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The Benefit of Information Sharing in a Logistics Outsourcing Context

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The benefit of information sharing in a logistics outsourcing context

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Abstract: The goal of this article is to examine the value of information sharing in outsourcing of logistics activities. Our examination is in the context of a fairly complex network in which location and capacity of carriers are considered. The current research also examines the moderating effect of network settings on the benefit of information sharing. A core component of our methodology is use of computational experiments to provide a variety of logistics network conditions under which we investigate information sharing value. The investigation involves comparing two strategies, namely full and no information sharing. Underlying the experiments are procedures to optimise the network under each strategy. The procedures are based on exact methods that combine integer linear programming with exhaustive enumeration. To gauge the robustness of the insights, we applied formal analysis of variance techniques to the data from the numerical experiments. The obtained insights are helpful to managers for selecting appropriate logistics service providers and level of information exchange.

Keywords: information sharing; logistics outsourcing; supply chain coordination.

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Biographical notes: Zolfagharinia is a PhD candidate in the Supply Chain Management field at Wilfrid Laurier University's School of Business & Economics. The value of information sharing in supply chain and logistics networks is among his main research interests. He is the 2011 winner of the provincial award (province of Ontario) for best paper in the student paper contest run by Supply Chain Logistics (SCL) Canada.

Michael A. Haughton is Professor of Operations & Decision Sciences in Wilfrid Laurier University's School of Business & Economics. His primary research addresses issues of managing transportation, logistics and supply chain operations in contexts such as vehicle dispatch/routing and trans-border trade. He has published and presented his research extensively. Among his recent scholarly awards is being selected as the 2008–2009 Fulbright Visiting Research Chair at Arizona State University's Centre for Trans-border Studies.

1 Introduction

This paper seeks to answer a crucial question that a shipper must address in defining the scope of its logistics outsourcing: "*How much information should be shared with its carriers?*". The level of information sharing can be so high that the carrier is effectively part of the shipper's organisation and is thus well positioned to make operational-level logistics decisions (timing and quantity of shipment deliveries) that are optimal for the shipper. In such instances, the carrier is viewed as a full-scope Logistics Service Provider (LSP) rather than a mere provider of transportation services. A logical and intuitive inference from the literature on supply chain information sharing and coordination (e.g., Li and Wang, 2007; Chan and Chan, 2009; Chen and Lee, 2009) is that the arrangement outlined above is superior to other arrangements with lower levels of information sharing. However, there is general agreement that the benefit of shared information mainly depends on important factors such as supply chain structure, type of shared information, level of shared information and measures of performance. Therefore, it is not surprising to see a wide variety of reported results in the literature. For example, in a dyadic supply chain, Helper et al. (2010) show that the benefit of sharing demand information is highly moderated by supplier capacity. They summarised their findings as follows: higher capacity yields lower benefits. However, in a divergent supply chain, Bakal et al. (2011) illustrate that the benefit of shared information will drop when the supplier capacity becomes smaller.

This is also true about the magnitude of supply chain benefits from information sharing. On one hand, some studies found the value of information sharing to be insignificant in some settings (e.g., Raghunathan, 2001; Bakal et al., 2011). On the other hand, some works illustrate high benefits from information sharing. For example, Liu et al. (2009) report a maximum saving of 40% in long-run average cost of the retailer in a dyadic supply chain and Hosoda et al. (2008) found the benefit of sharing point of sale information to be remarkably high (between 8–19%) for a supplier in a similar structure.

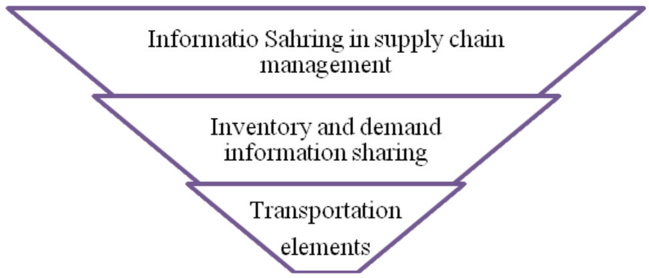
Considering the mixed results in the literature, it is clear that the *magnitude* of supply chain benefits from information sharing remains unclear in some supply chain structures. In logistics outsourcing contexts, the magnitude is important for shippers to evaluate whether it outweighs the costs to design and administer highly integrated inter-firm information sharing and coordination arrangements. Moreover, they need to evaluate the possible risks of shared information. This paper's central contribution is to provide some needed clarity by quantifying the value of information sharing in logistics outsourcing.

The paper's other contributions stem from the fact that the research context is a network comprising multiple geographically dispersed suppliers (as well as carriers and consignees). As such, we consider situations in which the goal under full information sharing and coordination is to make operational-level logistics decisions that are globally optimum for the entire network rather than just for an individual shipper. In assessing the value of information sharing, the paper addresses crucial questions concerning the moderating effects of factors that define supply chain structures. The factors considered include network size, demand fluctuation, the ratio of per unit inventory shortage cost to holding cost and the number and transportation capacity of carriers. To clarify how the present work to address those questions will extend the existing body of knowledge, the next section (Section 2) reviews the relevant literature on the value of information sharing. The review specifies the gaps in the existing literature that provide justification for the present study. In Section 3, the logistics outsourcing problem and related assumptions are described. Solution procedure for both no information sharing and full information sharing situations are proposed in Section 4. Section 5 is devoted to design test problems. The findings and related insights are discussed in Section 6. Section 7 concludes the paper with a summary of the key contributions and future research directions.

2 Literature review

Inter-organisational information sharing is known as an important supply chain coordination mechanism (Arshinder et al., 2008). Information sharing and its role in enabling integration and improved supply chain performance have attracted much attention within the supply chain literature (Sahin and Robinson, 2002; Chen, 2003; Huang et al., 2003; Larson and Kulchitsky, 2008; Chen and Lee, 2009; Chan and Chan, 2009; Azadeh et al., 2011). Our approach to reviewing that aspect of the literature is depicted in Figure 1. In this approach, after briefly reviewing studies on information sharing in supply chains, we sequentially narrow the review to those studies that evaluate the benefit of information sharing while addressing transportation elements.

