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A carrier collaboration problem for less-than-truckload carriers: characteristics and carrier collaboration model

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This paper addresses a single-carrier collaboration problem (SCCP) in which a less-than-truckload (LTL) carrier of interest seeks to collaborate with other carriers by acquiring capacity to service excess demand. The SCCP is addressed from a static (planning) perspective to gain insights into 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 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. Single- and multiple-product SCCPs are formulated as binary (0–1) multi-commodity minimum cost flow problems and are solved using the branch-and-cut algorithm. Experiments are conducted for two transfer cost policies to illustrate insights into the computational performance under varying 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.

Keywords: collaborative logistics; freight transportation; less-than-truckload trucking; minimum cost flow

1. Introduction

Less-than-truckload (LTL) carriers have begun to develop a new generation of strategies that make use of excess capacity which can form the basis for some form of collaboration. Such collaborative efforts can lead to more system-wide efficiency (Langevin and Riopel 2005). They can help firms reduce costs, decrease lead times, increase asset utilisation, and improve overall services levels (Agarwal and Ergun 2008; Esper and Williams 2003). Recent trends in the freight transportation domain indicate that an increasing number of carriers that are categorised 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 information and communication technologies (ICTs) (O'Reilly 2005).

However, the problem faced by these small- to medium-sized carriers is: how to collaborate to decrease operational costs so as to improve operational efficiencies? One viable option is the

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sharing of capacity (Kale, Evers, and Dresner 2007). Sharing capacity across collaborating carriers is not an 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 minimise 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. The proposed approach would preclude the prepositioning of assets since the carrier of interest is only interested in utilising collaborative resources available to it *a priori* so as to minimise additional costs. While the prepositioning of assets incurs costs, it also commits valuable resources of the carrier. This reduces flexibility in both the operational plan and the exploration of cheaper alternatives.

Other options outside a collaborative exist, but may not be cost effective in some instances for the small- to medium-sized LTL carriers. For example, 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 (Prozzi, Spurgeon, and Harrison 2000). 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 (Prozzi, Spurgeon, and Harrison 2000). 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.

To study the small- to medium-sized carrier collaboration problem, we focus on a carrier of interest who needs additional capacity to service loads for different origins and destinations. This carrier collaborates with a network of other LTLs to meet demand requirements. The demand is assumed to be fixed and time invariant. This assumption will be addressed in future work to study the effects of holding costs and time-dependent collaborative capacities on the collaboration. 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 labelled the single-carrier collaboration problem (SCCP). The SCCP problem is studied in a static context here to derive insights into the potential for collaboration. Thereby, the collaborative capacities on the network links are assumed to be known *a priori*. 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.

The remainder of the paper is organised as follows. Section 2 reviews the literature on carrier collaboration, primarily from the TL carrier domain, but also liner shipping, air cargo, and rail freight. Section 3 discusses the characteristics of the LTL carrier collaboration problem. Section 4 describes the cost parameters and the formulation of the static SCCP. Section 5 discusses the study experiments and summarises the insights from the results. Section 6 performs sensitivity analyses and studies the effects of collaboration to compare the SCCP strategies to the short-term leasing option, analyse the impacts of increasing fuel prices, and estimate the levels of collaborative capacity utilisation. Section 7 presents some concluding comments.

2. Carrier collaboration literature

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 (TLs are characterised by fully loaded long-haul direct trips in contrast to LTL operations which are shorter in distance with frequent stops). For a broader introduction and solution approaches to collaboration in the freight industry refer to Bailey, Unnikrishnan, and Lin (2011) and Hernández, Unnikrishnan, and Awale (2012). 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 (2008, 2010) address carrier collaboration in sea cargo, by modelling the distribution and allocation of revenue and the design of the collaborative network. Similarly, Houghtalen, Ergun, and Sokol (2011) 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 utilising 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 programmes where the fleet seeks to minimise routing costs. The outside carrier is simply modelled 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 optimisation 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 optimisation 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 analysed using a simulation procedure for a TL 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 centres, 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 (Belman and White 2005; Taylor et al. 1999). Compared to the TL network, the point-to-point topology adds additional complexity due to the numerous terminal locations that are utilised 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 centres, 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 modelled 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 modelling of time-dependent collaborative capacities will be addressed in future work through an extension of the static SCCP.

