USDOT Region V Regional University Transportation Center Final Report

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Modeling of Collaborative Less-than-truckload Carrier Freight Networks

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TECHNICAL SUMMARY

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Title

Modeling of Collaborative Less-than-truckload Carrier Freight Networks

Introduction

Less-than-truckload (LTL) carriers, which operate on thin margins, have significant negative impacts due to empty trips, idled capacity on lots, and rising energy costs. The impacts can cascade to other industries; for example, empty trips may affect global food prices. Recent advances in Internet and information communication technologies (ICT) foster the possibility of innovative new business and operational paradigms within the small- to medium-sized LTL industry to address these concerns. One promising innovation is the concept of LTL carrier-carrier collaboration, which provides opportunities for LTL carriers to exploit synergies in operations (such as excess capacity), reduce costs associated with fleet operation, decrease lead times, increase asset utilization (power units), and enhance overall service levels. LTL carrier-carrier collaboration is a relatively unexplored concept within the freight domain, where past studies have focused on collaboration within the truckload (TL) carrier, liner shipping, airline, and rail industries. This research seeks to understand and develop LTL collaborative paradigms from the supply and demand perspectives, thereby filling a key gap in the current freight collaboration literature.

Findings

Based on a survey of freight carriers, we obtain the following findings. First, carriers show propensity for collaboration. Variables related to collaboration were found to be significant in the mixed logit model developed in the study, including “carrier’s concern for rising fuel prices”, “very likely to collaborate for increased fuel savings” and “non-unionized carrier collaboration.” The significance of these variables illustrates that LTL carriers are concerned with the potential economic impacts of fuel price fluctuations and the possibility of forming collaborative alliances. On the opposite side of the spectrum, the capital investment alternative was considered to be the least viable option. This implies that the LTL carriers surveyed are less likely to commit assets for the acquisition of additional capacity for meeting demand requirements under a short-term planning horizon. Hence, collaborative alliances can provide a critical strategy for the survivability of LTL carriers in a highly competitive industry, especially under economic downturns and fuel price fluctuations.

This study modeled the LTL collaborative paradigm as a binary (0-1) minimum cost flow problem which takes advantage of the LTL notion of transfer and that of the specific point-to-point operating network of the small- to medium-sized LTL carriers. The experiment results indicated that the carrier collaborative paradigm can potentially increase capacity utilization for member carriers, thereby generating the potential to gain revenue on empty-haul trips. In addition, as the degree (or level) of collaboration increases, the relative attractiveness of utilizing collaborative capacity increases compared to the non-collaborative alternative. The non-collaborative alternative can become attractive only at relatively high fuel prices, at points where the benefits of collaboration are negated. The transfer cost policy can have differential effects on capacity utilization, leading to implications for terminal congestion and design.

Recommendations

The research addressed in this project suggests that the carrier-carrier collaborative paradigm can represent an important and viable option for the LTL small- to medium-sized carrier industry in terms of their long-term sustainability, while leveraging recent ICT technological advances in an innovative manner. Further, this research serves as a building block for exploring a new generation of analytical frameworks for LTL carrier collaboration.

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CHAPTER 1. INTRODUCTION

1.1 Background and Motivation

The less-than-truckload (LTL) carrier industry represents a segment of the trucking industry which specializes in the movement of "mid-sized" shipments as opposed to very small (parcel carrier) or very large (truckload) shipments. Typically the size of shipment ranges from a few hundred pounds to about 48,000 pounds, which are then moved over a network of warehouses, depots, and distribution centers. The movement of goods over these networks produces a significant amount of empty trips (moving empty), leading to additional costs to the carriers. These costs are then passed on to members of the supply chain through increased rates.

Moving empty can greatly impact the profitability of the LTL carrier industry which already operates under thin profit margins. Consequently, the carrier segment that experiences the greatest impacts due to their size and scope within the LTL industry is the small- to medium-sized LTL carriers. That is, there are fewer large LTLs in operation today compared to hundreds of smaller- to medium-sized LTLs (Belman and White III, 2005). As a result of this dichotomy, larger more-established LTL carriers can afford to reject shipments and/or simply absolve themselves from the responsibility of shipments that do not sufficiently yield any monetary gain. These carriers can afford to do so because of the economies of scales under which they operate. By contrast, the small- to medium-sized LTL carrier segment is entrenched in an everyday struggle to maintain profitability. Therefore, the ability of these carriers to remain competitive hinges on how well they can manage their current fleets in terms of efficiently utilizing existing capacity.

Additional operational stresses have mounted for the small- to medium-sized LTL carrier industry since the advent of the Internet in the 1990s. The Internet has changed the spatial distribution patterns of demand, which has created geographical coverage problems for LTL carriers with respect to meeting on time pickup and delivery of goods. This spatially spread demand has stretched the capabilities of these carriers in terms of providing sufficient capacity to meet the demand requirements, and as a result has also created an increase in the number of empty trips (deadheading). However, while the Internet has introduced new challenges, it has also created potential new opportunities for carriers to benefit from the increased coverage. That is, these carriers can now penetrate markets once deemed inaccessible. With this new possibility, these carriers are seeking to establish relationships with similar carriers to enhance operational efficiency, which are made possible through the increased use of the Internet (e-commerce activities), and the relative affordability and advances in the capabilities of information communication technologies (ICT).

As a result, the increased use of the Internet and ICT is fostering new business and operational paradigms within the small- to medium-sized LTL industry. One manifestation of this is the increase in carrier-carrier collaboration; LTL carriers have begun to develop a new generation of strategies that exploit synergies (such as excess capacity) which can form the basis for some form of collaboration. Such collaborative efforts are innovative and can lead to more system-wide efficiency. They can help firms reduce costs (fuel costs), decrease lead times, increase asset utilization, and improve overall service levels (Agarwal and Ergun, 2008; Esper and Williams, 2003).

Collaboration between carriers has emerged as a deployable alternative for small- to medium-sized less-than-truckload (LTL) carriers to improve fleet usage and increase operational efficiency. This research attempts to fill the gap in current collaborative freight transportation literature from the perspective of the LTL industry. In addition, this research seeks to develop LTL carrier collaborative models to gain insights on the viability of the collaborative paradigm in the LTL industry.

1.2 Objectives

The primary objective of this project is to provide an analytical foundation for exploring the LTL collaborative paradigm from both the demand side (econometric modeling) and supply side (network modeling) perspective of small- to medium-sized LTL carriers. The proposed demand side approach is motivated by the need to understand the propensity of LTL carriers to collaborate, and the supply side approach is motivated by the need to identify collaborative opportunities over an LTL operating network to improve operational efficiencies. The specific problems addressed to achieve these objectives are:

(i) Review the current state-of-the-art of the collaborative paradigm for the freight transportation industry from the following perspectives: a) to identify the technologies that are influencing collaboration, b) to identify the various collaborative efforts analyzed in the literature, c) to identify emerging issues for LTL carrier-carrier collaboration, and d) to identify issues and characteristics specific to LTL carrier-carrier collaboration.

(ii) Develop an econometric modeling approach to determine the propensity for carrier collaboration within the LTL industry.

(iii) Develop an optimization model from a static planning perspective for a single carrier of interest to gain insights on the potential for LTL carrier-carrier collaboration. The primary focus of this is to determine the potential benefits of LTL carrier collaboration in terms of fuel costs savings, and capacity utilization under fixed and variable transfer costs and single and multiple product shipments.

1.3 Organization

This project is divided into five chapters. Chapter 2 reviews the current state of the collaborative paradigm. We review technologies that influence collaboration within the freight industry. Further, we review potential innovations in collaboration that technological advances make possible, with particular focus on LTL carrier-carrier collaboration and related emerging issues. We then discuss some key collaboration issues and characteristics for small-to medium-sizes LTL carrier-carrier collaboration.

Chapter 3 presents an approach based on data from a survey addressing the propensity for LTL carrier collaboration. Cluster analysis techniques are employed to identify groupings in the LTL carrier population on the basis of the five alternatives: (i) lease capacity from a rental services provider, (ii) make additional capital investment; that is, purchase addition power units, (iii) collaborate with another carrier, (iv) reject the load, and (v) other options. A mixed (random parameters) logit model is estimated to predict the probability of an LTL carrier belonging to a specific cluster group. The insights from the analysis indicate that the carrier groupings are influenced by a complex interaction of factors, and that the effect of some factors can vary across the carriers. The results show that the mixed logit model can provide a greater understanding of the interactions of variables which correlate with carrier groupings than traditional discrete choice models.

Chapter 4 addresses a single carrier collaboration problem (SCCP) in which an LTL carrier of interest seeks to collaborate with other carriers by acquiring capacity to service excess demand. The SCCP problem is addressed from a static (planning) perspective to gain insights on the potential of the collaboration concept for carriers, and its ability to alleviate the effects of increased fuel prices. The study also explores the impact of the degree of collaboration represented by the collaborative discount rate (for the collaborative capacity) on the carrier of interest. The collaborative strategies are compared to the non-collaboration option represented by a short-term leasing strategy, and the relative benefits of collaboration are computed. Experiments are conducted for two transfer cost policies to illustrate insights on: the computational performance under various factors, the effects of different degrees of collaboration, and the impacts of energy costs on the potential for collaboration. The results illustrate that a higher degree of collaboration leads to increased benefits for the carrier of interest and reduced dead-heading for the collaborating carriers. Collaboration also can be critical for the survival of the small- to medium-sized LTL carriers as energy prices escalate given the small industry-wide profit margins.

Chapter 5 summarizes the overall insights from the research and discusses future research directions.

CHAPTER 2. LESS-THAN-TRUCKLOAD CARRIER COLLABORATIVE NETWORKS: ISSUES AND CHARACTERISTICS

2.1 Introduction

Since the advent of the Internet in the 1990s, the less-than-truckload (LTL) industry has become more competitive than ever before. Shippers, usually larger manufacturers and retailers that have increased their transportation requirements due to innovative inventory practices and increased activity in e-commerce, have spurred the competition (Song and Regan, 2004). In addition, the Internet, along with information communication technologies (ICT), is prompting changes to the structure of transportation marketplaces by fostering more spatially spread demand (Anderson et al., 2003). These innovations have created new challenges for LTL carriers in the form of increased costs related to deadheading (moving empty) and increased energy prices. The greatest economic impact has been felt in the small- to medium-sized LTL trucking industry, which has endured increased costs that affect their ability to sustain profits. Low margins of profitability, spatially spread demand, and intense competition have incited a trend to seek solutions through information communication technologies (ICT) and the Internet (Mowery, 1999). One manifestation of this is the increase in small- to medium-sized LTL carrier-carrier collaboration. That is, the small- to medium-sized LTL carriers have begun to develop a new generation of strategies that exploit synergies (such as excess capacity), which form the basis for some forms of collaboration.

Collaboration is a relatively new concept within the LTL industry, although collaborative efforts have been observed between shippers, and between shippers and carriers. Overall, the body of research devoted to carrier-carrier collaboration in truckload carrier, liner shipping, airline, and rail industries is rich. However, there is a remarkable gap from the perspective of LTL carrier-carrier collaboration. To fill this void, we aim to add to the body of collaborative works by, first, reviewing the technologies that facilitate the various forms of collaboration found within the freight industry. By seamlessly connecting the collaborative partners, ICT technologies play an integral role in the facilitation of collaborative efforts. Next, we review the different forms of collaboration made possible by technological advances in shipper-shipper, shipper-carrier, and carrier-carrier collaboration. We then introduce the carrier-carrier paradigm from the perspective of the small- to medium-sized LTL carrier industry and present emerging issues that affect this form of collaboration followed by specific obstacles and characteristics.

The remainder of the chapter is organized as follows: Section 2.2 introduces the technologies influencing collaboration. Section 2.3 presents the various forms of collaboration with the freight industry. Section 2.4 discusses the emerging issues from the perspective of small- to medium-sized LTL carriers. Section 2.5 describes the various issues and characteristics with respect to the small- to medium-sized LTL carriers. Section 2.6 presents a summary and concluding remarks.

2.2 Technology Influencing Collaboration

Recent technological advances in the Internet, telecommunications, navigation and positioning, data exchange and fusion are making collaboration possible within the freight industry. Table 2.1 illustrates some of the technologies that are enabling collaboration.

2.2.1 Internet

Increased use of the Internet has nurtured new business paradigms through e-commerce. The trucking industry views e-commerce as those business processes that permit transactions and trade to take place on the web, as well as processes that use the Internet as a repository, an enabler, and a conduit of information (Nagarajan et al., 2000). E-commerce has changed the landscape of an already competitive trucking industry, especially the LTL industry. Trucking firms are using the Internet to form collaborative alliances through e-commerce opportunities. In so doing, they take advantage of quick accessibility to valuable information, communicative reach, and endless connectivity of the Internet. These tools allow them to exploit synergies among collaborators (for example, capacity availability in real time) , to explore newer opportunities for businesses, and to exploit the interconnectedness between collaborators, allowing them to expand their competitive reach to newer markets and improve efficiency to current services areas.

2.2.2 Telecommunications

Advances in telecommunications facilitate collaborative efforts by providing the necessary tools for real-time operational information to customers and/or partners. Tools such as electronic data interchange (EDI) and the Internet (for example, via email) seamlessly connect trucking firms and are more easily accessible and affordable through advances in satellite, cellular, and fiber optic technologies (for example, telephone line). From the perspective of collaboration, telecommunication technologies permit the connectivity of transportation networks through the seamless sharing of collaborative information, such as pickup and delivery of shipments, shipment transfers, and/or on any capacity that may need to be acquired to handle present or future shipments.

2.2.3 Data Exchange and Fusion

Advances in data exchange and fusion technology permit firms under a collaborative to share information without hindering or jeopardizing their competitiveness in a market. This is made possible through advances in the design of computer systems that ensure the convenient, flexible, secure, and adaptable blending of information from a wide range of independent informational sources (Mowery, 1999). One other form by which this could occur is through what is called secure multiparty computation (SMC). SMC is a cryptographic protocol among a set of participants, where some of the inputs needed for the interaction have to be hidden from participants other than the initial owner (Atallah et al., 2003). This technology allows a collaborative to exchange data and to share information critical to the success of the collaborative effort without hindering the firm or its partners.

2.2.4 Navigation and Positioning

For the collaborative (especially between carriers), near real-time tracking of the fleet is critical in improving efficiency (that is, the efficient use of collaborative capacity over the transportation network). Advances in navigation and positioning technologies have taken trucking from the use of pay phones to relay location information to automatic vehicle location (AVL) systems that constantly track entire fleets in real time (Mowery, 1999).

Smaller- to medium-sized firms are now finding that technology has become more affordable. Affordable technology allows firms to collaborate and exploit synergies from both the business and operational standpoints. The success of a collaborative will hinge on the willingness of partners to adapt to the changing times and trends in technology. Depending on the type of collaborative, the adoption of specific technologies will often be an essential component to success.

2.3 Forms of Collaboration

Members of logistics networks that take advantage of affordable information communication technologies have a significant advantage in making use of the opportunities that collaboration may bring. That is, a collaborative conceivably employs these technologies to provide the means for members to manage their relationships with logistic partners to utilize synergies (for example, services and excess capacity) that may exist and that would permit increased operational efficiency through reduced operational costs.

While the collaborative concept is relatively new within the transportation domain, logistics networks can apply it in various forms. Figure 2.1 illustrates the various forms of collaboration within a logistical network.

2.3.1 Shipper-Shipper Collaboration

As seen in Figure 2.1, within the shippers circle, shipper-shipper collaboration (for example, Kimberly-Clark and Lever Faberge) is geared towards improving the transportation performance of shippers. In this model, shippers may share information on shipping requirements. If one shipper has extra needs, it can negotiate with a second shipper in the collaborative community that has excess contracted capacity, thus creating cost savings for both shippers. The first shipper may receive below market prices for carrier capacity, while the second shipper may avoid defaulting with its contract carrier for reneging on contracted capacity (Kale et al., 2007). The shipper-shipper collaboration paradigm has been studied through both empirical studies and from operations research domains.

From the empirical domain, Bagchi et al. (2005) investigate the role of information sharing and collaboration among suppliers in Europe through a survey of 149 companies. Their study concludes that although collaboration has its benefits (improved performance), companies are quite cautious when it comes to information sharing and decision-making integration. Akintoye et al. (2000) report on a survey of the 100 largest contractors by value of projects in the United Kingdom (UK) on their opinions toward supply chain collaboration. Their study indicates that supply chain collaboration and management is an important element of construction. However, their results also indicated that companies must effectively address issues of trust, appropriate support structures, and ignorance to the supply chain philosophy if the construction industry in the UK adopts supply chain collaboration. Skjoett-Larsen et al. (2003) conduct a survey on the opinions of 218 companies in Denmark towards supply chain management and on collaborative planning, forecasting, and replenishment. Their results state that the companies in general had a positive attitude towards inter-organization collaboration. Also, their study indicated that specific aspects such as trust and common goals were highly significant factors for a successful collaborative.

From the operations research perspective, Ergun et al. (2007) developed one of the first shipper-shipper collaborative models that provided the means for shippers to share capacity. These models aimed to lower the costs incurred by transportation providers. The authors developed mathematical models for shipper-shipper collaboration for truckload (TL) movements based on a set covering formulation with the objective of finding a minimum set of weighted cycles in a network such that all the lanes are covered. Further, they develop heuristics to develop continuous tours. Nandiraju and Regan (2007), on the other hand, introduce a heuristic pricing allocation mechanism for shipper-shipper collaboration with the aim to lower logistics costs and improved asset utilization of both TL and LTL transportation providers. The authors formulate the shipper-shipper collaborative problem as a set packing problem that creates continuous move tours that are put out to bid and assigned to carriers.

