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Service level, cost and environmental optimization of collaborative transportation

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A B S T R A C T

Less than truckload is an important type of road-based transportation. Based on real data and on a collaboration with industry, we show that a collaborative approach between companies offers important benefits. We propose to develop partnerships between shipping companies and to synchronize their shipments. Four operational collaborative schemes with different objectives are developed. The first one focuses on minimizing shipping costs for shippers. The second and third ones minimize the carrier's costs and the environmental cost, respectively. The fourth one is a combination of all three. The results of our computational experiments demonstrate that collaboration lead to significant cost reductions.

1. Introduction

Road transportation of freight plays a central role in modern manufacturing industries. In many cases, trucking continue to be the dominant mode of transportation even across borders, such as the case of Canada and the United States. In 2014, 44.4% ($179 billion) of exports and 69.1% ($192 billion) of imports were transported by trucks between Canada and the United States, representing 54.5% of overall trade between these two countries, and 42.7% of all Canadian trade (Transport Canada, 2014).

Road transportation can be split in two types of shipping: truckload (TL) and less than truckload (LTL). TL shipping is the most advantageous option in terms of cost and service quality. It consists of a fully or partially loaded truck going to a single destination at a fixed price (Toptal and Bingöl, 2011). TL shipping does not require multiple pickups and deliveries compared to LTL. TL freight is also priced significantly lower per unit. On the other hand, LTL shipping is appropriate for the shippers who do not have a big cargo and do not want to pay the entire truck cost (Özkaya et al., 2010). Since it needs more loading and unloading operations and often a visit to a consolidation center, LTL transportation is generally slower and more costly per unit.

There are three common ways for carriers to charge for LTL shipments. Depending on their specializations, their activity areas (types of products transported) and their partnerships with clients, they can use *weight* pricing, *pallet position* pricing or *linear feet* pricing. An LTL pricing grid essentially presents the price charged to travel from the distribution center to a given location (one single delivery) depending on the quantity (expressed in weight, pallets or linear feet) and the type of product shipped. This pricing grid includes several implicit costs such as distance-based components (fuel, maintenance, tolls, etc) and temporal-based components

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(equipment depreciation, salary, etc). Knowing the distance and the time to a destination, economies of scale arise because all the items in a shipment share the fixed cost of the vehicle utilization (Daganzo, 2005; Tsao and Lu, 2012). Thus the fixed components from an origin-destination route are paid for each vehicle used.

LTL pricing grids advantage carriers because there are no financial benefits for shippers to manage and synchronize more effectively their expeditions throughout several destinations. Even if they dispatch to close destinations, they are generally charged separately. Some carriers accept as one single shipping (at a better rate) two different loads for destinations which are close together. This is called multi-drop LTL and associated rates are generally negotiated through special contracts. In this case, carriers may charge a fee for each additional drop. Hence, multi-drop LTL decreases costs and the number of non-synchronized movements that cause significant economic and environmental losses. Unfortunately, this option is not frequently used by freight shippers and carriers.

This paper is positioned within the field of collaborative transportation management, which includes shippers and carriers collaboration. They are often considered independently due to their perspectives and benefits for each side. Carrier collaboration seems to be more studied in the literature (Yilmaz and Savasaneril, 2012). Cruijssen et al. (2007) assess the potential benefit of this horizontal cooperation between carriers in a large empirical study in Europe. The objective is the minimization of total transportation costs based on distance and it is often formulated as a pickup and delivery problem with time-windows (Savelsbergh and Sol, 1995; Cordeau et al., 2007; Krajewska et al., 2008; Dai and Chen, 2009). Since there are several carriers serving a set of shippers, there will be a global profit from sharing their infrastructure and maximizing vehicle loading (Liu et al., 2010a). Agarwal and Ergun (2010) study carrier alliances in the liner shipping and determine side payments that align decisions of carriers within the coalition. Berger and Bierwirth (2010) and Wang and Kopfer (2014) present a carrier collaboration in which requests are optimally shared. Liu et al. (2010b) study a problem in which a TL carrier receives requests from shippers and decides upon using his vehicles or outsourcing the request. Zhang et al. (2017) consider a carrier collaboration network for the e-commerce logistics system with multiple LTL carriers and vehicle types.