3. Problem characteristics

3.1. *TL versus LTL operations*

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 centres, and/or depots. Also, their planning periods are less than those of the TL industry. Further, LTL shipments are characterised by shorter-haul distances (Belman and White 2005). 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.

In contrast, from an operational perspective 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 under carrier–carrier collaboration.

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 (Prozzi, Spurgeon, and Harrison 2000; Trego and Murray 2010). 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 (Trego and Murray 2010). This is because carriers desire to minimise the number of empty hauls they experience. In doing so, carriers can negotiate potential rate benefits (i.e. 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.

3.3. *Static planning perspective*

To gain insights into the potential for carrier collaboration for the small-to-medium LTL industry, the SCCP 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 provides insights into 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.

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: (1) fixed (based on a contracted fixed cost) and (2) variable (based on the shipment volume).

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 categorised 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 specialised 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. Mathematical model

4.1. *Problem description and assumptions*

We first present a mathematical formulation for a single-product static SCCP 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, which indicate their available collaborative capacities and rates. In addition, the formulation assumes the following: (1) the carrier of interest will use its available capacity first before collaborating, (2) the transfer costs are divided equally between the collaborative carriers and the carrier of interest, (3) a shipment is not split to multiple carriers during a transfer, (4) a shipment is not split to multiple truck routes (arcs) of the same carrier during a transfer, and (5) 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 refers to a collaborative strategy in which the carrier of interest seeks a set of collaborative routes which minimise 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.

4.2. *Cost parameters*

The total cost that the carrier of interest seeks to minimise consists of two components: (1) the collaborative rates that include two primary LTL costs and (2) the transfer costs.

The collaborative rates are formed using 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:

$$L_a = \alpha \tilde{d}_a + \beta \tilde{w}. \tag{1}$$

In Equation (1), L_a represents the linehaul costs for arc a, $\tilde{d}_a$ represents the arc distance for arc a, and $\tilde{w}$ represents the total shipment weight. α and β represent positive monetary values that depend on the shipment characteristics.

The surcharge cost function is

$$S_a = \gamma L_a, \tag{2}$$

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 (1) and (2):

$$\varsigma_a = (1 - \delta) L_a + S_a, \tag{3}$$

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. Typically, discounts are assessed by LTL carriers to either increase market share through attractive rates or on the basis of shipment volume (Özkaya et al. 2010). 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, labour, 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 3.4. In addition, as stated earlier, the transfer costs are divided equally between the collaborating carriers and the carrier of interest.

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 characterisation of the formulation properties.

4.3.1. *Sets*

Let a shipment $k \in K$ be served by a set of fixed transshipment facilities $i \in N$ (also labelled facilities or nodes) which are interconnected by transit corridors $a \in A$ (also labelled 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.

4.3.2. *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.

4.3.3. *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.

4.3.4. *Constraints*

Next, we formulate the constraint set of the SCCP. It consists of two sets of constraints. The first set of constraints (4a, 4b, 4c, and 5) model the independent transshipment of shipments through the collaborative networks. The second set of constraints establishes an upper bound on the available collaborative carrier capacity (in terms of volume). The constraints are as follows:

$$-\sum_{q\in Q}\sum_{a\in\Gamma(i)} Y_{kaq} = -1 \quad \forall i \in O(k),\ k\in K, \tag{4a}$$

$$\sum_{q\in Q}\sum_{a\in\Gamma^{-1}(i)} Y_{kaq} - \sum_{q\in Q}\sum_{a\in\Gamma(i)} Y_{kaq} = 0 \quad \forall i \in N\backslash\{O(k), D(k)\},\ k\in K, \tag{4b}$$

$$\sum_{q\in Q}\sum_{a\in\Gamma^{-1}(i)} Y_{kaq} = 1 \quad \forall i \in D(k),\ k\in K, \tag{4c}$$