2.3.2 Shipper-Carrier Collaboration

Shipper-carrier collaboration (between both circles in Figure 2.1), which can also be referred to as collaborative transportation management (CTM), considers collaboration between shippers and carriers where shippers and carriers share on shipment forecast information. Although this type of collaboration tends to be shipper controlled, some neutral exchanges do exist. Such neutral communities typically strive to benefit both parties; therefore, carriers may achieve higher capacity utilization and shippers fewer short shipments through information sharing (Kale et al., 2007). The academic literature is mainly focused on improving the relationships between the shipper and primarily TL carriers (Kale et al., 2007; Lynch, 2001; Esper and Williams, 2003).

From the empirical domain, Ha (2007) conducts both descriptive data analyses and path analysis with latent variables (a statistical method of finding cause/effect relationships) on the data obtained from 130 survey responses from motor carriers (for hire) and the shippers they serve. The study concludes that carriers improve service performance and increase shippers supply performance through collaboration.

2.3.3 Carrier-Carrier Collaboration

Finally, carrier-carrier collaboration (within the carrier circle) would consider the management of their relationships with shippers (that is, shippers would not mind having a carrier different from their usual contracted carrier to ship their goods). To accomplish this, the carriers would have to share capacity and shipment information for their own benefit (Kale et al., 2007). Therefore, the ability for a carrier, especially a small- to medium-sized one, to make a profit in a highly competitive market between carriers hinges on its ability to minimize its cost over a collaborative network. Recent trends in the freight transportation domain indicate that more and more carriers categorized as small to medium have begun to collaborate as a means to increase slim profit margins and level of competitiveness (O’Reilly, 2005). LTL carrier-carrier studies are nonexistent; though other industries have studied the collaborative paradigm using operations research methods.

Song and Regan (2004) introduced the notion of carrier-carrier collaboration in the TL industry. Carrier-carrier collaboration is assumed to occur in a post-market exchange where shipments on non-profitable lanes, assumed to be static and pre-determined by an optimization routine, are auctioned off to other carriers in the collaborative network. Figliozzi (2006) extends the auction-based collaborative carrier network by introducing a dynamic mechanism which is incentive-compatible. The mechanism is analyzed using a simulation procedure for a truckload pick-up and delivery problem. A reduction in dead-heading trips of up to 50% was observed using existing capacity.

Carrier-carrier collaboration has been studied in liner shipping, air cargo, and rail freight industries as well. Agarwal and Ergun (2008a, 2008b) address carrier collaboration in sea cargo, by modeling the distribution and allocation of revenue and the design of the collaborative network. Similarly, Houghtalen (2007) addresses carrier-carrier collaboration in the air cargo industry, by proposing a mechanism that allocates both the collaborative resources (such as capacity) and profits by appropriately setting prices for the resources. Likewise, Kuo et al. (2008) address multi-carrier collaboration in the rail freight industry, by proposing a simulation-based assignment framework for testing three collaborative decision-making strategies for track allocation over an international intermodal network.

This chapter will focus on this developing paradigm between carriers termed carrier-carrier collaboration within the LTL industry and will serve as an evaluation of the current trends in carrier-carrier collaboration.

2.4 Emerging Carrier Collaborative Issues

The Internet and ICT technologies are becoming an integral part to the operations of many of today's trucking companies, especially small- to medium-sized LTL firms. Since the advent of the Internet in the 1990s, the freight transportation industry has become more competitive than ever before. To survive in such environment, these carriers have developed new business and operational paradigms.

One manifestation of this shift is in the increase in LTL carrier-carrier collaboration, which seeks to exploit synergies (for example, excess capacity) in operations. In addition, many of these smaller carriers turn to cooperative alliances with the aim of addressing many emerging concerns such as: (i) the increase in requirements by shippers, and (ii) the influence of both the Internet and ICT technologies in increased competition and in the formation of new transportation marketplaces. Thus, the challenge for the carrier-carrier collaborative networks will come from being able to address these issues within a cooperative alliance and to create win-win situations for all members in the alliance.

Due to innovative inventory practices (for example, just-in-time) and the increased use of e-commerce, shippers, usually larger manufactures and retailers, are increasing their transportation requirements (Song and Regan, 2004). Increased transportation requirements derive from the fact that demand is becoming more spatially spread, which puts a considerable amount of pressure on the smaller-to medium-sized LTL firms to compete and still make a profit. In order to stay competitive, the carrier-carrier collaborative must adapt by investing in the latest communication technologies coupled with specialized routing and scheduling, vehicle monitoring, and tracking software. An increased investment in new technologies will provide the collaborative with the ability to reduce some of the inefficiencies in their current operations such as capacity utilization issues (empty trips) and increased competition from other alliances. Furthermore, the carrier-carrier collaborative can turn to e-commerce and/or web-based solutions to increase capacity utilization and operations (Golic and Davis, 2003; Golob and Regan, 2002). One manifestation of a web-based solution comes in the form of online transportation market places. Such markets can provide opportunities to strengthen carrier-carrier collaborative, but this method requires the use of the Internet.

The Internet, along with information communication technologies (ICT), is pioneering changes to the structure of transportation marketplaces by fostering more spatially spread demand. New transportation marketplaces are emerging from advances in technologies (for example, online auctions) that are used in conjunction with the Internet to match shippers (demand) and transportation capacity (what carriers offer) from virtually anywhere. These transportation exchanges are Internet services that bring together buyers (shippers) and sellers (carriers) of transportation services in order to increase the efficiency of both shipper and carrier operations (Song and Regan, 2004; Figliozzi et al., 2003). These new businesses create opportunities for small- to medium-sized carriers by providing shipments that allow for an increased utilization of capacity. With the extra demand availability and the worldwide influence of the Internet, competition still becomes an issue. Hence, these new forms of transportation markets in the form of online auctions have fostered competition between the few larger trucking companies and the many small-to-medium ones.

Therefore, a carrier-carrier collaborative would have the ability to close the gap between it and the larger more established competitors by potentially providing sufficient capacity to future shippers, allowing them to vie for the same shipment consignments. The challenge comes in the increased competition from larger carrier-carrier collaborative networks, and larger single carriers with sufficient capital and economies of scale. In addition, the carrier-carrier collaborative will need to position itself as a reliable entity in order to draw the attention of shippers through these freight transportation marketplaces.

Technology advancements and the increased use of Internet-type solutions create opportunities for carriers to increase efficiencies through carrier-carrier collaborative efforts. Thus, investment in newer and more advanced technologies will provide the necessary tools for seamless connection amongst partners in the carrier-carrier collaborative, allowing them to position themselves more profitably in an already competitive market.

2.5 LTL Collaborative Network Issues and Characteristics

Current carrier-carrier collaborative literature deals with some of the obstacles either involved in trying to address shipments that are not desirable by a contracted or preferred carrier, or cannot be served due to some lack in capacity. The following sections introduce other characteristics and issues related to LTL carrier-carrier collaboration in more depth that need attention when modeling a carrier collaborative system for the small- to medium-sized LTL trucking industry. These issues and characteristics relate to: (i) shipment time window, (ii) collaborative transfers, (iii) product type, (iv) equipment quality, (v) in-transit and holding costs, (vi) multiple carriers, (vii) pricing mechanism for fair cost allocation, (viii) stochasticity of demand and capacity availability, and (ix) time scale.

2.5.1 Shipment Time Windows

From the moment an LTL carrier accepts to serve a shipment, the carrier is under the clock to deliver that cargo to its respective customer or client. In the carrier industry, this period of time that is needed to deliver the cargo is known as a time window. A time window is basically a time period defined by the time a shipment is acquired to the time it needs to be delivered (Chen and Hsiao, 2003). Time windows are an integral part of a collaborative effort since the coordination of the system depends on location of existing capacity, which itself has an associated time availability window that will allow for the on-time delivery of the shipment. Identifying which collaborative carriers are available is dependent upon the time a shipment is received for delivery and the identification of capacity that is available in the network at the needed time. Not all carriers will have capacity available. Situations will arise in which the collaborative carrier (carrier seeking capacity) will have to wait until some capacity is available. This idle time can produce additional costs that the carrier incurs. The capacity may be in transit to the transfer facility or in wait for the unloading of its current cargo at the transfer facility. In such cases, the carrier's collaborative path will be the path that will allow it to meet its time window constraints even though the carrier will have to wait for some time. The challenge then comes from the decision of when a shipment should leave the origin facility and how early it can reach the destination facility. This decision is crucial since available capacity as mentioned earlier may or may not be available at the next facility.

Hence, time windows are one of the most important factors to consider when modeling an LTL carrier-carrier collaborative network since the network configuration changes over time. That is, collaborative capacity is what is considered to be dynamic, since collaborative capacity that is primarily underutilized will be that capacity that is considered excess (for example, capacity at lots, or capacity that would otherwise be an empty haul trip) by the collaborative carriers.

2.5.2 Transfers

In order for a collaborative effort to be efficient, the transfer of shipments between carriers would need to be coordinated to meet time window constraints. A transfer is the loading and/or unloading of a shipment or part of a shipment to be reassigned to another carrier with excess capacity to handle it. A carrier of interest might seek another carrier's excess capacity if that capacity is being offered at a bargain price allowing the carrier of interest to still make a profit, or it might acquire capacity beforehand in anticipation of future shipment demand increases or as in the case of a possible emergency or setback.

The locations of transfers are dependent upon the temporal and spatial availability of capacity. Further, they are dependent on the cost associated with the handling of the transfer. These costs can either be fixed or variable, and these costs can be on a fixed per unit, per weight, or per volume unit basis. These costs may depend on the transfer point (for example, city) in which they occur, as well as incoming and outgoing trucks, for example, the cost of the crew unloading or loading the trailer and any cost associated with the operation of the actual vehicle (Boardman, 1997). From the perspective of a single carrier of interest, if the cost of transferring to use someone else's capacity within the collaborative effort is profitable along an origin-destination pair, a transfer will occur. Still, transfer costs can be very costly—around 5% and higher (for example, 50%) of the costs incurred by the carrier of interest (Hover and Giarratani, 2005). One reason that a carrier might transfer its shipment at a transfer facility (warehouse/depot) could be that it has acquired a return shipment increasing its capacity utilization. In addition, it may have no other choice but to acquire capacity because it cannot fully serve the shipment because of lack of capacity.

In a multiple carrier environment, carriers may behave similarly at transfer facilities that have, in general, been the origins or destinations of their operations. A key aspect of the collaborative problem is where to transfer at a minimum cost so as to meet the time restriction imposed by the shipment and if a transfer is needed.

2.5.3 Product Type

Since not all goods are homogenous and their transportation requirements differ, the type of product to be shipped adds a level complexity to collaboration. Usually a product is simply something of value that can be bought or sold, such as a manufactured good or raw material. Further, a product can be separated into two categories: perishable and non-perishable goods. Perishable products are goods that decay (spoil) or can damage easily (for example, fruits, meats, medical supplies, etc.). The handling of such goods requires special units that can slow the decay process or limit the amount of damage incurred during the transportation phase (see next section on equipment quality). Non-perishable commodities are goods of low value and have limited requirements on transport (for example, coal, can goods, etc).

The challenge for a collaborative effort is to match the product type with the appropriate carrying units to facilitate such good. The temporal and spatial availability of such carrying units becomes complex since not all carriers in the collaborative may carry heterogeneous units to facilitate the different product types. Restrictions that contribute to the complexity of the product types are the size or volume of the shipment. There should be enough capacity to accommodate the movement of the product.

Associated with the size of the shipment is the weight of the product. Weight is regulated by each individual state and must be adhered to; this especially applies to non-perishable goods since they tend to be shipped in larger quantities and may weigh much more than perishable goods.

2.5.4 Equipment Quality

The quality of the carrier equipment becomes an important factor when dealing with customers (shippers) who have specific shipping requirements. For example, perishable consumables can only be shipped on high-quality and refrigerated trailers. Therefore, if a carrier in the collaborative network needs extra capacity to haul these types of goods, it must ensure that the borrowed capacity meets the customer’s requirements. In other words, the specialization of the equipment is tied directly to commodity type.

2.5.5 In-Transit and Holding Costs

An important issue to consider in a collaborative effort is the in-transit and holding (idleness) costs. In-transit inventory is inventory on the trucks (units) that is being moved from the origin to destination. Once the shipment has been picked up from the source, the inventory on the trucks begins to incur costs. Given the nature of the product being shipped, as mentioned earlier (see product type), these costs can be substantial for a shipper. Moreover, holding costs, which we define as the costs associated with the idleness of a loaded collaborative carrier waiting to transfer goods to another carrier, can have a considerable impact on the formation of the collaborative routes. The reason is that a typical shipment may spend over 50% of the time it takes to deliver at transfer points due to delays (Cheung and Muralidharan, 2000). Some examples of delays include possible mechanical breakdowns and congestion on the physical network as well as at the terminals, depots, and/or warehouses. In such cases, the holding costs may come from increased pay to the driver for waiting, delivery delay costs (especially on perishable items), potential revenue lost from idled capacity, and increased transfer site fees for utilized space. Thus, the challenge for a collaborative is being able to minimize the effect of these costs on the formation of collaborative routes.

2.5.6 Multiple Carriers

In reality, multiple carriers are making individual decisions in order to improve the efficiency of their operations, thereby exhibiting different behavioral tendencies that can affect how collaborative routes are eventually formed. That is, some carriers may be purely revenue driven (these carriers will charge higher collaborative rates independent of how much volume they serve), volume oriented (these carriers are more concerned with establishing density on shipment routes between terminals), or profit oriented (these carriers will adjust rates given the amount of volume shipped). Hence, the challenge from a modeling standpoint is how to account for the varying carrier behavioral tendencies in a single collaborative framework.

2.5.7 Pricing Mechanism

Online procurement auctions are being used in varying degrees to dynamically match shipments and transportation capacity. These auctions can provide a powerful means to allocate resources like capacity (Figliozzi et al., 2003). Online procurement auctions in freight transportation are mostly used by shippers whose preferred carriers have rejected the shipments due to time window constraints, capacity availability, and/or for monetary reasons (such as shipment may not be profitable). From a carrier perspective, larger carriers who may have accepted shipments that cannot be delivered or serviced may post the shipments online for auction. Therefore, auctions become a tool for both shippers and carriers to allocate the shipments to others that may have the resources to do it (for example, capacity). The drawback is that there is no guarantee that the shipments will be taken during the auction process.

Within a carrier collaborative network, online procurement may not be the best form of allocating shipments and/or resources such as capacity because in an industry like LTL freight, most time windows are relatively short. It would take valuable time, for example, for the carrier to put up the shipments or even capacity to auction with no guarantee of acceptance.

One alternative to online procurement is that of hedging for current and future needs. The price can be determined from a various array of potential factors such as current market values, frequency of partnered business (that is, history of working with the same carrier(s)), and guaranteed constant future shipments. Further, the price a carrier is willing to pay for additional capacity from collaborative carriers may depend on various factors, such as amount needed, destination of shipment, pickup and delivery time windows, location of needed capacity, transfers, and product type, to name a few.

As such, price discounts can be gained if capacity is secured beforehand in anticipation of shipment needs. However, the challenges for an LTL carrier-carrier collaborative comes in how to negotiate fair rates amongst the partners in the collaborative network as to ensure a win-win situation for all involved. From an application viewpoint, third party logistics firms (3PL) can potentially provide a carrier collaborative a platform in which to meet. These intermediaries can then provide the necessary technological support (that is, the means to create transactions) to induce collaboration amongst the LTL carriers.

2.5.8 Stochasticity

The stochasticity of shipments and the variability of capacity add additional complexity to LTL carrier-carrier collaboration. The competitive nature of the LTL carrier industry is such that shipments can be hard to come by in some regions. In order to secure capacity to fulfill the demand requirements, a carrier must project its needs and hedge for those needs. If the secured capacity is not used, a carrier's profits are trimmed in order to cover the added or unused capacity costs. The carrier can turn around and put its capacity in the market to recover the loss or potentially make a profit.

In practice, not all events can be accurately predicted or even known. Still, collaboration promises potential benefits when carriers undergo unforeseeable events, such as vehicle breakdowns, assuming that a collaborative carrier is nearby with excess capacity. With the advancements in ICT technologies, a carrier in need is just a text message away.

2.5.9 Time Scale Dimension

Crainic (1999) introduced 3 different planning levels: strategic, tactical, and operation planning. The strategic planning horizon refers to a long-term planning such as terminal location, and physical network planning which typically has units of time in weeks, months, and/or years. The tactical planning horizon refers to medium-term planning such as the design of the service network, which may have unit of time in days, weeks, and/or months. In reference to the design of the LTL carrier-carrier collaborative network, these first two planning horizons can be seen as static planning of the collaborative network. That is, these planning horizons would allow for the design of the collaborative network in terms of identifying transfer facilities, and minimizing fuel consumption. The operational planning horizon is defined as the short term horizon that deals with dynamic (time issue) aspects of trucking operations such as driver restrictions, idle time, and availability of collaborative capacity, to name a few. So when will collaborative capacity be available for a carrier partner to utilize?

The availability of collaborative capacity increases the complexity of carrier-carrier collaborative models because collaborative capacity is dynamic. That is, the collaborative capacity may be available at one time interval and not the next. Thus, the dynamic nature of the problem requires special attention especially in a highly dynamic LTL industry. When designing the LTL-carrier-carrier collaborative network, the operational planning horizon can be seen as dynamic planning. That is, the operational planning horizon would allow for the design of the collaborative network in terms of the dynamic nature of the capacity. Likewise, it would allow for the inclusion of other important factors such as in-transit and holding costs (see in-transit and holding costs).

For a carrier-carrier collaborative to succeed, synergies must be exploited in both the planning and operational aspects of such networks. The issues and characteristics presented illustrate the potential for modeling such collaborative efforts amongst carriers and gives direction to addressing the various complexities of such networks. Some of these issues and characteristics go hand-in-hand and need to be addressed in the same modeling framework. For example, a model that imposes some sort of time window must also consider transfers and associated costs. These relationships increase the complexity of the problem.

