example, for a carrier serving the shipment h charged with a price p_h following the route r_h, the total profit associated with this shipment is $\Pi(h) = p_h - c(r_h) - c_o$, where $c(r_h)$ is the total cost related to the operation of route r_h, and c_o are fixed costs. To observe how route definition affects the value of the prices, assume that there is another shipper that needs transportation for a shipment k and requests a quote from the carrier. If the carrier decides to charge a price p_k for that shipment, the corresponding total profit would be $\Pi(h,k) = p_h + p_k - c(r_{h\cup k}) - c_0$, where $r_{h\cup k}$ is the route serving both shipments h and k. For a rational carrier it is expected that $\Pi(h) \leqslant \Pi(h,k)$, and therefore, $c(r_{h\cup k}) - c(r_h) \leq p_k \leq \hat{p}_k$, where $\hat{p}_k$ is an upper bound determining the maximum price that the shipper is willing to pay for this service. Notice that if the carrier can serve both shipments following the same route, then $c(r_{h\cup k}) = c(r_h) + \Delta c$ where Δc is a small cost increment and, therefore, $\Delta c \leqslant p_k \leqslant \hat{p}_k$. Furthermore, p_k might be reduced down to Δc without affecting the carrier profits. But, if the new shipper accepts to pay a price $p_k > \Delta c$ that would imply more profits for the carrier. This shows that bidding for lanes complementary to the routes currently operated by the carrier has the potential of reducing the prices charged to these lanes and increasing the probability of getting the contracts. The variable costs for these routes depend on operational characteristics of the carrier, e.g., the number of vehicles operated, total distance traveled, repositioning of vehicles, geographical location of the pickups and deliveries, current commitments, location of the depot, among others. Considering all these elements in the construction of a bid is not easy and potentially leads to suboptimal solutions.

The complexity of building competitive bids has been studied by several researchers. In their seminal works, Song and Regan (2003, 2005), investigate the benefits perceived by carriers that participate in combinatorial auctions. They conclude that these auctions are more beneficial than simple sequential sealed-bid auctions and present methods for bid valuation and bid construction that require the solution of a NP-hard problem. The models presented by Song and Regan assume that the carrier has availability of vehicles at each node in the network, unlimited vehicle capacity and Truckload (TL) operation. In this context, Wang and Xia (2005) clarify the bidder's optimality criterion and present heuristic methodologies to solve this problem. They consider a central depot, which relaxes one of the previous assumptions. Additionally, Lee et al. (2007) approach this problem based on a vehicle routing methodology. Their formulation constructs routes by optimally trading off repositioning costs of vehicles and the rewards associated with servicing lanes. Likewise, this formulation relaxes some of the previous assumptions and is solved using a suitable methodology based on column generation. Once again, their formulation is only appropriate for carriers with TL operations. Finally, Chang (2009) develops a bidding advisory model for TL carriers using a minimum cost network flow problem.

Previous biding advisory models focus primarily on carriers with TL operations, where shipments are sent directly from origin to destination using an exclusive truck -similar to the use of taxis by passengers. This type of operation is mainly driven by economies of scope. These economies are achieved when there are follow-up loads that reduce the number of empty trips in a given trip chain/route (Caplice, 1996; Jara-Diaz, 1981, 1983). This concept is illustrated with the following case based on the previous example, as well as the directed network and demand scenarios shown in Fig. 1 (*i*, *ii*, and *iii*). Without loss of generality, let us assume unitary traversing costs c_{ij} for each link (i,j) in the network. For a TL carrier in Scenario (i) (Fig. 1), the route $r_h^{(i)}$ involves picking up the shipment h at node 1, traveling to node 2, delivering at node 3 and returning empty to node 1 via node 4, i.e., trip chain $r_h^{(i)} = \{(1,2),(2,3),(3,4),(4,5)\}$, and total cost $c(r_h^{(i)}) = 4$ units (notice that the superscript in parenthesis indicates the referred scenario). In scenario (ii), the TL carrier has to pick up k at node 2 and deliver it at node 4. This implies a new trip chain $r_{h\cup k}^{(ii)} = \{(1,2),(2,3),(3,2),(2,4),(4,1)\}$ with total cost $c(r_{h\cup k}^{(ii)}) = 5$ units. Thus, the price charged to the new shipment $p_k^{(ii)}$ has to be defined in the range $[\Delta c^{(ii)}, \hat{p}_k]$, where $\Delta c^{(ii)} = c(r_{h\cup k}^{(ii)}) - c(r_k^{(i)}) = 1$, i.e.,