$$\sum_{a\in\Gamma(i)} Z_{aq} \le 1 \quad \forall i \in N,\ q\in Q, \tag{5}$$

$$\sum_{k\in K} d_k Y_{kaq} \le w_{aq} Z_{aq} \quad \forall a \in A,\ q\in Q, \tag{6}$$

$$Y_{kaq} \in \{0,1\} \quad \forall a\in A,\ k\in K,\ q\in Q, \tag{7}$$

$$Z_{aq} \in \{0,1\} \quad \forall a\in A,\ q\in Q. \tag{8}$$

Constraint set (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 Equations (4a), (4b), and (4c), which correspond to the origin, intermediate, and destination nodes/facilities in the network, respectively.

Constraint (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 (6) represents the collaborative capacity constraint; it ensures that the capacity acquired from a carrier (left-hand side of Equation (6)) is less than its available capacity (right-hand side of Equation (6)) on that transit corridor. Constraint sets (7) and (8) represent the 0–1 integrality conditions for the decision variables.

4.3.5. *Objective function*

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

$$\text{Min} \sum_{k\in K}\sum_{a\in A}\sum_{q\in Q} \varsigma_{aq} d_k Y_{kaq} + \sum_{a\in A}\sum_{q\in Q} \phi_a Z_{aq}. \tag{9}$$

The objective function minimises 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 (9) subject to constraints (4)–(8) represents the mathematical formulation of the static single-product SCCP. The next subsection discusses some of its properties.

4.3.6. *Properties*

4.3.6.1. 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 (4a), (4b), and (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 (e.g. warehouses, depots, and/or distribution centres) and the static arcs which are transit corridors corresponding to the collaborative carriers. It can be noted that constraints (4a), (4b), and (4c) can be written independently for each shipment. Constraints (5) and (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 characterised 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 (e.g. large LTL carriers with large network sizes) to handle constraint sets (5) and (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, Magnanti, and Orlin 1993; Martin 1999).

4.3.6.2. Total unimodularity. The formulation is characterised 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 programme 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 problem instances involving large networks, where decomposition methods may be appropriate (as discussed in Section 4.3.6.1), 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 path 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 (4a), (4b), and (4c), along with the integrality constraints (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:

$$\sum_{q \in Q} Y_{kaq} \leq 1 \quad \forall a \in A,\ k \in K. \tag{10}$$

4.4. *Multiple-product problem extension*

The multiple-product formulation models the possibility that 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)–(9) by including the product type. The total unimodularity property (see Section 4.3.6.2) holds for this extension as well due to the separability of each shipment by product type.

4.5. *Variable transfer cost policy*

In Section 4.3, Equation (9) assumes that transfer costs are a fixed contracted amount independent of the shipment volume. However, as discussed in Section 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 (9) ϕ_a is replaced by ϕ_{ak} to obtain the new objective function:

$$\text{Min} \sum_{k \in K} \sum_{a \in A} \sum_{q \in Q} \varsigma_{aq} d_k Y_{kaq} + \sum_{k \in K} \sum_{a \in A} \sum_{q \in Q} \phi_{ak} Z_{aq}. \tag{11}$$

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

5. Study experiments

The study experiments seek to analyse 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 analyse the benefits of collaboration: (1) as an alternative to the non-collaborative short-term leasing strategy through varying collaborative discount rates δ and (2) as fuel/energy costs increase.

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. 2003). 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 were simulated using a uniform distribution on the LTL industry observed ranges (ABF 2008; Belman and White 2005; Boardman 1997; Bureau of Transportation Statistics 2008; Fleetseek 2008) and those of third-party capacity providers Ryder (2008) and Budget (2008). The simulated data consist of (1) the collaborative rates from Equation (1), (2) the transfer costs (for both the fixed and variables cases), (3) the short-term leasing costs, (4) the demand for multiple shipments (for single- and multiple-product cases), and (5) 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 2008; Ryder 2008):

$$\rho_k = T_k(\cdot) + D_k(\cdot) + U_k(\cdot), \tag{12}$$

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.