A major issue that a carrier collaborative network faces is how to best allocate and price capacity for the collaborative effort. The type of pricing mechanism used can greatly affect the willingness of the carriers to collaborate, especially if there are multiple carriers present with the need for the same capacity. As presented in the literature, an auction-type mechanism can be a solution, but there still exists the possibility that the shipment will not be served.

Planning horizons affect carrier collaboration operations in many different ways. For example, carriers must plan ahead of time or at least have the ability to create operational plans in advance of a shipment. This usually would require carriers to identify the needed equipment, its quality, how will it be shipped (which modes), potential costs, etc. Therefore, to model a carrier collaborative network, these issues and characteristics must be considered in collaborative models to increase the level of the system realism.

2.6 Summary

In this chapter, we reviewed collaboration in the freight industry pertaining to the emerging paradigms prompted by advances in ICT and the increasing use of the Internet.

Further, we focused on LTL carrier-carrier collaborative networks and present ongoing and emerging issues related to such collaboration. Overall, we find that much of the literature presented in carrier-carrier collaboration focuses on either the use of some form of auction pricing mechanism to allocate shipments on an online transportation marketplace or contracting an outside carrier to deal with the shipments independent of what routes are created with no guarantee. Although these models tackle the problem of capacity utilization to reduce deadhead miles, they fail to address collaborative issues and network characteristics in order to improve system performance to guarantee shipment deliverance.

First, we conclude that advances in technologies such as the Internet and ICT facilitate LTL carrier-carrier collaboration by providing the necessary tools to communicate and exchange information. These tools have become increasingly more affordable over the years giving rise to greater potential utilization in the future.

We also conclude that due to increasing transportation requirements by shippers that LTL carrier-carrier collaborative networks will provide the necessary platform to maintain an ever-demanding supply chain. In addition, by creating networks of collaborative carriers to move shipments more efficiently, these carriers will not have to worry if enough capacity is available on the lot to service current and/or future shipments.

Further, understanding of collaborative and network issues allow for a more realistic model which will provide transportation services more efficiently to shippers but will also take advantage of existing synergies on both the planning and operational sides of such networks. Such models will sustain not just existing synergies but will provide a mechanism by which carriers can negotiate the exchange of capacity or information related to such collaborative networks.

Table 2.1 Technology and collaborative potential

	Collaborative potential
Internet	Information wealth, interconnectedness, and e-commerce
Telecommunications	Wireline and wireless connectivity
Data exchange & fusion	Data and information sharing possibility
Navigation & positioning	Route guidance, vehicle locations, and computer dispatch

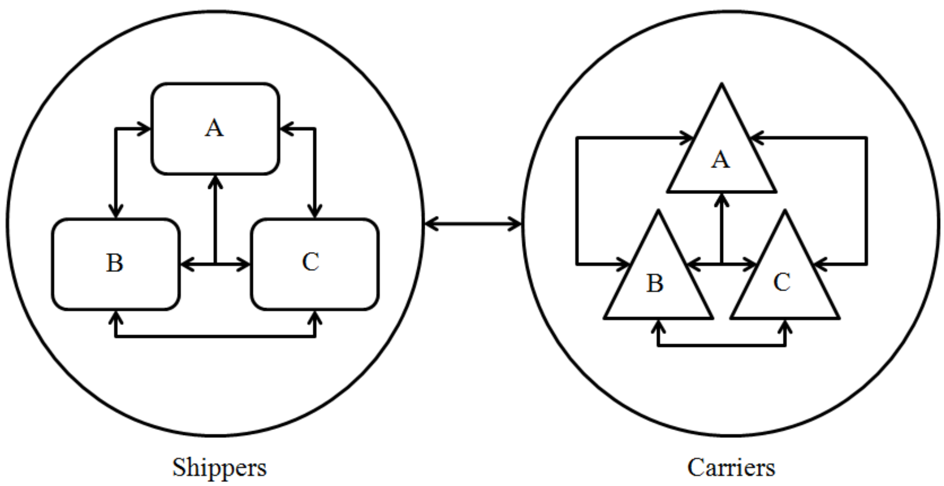


Figure 2.1 Shipper-Shipper, Shipper-Carrier, and Carrier-Carrier Collaborative Forms

CHAPTER 3. AN EXPLORATORY ANALYSIS OF THE PROPENSITY FOR FREIGHT CARRIER COLLABORATION

3.1 Introduction

The Internet and information communication technologies are becoming an integral and important part in the operations of many of today's less-than-truckload (LTL) trucking companies. Since the advent of the Internet in the 1990s, the LTL transportation industry has become more competitive with LTL carriers of all sizes seeking the latest innovative approaches to reduce the economic impacts of empty hauls and rising fuel prices to maintain a competitive edge. As part of this, collaboration among carriers has emerged as a potential viable alternative for the LTL carrier industry (Hernandez and Peeta, 2010). Such collaboration entails capacity-sharing between LTL carriers whereby excess capacity from some of the carriers on some of the route segments would be purchased (at a collaborative discount price) by an interested carrier to service its demand. Previous studies in the Truckload (TL) carrier, liner shipping, and supply chain context suggest that collaboration can lead to more system-wide efficiency through reduced costs, decreased lead times, increased asset utilization, and improved services levels (Agarwal and Ergun, 2008; Esper and Williams, 2003; Corsten and Kumar, 2005; Kale et al., 2007).

The LTL carrier industry represents a segment of the trucking industry which specializes in the movement of "middle-sized" shipments as opposed to very small (parcel carriers) or very large (truckload carriers) shipments. Typically the size of shipment ranges from a few hundred pounds to about 48,000 pounds. LTL shipments are typically moved over a network of warehouses, depots, and distribution centers as opposed to the TL industry which ships direct (shipper to client). In addition, the LTL trucking segment experiences the largest number of empty haul trips, which impacts their ability to sustain profitability in a highly competitive industry. Given these operational challenges this industry stands to gain from the developments of collaborative paradigms.

There have been a number of studies that have explored the potential impacts of collaboration. Several of these studies have looked at collaboration as a means of enhancing operational efficiency (increasing capacity utilization) between carriers by applying various operations research methods (Hernandez and Peeta, 2010; Song and Regan, 2004; Figliozzi, 2006; Agarwal and Ergun, 2008; Kuo et al., 2008). Other studies have more generally considered supply chain and shipper-carrier collaborations. For example, Bagchi et al. (2005) investigated the role of information sharing and collaboration among suppliers in Europe and conclude that though collaboration has its benefits (improved performance), companies are quite cautious about integrating information sharing and decision-making. In a U.K. based survey, Akintoye et al. (2000) found that supply chain collaboration and management was considered important but that trust, the lack of appropriate support structures, and differing supply chain philosophies are potential barriers to supply chain collaboration. These findings were confirmed by Skjoett-Larsen et al. (2003) in their study of 218 companies in Denmark.

Finally, in the shipper-carrier collaboration context, Ha (2007) undertook a latent variables analysis to uncover cause/effect relationships and concluded that through collaboration carriers improve service performance. Furthermore, it was found that collaboration is closely tied to areas that do not require additional direct investments such as length of relationship, information sharing, and skill/knowledge sharing. However, this form of collaboration tended to be shipper controlled and the carriers are in essence under contract.

While past studies have shown that collaboration is a viable option and that factors related to trust, information sharing, length of relationship, and common goals can play an important role for a successful collaborative, the methodological approaches used in these studies only addressed attitudes in favor or against collaboration. That is, these studies do not compare the benefits of collaboration with other viable alternatives that may be preferred by these industries (for example, long term contractual agreements, mergers, etc).

Another factor that has not been given adequate consideration is the potential roll of third-party logistics providers (3PLs). Third-party logistics providers are firms that offer an array of transportation solutions to both their shipping and carrier clients. From the carrier perspective, these services have traditionally included shipment acquisition opportunities, technology support, and the leasing of capacity (Regan and Song, 2001; Hertz and Alfredsson, 2003). However, identifying or facilitating collaborative efforts is not a current service provided by 3PLs to their LTL carrier affiliates. To the best of our knowledge, this study is the first to model the carrier-carrier collaborative paradigm from the perspective of the LTL industry through the use of econometric modeling techniques.

With these points in mind, our study aims to add to the current literature by proposing a methodological approach that takes into account the propensity for LTL carrier collaboration and/or other viable options. Such options include: lease capacity from a rental services provider; make additional capital investment—that is, purchase additional power units; collaborate with other carriers; reject the load; and other (third-party logistics firms, haul as much as possible, take multiple trips). This is done through the application of multivariate analysis techniques (that is, cluster analysis) and a discrete choice model. Through this, we seek to provide the LTL carrier and third-party logistics (3PL) industries with the necessary tools to enable them to identify potential collaborative opportunities and encourage collaboration.

3.2 Data

Information on the propensity for LTL carrier collaboration was collected from a survey of LTL companies around the Midwest (Indiana, Illinois, Iowa, Ohio, Michigan, Kansas, Minnesota, Wisconsin, and Nebraska). The potential respondents and their contact information were drawn from a database of over 2000 LTL carriers. The questions were posed to operational and logistics managers in charge of operations. The survey was conducted through an online questionnaire with an average completion time of just over 15 minutes. The survey respondents were asked via email if they were willing to participate in a survey and, if so, they were directed to a link for the online questionnaire. A total of 980 emails were sent to 457 local carriers, 425 regional carriers, and 98 national carriers. A total of 148 complete responses were collected for an overall response rate of 15%. Of the 148 responses, 62 were from local carriers, 71 from regional carriers, and 15 from national carriers. The responses rates for the local, regional, and national carriers were 13%, 17%, and 15%, respectively. There are at least three reasons for the relatively low response rate. First, respondents were not previously informed about the survey questionnaire. Second, respondents were potentially at the mercy of their firm's information-technology policies that prohibit them from opening documents and/or clicking on links from unknown senders. And third, the respondents were not willing to share information they deem proprietary. The survey was conducted over a three month period.

Table 3.1 illustrates the descriptive statistics for some of the variables included in the survey. The first variable reflects the adoption of navigation and positioning technologies by the surveyed carriers. The statistics indicate that on average 65% of the surveyed carriers use these technologies in some form. The costs associated with empty hauls and idled capacities were on average 10.9% and 1.6% of the total annual costs (respectively) for the surveyed carriers. With respect to unionization, the survey results indicated that 9.5% of the carriers were affiliated with a union. In regards to rising fuel costs, 85% of the carriers expressed concerned. Further, only 27% of the carriers owned transportation facilities and a very small percentage of them were concerned with driver turnover.

Table 3.2 presents statistics related to the largest potential barrier for carriers collaborating with other carriers. Using a scale from 1 to 5, with 1 representing a large potential barrier for a carrier collaborating with other carriers and 5 for a small potential barrier. The results illustrate that the lack of a fair allocation mechanism for the distribution of collaborative revenues was considered by the surveyed carriers to be the biggest barrier. However, a shipper's willingness to accept transportation handling from a carrier's collaborative partner was also considered, on average, to be a significant barrier to collaboration. In addition, a secure method of information sharing between carriers was also considered, on average, to be a significant barrier to collaboration.

Table 3.3 shows the descriptive statistics for the viable transportation alternatives for meeting demand requirements in the short-term. Using a scale from 1 to 5, with 1 being a very viable transportation alternative for meeting demand requirements in the short-term to 5 being a poor transportation alternative for meeting demand requirements. The results indicate that collaboration was regarded highly by the surveyed carriers compared to the other options (lowest mean score). However, the “lease” and “other” options were also regarded by the surveyed carriers to be relatively good alternatives for addressing demand requirements in the short-term. By contrast, the capital investment alternative was regarded on average to be the least viable (high mean score). In terms of the “other” option, about two thirds of the respondents said that they would employ the services of a third-party logistics provider.

3.3 Cluster Analysis

To form the LTL carrier subgroups a cluster analysis was performed. Cluster analysis is a multivariate technique that is used to uncover structures within a data set (Anderberg, 1973). The objective of cluster analysis is to group (cluster) data based only on information found in the data such that the elements within these groups have a high degree of association—that is, the greater the similarity (or homogeneity) within a group and the greater the difference between groups, the better or more distinct the clustering (Tan et al., 2006). There are two types of clustering mechanisms: hierarchical (nested) and nonhierarchical (partitioned). In the former procedure, a hierarchy or treelike structure is formed and composed of separate clusters. In contrast, the latter is a division of the data points through cluster centers into non-overlapping subsets such that each data point belongs to only one subgroup (Tan et al., 2006). In this study, we use both these clustering mechanisms. In the first step, the hierarchical clustering mechanism is used to determine the number of clusters. The number of clusters can vary from one large cluster group containing all the data to a number of cluster groups equal to the number of data points in the analysis. In the second step, the number of clusters is used as input for the non-hierarchical mechanism to develop the cluster centers (the carrier clustering categories). The cluster centers are the initial means (starting points) of the clusters and the data is grouped around these preselected means.

The cluster analysis conducted in this study used the five viable transportation alternatives ranked by carriers for meeting demand requirements as the basis of the analysis: leasing capacity from a rental services provider; making additional capital investment; collaborating with other carriers; rejecting the load; and other. The mean and standard deviations of the survey responses for these alternatives are shown in Table 3.3.

To determine the cluster groups, a nonhierarchical clustering procedure, the k-means method, was used on the data. The k-means method begins by selecting several clustering centroids (centers) and assigning each data point to the closest centroid. The centroids of each of the formed clusters are then updated based on the points assigned to them. This is repeated until no points change clusters, or equivalently until the centroids remain the same (Tan et al., 2006). As mentioned earlier, the nonhierarchical method (k-means) requires predefining the initial number of clusters centers. The average linkage hierarchical procedure was conducted on the data to determine the initial number of cluster centers. Using this procedure, it was observed that distinct carrier transportation alternative choice behavior emerged for three clusters, as shown in Figure 3.1. Once the number of clusters was established, a k-means method was conducted on the five transportation alternatives for meeting demand requirements in the short-term. Table 3.4 illustrates the final clusters centers (with corresponding standard deviations) selected by the k-means method for the three cluster solutions. These clusters represent a mathematical average of the rankings for the carriers within each cluster and, as such, do not necessarily correspond to the actual rankings, which are integers (1 through 5). The rankings represent the viability of an alternative for a surveyed carrier (1 being highly viable, and 5 being less viable).

Examining the degree of viability carriers placed on an alternative helped determine the major characteristics for each cluster group. Rankings to the question were categorized into two groups: highly viable, and less viable. If a carrier ranked an alternative to be the highly with a rank response of 1, 2, or 3, it was determined as being in the highly viable category. Carriers with rankings that were not highly viable (recorded as 4 or 5) were placed in the less viable category. Chi-square tests were then performed to determine if significant differences existed between the frequency of responses for the highly viable and less viable categories among the transportation alternatives in each cluster. As shown in Table 3.4, to distinguish between the clusters, they were labeled clusters 1, 2, and 3 based on the number of observations in the two categories and the results from the chi-square tests.

For cluster 1, leasing and collaboration are found to be important (*n* = 56, 37.84% of the sample). These carriers felt that leasing (mean = 1.91) and collaboration (mean 1.45) were highly viable transportation alternatives for meeting demand requirements in the short-term. As indicated by Figure 3.2(a), the number of responses falling in the highly viable option category was significantly greater than the number of responses in the less viable option for leasing and collaboration ($\chi^2_{(1)} = 52.02,\ p < 0.05$). In addition, all carriers in this cluster were located in the highly viable option category for leasing. Furthermore, capital investment ($\chi^2_{(1)} = 28.00,\ p < 0.05$), reject the load ($\chi^2_{(1)} = 24.38,\ p < 0.05$), and other ($\chi^2_{(1)} = 16.02,\ p < 0.05$) were found to be less viable transportation alternatives for carriers belonging to this cluster.

For cluster 2, collaboration, reject the load, and other (see Figure 3.2(b)) are found to be important (*n* = 54, 36.48% of the sample). The “reject the load” alternative was very important to these carriers (mean 1.93), and all carriers in this cluster were located under this alternative. Additionally, these carriers considered collaboration (mean = 2.33) and other (mean = 2.68) as highly viable transportation options for meeting demand in the short-term ($\chi^2_{(1)} = 38.40,\ p < 0.05$ and $\chi^2_{(1)} = 36.75,\ p < 0.05$, respectively). Leasing and capital investment were found to be significant as the less viable transportation alternatives for this cluster group of carriers ($\chi^2_{(1)} = 10.02$ and $\chi^2_{(1)} = 40.33,\ p < 0.05$, respectively).

For cluster 3, leasing, collaboration, and other (see Figure 3.2(c)) are found to be important (n = 38, 25.68%). The carriers in this subgroup felt that in addition to leasing (mean = 2.39) and collaboration (mean = 2.76), that the "other" alternative was highly viable (mean = 1.45). Except for one carrier, all others in this cluster considered the "other" alternative ($\chi^2_{(1)} = 35.03,\ p < 0.05$). As with the "other" option, leasing and collaboration were statistically significant for the highly viable option ($\chi^2_{(1)} = 21.81$ and $\chi^2_{(1)} = 27.27,\ p < 0.05,$ respectively). However, capital investment and "reject the load" were statistically significant for the less viable option ($\chi^2_{(1)} = 14.28$ and $\chi^2_{(1)} = 26.28,\ p < 0.05,$ respectively).

As the cluster analysis shows, three carrier behavioral subgroups can be identified. The first carrier subgroup consists of carriers that feel that leasing and collaboration are highly viable options. The second subgroup represents carriers that feel collaboration, reject load, and other are highly viable options. The third subgroup of carriers identifies leasing, collaboration, and other as highly viable options. A key observation to note is that the "collaborate" alternative is present in all three cluster groups. This means that collaboration is a viable alternative for all three carrier clusters. However, the rest of a carrier's choice set of viable alternatives may vary. Another observation from the cluster-level data suggests that leasing is a key alternative for local (small-size) and regional (medium-size) carriers (Belman and White, 2005).