Figure 1 The literature review approach (see online version for colours)



The studies, which have illustrated the benefits of information sharing, range from partial information sharing (e.g., the work of Hariharan and Zipkin, 1995) to full information sharing (e.g., the study by Moinzadeh, 2002). However, the terminologies in the related literature, such as full information sharing or partial information sharing, are relative rather than absolute terms, because studies address different types of information in different supply chain structures. Moreover, works on specific information sharing modes such as Vendor-Managed Inventory (VMI) include Chatzipanagioti et al. (2007) and Zhang et al. (2008), as well as Vigtil (2007), who argues that the benefits of information sharing depend on the type of information exchanged.

Given different types of information, it is essential to address potential pieces of information which can be exchanged between supply chain members. In a comprehensive literature review, Huang et al. (2003) proposed a framework to classify different types of information in the supply chain. This classification, called Production Information Model (PIM), covers information about product (Wu and Meixell, 1998), process (Wikner et al., 1991; Lau et al., 2002; Dobson and Pinker, 2006), inventory (Gavirneni et al., 1999; Cohen, 2000; Moinzadeh, 2002; Axsäter and Marklund, 2008; Savasaneril and Erkip, 2010), resource (Swaminathan et al., 1997; Barratt and Oke, 2007), order (Lee et al., 1997; Chen, 1999; Lee et al., 2000; Fleisch and Powell, 2001; Hsiao and Shieh, 2006; De La Fuente and Lozano, 2007; Wu and Cheng, 2008; Hosoda et al., 2008; Yu et al., 2010) and planning (Barbarosoglu and Ozgur, 1999; Cachon and Lariviere, 2001; Byrne and Heavey, 2006; Mishra et al., 2009; Zhu et al., 2011).

To quantify the value of information sharing in supply chain, performance measures play a critical role. Different studies use various measures of performance such as profit (e.g., Swaminathan et al., 1997; Dobson and Pinker, 2006), quality (e.g., Tsung, 2000), related inventory costs (e.g., Gavirneni et al., 1999) and so on.

Since our current work mainly focuses on the value of shared information related to demand and inventory on the supply chain cost, we narrow our review to relevant studies considering inventory and order information, rather than addressing all existing works. Inventory information has received much attention in the literature in comparison with the other types of information. The literature also clearly identifies that the benefit margin greatly depends on supply chain structures and demand assumptions (Ketzenberg et al., 2007).

For example, Gavirneni et al. (1999) study the impact of inventory information sharing on a dyadic supply chain structure consisting of one capacitated supplier and one retailer. They examine the proposed model under three different settings; no information sharing, partial information sharing and full information sharing. The authors report that moving from no-information sharing to partial information sharing will cause inventory-related costs to diminish by an average 50% within a range of 10–90%.

In another study, Cachon and Fisher (2000) evaluate the value of information sharing in a divergent supply chain structure with one supplier and N identical retailers under the assumption of stochastic stationary demand. They assess the proposed structure under two different conditions; no information sharing and full information sharing. For a continuous review policy in full information sharing mode, the supplier has access to information about retailers' inventory levels and determines replenishments. The experimental results illustrate an average of 2.2% saving in inventory-related costs, with a maximum of 12.1% saving.

Raghunathan (2001) considers a dyadic supply chain structure consisting of a single manufacturer and a single retailer under the assumption of non-stationary autoregressive demand. He investigates the model proposed by Lee et al. (2000) using an analytical method and a simulation model. The experimental results reveal that under full information sharing when the manufacturer has point-of-sale information, the manufacturer's saving is insignificant. Thus, the intelligent use of available information (like historical demands) is good enough for creating inter-organisational relationships.

The wide range of results from the aforementioned studies – information sharing benefits ranging from insignificant (Raghunathan, 2001) to 90% inventory cost reductions (Gavirneni et al., 1999) – underscores a key insight from the literature: the size of the benefits depends on the particular supply chain context. However, the literature is yet to provide clear guidelines on the relationships between supply chain parameters (e.g., structure and assumptions) and the magnitude of the benefits in some supply chain settings. This represents potential research areas on any unexamined supply chain structures.

Not including the above examples, the number of studies addressing the benefit of sharing inventory information (in the form of cost saving) on supply chain performance covers a wide range of supply chain structures with different assumptions (e.g., Gavirneni, 2001; Moinzadeh, 2002; Lau et al., 2002, 2004; Gavirneni, 2005; Huang and Iravani, 2007; Chiang and Feng, 2007; Axsäter and Marklund, 2008; Helper et al., 2010). Regarding supply chain structures, there are different streams of studies in the literature. One stream of the literature considers simple dyadic supply chain structures to analytically evaluate the benefit of inventory information sharing on supply chain performance (Gavirneni et al., 1999; Lee et al., 2000; Kurata and Yue, 2008). The other active streams focus on serial structures (Chen 1999; De Souza and Liu., 2000; Wu and Cheng, 2008) and divergent structures (Weng, 1999, Zhao et al., 2001, Zhao et al., 2002, Lau et al., 2002; Moinzadeh, 2002; Byrne and Heavey, 2006; Chiang and Feng, 2007; Axsäter and Marklund, 2008, ElHafsi et al., 2010). However, convergent structures (e.g., Zhang, 2006) and network structures (e.g., Barbarosoglu and Ozgur, 1999) have received little attention. It is not hard to see why convergent structures were not shown as frequently as serial and divergent structures, since the critical types of information in convergent structures are mainly the process and the resource information types (Tsung 2000; Fleisch and Powel, 2001; Swaminathan et al., 1997). But these limitations do not apply to studies on network structure. Even studies addressing the coordination between two or more members in network structures, such as production and distribution coordination between manufacturers and distributors, tackle centralised problems without considering the value of shared information at different levels (Mula et al., 2010).

If supply chains are considered as a network of organisations (Sahin and Robinson, 2002), network structure is undoubtedly the most comprehensive structure to explain supply chain performance in practice. However, very few studies examine the value of information sharing on supply chain performance with network structures.