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 2.40 GHz and 4 GB of RAM. The SCCP was solved using the branch-and-cut algorithm the in GAMS/CPLEX optimisation 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 (Belman and White 2005). That is, their network sizes are modest. As discussed in Section 4.6.3, for the larger and more complex carrier operations characterised 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.

5.3. *Experiment set-up*

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 SCCPs. The other parameters take values according to the following ranges: network size in terms of nodes 12 (Figure 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 (Table 1). All graphs are acyclic. In addition, four

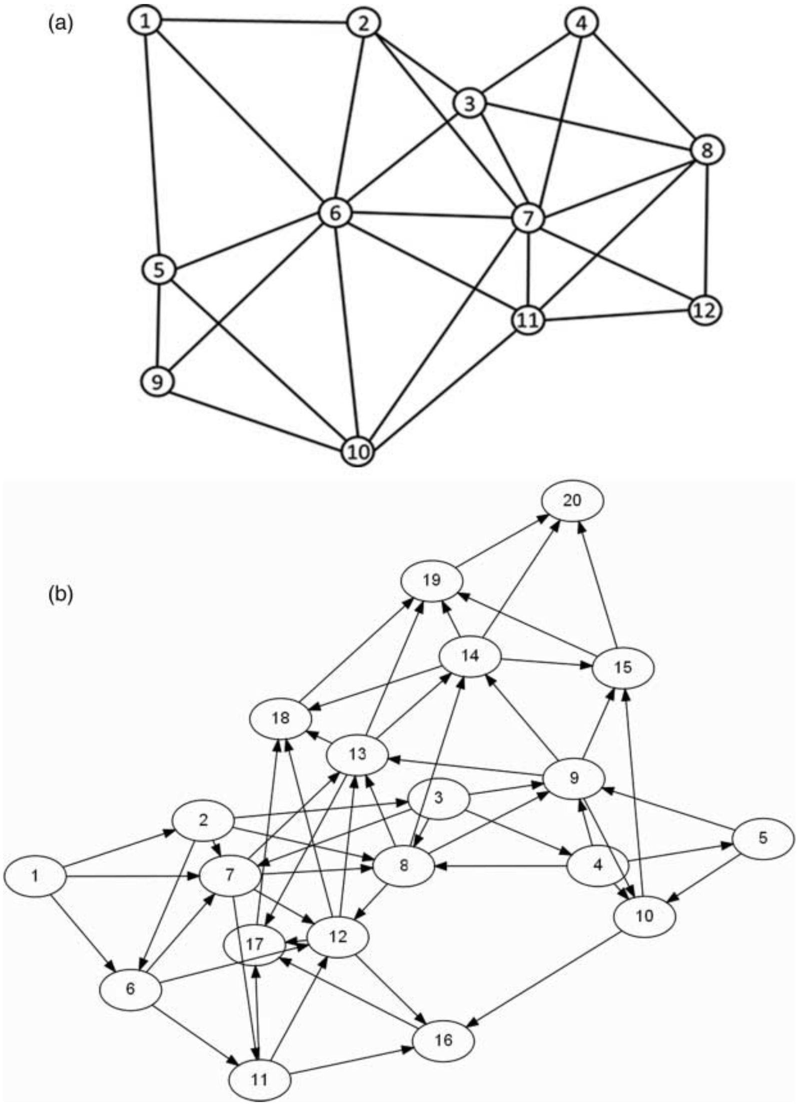

Figure 1. Physical representation of the 12-node network representing the Midwest USA and (b) randomly generated 20-node network.

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 are simulated, 10 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.

Table 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 (s)
12	29	1	2253	2212	1889	1403	1080	1.84	16.17	37.74	52.07	0.12
		5	13,146	12,664	10,579	7451	5366	3.67	19.53	43.32	59.18	0.31
		10	15,257	14,415	12,081	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	28,988	27,924	23,417	16,656	12,149	3.67	19.22	42.54	58.09	9.20
		15	34,848	34,381	28,740	20,278	14,637	1.34	17.53	41.81	58.00	22.10
		20	28,548	27,945	23,434	16,667	12,156	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	13,294	12,995	11,154	8393	6552	2.25	16.10	36.87	50.72	129.97
		30	20,506	19,717	16,714	12,209	9206	3.85	18.49	40.46	55.11	371.70

6. Analysis results

6.1. *Sensitivity analyses*

Tables 1 and 2 illustrate the results of the parameter sensitivity analyses for the fixed transfer cost case for the single-product and multiple-product SCCPs, respectively. Tables 3 and 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 1 to 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-shipments case in Table 1. This is because the 10 randomly generated rates and demands were, on average, higher for the 15-shipments case, resulting in higher costs.