3.4 Analysis of Clustering Probabilities

To achieve a better understanding of the operational and behavioral characteristics associated with carriers, we seek to develop a statistical model that can be used to determine the factors that affect the probabilities of carriers ending up in specific clusters (Ng et al., 1998). To do so, we start with a linear function that determines the probability that a carrier will end up in cluster i as,

$$S_{in} = \boldsymbol{\beta}_i \mathbf{X}_{in} + \varepsilon_{in} \tag{3.1}$$

where $\mathbf{X}_{in}$ is a vector of explanatory variables (operational and collaborative variables), $\boldsymbol{\beta}_i$ is a vector of estimable parameters, and ε_{in} is the error term. If ε_{in}'s are assumed to be generalized extreme value distributed, McFadden (1981) has shown that the multinomial logit results such that:

$$P_n(i) = \frac{EXP[\boldsymbol{\beta}_i \mathbf{X}_{in}]}{\sum_I [\boldsymbol{\beta}_i \mathbf{X}_{in}]} \tag{3.2}$$

where $P_n(i)$ is the probability that carrier n is in cluster i and I is the set of possible clusters.

As our data are likely to have a significant amount of unobserved heterogeneity (For example, relating to factors that make carriers more or less risk averse) we consider the possibility that elements of the parameter vector $\boldsymbol{\beta}_i$ may vary across carriers by using a random-parameters logit model (also known as the mixed logit model). Previous work by McFadden and Rudd (1994), Geweke et al. (1994), Revelt and Train (1997, 1999), Train (1997), Stern (1997), Brownstone and Train (1999), McFadden and Train (2000), and Bhat (2001) has shown the development and effectiveness of the mixed logit approach which can explicitly account for the variations (across carriers) of the effects that variables have on the carrier clustering categories (or choices) considered in this study. The mixed logit model is written as (see Train, 2003),

$$P_{in} = \int \frac{EXP[\boldsymbol{\beta}_i \mathbf{X}_{in}]}{\sum_I [\boldsymbol{\beta}_i \mathbf{X}_{in}]} f(\boldsymbol{\beta}_i | \boldsymbol{\varphi}) d\boldsymbol{\beta}_i \tag{3.3}$$

where $f(\boldsymbol{\beta}_i|\varphi)$is the density function of $\boldsymbol{\beta}_i$, $\boldsymbol{\varphi}$ is a vector of parameters of the density function (mean and variance), and all other terms are as previously defined. This model can now account for carrier-specific variations of the effect of $\mathbf{X}$ on carrier clustering probabilities, with the density function $f(\boldsymbol{\beta}_i|\boldsymbol{\varphi})$ used to determine $\boldsymbol{\beta}_i$. Mixed logit probabilities are then a weighted average for different values of $\boldsymbol{\beta}_i$ across carriers where some elements of the vector $\boldsymbol{\beta}_i$ may be fixed and some randomly distributed. If the parameters are random, the mixed logit weights are determined by the density function $f(\boldsymbol{\beta}_i|\boldsymbol{\varphi})$ (Milton et al., 2008; Washington et al., 2010).

Maximum likelihood estimation of the mixed logit model shown in Equation (3.3) is undertaken with simulation approaches due to the difficulty in computing the probabilities. The most widely accepted simulation approach uses Halton draws which is a technique developed by Halton (1960) to generate a systematic non-random sequence of numbers. Halton draws have been shown to provide a more efficient distribution of the draws for numerical integration than purely random draws (Bhat, 2003; Train, 1999).

3.5 Mixed-Logit Estimation Results

A mixed logit model is estimated using simulation-based maximum likelihood with 200 Halton draws. This number of draws has been empirically shown to produce accurate parameter estimates (Bhat, 2003; Milton et al., 2008; Gkritza and Mannering, 2008). With regard to the distribution of the random parameters, consideration was given to the normal, lognormal (which restricts the impact of the parameters to be either negative or positive), triangular, and uniform distributions. However, only the normal distribution was found to be significant.

Table 3.5 provides the summary statistics of the variables found to be significant in the model and Table 3.6 shows the results of the mixed logit model estimation. The estimated parameters included in the model are statistically significant and the corresponding signs are plausible. In addition, two parameters that were found to be random had statistically significant standard errors for their assumed distribution. Also, for the parameters whose standard errors were not statistically different from zero, the parameters were fixed to be constant across the carrier population. Two parameters were found to vary across the carrier population; the non-unionized carrier collaboration variable and percentage of business generated by electronic data interchange (see Table 3.5 for descriptive statistics of key variables). In addition, the normal distribution was found to provide the best statistical fit for these two random parameters.

With regard to the specific results in Table 3.6, all the parameters corresponding to the first carrier clustering category (lease and collaborate) were fixed across the carriers. The parameter estimate for the percentage of haul trips less than 50 miles was found to be significant. Hence, we find that if a carrier experiences a high percentage of haul trips less than 50 miles they are more likely to be in the “lease and collaborate” cluster (the elasticity shows that, on average, a 1% increase in this variable results in a 0.916% increase in the probability of selecting this category). This may indicate that leasing of capacity and collaboration in regards to demand fulfillment opportunities may be more readily available to these carriers due to their range of operations.

Next, the percentage of empty haul trips annually was also found to be significant and negative with, on average across carriers, a 1% increase in this variable resulting in a 1.4% decrease in the probability of selecting the “lease and collaborate” cluster. This indicates that carriers with a high percentage of empty haul trips are more likely to be in a cluster other than “lease and collaborate.”

The indicator variable representing carriers’ concern with rising fuel prices was significant and showed that those carriers indicating that rising fuel costs would make them more likely to collaborate were significantly more likely to be in the “lease and collaborate” cluster. Carriers with the fuel-price concern are interestingly more likely to be in the lease-collaborate cluster than they are to be in the lease-collaborate-other cluster (with the other including the services of third-party logistics firms).

Carriers that identified shippers’ willingness to accept collaborative transportation as being the largest barrier to collaboration were less likely to be in the lease-collaborate cluster (elasticities show the decrease to be 26.7% on average). This suggests that carriers seem more willing to have collaborate and lease as viable options for meeting demand requirements if they believe shippers will be indifferent to how the shipment is made.

The percentage of business generated by the Internet was found to be significant. Here, we find that for every 1% increase in the percentage of business generated through the Internet, carriers had a 0.901% higher probability of being in the “lease and collaborate” cluster, on average. It is interesting that this variable was found to increase the probability of being in clusters that involve leasing and thus less likely to be in the “collaborate, reject load and other” cluster.

For the second clustering category (collaborate, reject load, other), two variables were found to be significant. First, the parameter estimate associated with non-unionized carriers believing that non-unionization could be a barrier to collaboration was found to be significant and normally distributed with a mean of 1.279 and standard deviation of 3.090. This implies that for roughly 66% of the observations, the more a non-unionized carrier believes non-unionization could be a barrier to collaboration the more likely they were to be placed in the “collaborate, reject, and other” cluster, while for the remaining 34% they were less likely to be in this category. The dichotomy of this result shows that perceptions of the effect that non-unionization (and by inference unionization) will have on collaboration varies considerably across the carrier population.

The percentage of haul trips more than 500 miles was also found to be significant and fixed across the carriers in for the second cluster. With respect to this variable, if a carrier experiences a high percentage of haul trips greater than 500 miles, it is more likely to be in the “collaborate, reject load, and other” cluster. This may indicate that collaboration, rejecting load, and some “other” option with respect to demand fulfillment opportunities may be more feasible due to the larger range of operation for this carrier.

For the third clustering category (lease, collaborate, and other), three variables were found to be significant. The indicator variable for local carriers showed that they were more likely to be in the “lease, collaborate, and other” cluster. This finding suggests that local carriers may be more inclined to consider leasing, collaboration, and some “other” option (which would include third-party logistics firms) as viable alternatives to meet demand requirements in the short-term. This could be due to their scope of operations and the availability of these options.

As with clustering category 1 (lease and collaborate), the percentage of business generated by the Internet was found to be significant for clustering category 3 (lease, collaborate, and other). The one difference is that carriers in this category would consider the "other" option as a viable option in addition to lease and collaborate.

Finally, the percentage of business generated by electronic data interchange was found to be significant and normally distributed with a mean -0.164 and a standard deviation of 0.088. This implies that for roughly 97% of the surveyed carriers. The higher the percentage of business generated through electronic data interchange, the less likely carriers were to be in the "lease, collaborate, and other" cluster. For 3% of carriers, the higher the percentage of business generated through electronic data interchange the more likely they were to be in the "lease, collaborate, and other" cluster. The general negative finding of this variable may be reflecting the perceived role that 3PLs (which would comprise a significant portion of the "other" component of this cluster) play as services providers to the LTL carrier industry—that is, electronic data interchange is potentially being viewed by these carriers as a service performed by the 3PL industry. This may be the case because two thirds of the surveyed carriers recorded 3PLs as being a viable alternative under the "other" option. Furthermore, this may imply that electronic data interchange technologies are still not being widely adopted by the LTL carrier industry. More broadly, Golob and Regan (2002) also found that electronic data interchange was not widely accepted by LTL companies and concluded that larger LTL carriers were more likely to adopt electronic data interchange than small- to medium-sized LTL carriers.

3.6 Summary

In this paper, we analyze the viability of five options for LTL carriers to meet demand under a short-term planning horizon: (i) lease capacity from a rental services provider, (ii) make additional capital investment—that is, purchase additional power units, (iii) collaborate with other carriers, (iv) reject the load, and (v) other. The data for the analysis were drawn from a 2009 survey of more than 148 LTL trucking companies operating in the Midwest. Cluster analysis was used to identify viable option subgroups of LTL carriers. Three distinct cluster groups were identified and a mixed (random parameters) logit model was then estimated to determine the probability of a carrier being placed in a particular clustering category.

The results of the analyses provide some interesting findings. First, carriers have an increased propensity towards collaboration as illustrated from all three carrier clustering categories having the "collaborate" alternative as a most viable option. Second, variables related to collaboration were found to be significant in the mixed logit model. More specifically, variables such as a carrier's "concern for rising fuel prices and very likely to collaborate for increased fuel savings" and "non-unionized carrier collaboration." The significance of these variables illustrates that LTL carriers are concerned with the potential economic impacts of fuel price fluctuations and the possibility of forming collaborative alliances. On the opposite side of the spectrum, the capital investment alternative was considered to be the least viable option across the three clustering categories. This implies that the LTL carriers surveyed are less likely to commit assets for the acquisition of additional capacity for meeting demand requirements under a short-term planning horizon.

It is also interesting to note which variables were not found to be significant in determining the probability of firms ending up in specific clusters. For example, Table 2 shows that "lack of a fair allocation mechanism for collaboration revenues" and "secure method of information sharing between carriers" were both considered large barriers to collaboration. However, the model estimation results show that these opinions seem to be shared uniformly among the clustered firms and are thus not significant in distinguishing one clustering from another.

Finally, it is important to recognize that collaborative alliances can provide a critical strategy for the survivability of LTL carriers in a highly competitive industry; especially under economic downturns and fuel price fluctuations. The modeling approach presented in this paper offers a flexible methodology that can be used to better understand the factors that make collaboration between carriers more or less likely. Using this same approach with an expanded sample of carriers could provide important new insights into the collaboration process, and the effect of carrier size, and would be a natural direction for future work.

Table 3.1 Descriptive statistics of select variables included in survey

Variable	Value
Percent using global positioning, automatic vehicle location and/or computer aided dispatch for day to day operations	64.9
Percent of annual costs attributed with empty haul trips	10.94
Percentage of annual costs attributed to idled power units	1.65
Percentage of carriers indicating they are unionized	9.5
Percent concerned with rising fuel costs	85.1
Percent owning transportation facilities and/or terminals for consolidation transfers, warehousing and/or distribution activities	27.1
Percent indicating that driver turnover is a concern for their operations	9.5

Table 3.2 Descriptive statistics for a carrier's largest potential barrier to collaborating with another carrier (Scale from 1 to 5, 1 representing the largest potential barrier, 5 the least.

Barriers	Mean	Standard deviation
Lack of fair allocation mechanism for collaboration revenues	2.446	1.557
Secure method of information sharing between carriers	2.649	0.848
Scope of operation	3.432	0.809
Carrier's impression of shipper willingness to accept transportation handling from collaborative partner	2.689	1.586
Other	3.784	1.554

Table 3.3 Descriptive statistics for the viable transportation alternatives for meeting demand requirements in the short-term (Scale from 1 to 5, 1 representing the most viable alternative, 5 the least)

Alternative	Mean	Standard deviation
Leasing capacity from a rental services provider	2.615	1.164
Make additional capital investment (purchase power units)	4.344	0.945
Collaborate with another carrier	2.108	1.273
Reject/not accept the load	3.345	1.328
Other	2.588	1.172

Table 3.4 Cluster means (standard deviation) and groups based on each viable option for short term capacity needs

	Cluster 1	Cluster 2	Cluster 3
Variable	Mean (std. dev.)	Mean (std. dev.)	Mean (std. dev)
Leasing capacity from a rental services provider	1.911 (0.769)	3.500 (0.986)	2.395 (1.079)
Make additional capital investment (purchase power units)	4.336 (0.978)	4.556 (0.64)	4.053 (1.184)
Collaborate with another carrier	1.446 (0.658)	2.333 (1.625)	2.763 (0.913)
Reject/not accept the load	4.036 (0.687)	1.926 (0.929)	4.342 (0.627)
Other	3.268 (1.036)	2.685 (0.928)	1.447 (0.760)

Table 3.5 Descriptive statistics of key variables

Variable	Mean	Standard deviation
Percentage of haul trips less than 50 miles	41.277	34.224
Percentage of empty haul trips annually	17.446	8.642
Fuel indicator variable (1 if rising fuel concern would make the carrier very likely to collaborate for fuel saving, 0 otherwise)	0.811	0.392
Collaboration indicator variable (1 if carrier identifies shipper willingness to accept collaborative transportation as the largest barrier to collaboration, 0 otherwise)	0.351	0.478
Percentage of business generated by the Internet	21.041	21.127
Non-unionized carriers could be a barrier to collaboration (if non-unionized: 1–strongly disagree, 2 –disagree , 3– neutral, 4–agree, 5–agree strongly, 0 if unionized) (standard deviation of parameter distribution)	1.655	1.045
Percentage of haul trips more than 500 miles	4.818	14.357
Local – carrier indicator (1 if carrier is a local carrier, 0 otherwise)	0.419	0.494
Percentage of business generated by electronic data interchange	11.946	15.227

Table 3.6 Mixed logit estimation for predicting the probability of an less-than-truckload carrier being in a viable option cluster group for capacity needs in the short term (all random parameters are normally distributed

Variable	Parameter estimate	t-Statistic	Direct elasticity
Cluster 1 (Lease and collaborate)			
Percentage of haul trips less than 50 miles	0.061	3.244	0.916
Percentage of empty haul trips annually	-0.146	-3.425	-1.399
Fuel indicator variable (1 if rising fuel concern would make the carrier very likely to collaborate for fuel saving, 0 otherwise)	2.602	3.738	0.906
Collaboration indicator variable (1 if carriers' willingness to accept collaborative transportation is identified as the largest barrier to collaboration, 0 otherwise)	-1.346	-1.968	-0.267
Percentage of business generated by the Internet	0.0845	1.944	0.901
Cluster 2 (Collaborate, reject load, and other)			
Non-unionized carriers could be a barrier to collaboration (1–strongly disagree, 2–disagree , 3–neutral, 4–agree, 5–agree strongly) (standard deviation of parameter distribution)	1.279 (3.090)	2.155 (2.214)	0.894
Percentage of haul trips more than 500 miles	0.115	1.794	0.089
Cluster 3 (Lease, collaborate, and other)			
Local – carrier indicator (1 if carrier is a local carrier, 0 otherwise)	4.599	3.281	1.101
Percentage of business generated by the Internet	0.115	2.419	1.147
Percentage of business generated by electronic data interchange (standard deviation of parameter distribution)	-0.164 (0.088)	-2.586 (1.737)	-0.535
Number of observations	148		
Log-likelihood at zero	-162.59		
Log-likelihood at convergence	-119.39		