The other important gaps concern the limited scope of previous studies. Notable among those gaps is the limited treatment of transportation costs. By and large, previous studies viewed costs savings in terms of inventory costs, with little consideration of transportation costs. Although joint transportation and inventory related models have been well investigated, most of them tackle the problem under deterministic parameters (Federgruen and Zheng, 1992; Li et al., 2004; Toptal et al., 2003). Recent review papers on dynamic inventory–routing problems (Moin and Salhi, 2007; Andersson et al., 2010) emphasise a great need for stochastic models because of inherent real-world uncertainty. As noted by Gurbuz et al. (2007), the consideration of stochastic demand in coordinating replenishment and shipment literature is relatively limited. Moreover, there are very few studies that examine the benefit of information sharing while taking transportation elements into account (e.g., Sternberg, 2011).

For example, Zhao et al. (2002) address impacts of forecasting error on the value of shared information. Using a simulation model for a supply chain with one manufacturer and four retailers, they incorporate transportation costs incurred by both the supplier and retailers. Retailers pay transportation cost for fulfilling their requests and the supplier pays transportation cost in case of backorder products. However, transportation costs are computed without considering transport providers' locations and capacities.

Using a multi-agent-based simulation model, Lau et al. (2004) evaluate the value of shared information in three different divergent structures. Their results illustrate a reduction in average cost from 8 to 28% under different information sharing modes. Since the authors assumed that there is only one 'transport' agent with infinite capacity, their analyses do not evaluate the effect of transport provider on information sharing benefits.

Axsäter and Marklund (2008) investigate a divergent supply chain structure with non-identical retailers using continuous review policy and facing stochastic demand with Poisson distribution. Given the inventory position of retailers, transportation time and cost structures, a new replenishment policy was derived at the warehouse level. It was also proved that the proposed policy is optimum among a broad range of position-based policies.

The work by Sternberg (2011) validates an information sharing model in the trailer transport environment. The proposed model was designed based on interviewing transport actors and reviewing their documents. That work is an extensive study of an international transportation setup and a model which has been implemented in practice as a pilot project.

Despite the useful insights in these studies addressing transportation costs and demand uncertainty, there are very few attempts to evaluate the value of information sharing on supply chain performance in such settings. Thus, there is still need for extended research to yield clearer understanding of the value of information sharing. Although there is no routing decision in our model, to the best of our knowledge, this is one of the first attempts examining the impact of transportation elements (e.g., number and capacity of carriers) on the benefit of sharing inventory information in terms of supply chain performance. To this end, the present research can be summarised as contributing to the literature along three main dimensions:

1. Addressing demand uncertainty in a context where inventory decisions (size and timing of replenishment deliveries) must explicitly account for transportation cost. An important aspect of this contribution involves modelling the reality that the travel distance spanning the geographic locations of the carrier, the supplier and the demand point is a determinant of transportation costs.
2. Moving beyond the typical supply chain structures used in previous studies to consider a network with multiple suppliers, demand points and (capacitated) carriers that are all geographically dispersed (see Baita et al. (1998) for more detail about network settings).
3. Including carrier parameters (capacity and number of carriers) among the factors that can influence the value of information sharing to produce a fuller set of insights into what the influential factors are. These carrier parameters are commonly not considered in previous studies.

3 Model definition

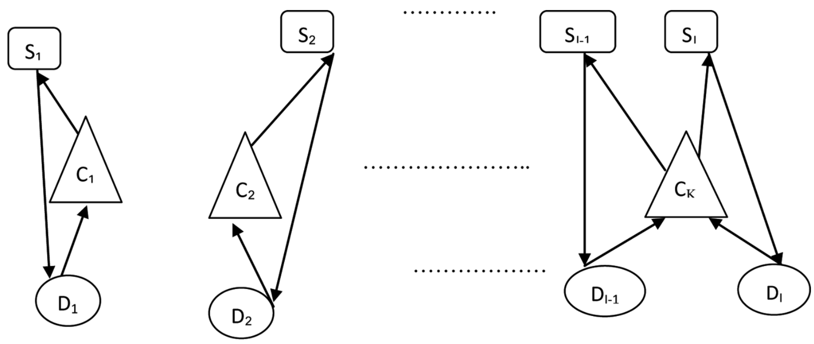
We suppose a network with three different groups of participants: suppliers (S), carriers (C) and demand points (D). Only one item considered in the network and capacity of each supplier is enough to cover the demand of each demand point. Each carrier has its own fleet with known and constant capacity defined as the number of demand points the carrier can serve. Each demand point can be served by any supplier/carrier pair (subject to the carrier's capacity) and does not split its requests across suppliers or carriers in the planning horizon. Other model assumptions are as follows:

- Demand of each demand point is stochastic and independent from demand of other demand points and follows a Poisson distribution function.
- The demands that are not satisfied are treated as backorder demand.
- No supplier can serve more than one demand point, but each carrier can.
- Given the long distance between suppliers and demand points (e.g., USA-Canada cross-border transportation), full truck load transportation is considered for goods delivery.
- Number of suppliers is assumed to be enough for supplying demand points.

- It is worth noting that as practical matter, a demand point is unlikely to be a single end customer. Rather, it may be viewed as either of the following:
  - a high capacity distribution centre which is responsible for serving clusters of small customers in particular regions
  - a virtual customer that is representative of customers in close proximity to each other (distances among those customers can be treated as negligible vis-à-vis the distance between suppliers and demand points).

The schematic of the proposed network is illustrated in Figure 2. The number of carries 'K' can be equal to, smaller or bigger than the number of demand points and suppliers, I and J, respectively.

Figure 2 A possible allocation of different participants in the proposed model



Because of the 'I' independent demand points in the model, total expected logistics cost of the network can be partitioned into 'I' separate total expected costs. Total expected cost for each demand point consists of average holding inventory cost, shortage cost, purchasing cost and ordering cost during the planning horizon. Thus, the goal of the proposed model is to minimise total expected logistics cost of the network by following simultaneous decisions:

- Assignment decisions: assigning a carrier–supplier pair to serve a demand point.
- Inventory decisions: determining order quantity and reorder point for each demand point based on assignment decision while satisfying capacity of each carrier (based on the assumption that all demand points use a continuous review policy).

For each of the J*K supplier–carrier pairs that a demand point can be assigned to, determination of the demand point's expected total ordering cost, inventory carrying cost and shortage cost is based on following considerations.

- Ordering cost contains two major components:

  1 Fixed ordering cost regardless of distance and quantity (including all costs of releasing order and fixed cost of dispatching truck).