The CPU computational times in Tables 1–4 are based on the 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-product cases are solved using relaxations only at the level of the binary decision variables. Thereby, the underlying linear programmes, coupled with the unimodularity property, provide relatively good bounds for the branch-and-cut algorithm.

Figures 2 and 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 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.

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

Table 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 (s)
12	29	1	3089	3033	2690	2176	1833	1.81	12.91	29.55	40.66	0.41
		5	17,204	16,596	14,159	10,504	8067	3.54	17.70	38.95	53.11	0.54
		10	37,424	35,466	29,900	21,550	15,984	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	20,908	20,168	17,290	12,973	10,094	3.54	17.30	37.95	51.72	0.97
		15	27,454	27,091	23,194	17,349	13,452	1.32	15.52	36.81	51.00	25.35
		20	28,988	28,389	24,348	18,287	14,247	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	13,193	12,902	11,196	8638	6932	2.20	15.13	34.52	47.46	110.54
		30	21,328	20,538	17,605	13,206	10,273	3.70	17.46	38.08	51.83	588.99

Table 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 (s)
12	29	1	2872	2783	2440	1926	1583	3.10	15.04	32.94	44.88	0.19
		5	16,121	15,820	13,735	10,607	8522	1.86	14.80	34.20	47.14	0.25
		10	21,442	20,500	18,115	14,538	12,154	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	25,096	24,436	21,898	18,090	15,552	2.63	12.74	27.92	38.03	8.80
		15	30,178	29,644	25,064	18,193	13,612	1.77	16.95	39.71	54.89	30.10
		20	33,565	32,907	29,269	23,811	20,172	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	12,082	11,640	10,794	9525	8678	3.66	10.66	21.17	28.18	4.24
		15	22,124	20,930	19,662	17,759	16,490	5.39	11.13	19.73	25.46	39.15
		20	34,222	32,316	30,360	27,426	25,470	5.57	11.29	19.86	25.58	186.96
		30	27,663	26,988	24,055	19,656	16,723	2.44	13.04	28.94	39.55	1571.10

Table 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 (s)
12	29	1	2711	2587	2264	1778	1455	4.58	16.49	34.42	46.33	0.24
		5	17,209	16,327	13,886	10,224	7783	5.12	19.31	40.59	54.77	0.31
		10	25,783	25,352	22,059	17,119	13,825	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	26,995	25,636	22,755	18,432	15,550	5.03	15.71	31.72	42.40	10.48
		15	40,828	39,755	35,814	29,902	25,961	2.63	12.28	26.76	36.41	84.31
		20	51,028	49,350	45,294	39,208	35,152	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	14,218	13,439	12,545	11,205	10,311	5.48	11.77	21.19	27.48	7.23
		15	26,362	24,941	23,606	21,604	20,270	5.39	10.46	18.05	23.11	72.64
		20	28,799	28,206	26,477	23,883	22,154	2.06	8.06	17.07	23.07	604.10
		30	45,513	43,018	39,673	34,656	31,311	5.48	12.83	23.85	31.20	3025.11