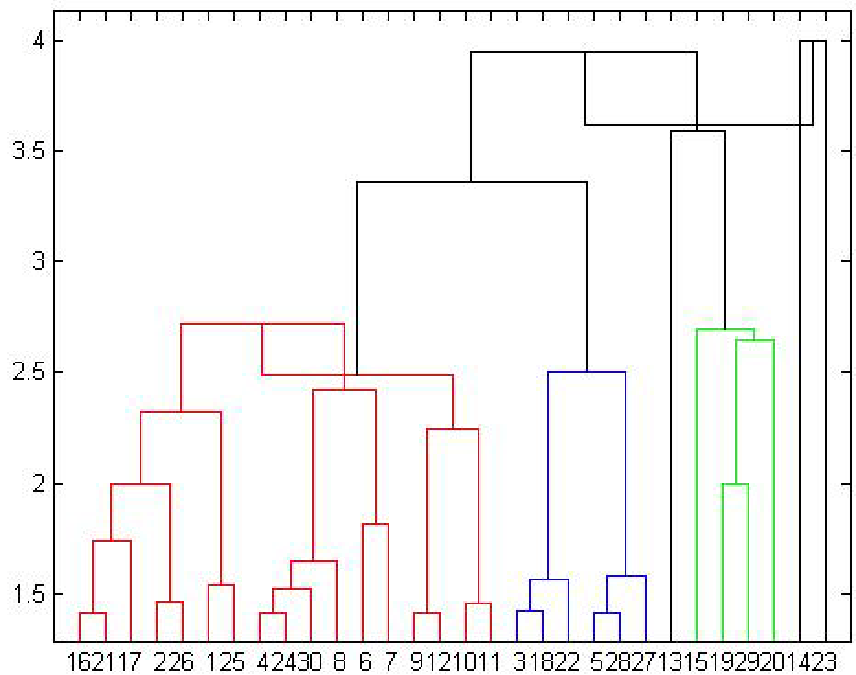
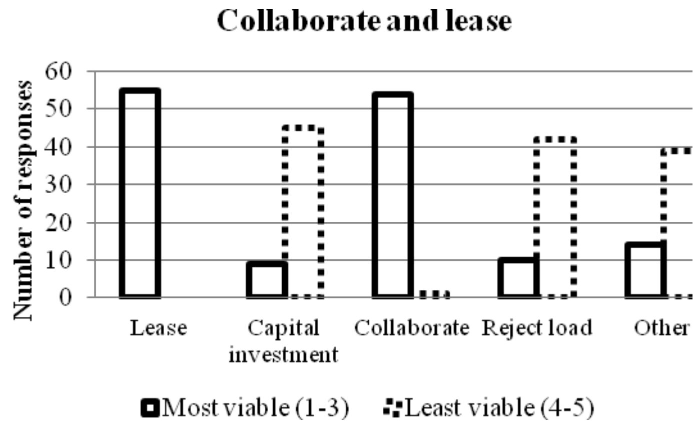
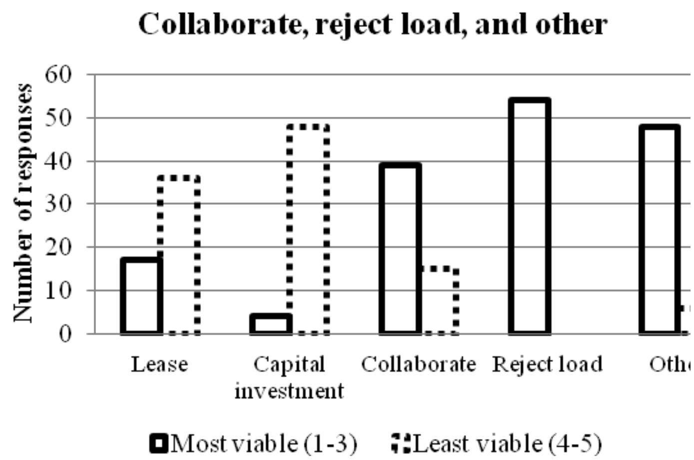


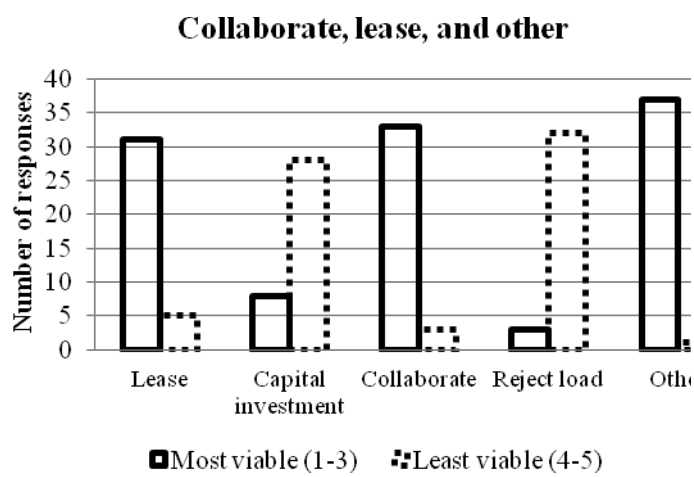
Figure 3.1 The Resulting Dendrogram Plot from the Hierarchical Clustering Mechanism



(a)



(b)



(c)

Figure 3.2 Comparison of Responses of the Three Cluster Groups for Most Viable Options with Least Viable Option

CHAPTER 4. STATIC SINGLE CARRIER COLLABORATION PROBLEM FOR LESS-THAN-TRUCKLOAD CARRIERS

4.1 Introduction

The increased use of the Internet and information communication technologies (ICT) is fostering potentially new business and operational paradigms within the less-than-truckload (LTL) industry. One manifestation of this is the increase in carrier-carrier collaboration; LTL carriers have begun to develop a new generation of strategies that exploit synergies (such as excess capacity) which can form the basis for some form of collaboration. Such collaborative efforts are innovative and can lead to more system-wide efficiency. They can help firms reduce costs, decrease lead times, increase asset utilization, and improve overall services levels (Agarwal and Ergun, 2008; Esper and Williams, 2003). Carrier collaboration can be seen in different stages of a logistics network (Langevin and Riopel, 2005). Therefore, a successful carrier-carrier collaborative network conceivably would consider the management of their relationships with logistic partners, like shippers (for example, that shippers would not mind having a different carrier other than their usual contracted carrier to ship their goods for part of the route). To accomplish this, the carriers would need to share capacity and shipment information for the benefit of the collaborative operation (Kale et al., 2007). The potential for carrier collaboration is synergistically aided by parallel developments in the data security protocol domain, which can protect the proprietary operational plans of carriers. The ability of an LTL carrier, especially one which is small- to medium-sized, to make a profit in a highly competitive market hinges on its ability to minimize its costs. Recent trends in the freight transportation domain indicate that an increasing number of carriers who are categorized as small- to medium-sized have begun to collaborate as a means to increase already slim profit margins as well as to increase their level of competitiveness given the affordability and the increased use of the Internet and ICT technologies (O'Reilly, 2006).

The problem faced by the small- to medium-sized carriers is: how to collaborate to decrease operational costs so as to improve operational efficiencies? One viable option is the sharing of capacity. Sharing capacity across collaborating carriers is no easy task, especially if the carriers are spatially spread. The ability to coordinate such collaborative activities becomes a network design problem for the carrier fleet dispatchers in the sense that the carriers must coordinate the routing and loading and unloading of the demand over the collaborative network. To coordinate the transfers (loading/unloading) of the demand, the carriers within the collaborative network must first assure that their needs are met before committing the excess capacity to the collaborative operation. Further, the carrier of interest (which is the carrier seeking the additional capacity) must plan in advance the collaborative routes that will minimize its cost for shipping the excess demand, including the costs associated with transfers. This would require prior knowledge of the existing operating networks and the locations of the available collaborative capacity of the collaborating partner carriers.

Other options outside a collaborative exist, but are not cost effective in most instances. A viable option for a carrier other than collaborating is the short-term leasing of capacity (power unit rentals) from a third party provider. The leasing of capacity is readily available, but most often relatively expensive for these types of carriers to consider. This is often attributed to the costs of acquiring the leases (such as insurance, period of lease, size, and availability at time of need). Further, such leases can eat into potential gains under short-term planning horizons, as the leased capacity usage depends on the demand arrival profile. Another option is capital investment (power unit acquisition), which can be a very expensive alternative for short-term planning purposes. The overall cost to the LTL carrier for this option depends on the specific product mix it ships and whether the new acquisition is needed for long-term operations.

Carrier collaboration can be both an opportunity for carriers to reduce costs, by reducing the number of empty trips and idled capacity on lots, and a way to become more competitive. The focus of this paper is to model an LTL carrier-carrier collaborative network from the perspective of a single carrier and to illustrate the potential savings from such collaborative networks. To the best of our knowledge, the literature in the LTL carrier collaboration domain is sparse. However, some relevant literature on carrier collaboration exists from the perspective of the truckload (TL) industry.

To study the carrier collaboration problem, we focus on a single carrier of interest who needs additional capacity to service loads for different origin and destinations. This carrier collaborates with a network of other LTLs to meet demand requirements. As the problem is from the perspective of a single carrier in a collaborative network of small- to medium-sized LTL carriers, the problem will be labeled the single carrier collaboration problem (SCCP). The SCCP problem is studied in a static context here to derive insights on the potential for collaboration.

The remainder of the chapter is organized as follows: Section 4.2 reviews the literature on carrier collaboration, primarily from the TL carrier domain, but also liner shipping, air cargo, and rail freight. Section 4.3 discusses the characteristics of the LTL carrier collaboration problem. Section 4.4 describes the cost parameters and the formulation of the static SCCP problem. Section 4.5 discusses the study experiments and summarizes the insights from the results. Section 4.6 performs sensitivity analyses and studies the effects of collaboration to compare the SCCP strategies to the short-term leasing option, analyze the impacts of increasing fuel prices, and estimate the levels of collaborative capacity utilization. Section 4.7 presents some concluding comments.

4.2 Literature Review

Little literature is available on LTL carrier collaboration. This may be due to the recent notion of carrier collaboration within this industry. Most literature dealing with ground carrier collaboration is related to the TL industry. Carrier collaboration has also been studied for other modes such as air cargo, liner shipping, and rail freight. Most of these studies deal with the issue of efficient allocation of collaborative capacity in the system and focus on operations research approaches to model the problem (such as vehicle routing problems). Agarwal and Ergun (2008a, 2008b) address carrier collaboration in sea cargo, by modeling the distribution and allocation of revenue and the design of the collaborative network. Similarly, Houghtalen (2007) address carrier-carrier collaboration in the air cargo industry, by proposing a mechanism that allocates both the collaborative resources (such as capacity) and profits by appropriately setting prices for the resources. Kuo et al. (2008) address multi-carrier collaboration in the rail freight industry, by proposing a simulation-based assignment framework for testing three collaborative decision-making strategies for track allocation over an international intermodal network.

From the trucking industry perspective, although not explicitly collaboration, Chu (2005) and Ball et al. (1983) introduce the notion of utilizing an outside ground carrier if demand cannot be met by the capacity of current fleet in the context of a vehicle routing problem. The problems are formulated as integer programs where the fleet seeks to minimize routing costs. The outside carrier is simply modeled as a binary decision variable with associated costs, and is not incorporated in the choice of routes.

Song and Regan (2004) introduce the notion of collaboration among TL carriers. Collaboration is assumed to occur in a post-market exchange where loads on non-profitable lanes, assumed to be static and pre-determined by an optimization routine, are auctioned off to other carriers in the collaborative network. The carrier of interest calculates a reservation price for the load and notifies its peer carriers in the collaborative network; hence, capacity may not be an issue. It is assumed that the other carriers use the same optimization routine to pre-determine the profitability of the load and then submit their bid. If no appropriate bids are placed, the load is simply withdrawn. The study focuses primarily on the economic feasibility of such a carrier collaboration mechanism. Figliozzi (2006) extends the auction-based collaborative carrier network by introducing a dynamic mechanism which is incentive-compatible. The mechanism is analyzed using a simulation procedure for a truckload pick-up and delivery problem. A reduction in dead-heading trips of up to 50% was observed using existing capacity. As with Song and Regan (2004), the possibility exists that the load may not be picked up during the bidding process. In addition, the study assumes that carrier networks overlap completely. Also, these studies do not consider the impacts of transfers and the associated costs.

In summary, in the context of the carrier collaboration problem, the current literature addresses collaboration mostly through market allocation mechanisms. However, network implications in terms of routing are not considered or discussed. That is, by considering the physical network over which the carriers operate, additional benefits and operational planning insights can potentially be gained. A key difference between the physical networks over which the TL industry and the small- to medium-sized LTL carriers operate is that the LTL network involves moving shipments over an array of warehouses, depots, and distribution centers while the TL industry ships direct from shipper to client. Among LTL network topologies, point-to-point networks are mostly used by small- to medium-sized LTL carriers and hub-and-spoke networks are adopted by larger LTL carriers. The hub-and-spoke systems require significant infrastructure investments and scheduled operational plans that can be justified mostly for large LTL carriers. By contrast, the point-to-point networks move LTL shipments directly between facilities, such as end-of-line terminals, without intermediate stops to consolidate loads. Hence, opportunities for carrier collaboration arise because of the increased likelihood of dead-heading during return trips. Thereby, the various shipment facilities provide opportunities for small- to medium-sized LTL carriers to collaborate by serving as potential transfer points for collaborative loads. Further, these carriers have greater incentive to share infrastructure to reduce costs as they operate on narrow profit margins. The point-to-point network configuration has two significant advantages over hub-and-spoke systems used by larger LTL carriers: (1) they do not have to deviate to potentially distant intermediate terminal locations, thereby making the trips faster, and (2) they save carriers additional transfer and transit costs by bypassing consolidation terminals (Bellman and White III, 2005; Taylor et al., 1995). Compared to the TL network, the point-to-point topology adds additional complexity due to the numerous terminal locations that are utilized daily by the LTL carriers.

The studies discussed heretofore deal with TL firms allocating demand that is not profitable, through some pricing mechanism, to a group of collaborative carriers.

Further, there is no guarantee that this demand will be served. By contrast, the notion of collaboration for the LTL industry deals with the actual swapping and/or transferring of the material goods from one firm to another at transfer facilities (warehouse, cross-docking facilities, distribution centers, and/or depots). This is a key conceptual difference related to the notion of collaboration between the TL industry and the LTL context addressed in this paper.

To the best of our knowledge, no previous study has modeled a static carrier-carrier collaboration problem for the small- to medium-sized LTL industry. In addition, this work differentiates itself from the previous studies in that the physical network over which the small- to medium-sized carriers operate is considered, along with the associated costs of transfers. The static SCCP represents a starting point to address the small- to medium-sized LTL collaborative paradigm, and assumes prior knowledge of the collaborative capacities. The modeling of time-dependent collaborative capacities will be addressed in future work through an extension of the static SCCP.

4.3 Problem Characteristics

4.3.1 TL versus LTL Operations

In general, the studies on carrier collaboration in the trucking industry have addressed allocation of the demand to collaborative carrier partners primarily through some sort of market mechanism (such as online auctions) in the TL sector. This is reasonable because most TL operations deal with direct-to-customer services and may see few opportunities to fill capacity. Also, TL operations tend to be long haul in nature and with longer planning periods. Hence, actual sharing of capacity may not be feasible.

LTL carrier collaboration entails the need to explore paradigms to borrow or swap (cross-docking) capacity. LTL carriers are more likely to be connected to warehouses, distribution centers, and or depots. Also, their planning periods are less than those of the truckload industry. Further, LTL shipments are characterized by shorter haul distances. This motivates the potential for seeking carrier collaborative networks rather than acquiring demand using some market mechanism. This is synergistically aided by the fact that LTL carriers tend to share facilities with other LTLs, creating overlaps that can be exploited for collaborative purposes. This is especially so for small- to medium-sized LTL carriers that may need additional capacity or have additional capacity to collaborate.

4.3.2 Short-Term Leasing versus Carrier Collaboration

Often carriers may not have the available capacity (power units, truck plus trailer) to service a load for one or more reasons: current capacity is tied up with other shipments, mechanical failures, etc. In such instances leasing capacity is an option. Many companies offer short-term leasing opportunities (Ryder, Budget, For-hires) to these carries, but these tend to be very costly for multiple reasons as discussed earlier. Besides costs, another issue is that the availability of capacity may be limited.

Carrier collaboration can provide the additional capacity from potentially numerous sources at possibly cheaper rates. This is because carriers desire to minimize the number of empty hauls they experience. In doing so, carriers can negotiate potential rate benefits (that is, discount from the usual base rates) and decide to serve niche lanes to increase the efficiency of their current fleet as well as alleviate the impacts of rising energy costs because of the more frequent loaded trips.

4.3.3 Static Planning Perspective

To gain insights on the potential for carrier collaboration for the small-to-medium LTL industry, the SCCP problem is studied in a planning context. While the time dimension is important to capture the effect of the spatial availability of capacity as well as the effect of holding costs at transfer points, the SCCP problem provides insights on the potential value of collaboration, in addition to identifying strategies to mitigate the negative consequences of higher fuel prices. The SCCP considers transfer costs in a static sense, thereby ensuring that a key cost component is factored in the network.

4.3.4 Transfers and Transfer Costs

A transfer is the loading and/or unloading of a shipment, or part of a shipment, to be reassigned to another carrier with excess capacity to handle it. The locations of transfers depend on the temporal and spatial availability of capacity. Further, they depend on the cost of the handling of the transfer. Transfer costs can be high, and range from 5% to 50% of the costs incurred by the carrier of interest for shipments depending on the transfer locations, contractual agreements, and related characteristics (Boardman, 1997). In this study, we consider two types of transfer cost policies: (i) fixed (based on a contracted fixed cost), and (ii) variable (based on the shipment volume).

4.3.5 Product Type

A product is an entity of value that can be bought or sold, usually finished goods or raw material. It can be categorized into perishable or non-perishable. Perishable products are goods that spoil with time or can get damaged easily (fruits, meats, medical supplies, etc). Their handling requires special freight units (such as refrigerated containers) that can slow the decay process or limit the amount of damage incurred during the transportation phase. Non-perishable products are goods that do not typically have specialized transportation needs (such as coal, canned goods, etc.). Many product types can be bundled within a single container unit depending on their classification. A key issue for a collaborative effort is to match the product type with the appropriate freight containers.

4.4 Mathematical Model

4.4.1 Problem Description and Assumptions

We first present a mathematical formulation for a single product static SCCP problem from the perspective of a single carrier, referred to as the carrier of interest. Later, we extend it to incorporate multiple product types to differentiate collaborative capacities available for perishable and non-perishable goods.

The small- to medium-sized collaborative carriers are represented as having a network structure of lanes (referred to as arcs here), which can be geographically identical, overlapping in some segments, and/or adjacent to the carrier of interest, that indicate their available collaborative capacities and rates. In addition, the formulation assumes the following: (i) the carrier of interest will use its available capacity first before collaborating, (ii) the transfer costs are divided equally between the collaborative carriers and the carrier of interest, (iii) a shipment is not split to multiple carriers during a transfer, (iv) a shipment is not split to multiple truck routes (arcs) of the same carrier during a transfer, and (v) a volume-based capacity; that is, we do not consider the number of individual power units (truck with a trailer), but rather the total volume available through those power units. It is also assumed that the collaborative carriers accept the liability for the safe delivery of the shipments.