Shipper collaboration, on the other hand, considers only a single carrier and focuses on finding optimal routing decisions for different shippers, minimizing the distance (Ergun et al., 2007b). Shippers may benefit by establishing a private community in which they share information (Kale et al., 2007). These benefits come from the ability to use advanced information on available capacity to better use the spot market. There are two main variants of this problem. The first one arises with large-scale shippers having enough volume to fill a truck and collaborating with other shippers to guarantee back-hauls for the carrier (Yilmaz and Savasaneril, 2012). Since the price paid includes all the implicit truck-repositioning costs such as returning to its distribution center (potentially empty), the shipper can negotiate significant discounts by guaranteeing that the carrier will have back-haul cargo (Ergun et al., 2007a). The second variant arises with shippers making occasional small shipments who collaborate with other shippers by consolidating their cargo to share a single line-haul in order to pay a price closer to that of a TL. To obtain savings, the origin and destination of shipments must be reasonably close. This is the context in which this paper is positioned. Ergun et al. (2007a,b) address a shipper collaboration problem in which fixed schedules are used to reduce dead-hauling cost by making repeatable continuous movements. Frisk et al. (2010) study the collaboration among eight lumber shippers in forest transportation to obtain one-way TL shipments. Kale et al. (2007) study three types of collaborative transportation: when only shippers collaborate, only carriers collaborate, and both shippers and carriers collaborate. The collaborative networks are assumed to operate as a spot market. The utilization of transportation hubs with collaboration is studied in Groothedde et al. (2005) in which several shippers use a network of transportation hubs in many-to-many markets.

In the LTL context, Audy et al. (2011) present a case study of four Canadian furniture manufacturers. The authors design a cost-allocation scheme and provide a sensitivity analysis on the savings needed to convince manufacturers for joining the coalition. Cruijssen et al. (2010) study the case of Dutch groceries in which shipper collaboration is facilitated by a logistics service provider. Consolidation of orders results in savings due to more efficient routes. Zhou et al. (2011) compare two levels of collaboration in a market characterized by randomly arriving loads with delivery deadlines. Consolidation levels are determined through simulation. Yilmaz and Savasaneril (2012) address the coalition formation among small shippers in a transportation market characterized by uncertain demands using a game theoretical approach. They show that shippers always benefit from the collaboration. Estrada-Romeu and Robusté (2015) present a methodology to identify when freight consolidation strategies are cost-efficient. Shipments are assigned based on proximity and cost criteria and improved with a tabu search algorithm.

Most of the existing literature focuses on gains or cost sharing among partners, and some on distance minimization. We take a more encompassing approach, assessing not only costs or distances, but also service levels in the sense that we evaluate transportation operations and departure timing as well. Cost impacts for shippers and carrier are studied in order to design balanced scenarios.

Moreover, not only costs and time influence shipping decisions. Transportation activities account for 27% of the total global CO_2 emission, and among them the top CO_2 producer is road transportation (78.8% of all transportation emissions) (Bektaş et al., 2016). Other types of emissions, such as methane (CH_4) and nitrous oxide (N_2O), are also important greenhouse gases (GHGs), and are accounted for in what is called CO_2 equivalent (CO_2e) emissions (MERN, 2014). A recent but growing body of research focuses in green logistics activities (Demir et al., 2012). Recent developments in this area include Demir et al. (2011), Dekker et al. (2012), Erdoğan and Miller-Hooks (2012) and Lin et al. (2014). Incorporating fuel consumption models into classical routing is a way of explicitly accounting for emissions in the route planning, in what is called Pollution-Routing Problems (Bektaş and Laporte, 2011; Demir et al., 2014).

We have partnered with three Canadian manufacturing companies in the province of Québec operating in the same industrial park and having many LTL shipments to the United States. Based on this collaboration, we propose to develop partnerships with other companies who share common client locations and by synchronizing their shipments. Most shippers form the park use different