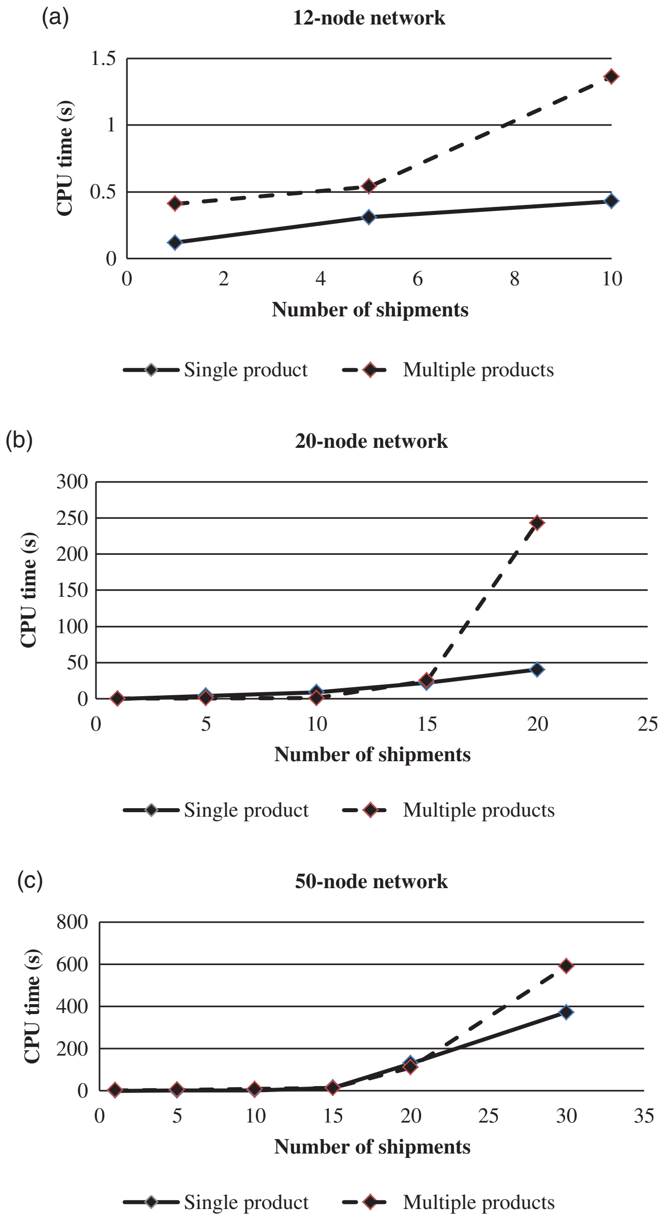

Figure 2. Computational times for single and multiple product formulations for the fixed transfer cost policy.

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 1–4. However, for the variable transfer cost policy, the benefit from collaboration is lower, especially as the degree of collaboration increases, as shown in Tables 3 and 4. This is because the cost burden from the transfer costs increases with the degree of collaboration.