  2 Variable (location-dependent) cost, which is a linear function of the tour length between carrier, supplier and demand point, is the sum of travel costs from carrier to supplier (for shipment pick-up), from supplier to demand point (for shipment delivery) and from demand point back to the carrier's domicile.

- Since total inventory carrying cost and shortage cost are functions of demand during lead time, then they are also both functions of the duration of lead time, which is the sum of two components:

    3 A fixed period of time for releasing and processing order; it is assumed to be independent of the network participants' geographic locations and identical for all J*K*I combinations of supplier, carrier and demand point.

    4 A location-dependent period of time to complete the pick-up and delivery legs of the tour; i.e., distance to complete those legs of the tour for a particular supplier-carrier pair serving a particular demand point determines the location-dependent component of lead time for that unique combination of supplier, carrier and demand point.

The above considerations illustrate that, through travel distance and leadtime, the location of any demand point in relation to the locations of its assigned supplier-carrier pair will influence the demand point's inventory holding cost, shortage cost and the transportation cost component of order costs. A corollary is that a poor set of assignments will cause the demand points to incur unnecessarily high logistics costs.

The following notations, parameters and variables are relevant in the procedures to search for assignments that minimise unnecessary logistics costs.

Notations

S: Set of all suppliers.
C: Set of all carriers.
D: Set of all demand points.

Model parameters

A_i: Annual shortage cost per unit for demand point i ($i \in D$).
P: Price per item.
C_i: Ordering cost per order for demand point i ($i \in D$).
D_i: Daily demand of demand point i in units (random variable with Poisson distribution function).
M_i: Demand during leadtime, leadtime demand, in unit (random variable) with probability of $P(M_i)$ for ith demand point ($i \in D$); it follows from the Poisson distribution of daily demand that demand during lead time is also Poisson distribute.
R_i: Average annual demand in unit for demand point i ($i \in D$).
H_i: Annual unit holding cost per unit in demand point i ($i \in D$).
W_k: Capacity of carrier k ($K \in C$).

Variables

B_i: Reorder point in unit for ith demand point ($i \in D$).
Q_i: Order quantity in unit for ith demand point ($i \in D$).

$$X_{ijk} = \begin{cases} 1 & \text{If demand point } i \text{ is served through supplier } j \text{ by carrier } k \ (i \in \text{D}, \ j \in \text{S}, \ k \in \text{C}) \\ 0 & \text{Otherwise.} \end{cases}$$

4 Solution procedures

The objective function of the proposed model is summation of total expected logistics costs of each demand point, where total expected logistics costs comprise purchasing cost, average ordering cost, average holding cost and average shortage or backorder cost. However, the specific set of assignments that yield the objective function value depends on how much information the demand point divulges in outsourcing logistics activities. That is, it depends on the degree of information sharing with the LSP (which can be a third party logistics provider (3PL), an association of carriers, etc.). Following the literature's common approach to evaluate the benefit of information sharing (e.g., Lee et al., 2000; Cachon and Fisher, 2000; Raghunathan, 2001; Axsäter and Marklund, 2008), two different strategies, namely, no-information and full-information sharing will be considered.

4.1 The no information sharing strategy

Under this strategy, the information available to the LSP for the assignment decision is limited to network participants' locations (which determine the tour lengths and the associated transportation costs). Thus, in such circumstance, the LSP tries to provide the best service to its clients (demand points) by allocating appropriate carriers to demand points to minimise overall transportation costs. Having this decision made, each demand point then determines its best order quantity and reorder point to minimise individual total expect logistics cost.

Therefore, the problem under no-information sharing is easily formulated in two steps: in the first step, an assignment problem is modelled using linear integer programming to minimise the total transportation cost. Since it is assumed that transportation cost is a linear function of distance, minimising total distance will result in minimum overall transportation cost. Having d_{ijk} as total tour distance the distances between supplier *j*, demand point *i* and carrier *k*, the mathematical programming formulation is:

$$\text{Min} \sum_{j \in S} \sum_{i \in D} \sum_{k \in C} X_{ijk} * d_{ijk} \tag{1}$$

$$\sum_{j \in S} \sum_{k \in V} X_{ijk} = 1, \qquad \forall i \in D \tag{2}$$

$$\sum_{i \in D} \sum_{k \in V} X_{ijk} \leq 1, \qquad \forall j \in S \tag{3}$$

$$\sum_{i \in D} \sum_{j \in S} X_{ijk} \leq W_k, \qquad \forall k \in C \tag{4}$$

$$X_{ijk} = 0,1 \qquad \forall i \in D, \forall j \in S, \forall k \in C. \tag{5}$$

The objective function to be minimised is total travel distance in the network subject to constraints in equations (2)–(5). Equalities (2) ensure that each demand point is served by exactly one carrier via one supplier. Inequalities (3) guarantee that no supplier will serve more than one demand point. Inequalities (4) satisfy the capacity constraints of carriers. The last non-functional constraints (5) ensure that the decision variables can only take binary values.

Given the established assignments from the first step, the second step is for each demand point to make replenishment decisions that minimise its own total expected logistics cost. This will be simply achieved through optimising the following formula (6) for each demand point *i*,

$$PR_i + \frac{R_i}{Q_i} C_i + H_i \left(\frac{Q_i}{2} + B_i - \overline{M}_i \right) + A_i \frac{R_i}{Q_i} \sum_{M_i = B_i}^{\infty} (M_i - B_i) P(M_i). \tag{6}$$

It is important to note that C_i, the ordering cost for demand point *i*, is a parameter in this step that is result of solving mathematical programming in the first step. Differentiating total expected logistics cost respect to Q_i and B_i and setting equal to zero, we have:

$$Q_i = \sqrt{\frac{2R_i \left[C_i + A_i E(M_i > B_i) \right]}{H_i}} \tag{7}$$

$$F(B_i) = 1 - \frac{H_i Q_i}{R_i A_i}. \tag{8}$$

The procedure to obtain optimum reorder point and order quantity is iterative (Tersine, 1993). First, compute Q_i with $E(M_i > B_i) = 0$, then the obtained Q_i is used to calculate B_i. Having value of B_i, update $E(M_i > B_i)$ and recalculate Q_i. Since the objective function is shown to be convex, repeating the procedure will result in optimum solution. In the case of discrete demand (which is considered in this study), the optimum reorder point is determined after satisfying the following condition:

$$F(B_i^*) \leq 1 - \frac{H_i Q_i}{R_i A_i} < F(B_I^* + 1) \tag{9}$$

And the optimum order quantity is a positive integer number $\lfloor Q^* \rfloor$ or $\lfloor Q^* + 1 \rfloor$, with minimum total expected logistics cost (if obtained Q^* from formula (7) is non-integer).

