

Carrier Managed Transportation in Supply Chain Management

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Logistics Transportation is an indispensable step that connects production, storage, and the final customers. Plenty of previous research has been done to achieve the goals such as low cost, high accuracy in timing, good customer service, and low damage rate, within the transportation system. However, most of those improvements are on the operational level. There are few supply chain collaborations that try to optimize logistics transportation from a strategic level.

This thesis proposes a new collaboration policy, *Carrier Managed Transportation* (CMT). It is a coordinated relationship between the carrier and the clients in a supply chain. As opposed to the traditional approach, where the client decides when to request shipments of the products, in CMT, the carrier will make these decisions on their behalf through information sharing.

Due to the complexity in relationships and responsibilities of chain members, we divide the business scenarios into four cases and discuss the impact of CMT on each case. Comparisons and numerical examples across cases are also provided, along with some conclusions regarding the implementation of CMT.

Keywords: Logistics; Transportation; Distribution; Supply Chain Collaboration

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Chapter 1 Introduction

1.1 Transportation in logistics and the supply chain

Transportation is one of the two pillars in the logistics and supply chain activities. It is an indispensable step that connects production, storage, and the final customers. By moving the required quantity of products to a designated location, transportation creates value for those products. Three parties are involved in a transportation system: the carrier, the shipper, and the consignee.

Simply speaking, the carrier is the party who offers transportation services. Both the shipper and the consignee are clients to be served. The shipper is the party who wants to send out the goods, and the consignee is the one who will receive them. That is, the products originate from the shipper, and terminate at the consignee. The carrier provides transportation to realize the movement of freight between the two parties.

There are some criteria to define a favorable transportation system: low cost, high accuracy in timing, good customer service, and low damage rate. Much research has been done at the operational and practical levels to optimize the transportation cost. For example, freight consolidation is the most frequently applied technique to lower the total expense. This shipment strategy combines small deliveries and dispatches them as a larger single load, utilizing scale economies. However, not much has been done to improve the transportation

performance from a strategic level. The following figure indicates the parties in a transportation system, and how consolidation is performed:

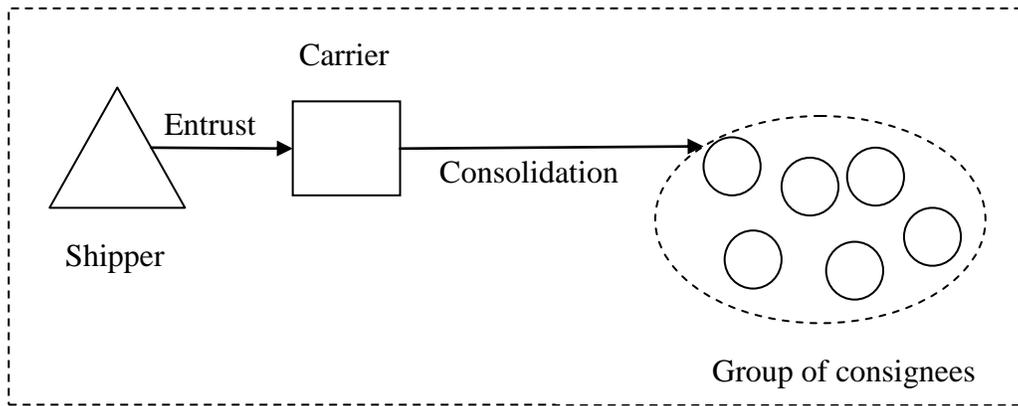


Figure 1-1: Consolidation in a transportation system

In this thesis, we will propose a new strategy that also has the potential to better utilize the transportation system.

1.2 Supply chain collaboration and Carrier Managed Transportation

Since the mid 1990's, supply chain collaboration has become a major trend of supply chain strategy, which has gained extensive attention from both academics and practitioners. Various degrees of coordination have emerged with the development of supply chain management. Categorized by logistics activities, these are collaborative planning, collaborative forecasting, and collaborative replenishment. From the perspective of the whole supply chain, some firms merged vertically with companies upstream or downstream in the process of coordination, while other collaboration strategies keep the independence of the chain members. These coordination strategies are all aimed at reducing costs of

the parties involved, building up business relationships, and improving the performance of the supply chain. The wide discussion of collaboration has also yielded a wealth of concepts, such as vendor managed inventory (VMI), Continuous replenishment, Quick response, and Efficient Consumer Response, e.g. Daugherty et al. (1999) and Simchi-Levi et al. (2000).