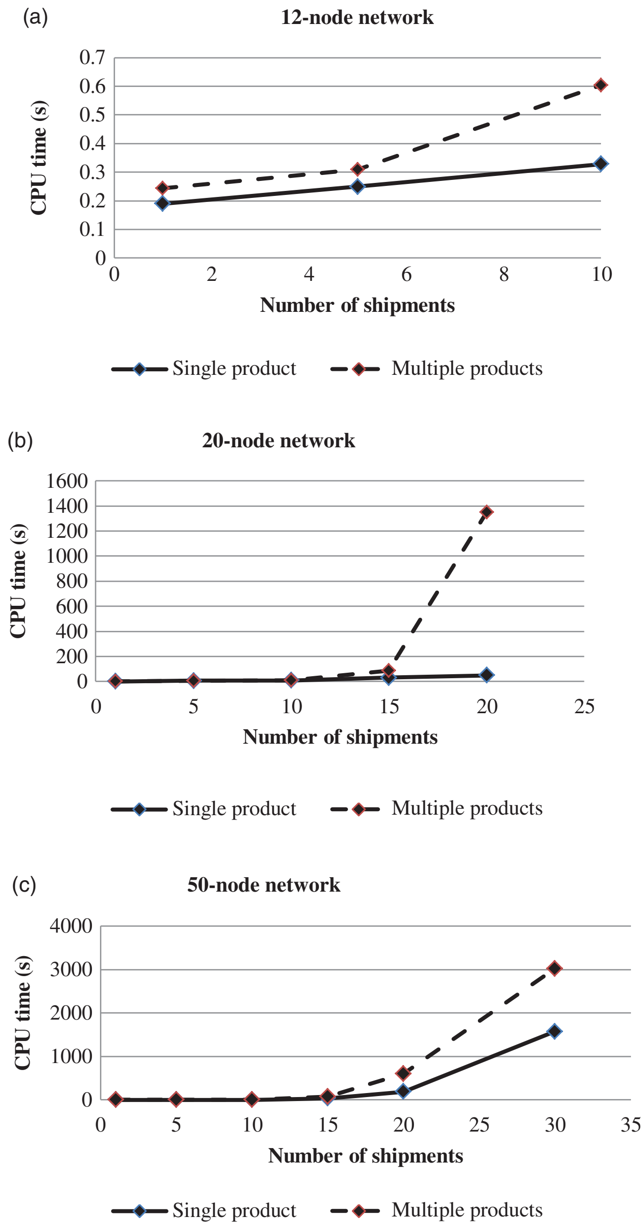

Figure 3. Computational times for single and multiple product formulations for the variable transfer cost policy.

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 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

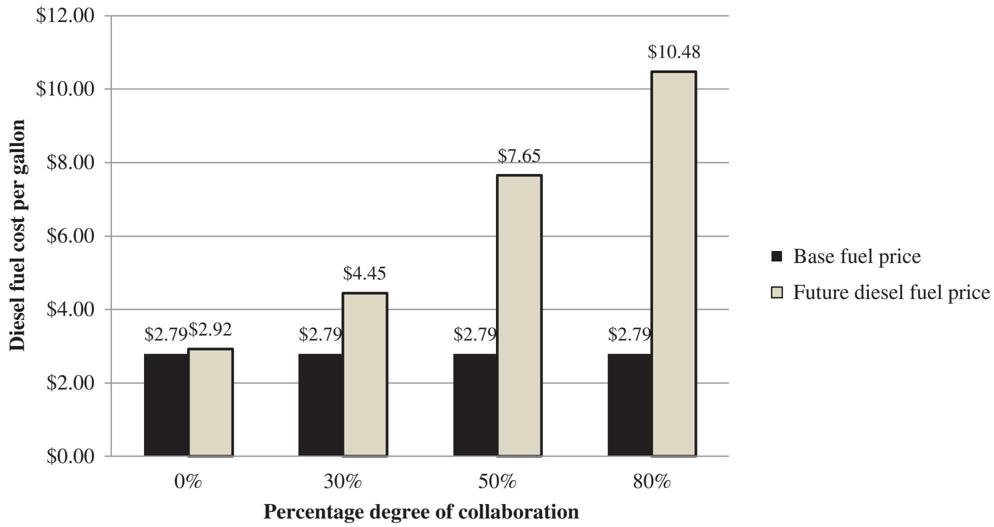

Figure 4. Average breakeven point at which the non-collaborative alternative becomes attractive to the carrier of interest (base fuel price = $2.79).

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, represent the average over the 10 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.

Table 5. Percentage collaborative capacity utilisation for the single- and multiple-product cases (fixed transfer cost policy).

			Single-product case	Multiple-product case				
			Average percentage collaboration capacity utilisation	Average percentage collaboration capacity utilisation				Average percentage collaboration capacity utilisation 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 6. Percentage collaborative capacity utilisation for the single- and multiple-product cases (variable transfer cost policy).

			Single-product case	Multiple-product case				
			Average percentage collaboration capacity utilisation	Average percentage collaboration capacity utilisation				Average percentage collaboration capacity utilisation 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	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

As stated in Equation (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 (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 5 and 6 illustrate the average capacity utilisation 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 5), the capacity utilisation 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 6), the capacity utilisation for the single- and multiple-product cases is higher, and ranges from 50% to 65% and 43% to 66%, respectively. The increased utilisation in Table 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 (1) the degree of collaboration, (2) the impacts of fuel price fluctuations, and (3) the collaborative capacity utilisation. 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.

7. Concluding comments

In this paper, a static 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, synergised 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 utilisation 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 utilising 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 utilisation, 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 modelling 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.

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