4.2 *The full information sharing strategy*

Under this strategy, the information divulged to the LSP is not limited to locations, but also includes product information at each demand point; e.g., demand rate, holding and shortage cost. The LSP (who, in light of the degree of information sharing, is likely a fourth party logistics provider (4PL) or a non-asset based consulting firm) determines assignment and replenishment decisions simultaneously to minimise the total expected logistics cost of the network (formula 10). By accounting for product information that is not available to the LSP in the no information sharing strategy, the LSP in the full information sharing strategy is better positioned to reach a globally optimum solution for the entire network.

$$\sum_i PR_i + \sum_i \frac{R_i}{Q_i} C_i + \sum_i H_i \left(\frac{Q_i}{2} + B_i - \overline{M}_i \right) + \sum_i A_i \frac{R_i}{Q_i} \sum_{M_i = B_i}^{\infty} (M_i - B_i) P(M_i) \quad i \in D. \tag{10}$$

Although the above formulas models shortage cost as a charge per unit short and independent of time, the model can be easily modified for cases such as fixed cost per stock-out, charge per unit shortage per unit time and lost sales.

The solution procedure for full-information strategy consists of two phases. The first phase (coded in Matlab 2009b) is enumerating for each demand point all possible J*K supplier/carrier pairs that can serve it (i.e., all J*K*I combinations of supplier, carrier and demand point). The second uses output from the first phase to formulate and solve the problem of determining the supplier-carrier pair that should be assigned to each demand point to minimise the network's total expected logistics cost. The steps in the first phase are:

- From among the total of J*K*I possible combinations (assignments) select an arbitrary one that is yet to be enumerated; i.e., demand point *i* is assigned to supplier and carrier pair (*j,k*).
- For the assignment in step one, the Matlab algorithm computes fixed ordering cost and determines order quantity and reorder point (using formula 7 and 8) to minimise the objective function for demand point *i*. Then TEC_{ijk}, which is the corresponding minimum expected logistics cost for demand point *i* when its replenishments from supplier *j* are delivered by carrier *k,* is stored for use as a parameter in the second phase.
- Check if all J*K*I possible assignments have been enumerated. If so, the algorithm goes to the second phase; otherwise, it returns to step 1.

With the TEC_{ijk} values from the first phase as inputs, the second phase optimisation problem of minimising the network's total expected logistics cost reduces to a straightforward Integer Programming (IP) problem. Formula (11) shows the objective function that had to be minimised subject to the set of constraints (2–5), which are exactly constraints of the no-information sharing strategy. The Lingo 8 software was used to solve the IP.

$$\text{Min} \sum_{j \in S} \sum_{i \in D} \sum_{k \in C} X_{ijk} * TEC_{ijk}. \tag{11}$$

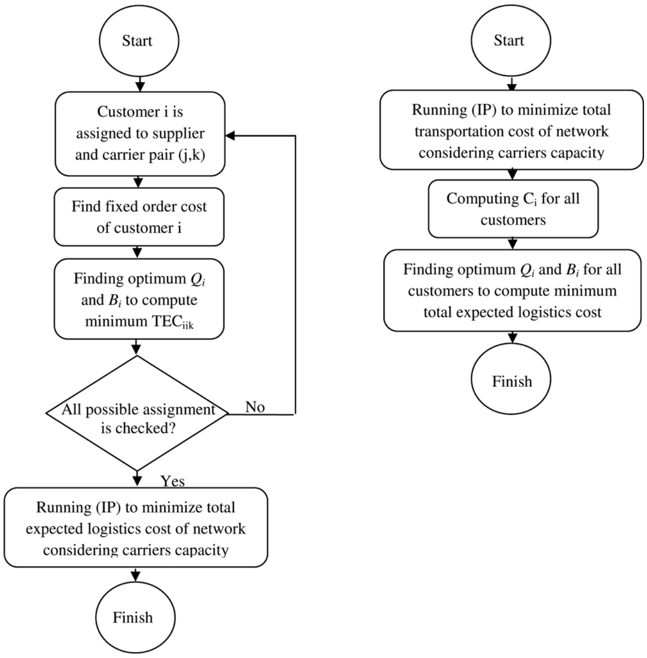
Figure 3 helps to clarify the distinction between the no-information sharing and the full information strategies by flowcharting the modelling process for each strategy. Comparing the proposed problem under two different conditions will help to evaluate the marginal value of information sharing in different settings. Consequently, the model under full information will be recommended whenever the gain in the form of cost saving outweigh the risk (or other imposed costs) associated with it.

5 Designing tests problems

Table 1 summarises the studied levels of the factors for which their effects on the value of information sharing were of interest. Considering important review papers on transportation network design (Crainic, 2000; Wieberneit, 2008), the factors chosen for analysis are network size, the number and capacity of carriers, demand fluctuation and ratio of per unit shortage to holding cost. Clarifying details on the factors and their levels in the experiments are as follows:

- *Network size*, defined by number of demand points and suppliers (assumed to be equal in our numerical study). Numbers of demand, points/suppliers are considered at two levels (5 and 15). Thus, numbers of nodes in the supply chain vary between 12 and 45.

Figure 3 Solution procedures for full information model (on the left) and no-information model (on the right)



- *Number of carriers*, specified as low (2 carriers) and high (equal to the number of suppliers/demand points (5 or 15)).
- *Carrier capacity*, defined as a number of demand point(s) that each carrier can serve and specified as high (each carrier is capable of serving all demands of the network) and low (each carrier can serve the rounded up integer value of I/K demand points; i.e., total number of demand points divided by total number of carriers, which means that the numerical value of carrier capacity corresponding to low depends on the network size and the number of carriers in the network).
- *Demand variation among demand points*, tested at two levels, 5% and 25% deviation from the overall average annual demand. This means that if overall average annual demand across all demand points is $\overline{R}$, then R_i, average annual demand of any demand point i will be generated from two discrete uniform distribution functions: $[0.95\overline{R}, 1.05\overline{R}]$ for variation = 5% and $[0.75\overline{R}, 1.25\overline{R}]$ for variation = 25%. Daily demand at i will still be Poisson distributed with an annual average = R_i.
- *Ratio of per unit shortage cost to per unit holding cost*; since the price of each item is independent of suppliers and there is only one item in the network, it is fair to assume the same holding and shortage costs cross all demand points. For each problem setting, the ratio (shortage to holding cost) is assessed at three different levels: 1, 2 and 10.