Among these concepts, VMI is well-known and popular in the industry. Under VMI, the supplier is given the required information and the full responsibility to maintain the inventory of the buyer. The supplier thus places orders on behalf of the buyer. According to Waller et al. (1999), this means that the vendor monitors the buyer's inventory levels (physically or via electronic messaging) and, from time to time, makes resupply decisions regarding order quantities and shipping. Transactions customarily initiated by the buyer (such as purchase orders) are initiated by the supplier.

The merits of VMI are mentioned in numerous articles. It is often cited that VMI has the following benefits: lower inventory levels, faster turnover rates, reduced ordering costs, and reduced out-of-stock costs, e.g. Angulo et al. (2004). Experience from big companies like Wal-Mart and Procter & Gamble also indicated that VMI is beneficial.

Unfortunately, there is no similar collaboration in transportation practices. Most of the time, transportation and distribution are still processed under traditional ways. That is, each party in the supply chain makes decisions with

little consideration about the situation of other parties. Meanwhile, the only information available is the delivery of orders established by shippers or consignees. According to Holweg et al. (2005), this is “The Traditional Supply Chain”, i.e. each level of the supply chain operates without considering the situation at other tiers. The best performance can be achieved if the supplier takes charge of the customer’s inventory replenishment on the operational level, and uses this visibility in planning his own supply operations. This type of supply chain was classified as “Synchronized Supply”. Now we want to examine whether the synchronized supply also has potential in the delivering practices.

We feel that the principles of VMI also apply in transportation and distribution. Therefore, we conceived a similar coordination model, now with the relationships among parties in a *transportation* system. The new concept is named “Carrier Managed Transportation”. Literally, it means that the carrier is given the responsibility to manage transportation for the clients.

This new supply chain coordination has not been explored previously. A definition would thus be helpful to precisely convey the idea; Carrier Managed Transportation (CMT) will be defined below. The crucial factors that will affect the implementation of CMT will be discussed as well.

Definition: Carrier Managed Transportation (CMT) is a coordinated relationship among the carrier, the shipper, and the consignee in a supply chain. As opposed

to the traditional approach, where the shipper or consignee decides when to request shipments of the products, in CMT, the carrier will make these decisions on their behalf through the sharing of information on the timing of planned replenishments.

Table 1-1 gives a detailed comparison of VMI and CMT:

Table 1-1: Comparison of VMI and CMT

	VMI	CMT
Initiative in decision making	Shifted from the buyer(s) to the vendor	Shifted from the customer(s) to the carrier
Order Quantity	Decided by the vendor	Specified by the customer(s)
Timing	Decided by the vendor, with consideration of requirements from the buyer(s)	Decided by the carrier, with consideration of requirements from the customer(s)
Quantity per shipment	Decided by the vendor	Decided by the carrier
Benefits	Integrated production and replenishment	Advantages in consolidation

From the carrier’s perspective, better consolidation and greater chance of back-haul transportation can bring down his operating cost, while improving customer service quality. The shipper or consignee can save on the cost of issuing shipments, ask for flexibility in shipping/receiving, get advance shipping notices, and share a portion of the savings from the carrier. CMT may have the

potential to lower the total cost of the whole supply chain, yet improve the performance and responsiveness at the same time. Meanwhile, CMT is aided by a long-term relationship between the chain members. This helps the supply chain to remain relatively stable and be easier to maintain.

1.3 Key words on a transportation agreement

To apply CMT in business, there are some key facts that we need to specify in a transportation contract. These include: roles and responsibilities of the companies involved, what type of transportation to use, etc. Below we explain two factors that will answer the previous questions.

1.3.1 Private fleet or common carrier

A “Private Fleet” is a set of vehicles operated by a company that offers transportation and distribution services, mostly for its own products. There are two points that will distinguish private fleet from a “Common Carrier”. One is that a common carrier offers services to the general public. Therefore, such a trucking firm has multiple clients compared to the few customers served by the private fleet. Another point is: For the common carrier, transportation or distribution is the core business of that firm; but for the company that operates a private fleet, usually this is not the case. Generally speaking, its private fleet can give the company greater priority, as the common carrier must serve each client “equally”.

1.3.2 Incoterms

Incoterms (International Commercial terms) are a series of pre-defined commercial terms published by the International Chamber of Commerce (ICC). Because of the global acceptance, these terms are widely used in international commercial transactions. Nowadays, Incoterms are also used in domestic business with the intention to clearly communicate the tasks, costs and risks associated with the transportation and delivery of goods.