The static SCCP problem refers to a collaborative strategy in which the carrier of interest seeks a set of collaborative routes which minimize its total cost while meeting its demand requirements. Hence, the carrier of interest may borrow some capacity from various collaborative carriers for different segments of the collaborative route. The problem is static in the sense that the demand is constant and the available capacities from the collaborative carriers are time invariant. By contrast, a dynamic version of the SCCP would entail the availability of time-dependent collaborative capacities from the collaborative carriers.

4.4.2 Cost Parameters

The total cost that the carrier of interest seeks to minimize consists of two components: (i) the collaborative rates that include two primary LTL costs, and (ii) the transfer costs.

The collaborative rates are formed using a modified version of the Shang et al. (2009) LTL linehaul and surcharge cost functions. The linehaul cost functions have the following form for each carrier in the collaborative operation:

$$L_a = \alpha \tilde{d}_a + \beta \widetilde{w} \tag{4.1}$$

In equation (4.1), L_a represents the linehaul costs for arc a, $\tilde{d}_a$ represents the arc distance for arc a, and $\widetilde{w}$ represents the total shipment weight. α and β represent positive monetary values that depend on the shipment characteristics.

The surcharge cost function is:

$$S_a = \gamma L_a \tag{4.2}$$

where S_a represents the fuel surcharge cost for arc a, and γ represents the Department of Energy's Diesel Fuel Index which is obtained as a percentage of the current cost of a gallon of diesel fuel. The collaborative rate ς_a for a carrier in the collaborative is computed using equations (4.1) and (4.2):

$$\varsigma_a = \delta L_a + S_a \tag{4.3}$$

where δ represents the collaborative discount rate. The discount rate δ is associated only with the linehaul costs as in practice carriers do not discount the fuel surcharge costs which are usually a percentage of the non-discounted linehaul costs. We view δ as representing the degree of collaboration among the carriers. Hence, a larger δ value would imply a greater degree of collaboration among the various carriers in terms of enabling the collaboration.

To account for the variability in various factors at transfer locations (e.g. size, location, terminal congestion, terminal delays, labor, equipment), the transfer costs ϕ_a are assumed to vary for each location (arc). For a specific location, we assume the transfer costs to be either fixed or variable as discussed in Section 4.3.4. In addition, as stated earlier, the transfer costs are divided equally between the collaborating carriers and the carrier of interest**.**

4.4.3 Single Product Problem Formulation with Fixed Transfer Costs

This section describes the mathematical programming formulation of the static SCCP for the single product case. The notation, constraints, and objective function are discussed, followed by the characterization of the formulation properties.

4.4.3.1. Sets

Let a shipment $k \in K$ be served by a set of fixed transshipment facilities $i \in N$ (also labeled facilities or nodes) which are interconnected by transit corridors $a \in A$ (also labeled arcs). The transit corridors $a \in A$ that originate from facility $i \in N$ are depicted as $a \in \Gamma(i)$ and those heading to facility $i \in N$ are $a \in \Gamma^{-1}(i)$. A shipment $k \in K$ may be served by a transit corridor $a \in A$ only through a collaborative carrier $q \in Q$ operating in this corridor. Fixed transshipment facilities $i \in N$ and collaborative carriers $q \in Q$ form our collaborative network. A shipment $k \in K$ will enter the collaborative network through an origin facility $O(k)$ and exit through a destination facility $D(k)$. For each shipment $k \in K$, its origin facility $O(k)$ and its destination facility $D(k)$ constitutes its origin-destination pair.

4.4.3.2. Parameters

Each shipment $k \in K$ has an associated volume d_k. The cost for acquiring a unit of capacity (volume) from a collaborative carrier $q \in Q$ on transit corridor $a \in A$ is the collaborative rate ς_{aq} (see Section 4.2). The fixed cost for transferring shipment on transit corridor $a \in A$ is ϕ_a (see Section 4.2).

The available collaborative capacity of a collaborative carrier $q \in Q$ for transit corridor $a \in A$ is w_{aq}. If a collaborative carrier $q \in Q$ does not provide service for transit corridor $a \in A$, it is assumed without loss of generality that its available collaborative capacity w_{aq} is 0.

4.4.3.3. Variables

If a shipment $k \in K$ is served through transit corridor $a \in A$ by collaborative carrier $q \in Q$, we define Y_{kaq} to take the value of 1, and 0 otherwise. This variable represents the collaborative capacity acquisition decision for the carrier of interest.

If a transfer takes place on transit corridor $a \in A$ to collaborative carrier $q \in Q$, we define Z_{aq} to take the value of 1, and 0 otherwise. It represents the collaborative shipment transfer decision variable for the carrier of interest.

4.4.3.4. Constraints

Next, we formulate the constraint set of the SCCP. It consists of two sets of constraints. The first set of constraints (4.4a, 4.4b, 4.4c, and 4.5) model the independent transshipment of shipments through the collaborative networks. The second set of constraints (4.6) establishes an upper bound on the available collaborative carrier capacity (in terms of volume). The constraints are as follows:

$$-\sum_{q \in Q} \sum_{a \in \Gamma(i)} Y_{kaq} = -1 \qquad \forall i \in O(k), k \in K \qquad (4.4a)$$

$$\sum_{q \in Q} \sum_{a \in \Gamma^{-1}(i)} Y_{kaq} - \sum_{q \in Q} \sum_{a \in \Gamma(i)} Y_{kaq} = 0 \quad \forall i \in N \setminus \{O(k), D(k)\}, k \in K \qquad (4.4b)$$

$$\sum_{q \in Q} \sum_{a \in \Gamma^{-1}(i)} Y_{kaq} = 1 \qquad \forall i \in D(k), k \in K \qquad (4.4c)$$

$$\sum_{a \in \Gamma(i)} Z_{aq} \leq 1 \qquad \forall i \in N, q \in Q \qquad (4.5)$$

$$\sum_{k \in K} d_k Y_{kaq} \leq w_{aq} Z_{aq} \qquad \forall a \in A, q \in Q \qquad (4.6)$$

$$Y_{kaq} \in \{0,1\} \qquad \forall a \in A, k \in K, q \in Q \qquad (4.7)$$

$$Z_{aq} \in \{0,1\} \qquad \forall a \in A, q \in Q \qquad (4.8)$$

Constraint set (4.4) represents the mass balance constraints and ensures the node flow propagation conservation for the carrier capacity acquisition decisions; at most one decision unit of capacity acquisition is propagated at that facility. It consists of (4.4a), (4.4b), and (4.4c), which correspond to the origin, intermediate, and destination nodes/facilities in the network, respectively.

Constraint (4.5) ensures that at most one arc/corridor is assigned to a carrier at a facility for a transfer, implying that a shipment is not split to multiple truck routes (arcs) of the same carrier during a transfer. Constraint (4.6) represents the collaborative capacity constraint; it ensures that the capacity acquired from a carrier (left-hand side of (4.6)) is less than its available capacity (right-hand side of (4.6)) on that transit corridor. Constraint sets (4.7) and (4.8) represent the 0-1 integrality conditions for the decision variables.

4.4.3.5. Objective function

The objective function of the SCCP problem seeks to minimize the total costs incurred by the carrier of interest and is represented as follows:

$$Min \sum_{k \in K} \sum_{a \in A} \sum_{q \in Q} \varsigma_{aq} d_k Y_{kaq} + \sum_{a \in A} \sum_{q \in Q} \Phi_a Z_{aq} \qquad (4.9)$$

The objective function minimizes the total additional cost incurred by the carrier of interest. It consists of two parts; the first part represents the collaborative capacity acquisitions costs, and the second part denotes the fixed transfer costs on the transit corridors where transfers occur. The acquisition costs are obtained as the summation of the product of the collaborative capacity acquisition rate ς_{aq}, the demand d_k, and Y_{kaq} (the decision on whether capacity is acquired on a transit corridor). The transfer costs are obtained as the summation of the product of the fixed transfer cost ϕ_a for a transit corridor and Z_{aq} (the decision on whether a transfer takes place on that transit corridor). Equation (4.9) subject to constraints (4.4) to (4.8) represents the mathematical formulation of the static single product SCCP. The next subsection discusses some of its properties.

4.4.3.6. Properties

Classification

The mathematical programming formulation of the static single product SCCP belongs to the class of binary (0-1) multi-commodity minimum cost flow problems. This is because constraints (4.4a), (4.4b), and (4.4c) are node flow conservation constraints on which "flow" propagates. The classification is further substantiated by the structure of the physical network in which the collaborative carriers operate; it is composed of static nodes which are fixed transshipment facilities (for example, warehouses, depots, and/or distribution centers) and the static arcs which are transit corridors corresponding to the collaborative carriers. It can be noted that constraints (4.4a), (4.4b), and (4.4c) can be written independently for each shipment. Constraints (4.5) and (4.6) are the transfer arc assignment and equivalent shared capacity constraints respectively, which bind the rest of the formulation together.

Exact methods such as branch-and-cut can be applied to solve reasonably-sized instances of these types of problems (Mitchell, 2000), as is the case in the current study because small- to medium-sized LTL carriers are characterized by modest collaborative network sizes. However, due to the aforementioned mathematical form, which is common in multi-commodity minimum cost flow problems, Lagrangian relaxation is an attractive solution methodology for large instances (for example, large LTL carriers with large network sizes) to handle constraint sets (4.5) and (4.6). As such, independent multiple minimum cost flow problems can be solved. Due to the 0-1 (binary) formulation, it translates to solving multiple independent shortest path problems. Other mathematical decomposition methods have also been proposed (Ahuja et al., 1993; Martin, 1999).

Total unimodularity

The formulation is characterized by the total unimodularity property, which guarantees that the optimum decision variable values are integers. This enables the circumvention of the much slower integer programming solution algorithms by the use of fast linear programming techniques.

The total unimodularity property aids our problem in the following ways. First, in this study involving small- to medium-sized LTL carriers, the branch-and-cut algorithm in GAMS/CPLEX is used which solves the linear program without the integer constraints to obtain the optimal solution. Here, the unimodularity property precludes the need for triggering the cutting plane algorithm. Second, for larger problems instances involving large networks, where decomposition methods may be appropriate (as discussed in Section 4.4.3.6.1), and unimodularity helps in the context of the decomposition to multiple independent shortest path problems. Thereby, for each independent shortest path problem we can drop the integrality constraints, solve the problem with linear shortest path algorithms (like the reaching shortest past algorithm), and find integer 0-1 solution sets which satisfy the original integrality constraints.

Third, the total unimodularity property implicitly addresses a key assumption precluding splitting of shipments among multiple carriers, as stated in Section 4.1. Constraints (4.4a), (4.4b), and (4.4c), along with the integrality constraints (4.7), intrinsically ensure that a shipment is not split to multiple carriers during a transfer. Therefore, the following constraint, which would otherwise be required, is redundant:

$$\sum_{q \in Q} Y_{kaq} \leq 1 \qquad \forall a \in A, k \in K \qquad (4.10)$$

4.4.3.7. Multiple product problem extension

The multiple product formulation models the possibility of the carrier of interest has to move non-perishable items and perishable items separately. Differentiating between the product types is important because many LTL carriers provide a mix of services to their clients. For example, they may move shipments that need some special handling requirements such as climate-controlled trailers for some perishables (e.g. meats, fruits, etc.) or a dry trailer for non-perishables (e.g. books, tires, etc.). Hence, to stay competitive, many LTL carriers may have a mix of trailers at their disposal that can handle a variety of shipping requirements. To represent multiple products, the product type is introduced in the SCCP as an index $p \in P$, where P represents the set of distinct products types. The formulation for the multiple product case is represented through a straightforward extension of equations (4.4) to (4.9) by including the product type. The total unimodularity property (see Section 4.4.3.6.2) holds for this extension as well due to the separability of each shipment by product type.

4.4.3.8. Variable transfer cost policy

In Section 4.4.3, equation (4.9) assumes that transfer costs are a fixed contracted amount independent of the shipment volume. However, as discussed in Section 4.3.4, transfer facilities may have pricing strategies based on shipment volume. That is, they may charge carriers a rate based on each shipment coming into the terminal. In such instances, as the number of transfer shipments increase for the carrier of interest on a transit corridor, the transfer costs incurred by that carrier will also increase. To account for the variability in terminal pricing policies, we consider the problem where the transfer cost is assumed to depend on the number of shipments. The corresponding formulation for the single product case differs from that of the fixed transfer cost formulation in that in equation (4.9) ϕ_a is replaced by ϕ_{ak} to obtain the new objective function:

$$Min \sum_{k \in K} \sum_{a \in A} \sum_{q \in Q} \varsigma_{aq} d_k Y_{kaq} + \sum_{k \in K} \sum_{a \in A} \sum_{q \in Q} \phi_{ai} \tag{4.11}$$

A similar modification is made to the objective function for the multiple product case.

4.5 Study Experiments

The study experiments seek to analyze the sensitivity of the model's performance to the following parameters: number of shipments and the network size. The model performance is assessed in terms of the computational time required to solve the problem to optimality. Further, experiments are performed to analyze the benefits of collaboration: (i) as an alternative to the non-collaborative short-term leasing strategy through varying collaborative discount rates δ, and (ii) as fuel/energy costs increase.

4.5.1 Data Generation

Data availability in the LTL trucking industry is primarily proprietary due to the potential loss of competitiveness to other firms in the same market. Obtaining such data in the future is becoming more likely due to recent technologies that allow the sharing of vital information without hindering the competitiveness of carriers. One of them is termed secure multiparty computation (SMC) which is a cryptographic protocol among a set of participants, where some of the inputs needed for the interaction have to be hidden from participants other than the initial owner (Atallah et al., 2004). In the future, technologies such as SMC will enable carriers in a collaborative network to share the necessary information seamlessly.

Since the aforementioned data security initiatives are currently not in the operational domain, the data used in this study was simulated using a uniform distribution on the LTL industry observed ranges (Boardman, 1997; Belman and White III, 2005; Fleetseek, 2006; Bureau of Transportation Statistics, 2005; ABF, 2006) and those of third party capacity providers Ryder (2006) and Budget truck rentals (2006). The simulated data consists of: (i) the collaborative rates from equation (1), (ii) the transfer costs (for both the fixed and variables cases), (iii) the short-term leasing costs, (iv) the demand for multiple shipments, and (v) the collaborative capacities (for single and multiple product cases).

The short-term leasing option is used to benchmark the benefits that arise through the carrier collaborative network. The leasing option represents a cost for the carrier of interest to service the excess demand. The associated cost function ρ_k is determined by the following equation (Budget truck rentals, 2006; Ryder, 2006):

$$\rho_k = T_k(\cdot) + D_k(\cdot) + U_k(\cdot) \tag{4.12}$$

where ρ_k represents the short-term leasing cost and is computed for the selected collaborative path for each shipment k. The function $T_k(\cdot)$ represents the costs associated with acquiring the short-term lease(s) for the additional capacity (vehicle size, rental, insurance, number of days, number of trucks, and fuel expenses), $D_k(\cdot)$ represents the costs associated with the driver(s) (wage per hour), and $U_k(\cdot)$ represents the costs associated with handling the loads (loading/unloading, equipment, duration costs). For the multiple product formulation, the product type is factored into each of the cost components through the varying degree of load requirements. For example, a climate-controlled trailer has a higher acquisition cost compared to a dry box trailer.

4.5.2 Solution and Implementation Details

The computing environment consists of a DELL XPS machine with an Intel Core™ 2 Duo processor T8300, under the Windows Vista™ operating system with 2.40GHz and 4GB of RAM. The SCCP problem was solved using the branch-and-cut algorithm the in GAMS/CPLEX optimization software version 22.9 with ILOG CPLEX 11.0.

The binary (0-1) multi-commodity minimum cost flow problem is solved using the branch-and-cut algorithm (Caprara and Fischetti, 1997; Martin, 1999) in GAMS/CPLEX. This algorithm is used because the scope of the operations in this study is that of small- to medium-sized LTL carriers. These carriers can be classified as local (carriers that typically operate within the confines of a state) or regional (carriers that typically operate between two or more states in a region), and may at most be associated with a dozen or so transfer facilities (Bellman and White III, 2005). That is, their network sizes are modest. As discussed in Section 4.4.3.6, for the larger and more complex carrier operations characterized by large LTL carriers, decomposition methods are expected to be more appropriate due to the added complexity from larger operating networks and number of shipments.

4.5.3 Experiment Setup

The experiments consider the carrier of interest and four other collaborative carriers, for a total of five collaborative carriers for both the single and multiple product SCCP problems. The other parameters take values according to the following ranges: network size in terms of nodes 12 (see Figure 4.1), 20 and 50 and the corresponding number of shipments from (1, 5, 10), (1, 5, 10, 15, 20), (1, 5, 10, 15, 20, 30), respectively. The 20-node and 50-node networks were randomly generated using MATLAB. The 50-node graph contains a high order of indegree and outdegree nodes, resulting in a relatively large number of arcs (see Table 4.1). All graphs are acyclic. In addition, four degrees of collaboration (δ) 0%, 30%, 50%, and 80% are used to assess the viability of the collaboration. For the multiple product case, we consider four product types. As the data is simulated, ten randomly generated data sets consistent with the LTL industry observed ranges are created for each test scenario (in terms of network size, number of shipments, and number of products). For each network size and number of shipments configuration, the collaborative rates and transfer costs are identical for the single and multiple product cases in the randomly generated data. However, the demand and collaborative capacities are different in the single and multiple product cases. The experiments are performed for the fixed and variable transfer cost cases.