The experimental design summarised in Table 1 covers 48 different combinations of the five factors (four factors with two levels each and one factor with three levels = $2^4 \times 3 = 48$).

Note that because the numerical specification of 'low carrier capacity' depends on two other factors: (1) network size ($I = J$) and (2) number of carriers (K), carrier capacity is nested within those two factors. Note that carrier capacity is nested within two other factors: (1) network size ($I = J$) and (2) number of carriers (K), because its numerical specification depends on those factors. For example, as stated earlier, the numerical specification of 'low carrier capacity' is the integer rounded up value of I/K (=8 for I = 15, K = 2). The 48 combinations of factor level settings resulted in 240 test problems because, to account for the effect of random variation within each setting, five test instances were randomly generated. The random variation across test instances was with respect to both the values of annual total demand and the spatial (geographic) positioning of the network participants.

Table 1 Different levels for parameters setting

Number of Suppliers /demand points	5				15			
Number of Carriers	2		5		2		15	
Carrier capacity	L (3)	H (5)	L (1)	H(5)	L (8)	H (15)	L (1)	H(15)
Demand Fluctuation	$U(0.95\bar{R},1.05\bar{R})$ and $U(0.75\bar{R},1.25\bar{R})$							
Ratio of shortage to holding cost	1, 2, 10							

To generate the location of nodes in the network, we consider a network that spans the border between the USA and Canada. It is important to note that we do not intend to investigate trans-border transportation issues such as border regulation in the analysis. However, choosing these two countries (for generating tests problems) is mainly based on high trade volume between them and the wish to study situations involving long distance transportation. Given that a high percentage of Canada's exports are to the USA (e.g., 75% of Canada's exports went to the USA in 2008), we focus on products exported from Canada to the US. Two key considerations in generating X and Y coordinates for the network participants were:

1 specifying that suppliers and carriers are in Canada and demand points are in the USA

2 limiting the geographic scope of the network to major Canadian provinces (Ontario and Quebec) and American states (Michigan, Chicago, New York, Pennsylvania, Wisconsin, Iowa and Ohio) involved in USA–Canada trade.

Table 2 shows the parameters with values that remained fixed across all 240 test problems. These parameter values are captured from the literature (see Swenseth and Godfrey, 2002).

Table 2 The value of parameters which are fixed in all test problems

Purchasing cost	\$50	Price per unit
Holding cost at demand point i	\$45	Unit holding cost per unit in a year
Overall average annual demand	10000	Units in one year
Place an order	\$30	Per order
Full truck load freight rate	\$1.85	Per mile

6 Experimental results

Table 3 shows the summarised results for each combination of factor level settings (results are averages across the five instances for each setting). Each row is for one particular setting. As an example, the first row shows a certain test instance in which the ratios of shortage to holding cost, demand fluctuation, network size, number of carrier and carriers capacity are 1, 25%, 5, High (H) and 5, respectively. For each setting, the table shows the cost saving (in percentage terms) achieved by full information sharing over no information sharing. The largest average

Table 3 Summarised obtained results for average expected logistics cost of two models

Test Prob.	Shortage/ Holding	Demand Fluc.	Network size	Carriers	Carrier Capacity	Solution time (min.)	Saving%
1-5	1	25%	5	H	5	<1.5	0.33%
6-10	1	5%	5	H	5	<1.5	0.05%
11-15	1	25%	5	H	1	<1.5	0.23%
16-20	1	5%	5	H	1	<1.5	0.31%
21-25	1	25%	5	L	5	<1.5	0.11%
26-30	1	5%	5	L	5	<1.5	0.00%
31-35	1	25%	5	L	3	<1.5	0.37%
36-40	1	5%	5	L	3	<1.5	0.22%
41-45	2	25%	5	H	5	<1.5	0.77%
46-50	2	5%	5	H	5	<1.5	0.24%
51-55	2	25%	5	H	1	<1.5	0.08%
56-60	2	5%	5	H	1	<1.5	0.10%
61-65	2	25%	5	L	5	<1.5	0.06%
66-70	2	5%	5	L	5	<1.5	0.61%
71-75	2	25%	5	L	3	<1.5	0.55%
76-80	2	5%	5	L	3	<1.5	0.07%
81-85	10	25%	5	H	5	<1.5	0.29%
86-90	10	5%	5	H	5	<1.5	0.10%
91-95	10	25%	5	H	1	<1.5	0.88%
96-100	10	5%	5	H	1	<1.5	0.36%
101-105	10	25%	5	L	5	<1.5	0.19%
106-110	10	5%	5	L	5	<1.5	0.78%
111-115	10	25%	5	L	3	<1.5	0.11%
116-120	10	5%	5	L	3	<1.5	0.08%
121-125	1	25%	15	H	15	<3.5	0.64%
126-130	1	5%	15	H	15	<3.5	0.52%
131-135	1	25%	15	H	1	<3.5	0.79%
136-140	1	5%	15	H	1	<3.5	0.56%
141-145	1	25%	15	L	15	<3.5	0.31%
146-150	1	5%	15	L	15	<3.5	0.52%
151-155	1	25%	15	L	8	<3.5	0.36%
156-160	1	5%	15	L	8	<3.5	0.20%
161-165	2	25%	15	H	15	<3.5	0.60%
166-170	2	5%	15	H	15	<3.5	0.69%
171-175	2	25%	15	H	1	<3.5	0.73%
176-180	2	5%	15	H	1	<3.5	0.63%
181-185	2	25%	15	L	15	<3.5	0.25%
186-190	2	5%	15	L	15	<3.5	0.29%
191-195	2	25%	15	L	8	<3.5	0.39%
196-200	2	5%	15	L	8	<3.5	0.28%
201-205	10	25%	15	H	15	<3.5	4.60%
206-210	10	5%	15	H	15	<3.5	0.68%
211-215	10	25%	15	H	1	<3.5	1.05%
216-220	10	5%	15	H	1	<3.5	0.62%
221-225	10	25%	15	L	15	<3.5	0.68%
226-230	10	5%	15	L	15	<3.5	0.45%
231-235	10	25%	15	L	8	<3.5	0.42%
236-240	10	5%	15	L	8	<3.5	0.66%

saving of 4.6% (for test instances 201–205) occurred when every factor is at its highest level. There is no saving when every factor except carrier capacity is at its lowest level (test instances 26–30). This evinces interaction between factors.

For a more detailed investigation of the main and interaction effects on the superiority of full information sharing over no information sharing, an analysis of variance (ANOVA) was conducted (results are in Table 4). Two-way interactions were the highest order interactions in the ANOVA because higher orders would reduce the error degree of freedom and test sensitivity. The R^2 (coefficient of determination) of 41.6% shows what percentage of logistics cost saving (due to information sharing) is explained by the main factors and their two-way interactions.

Table 4 ANOVA Test of five main factors and their two-way interactions

Source	Degree of freedom	F	P-Value
Shortage/ Holding (Ratio)	2	6.64	0.002
Demand fluctuation	1	10.52	0.001
Demand point/ Supplier (Size)	1	0.04	0.842
Carriers	1	12.39	0.001
Carrier Capacity	4	2.62	0.036
Ratio*Demand fluctuation	2	3.49	0.032
Ratio*Size	2	0.37	0.695
Ratio*Carriers	2	3.4	0.035
Ratio*Carrier Capacity	8	2.22	0.027
Demand fluctuation*Size	1	0.13	0.721
Demand fluctuation*Carriers	1	15.57	<0.001
Demand fluctuation*Carrier Capacity	4	2.88	0.024
Size*Carriers	1	12.39	0.001
Error	209		
Total	239		

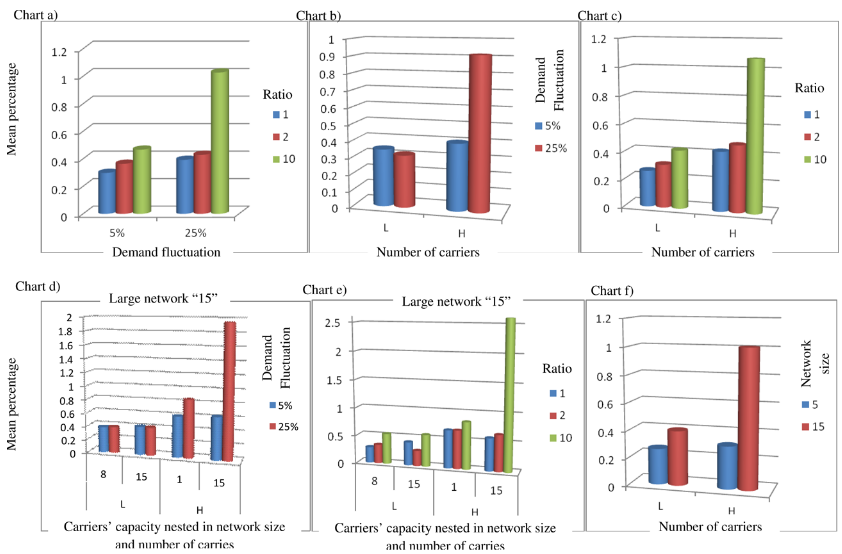
The results in Table 4 show that all main effects factors except network size are significant at the 5% significance level and all interactions except the interactions of size with demand fluctuation and size with ratio of shortage to holding cost are also significant. Since the moderating impact of most of the interaction effects are statistically significant, it is worth discussing two-way interactions rather than merely focusing on the main effects. Moreover, the different structure of the proposed problem makes the comparison difficult with current studies. However, considering the main effects, the obtained results illustrate that higher benefit of shared information in the presence of higher demand fluctuation. This is consistent with Lee et al. (2000) and Gavirneni (2001); however, Chen (1998) and Li et al. (2006) reach to totally different conclusions on this issue.

The result that network size is not a significant factor by itself may appear counter-intuitive. However, a closer look at this factor shows that enlarging the network does not always raise the penalty of operating in the no information sharing mode. A case in point is that by comparing tests problems 66–70 with 186–190 (see Table 3), in which the experimental settings are the same in all aspects except network size, one will notice that the saving in total expected logistics cost resulting from information sharing is higher in the smaller network. Thus, the normally expected growth in information sharing savings from the larger solution space caused by enlarging the network might be cancelled out or outweighed. More precisely, as the network size shrinks, failure to share information may have relatively larger consequences. The following simple example demonstrates how this can occur. Consider a small network consisting of just two demand points, two carriers (each with capacity of one) and two suppliers. In such a setting, if failure to share information causes erroneous assignment decisions, those network decisions would be completely wrong; i.e., all assignments deviate from optimum. One can use a given set of demand rates (as well as other factors) to illustrate that in the present example, this error from failure to share full information would be very costly. Comparing with general results in the literature, this is another interesting example that shows the benefit of shared information is dependent on problem definition. For example, Weng (1999) considered a divergent network with one manufacturer and multiple distributors and found that the benefit of shared information increases by decreasing number of distributors. The same conclusion appeared in works by Gavirneni (2001) and Moinzedeh (2002).

Figure 4 provides six charts to clarify the interaction effects on the value (i.e., logistics cost savings) from information sharing. Starting from the first chart (ratio of shortage to holding cost and demand fluctuation), it is clear that having higher shortage cost does not have significant effect on impact of information sharing on saving (in percentage) if demand fluctuation is low. However, the shortage effect is significant if demand fluctuation is high. The result is intuitive, because in the no information sharing strategy, the LSP lacks data on shortage cost and demand patterns. This means that the consequence of not sharing information with the LSP will become more serious when the lacked data items take higher values.

Another significant effect is the interaction of number of carriers and demand fluctuation. Chart (b) in Figure 4 illustrates that the effect of number of carriers on the savings from sharing information depends on the level of demand fluctuation. Though the number of carriers is, by itself, a significant factor, its effect is exacerbated by higher demand fluctuations.