4.6 Analysis Results

4.6.1 Sensitivity Analyses

Tables 4.1 and 4.2 illustrate the results of the parameter sensitivity analyses for the fixed transfer cost case for the single product and multiple product SCCP problems, respectively. Tables 4.3 and 4.4 show the results for the variable transfer cost case for the single product and multiple product problems, respectively. Columns 1 and 2 correspond to the number of nodes and number of arcs in each network, respectively. Column 3 corresponds to the number of distinct shipments considered for each network size. Column 4 illustrates the short-term leasing (non-collaboration) solution for the corresponding network size and number of shipments. Column 5 shows the collaborative costs to the carrier of interest under the four levels of capacity acquisition discounts (0%, 30%, 50%, 80%). Column 6 indicates the percentage savings under collaboration compared to the non-collaboration case for the four levels of capacity acquisition discount. The overall trends from Tables 4.1 to 4.4 indicate that the cost to the carrier of interest increases with the number of shipments under both the short-term leasing and collaboration alternatives. The one exception to this trend is the 15 shipments case for the 20-node network which has higher costs compared to the 20 shipment case in Table 4.1. This is because the ten randomly generated rates and demands were, on average, higher for the 15 shipments case, resulting in higher costs.

The CPU computational times in Tables 4.1 to 4.4 are based on branch-and-cut algorithm for each network size and number of shipments configuration. The computational times increase with the number of shipments for a network size, as well as with the network size itself. Each configuration is solved to optimality in a reasonable amount of time as the binary (0-1) multi-commodity minimum cost flow problem formulations for the single and multiple products cases are solved using relaxations only at the level of the binary decision variables. Thereby, the underlying linear programs coupled with the unimodularity property provide relatively good bounds for the branch-and-cut algorithm.

Figures 4.2 and 4.3 further illustrate the computational times for the single and multiple product cases under various configurations of network size and number of shipments, for the fixed and variable transfer cost policies, respectively. It indicates that the additional dimension of the number of products magnifies the computational complexity as the number of shipments increases, reflected by the substantial increase in the computational time over the single product case in the figures. However, in Figure 4.2 there are three instances in which the multiple product case has lower CPU times. This can be attributed to the randomly generated data, which in these instances had lower demand levels and increased collaborative capacities for the multiple product cases, leading to quicker solutions.

4.6.2 Effect of Collaboration

The potential for collaboration among carriers is investigated by focusing on the level of monetary savings due to collaboration as well as its ability to alleviate the effects of increased fuel/energy prices.

As stated earlier, the level of collaboration is reflected through the degree of collaboration, which takes values 0%, 30%, 50% and 80%. The 0% collaborative discount rate represents the typical linehaul costs charged by a member of the collaborative carrier network to a client outside the collaborative operation. Hence, it serves as a benchmark to compare the effects of different degrees of the collaboration in terms of discounting the collaborative rate. It is important to note that the 0% case also represents a collaborative strategy unlike the leasing option which is a non-collaborative strategy. The non-collaborative strategy represents the base case to compare all collaborative strategies (0%, 30%, 50%, 80% discounted rates). The 0% base collaborative discount rate case entails savings because of the increased operational efficiencies due to collaboration. In general, a higher discounted rate leads to a greater level of collaboration, as evidenced by the substantial increase in cost savings under higher discount rates in Tables 4.1 through 4.4. However, for the variable transfer cost policy, the benefit from collaboration is lower, especially as the degree of collaboration increases, as shown in Tables 4.3 and 4.4. This is because the cost burden from the transfer costs increases with the degree of collaboration.

While the relative attractiveness of the collaborative paradigm depends on the degree of collaboration, it is also partly dependent on the levels of fuel surcharge. This is in contrast to the transfer costs which, while factored in the collaborative paradigm, are fixed and thereby considered sunk costs. To study the effects of the fuel surcharge, a breakeven analysis is performed to illustrate the point at which the non-collaborative alternative becomes a viable option for the carrier of interest. Figure 4.4 illustrates the fuel price at which the non-collaborative option is attractive, on average, for the various collaborative discount rates for the fixed transfer cost policy. It uses a base diesel fuel price of $2.79. Thereby, for a 30% discount rate or degree of collaboration, the fuel price has to increase, on average to $4.45 per gallon for the non-collaborative alternative to become competitive. The breakeven fuel prices for the various discount rates, shown in Figure 4.4, represent the average over the ten simulated runs: (i) with a range of $2.78 - $3.10 and average of $2.92 for the 0% case, (ii) $4.36 - $4.90 and average $4.45 for the

30% case, (iii) \$7.35 - \$8.05 and average \$7.65 for the 50% case, and (iv) \$9.89 - \$10.76 and average \$10.48 for the 80% case.

As stated in equation (4.2), the fuel surcharge cost is a percentage of the non-discounted linehaul cost, where the percentage multiplier is based on the fuel price. Hence, as the collaborative discount rate increases, the impact of the linehaul cost in the collaborative rate (equation (4.3)) decreases, requiring greater increases in fuel price to make the non-collaborative option attractive. For example, at the 80% collaborative discount rate, the fuel price would have to be approximately \$10.48 or higher, which translates to about a 95.5% fuel surcharge on the non-discounted linehaul costs. Therefore, the carrier of interest gains from increased collaborative discount rates relative to the breakeven fuel price.

Tables 4.5 and 4.6 illustrate the average capacity utilization by the carrier of interest as a percentage of the collaborative capacity available from the collaborating partner carriers, for the fixed and variable transfer cost policies, respectively. The values represent the average over 10 runs conducted for each network size and number of shipments. For the fixed transfer cost policy (Table 4.5), the capacity utilization for the single product case ranges from 42% to 61% and that for the multiple product case ranges from 38% to 55%. However, for the variable transfer cost policy (Table 4.6), the capacity utilization for the single and multiple product cases is higher, and ranges from 50% to 65% and 43% to 66%, respectively. The increased utilization in Table 4.6 is a direct effect of the increased congestion at locations with lower variable transfer costs. In both tables, the results illustrate the potential to reduce empty hauls for the collaborating carriers. The results are significant because the opportunity for carriers to convert empty trips to revenue generating trips aids their slim profit margins, which can be critical during economic downturns and energy price escalations.

In summary, the study experiments provide insights into the viability of the collaborative carrier concept for different transfer cost policies in terms of: (i) the degree of collaboration, (ii) the impacts of fuel price fluctuations, and (iii) the collaborative capacity utilization. The results suggest that the attractiveness of the carrier collaboration paradigm increases with the collaborative discount rate. Also, the fuel surcharge has a greater impact at lower collaborative discount rates. Finally, the ability for collaborative carriers to increase revenue generating trips through reduced dead-heading can be important given the low profit margins across the LTL industry.

4.7 Summary

In this chapter, a static single carrier collaboration problem (SCCP) was introduced. It provides a planning mechanism for the design of collaborative routes for a carrier of interest for the single and multiple product cases. It addresses the operational issue of dead-heading through the leveraging of excess capacity from the perspective of small- to medium-sized LTL trucking firms, synergized by novel opportunities provided through advances in ICT and e-commerce. Single and multiple product binary (0-1) multi-commodity minimum cost flow problem integer programming formulations of the SCCP problem were presented. The branch-and-cut algorithm was used to solve the two problem formulations for network sizes consistent with the small- to medium-sized LTL industry.

The study results indicated that the carrier collaborative paradigm can potentially increase capacity utilization for member carriers, thereby generating the potential to gain revenue on empty-haul trips. In addition, as the degree (or level) of collaboration increases, the relative attractiveness of utilizing collaborative capacity increases compared to the non-collaborative alternative. The non-collaborative alternative can become attractive only at relatively high fuel prices, at points where the benefits of collaboration are negated. The transfer cost policy can have differential effects on capacity utilization, leading to implications for terminal congestion and design. The study illustrates that carrier collaboration can become a critical strategy for survival in a highly competitive industry, especially under economic downturns and fuel price fluctuations. To our knowledge, this is the first attempt at modeling an LTL carrier collaboration problem for the small- to medium-sized LTL trucking industry.

In ongoing research, we extend the SCCP to the dynamic case to derive insights in a real-world context. It considers holding costs which can be a key factor in determining the optimal set of routes for the carrier of interest. Furthermore, a collaborative rate mechanism is being explored to address the multiple carrier collaboration case.

Table 4.1 Comparison of no collaboration (short-term leasing) and carrier-carrier collaboration for the single product scenarios (fixed transfer cost policy)

Network size				Collaborative cost ($)				Percentage savings over no collaboration				
				Percentage degree of collaboration				Percentage degree of collaboration				
Number of nodes	Number of arcs	Number of shipments	No collaboration ($)	0%	30%	50%	80%	0%	30%	50%	80%	CPU time (seconds)
12	29	1	2253	2212	1889	1403	1080	1.84%	16.17%	37.74%	52.07%	0.12
		5	13146	12664	10579	7451	5366	3.67%	19.53%	43.32%	59.18%	0.31
		10	15257	14415	12081	8580	6246	5.52%	20.82%	43.76%	59.06%	0.43
20	55	1	2219	2148	1883	1484	1219	3.20%	15.14%	33.12%	45.07%	0.16
		5	7558	6628	5717	4350	3439	12.30%	24.36%	42.45%	54.50%	4.33
		10	28988	27924	23417	16656	12149	3.67%	19.22%	42.54%	58.09%	9.20
		15	34848	34381	28740	20278	14637	1.34%	17.53%	41.81%	58.00%	22.10
		20	28548	27945	23434	16667	12156	2.11%	17.91%	41.62%	57.42%	40.53
50	632	1	1231	1140	980	739	579	7.42%	20.42%	39.99%	52.98%	0.48
		5	3128	2926	2580	2062	1716	6.46%	17.52%	34.08%	45.14%	0.93
		10	7124	6091	5324	4174	3408	14.50%	25.27%	41.41%	52.16%	2.05
		15	9735	9014	7823	6036	4845	7.41%	19.64%	38.00%	50.23%	14.48
		20	13294	12995	11154	8393	6552	2.25%	16.10%	36.87%	50.72%	129.97
		30	20506	19717	16714	12209	9206	3.85%	18.49%	40.46%	55.11%	371.70

Table 4.2 Comparison of no collaboration (short-term leasing) and carrier-carrier collaboration for the multiple product scenarios (fixed transfer cost policy)

Network size				Collaborative cost ($)				Percentage savings over no collaboration				
				Percentage degree of collaboration				Percentage degree of collaboration				
Number of nodes	Number of arcs	Number of shipments	No collaboration ($)	0%	30%	50%	80%	0%	30%	50%	80%	CPU time (seconds)
12	29	1	3089	3033	2690	2176	1833	1.81%	12.91%	29.55%	40.66%	0.41
		5	17204	16596	14159	10504	8067	3.54%	17.70%	38.95%	53.11%	0.54
		10	37424	35466	29900	21550	15984	5.23%	20.10%	42.42%	57.29%	1.36
20	55	1	4043	3918	3525	2937	2544	3.10%	12.81%	27.36%	37.08%	0.46
		5	7043	6808	5973	4720	3885	3.34%	15.20%	32.99%	44.84%	0.74
		10	20908	20168	17290	12973	10094	3.54%	17.30%	37.95%	51.72%	0.97
		15	27454	27091	23194	17349	13452	1.32%	15.52%	36.81%	51.00%	25.35
		20	28988	28389	24348	18287	14247	2.07%	16.01%	36.92%	50.85%	243.14
50	632	1	1610	1499	1355	1139	994	6.91%	15.85%	29.26%	38.27%	3.00
		5	3051	2866	2526	2015	1675	6.07%	17.21%	33.96%	45.10%	5.21
		10	6013	5857	5091	3944	3179	2.60%	15.33%	34.41%	47.13%	8.04
		15	9117	8488	7388	5737	4637	6.90%	18.96%	37.07%	49.14%	13.41
		20	13193	12902	11196	8638	6932	2.20%	15.13%	34.52%	47.46%	110.54
		30	21328	20538	17605	13206	10273	3.70%	17.46%	38.08%	51.83%	588.99

Table 4.3 Comparison of no collaboration (short-term leasing) and carrier-carrier collaboration for the single product scenarios (variable transfer cost policy)

Network size				Collaborative cost ($)				Percentage savings over no collaboration				
				Percentage degree of collaboration				Percentage degree of collaboration				
Number of nodes	Number of arcs	Number of shipments	No collaboration ($)	0%	30%	50%	80%	0%	30%	50%	80%	CPU time (seconds)
12	29	1	2872	2783	2440	1926	1583	3.10%	15.04%	32.94%	44.88%	0.19
		5	16121	15820	13735	10607	8522	1.86%	14.80%	34.20%	47.14%	0.25
		10	21442	20500	18115	14538	12154	4.40%	15.52%	32.20%	43.32%	0.33
20	55	1	3842	3673	3280	2692	2299	4.40%	14.63%	29.93%	40.16%	0.19
		5	8959	8589	7576	6057	5044	4.12%	15.44%	32.39%	43.70%	5.13
		10	25096	24436	21898	18090	15552	2.63%	12.74%	27.92%	38.03%	8.80
		15	30178	29644	25064	18193	13612	1.77%	16.95%	39.71%	54.89%	30.10
		20	33565	32907	29269	23811	20172	1.96%	12.80%	29.06%	39.90%	47.70
50	632	1	1738	1674	1530	1314	1169	3.66%	11.95%	24.38%	32.72%	1.63
		5	4274	4044	3695	3172	2824	5.39%	13.55%	25.79%	33.93%	2.30
		10	12082	11640	10794	9525	8678	3.66%	10.66%	21.17%	28.18%	4.24
		15	22124	20930	19662	17759	16490	5.39%	11.13%	19.73%	25.46%	39.15
		20	34222	32316	30360	27426	25470	5.57%	11.29%	19.86%	25.58%	186.96
		30	27663	26988	24055	19656	16723	2.44%	13.04%	28.94%	39.55%	1571.10

Table 4.4 Comparison of no collaboration (short-term leasing) and carrier-carrier collaboration for the multiple product scenarios (variable transfer cost policy)

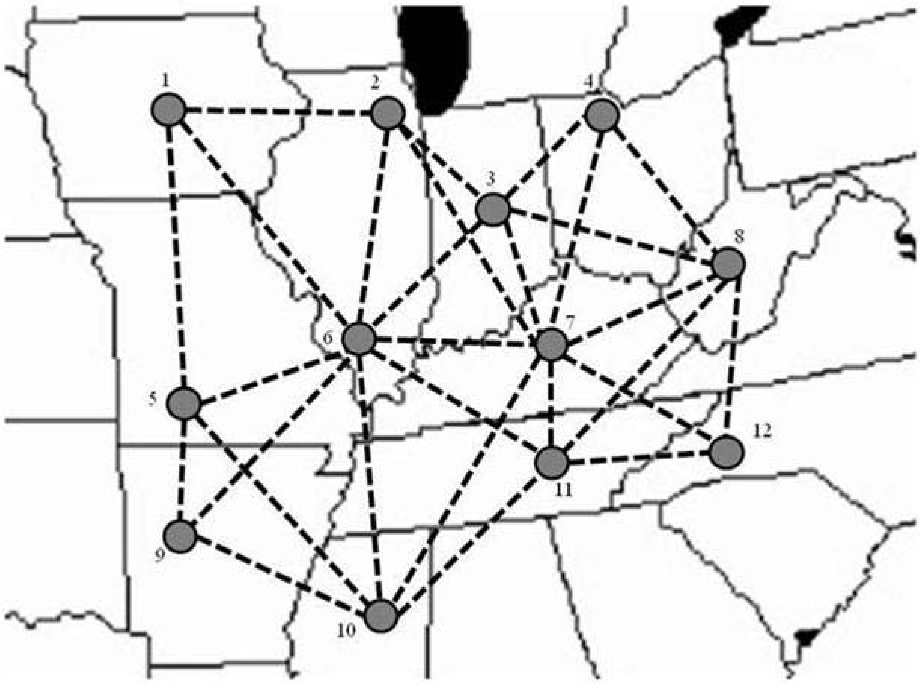
Network size				Collaborative cost ($)				Percentage savings over no collaboration				
				Percentage degree of collaboration				Percentage degree of collaboration				
Number of nodes	Number of arcs	Number of shipments	No collaboration ($)	0%	30%	50%	80%	0%	30%	50%	80%	CPU time (seconds)
12	29	1	2711	2587	2264	1778	1455	4.58%	16.49%	34.42%	46.33%	0.24
		5	17209	16327	13886	10224	7783	5.12%	19.31%	40.59%	54.77%	0.31
		10	25783	25352	22059	17119	13825	1.67%	14.44%	33.60%	46.38%	0.60
20	55	1	2372	2301	2036	1637	1372	3.01%	14.18%	31.00%	42.17%	0.47
		5	7275	7188	6350	5093	4255	1.19%	12.71%	29.99%	41.51%	6.95
		10	26995	25636	22755	18432	15550	5.03%	15.71%	31.72%	42.40%	10.48
		15	40828	39755	35814	29902	25961	2.63%	12.28%	26.76%	36.41%	84.31
		20	51028	49350	45294	39208	35152	3.29%	11.24%	23.16%	31.11%	1351.10
50	632	1	1514	1492	1332	1091	931	1.48%	12.04%	27.96%	38.52%	3.42
		5	4940	4778	4402	3837	3461	3.29%	10.90%	22.33%	29.95%	4.11
		10	14218	13439	12545	11205	10311	5.48%	11.77%	21.19%	27.48%	7.23
		15	26362	24941	23606	21604	20270	5.39%	10.46%	18.05%	23.11%	72.64
		20	28799	28206	26477	23883	22154	2.06%	8.06%	17.07%	23.07%	604.10
		30	45513	43018	39673	34656	31311	5.48%	12.83%	23.85%	31.20%	3025.11

Table 4.5 Percentage collaborative capacity utilization for the single and multiple product cases (fixed transfer cost policy)