Figure 4 Average percentage of saving in presence of two factors at different levels (see online version for colours)



The intuitive result can be understood by recalling that (a) the core logistics network design question is which supplier-carrier pair will serve each demand point and (b) under no information sharing, the LSP lacks decision support information on the expected demand's rate, holding and shortage costs. In other words, by making assignment decisions without considering the associated consequences on inventory costs at demand points, the LSP in the no information sharing strategy faces a higher risk of taking an inferior solution. And, as can be inferred from the earlier discussion of chart (a), this superiority is further magnified when the ignored information (demand fluctuation in this instance) assumes larger values. Chart (c) in Figure 4 conveys similar conclusions concerning the interaction between number of carriers and ratio of shortage to holding cost.

Chart (d) depicts the interaction between carriers' capacity and demand fluctuation. Because statistical tests found this interaction to be statistically significant for the large network but not for the small network, only the large network size findings are covered in chart (d). For easier exposition of the finding and its underlying intuition, the plot of capacity on the horizontal axis is divided into two parts: the first part, showing capacity increasing from 8 to 15, is labelled 'L', signifying the number of carriers is low (2 carriers) and the second part, showing capacity increasing from 1 to 15, is labelled 'H', signifying the number of carriers is high (15 carriers). The essential finding depicted in chart (d) is that if the number of carriers is high relative to network size, then the value of information sharing becomes more significant with increases in both carrier capacity (i.e., looser capacity constraints) and demand fluctuation. The intuition behind this result can be understood by the fact that increasing the carriers' capacity will enlarge the solution space (for both the full and no information sharing strategies, since they are subject to the same set of constraints). However, as noted in the previous paragraph, the two-step solution approach under no information sharing ignores relevant information in the first step (assignment decisions), thereby increasing the risk of missing higher quality network configuration solutions.

That risk is magnified when the solution space increases. As such, it is not surprising that chart (d) shows a conspicuous spike for the case when the solution space is enlarged through the availability of a large number of carriers (15 carriers) with a large capacity (each carrier having the capacity to serve all 15 demand points).

Chart (e) in Figure 4 tells a similar story as chart (d), except that the interaction of carrier capacity is now with the ratio of shortage to holding cost instead of with demand fluctuation. In short, information sharing is more valuable for larger values of the ratio of shortage to holding cost, number of carrier relative to network size and carrier capacity. The last chart (f) in Figure 4 depicts the interaction effect of network size and number of carriers. It suggests that network size has a significant effect on information sharing value when the number of carriers is large. As with the previous graphs, chart (f) underscores the impact of solution space; i.e., the enlarged solution space resulting from larger values for both network size and number of carriers raises the value of information sharing.

One important and interesting finding that seemed to be counterintuitive concerned the difference in overall total transportation costs between the two information sharing modes. The seemingly intuitive expectation is that the no information sharing mode should have lower total transportation costs. The reason is that transportation cost based on locations is the targeted criteria in making the assignment decisions. Recall that this is unlike the full information sharing solution approach of making assignment and replenishment decisions simultaneously. Yet, to the contrary, the results revealed total overall transportation cost to be higher for no information sharing in almost half of the test problems. Based on tests for statistical significance, total transportation cost under no information was not found to be lower than under full information sharing. The explanation lies in the fact that under no information sharing, assignment decisions have to be made using distance data to determine transportation cost *for a single snapshot trip* without the benefit of data on the number of replenishment orders (trips) required to satisfy demands throughout the year. This means that the snapshot-based transportation cost used as the criteria for assignment decisions under no information sharing might not fully capture the year's true total transportation cost. Consequently, those decisions are not guaranteed to yield total transportation cost that is smaller than under full information sharing.

7 Conclusion

In this study, we focused our attention on two strategies, namely, no information sharing and information sharing. Although partial information sharing (e.g., sharing inventory level or cost structures) can be viewed as an important strategy, the small benefit margin of full information sharing in comparison to no information sharing strategy convinced us not to extend our analysis to cover the third strategy.

The main contributions of our work are threefold. First, we explicitly address transportation parameters (i.e., cost and time) as crucial factors which impact inventory decisions. Second, the typical dyadic and divergent supply chain networks were extended to capture characteristics of a network structure. Third, the proposed model includes carrier location and capacity among the factors that can influence the value of information sharing through their impact on transportation parameters. Our approach helps to produce a fuller set of insights into what the influential factors are.

Valuable managerial insights are obtained from the numerical investigations. This study has found that the cost savings benefit achievable by clients when they share relevant information with their Logistics Service Providers (LSPs) such as carriers depends on several factors. Among those factors are the number of available LSPs and their transportation capacity, the variation of demand across clients that the LSPs serve and the clients' ratio of inventory shortage cost to inventory holding cost. Beyond extending the research literature by quantifying the logistics cost savings benefit of information sharing and clarifying how it is influenced by the aforementioned factors, the study's findings have important implications for managerial practice. The crux of those implications is that it is possible for the benefit of information sharing to be so small that it could be outweighed by its associated cost. Therefore, a key recommendation of this paper is that an LSP client should not automatically assume that information sharing and its companion concepts such as inter-firm coordination and integration will be beneficial. Instead, clients of LSPs must seek to understand how the set of parameters that define their logistics network is likely to impact the magnitude of benefits from sharing information with the LSPs. Network size is an interesting example in this regard. We found no statistical evidence that larger network size alone improves the value of shared information. However, its impact on supply chain performance may be remarkably significant when it is coupled with other factors.

Similar to other research studies, our current work is subject to *several limitations* which can be considered as a basis for future research. The following are four promising future research directions for investigating a broad range of problems concerning managerial decisions:

- Examining the value of information sharing under other types of shipment arrangements in which customers have common suppliers and shipment consolidation is used; e.g., hub-and-spoke. Our preliminary hypothesis is that the value of information sharing will be larger in those settings.

- Incorporating multi-stop routing operations in the network. In this study, the long distances between US demand points and Canadian supply points justified using full truck load and point-to-point assignments. Multi-stop routing for less-than-truckload deliveries would be applicable when distances are relatively short.
- Replicating the study for a multi-commodity network, which is what occurs most often in real-world cases.
- Considering inventories at more than one level (i.e., at both suppliers and demand points) to progressively expand the research scope towards the whole supply chain.

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