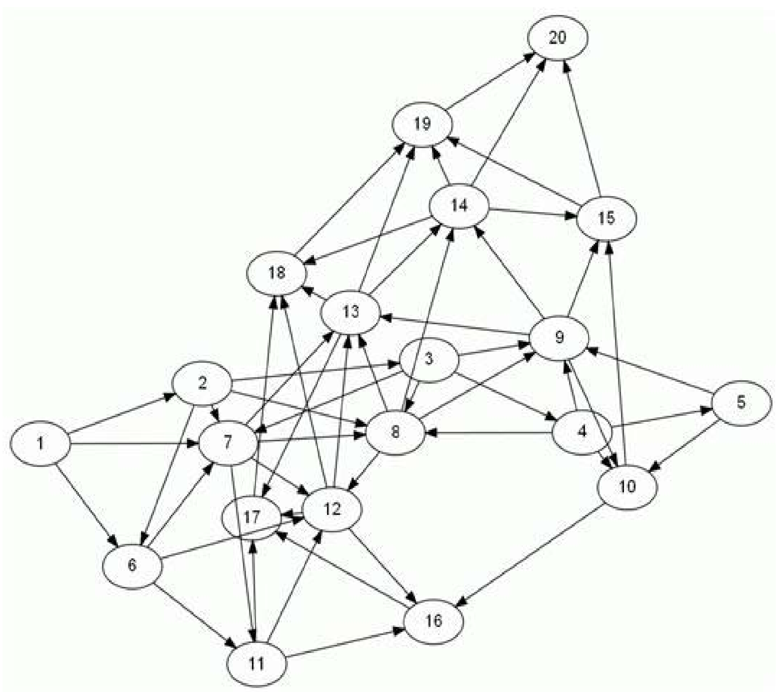
			Single product case	Multiple product case				
			Average percentage collaboration capacity utilization	Average percentage collaboration capacity utilization				Average percentage collaboration capacity utilization across the four product types
Number of nodes	Number of arcs	Number of shipments	1	1	2	3	4	
12	29	1	55%	59%	58%	44%	58%	55%
		5	60%	43%	34%	40%	41%	40%
		10	44%	49%	48%	37%	52%	47%
20	55	1	48%	51%	47%	52%	55%	51%
		5	49%	47%	33%	37%	36%	38%
		10	54%	41%	38%	43%	38%	40%
		15	61%	36%	33%	50%	59%	45%
		20	49%	34%	50%	43%	50%	44%
50	632	1	53%	44%	48%	51%	45%	47%
		5	46%	51%	37%	49%	36%	43%
		10	51%	52%	47%	54%	55%	52%
		15	54%	40%	38%	50%	58%	47%
		20	42%	55%	54%	55%	40%	51%
		30	46%	47%	48%	45%	47%	47%

Table 4.6 Percentage collaborative capacity utilization for the single and multiple product cases (variable transfer cost policy)

			Single product case	Multiple product case				
Number of nodes	Number of arcs	Number of shipments	Average percentage collaboration capacity utilization	Average percentage collaboration capacity utilization				Average percentage collaboration capacity utilization across the four product types
			1	1	2	3	4	
12	29	1	55%	59%	58%	44%	58%	55%
		5	60%	41%	56%	42%	34%	43%
		10	50%	43%	57%	59%	68%	57%
20	55	1	58%	51%	47%	52%	55%	51%
		5	54%	58%	52%	49%	62%	55%
		10	47%	61%	46%	43%	57%	52%
		15	52%	67%	43%	36%	53%	50%
		20	58%	64%	50%	43%	50%	52%
50	632	1	53%	44%	48%	51%	45%	47%
		5	58%	74%	52%	65%	49%	60%
		10	42%	47%	57%	52%	47%	51%
		15	54%	47%	66%	49%	48%	53%
		20	65%	42%	54%	52%	50%	50%
		30	60%	65%	59%	77%	64%	66%

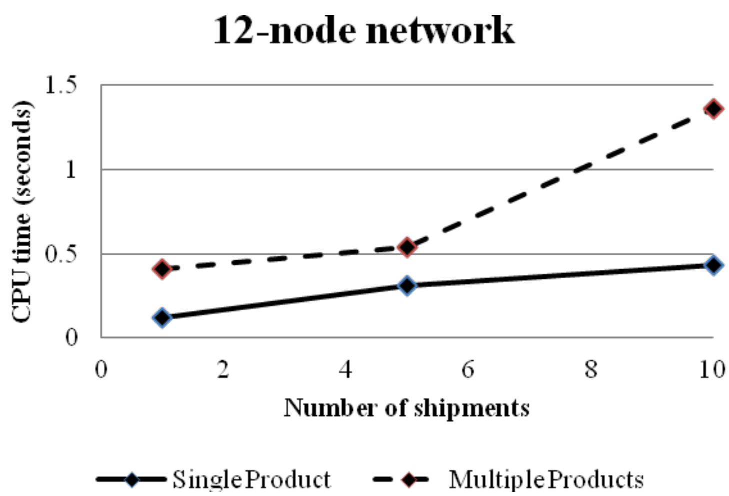


(a)

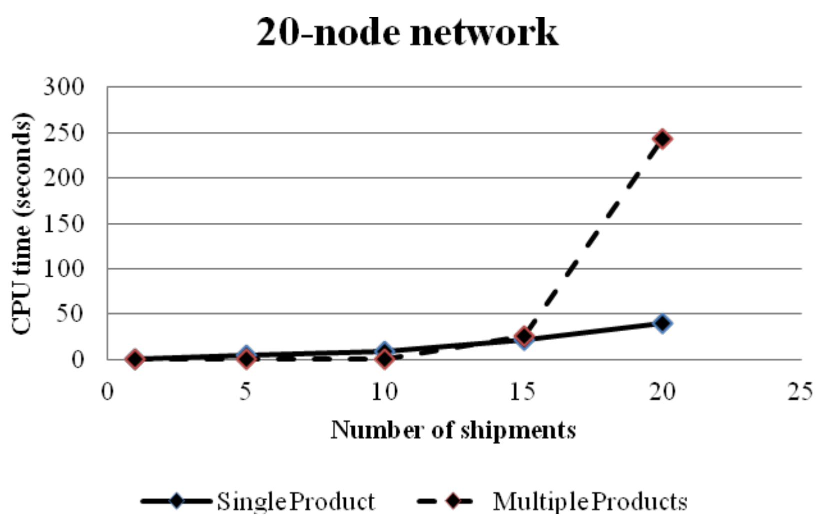


(b)

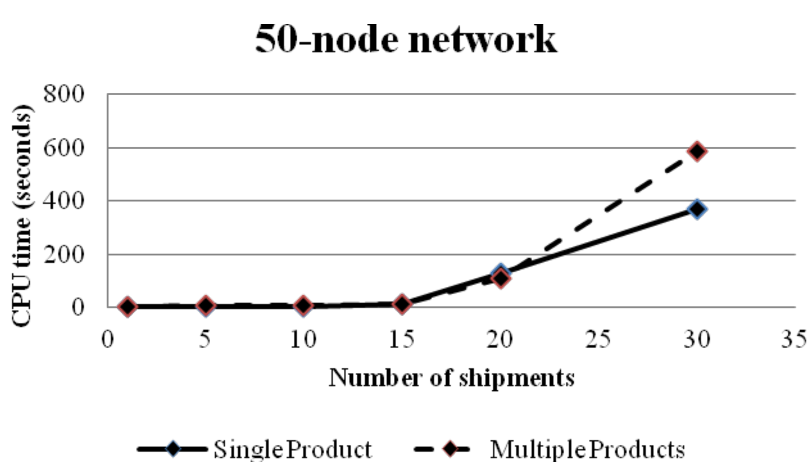
Figure 4.1 Physical Representation of the 12-Node Network Representing the Midwest U.S., and (b) Randomly Generated 20-Node Network


12-node network
CPU time (seconds)
1.5
1
0.5
0
0
2
4
6
8
10
Number of shipments
SingleProduct
MultipleProducts

(a)

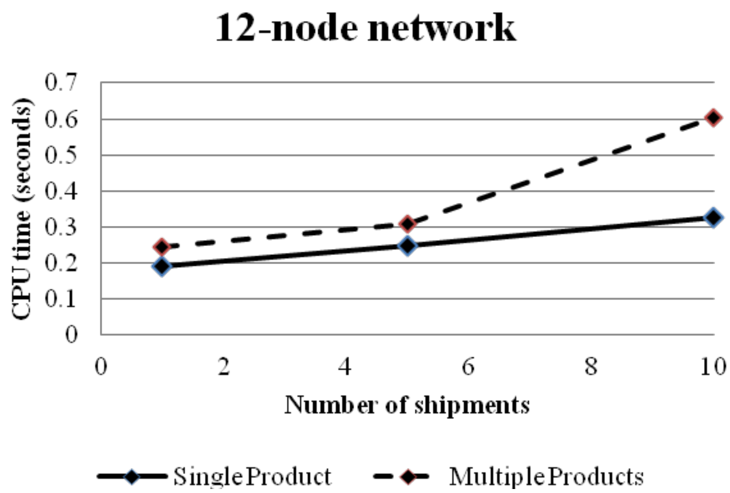

20-node network
CPU time (seconds)
300
250
200
150
100
50
0
0
5
10
15
20
25
Number of shipments
SingleProduct
MultipleProducts

(b)

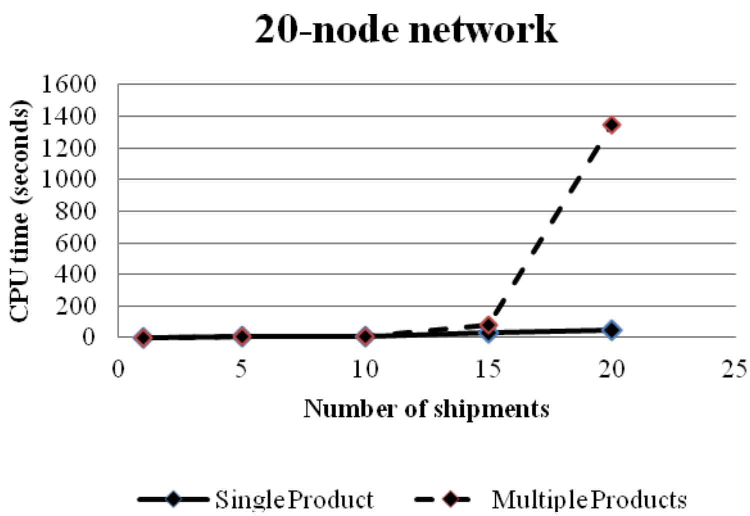

50-node network
CPU time (seconds)
800
600
400
200
0
0
5
10
15
20
25
30
35
Number of shipments
SingleProduct
MultipleProducts

(c)

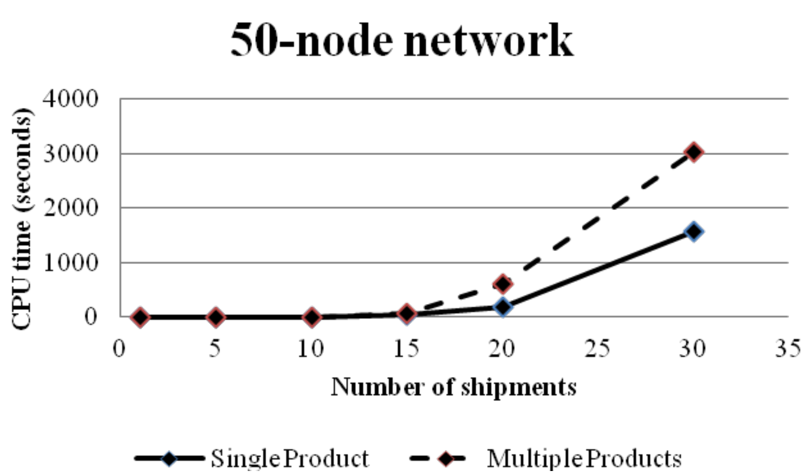
Figure 4.2 Computational Times for Single and Multiple Product Formulations for The Fixed Transfer Cost Policy


12-node network
CPU time (seconds)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
Number of shipments
SingleProduct
MultipleProducts

(a)


20-node network
CPU time (seconds)
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Number of shipments
SingleProduct
MultipleProducts

(b)


50-node network
CPU time (seconds)
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
Number of shipments
SingleProduct
MultipleProducts

(c)

Figure 4.3 Computational Times for Single and Multiple Product Formulations for the Variable Transfer Cost Policy

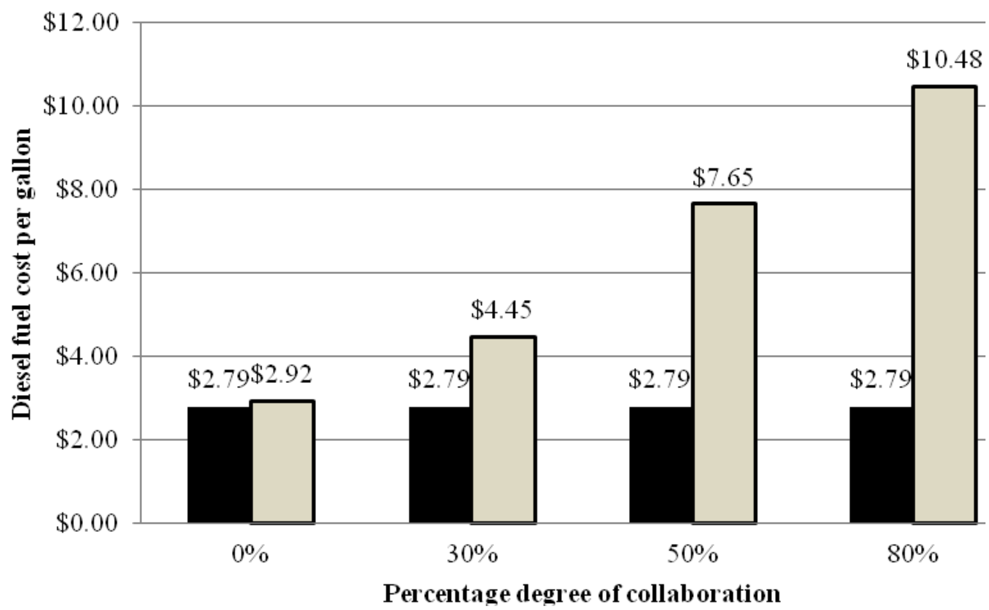


Figure 4.4 Average Breakeven Point at Which the Non-collaborative Alternative Becomes Attractive to the Carrier of Interest (Base Fuel Price =$2.79)

CHAPTER 5. CONCLUDING COMMENTS

This chapter presents concluding comments on this research, highlights its significance, and suggests directions for future research.

5.1 Summary and Conclusions

This study proposes an analytical framework to explore the LTL collaborative paradigm from the perspective of small- to medium-sized LTL carriers. We propose a carrier-carrier collaborative paradigm for the LTL small- to medium-sized carrier industry. Then, to determine their viability for collaboration, we conduct a survey of LTL carriers to determine their propensity to collaborate. We model the LTL carrier collaborative paradigm for both single and multiple carrier cases. A static single carrier collaboration problem (SCCP) is formulated to obtain preliminary insights on the potential for LTL carrier collaboration.

A multivariate technique and a mixed logit model were introduced to determine the propensity for LTL carrier collaboration (Chapter 3). The resulting modeling approach offers methodological flexibility that can be used by LTL carriers and 3PLs as a basis to induce collaboration between carriers and carrier affiliates, respectively. By using a combination of the proposed multivariate techniques and the mixed logit model to determine the probability of a carrier being placed in a particular clustering category, carriers and 3PLs can gain a greater understanding of the possible motivating factors that induce successful collaborative alliances. The study analyses provide significant implications for the collaborative carrier paradigm. First, carriers have an increased propensity towards collaboration as illustrated by all three carrier clustering categories having the “collaborate” alternative as the most viable option. Second, variables related to collaboration were found to be significant in the random parameters (mixed logit) model; specifically, variables such as a carrier's, "concern for rising fuel prices and very likely to collaborate for increased fuel savings", and "non-unionized carrier collaboration." The significance of these variables illustrates that LTL carriers are concerned with the potential economic impacts of fuel price fluctuations and the possibility of forming collaborative alliances.

As a starting point to analyze the LTL carrier collaborative paradigm, a single carrier collaboration problem (SCCP) was examined (Chapter 4). The SCCP problem was addressed from a static (planning) perspective to gain insights on the potential of the collaboration concept for carriers, and its ability to alleviate the effects of increased fuel prices. The study also explored the impact of the degree of collaboration represented by a collaborative discount rate (in terms of the cost of the collaborative capacity) on the carrier of interest. The SCCP problem was classified as a binary (0-1) multicommodity minimum cost flow problem and formulated for both single and multiple product type cases. The underlying graph structure may be exploited for very large instances through various efficient solution methodologies. The study results indicated that the carrier collaborative paradigm can potentially increase capacity utilization for member carriers, thereby generating the potential to gain revenue on empty-haul trips and decrease the impacts of fuel cost.

5.2 Future Research

In future research, the real-world deployment of the proposed multi-carrier LTL carrier-carrier collaborative paradigm entails the consideration of rolling horizon type implementation strategies. Further, the LTL collaboration problem can be extended to address the collaboration paradigm in terms of the location of the carriers (that is, where should they be physically located?) to maximize the level of collaboration. The LTL collaborative paradigm can be extended to multimodal freight networks, where transfers and shipment decisions are constantly made.

In summary, the research addressed in this project suggests that the carrier-carrier collaborative paradigm can represent an important and viable option for the LTL small- to medium-sized carrier industry in terms of their long-term sustainability, while leveraging recent ICT technological advances in an innovative manner. Further, this research serves as a building block for exploring a new generation of analytical frameworks for LTL carrier collaboration.

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