In North America (especially the United States), FOB terms are often applied on land. However, they were originally designated for water transportation, meaning “Free On Board,” i.e. on the vessel. The FOB term indicates the point at which the ownership of the goods changes.

Table 1-2 is a list of different FOB terms and their meanings. For illustrative purposes, we use the two typical terms, the first and the last one in Table 1-2, and name them FOB Origin and FOB Destination, respectively.

Basically, FOB terms specify a physical point in the transportation path; ownership of the goods is assigned to one party on each side of that point. For FOB Origin, that point is the seller’s location: the buyer is responsible for the products, once they are ready to be transported from the seller’s site. Therefore, the buyer needs to deal with everything that is relevant to getting the goods to her site. Similarly, under FOB Destination, the seller is responsible for the products until they arrive at the buyer’s location.

Table 1-2: FOB terms

Freight Terms	Buyer Takes Title of Goods	Buyer's Responsibilities	Seller's Responsibilities	Choice of Carrier
FOB Origin, Freight Collect	At point of origin or factory	Pays freight Owns goods in transit Files claims for any loss, damage or overcharges		Buyer chooses carrier: either using buyer's own fleet or common carrier
FOB Origin, Freight Prepaid and Allowed	At point of origin or factory	Owns goods in transit Files claims	Pays freight	Seller chooses carrier: either using seller's own fleet or common carrier
FOB Origin, Freight Prepaid and Added	At point of origin or factory	Pays freight Owns goods in transit	Adds freight to invoice	Seller chooses carrier: either using seller's own fleet or common carrier
FOB Destination, Freight Collect	At destination	Pays freight	Owns goods in transit Files claims	Buyer chooses carrier: either using buyer's own fleet or common carrier
FOB Destination, Freight Prepaid and Added	At destination	Pays freight	Adds freight to invoice Owns goods in transit	Seller chooses carrier: either using seller's own fleet or common carrier
FOB Destination, Freight Prepaid and Allowed	At destination		Pays freight Owns goods in transit Files claims	Seller chooses carrier: either using seller's own fleet or common carrier

*Based on <http://www.chassis-plans.com/PDF/fobterms.pdf>

1.4 Thesis outline

In Chapter 1, we introduce the various logistics concepts, and define our research problem and research scope. This is followed by the notation that will be used in the models in later chapters. Literature and past works referred to are reviewed briefly in Chapter 1 as well. As there is no previous research on Carrier Managed Transportation, the review mainly contains papers with the topic of VMI or transportation. Articles concerning transportation cost configuration and consolidation methods are also cited. Then, in Chapters 2 and 3, each case introduced in Chapter 1 is categorized by the carriers, i.e. by the party responsible for performing the transportation or for choosing the carrier. Those cases are discussed in detail, and illustrated by numerical examples. Chapter 4 contains the comprehensive numerical testing of the different parameters, and a comparison of the preceding cases. Several strong conclusions are drawn from the analysis. In the end, Chapter 5 summarizes all the work done in this thesis. For a new topic such as CMT, there are various choices for possible further research. Several suggestions on extending CMT and more complicated models are also provided in Chapter 5.

1.5 Relevant literature

Although Carrier Managed Transportation is a new concept, the theoretical principle is similar to VMI (Vendor Managed Inventory). Hence, the research

findings under the topic of VMI are worth making use of for reference in our study of CMT.

In the literature, Disney and Towill (2003) compared the expected performance of a VMI supply chain with a traditional “serially linked” supply chain, in terms of the impact on the “Bullwhip Effect”. They found that VMI is significantly better at responding to volatile changes in demand.

Dong and Xu (2002) evaluated the short-term and long-term impact of VMI on supply chain profitability by analyzing the inventory systems of the parties involved. They found that in the short-term VMI can accomplish what full channel coordination is set to accomplish; in the long-run, VMI could more likely increase supplier’s profit than in the short-run when both the buyer and the supplier adjust their production, distribution and marketing efforts to take advantage of lower system-wide inventory-related cost. However, the authors did not distinguish VMI and consignment inventory (CI), although the two concepts are not identical.

Based on a single vendor-buyer case, Gumus et al. (2008) analyzed the impact of inventory sourcing (IS), CI, and CI plus VMI, accounting for changes in certain cost parameters, and provided closed-form solutions indicating under which conditions a partnership is more favorable than others. Bookbinder et al. (2010) checked if VMI works or fails under independent decision making, VMI, and central decision making. As those authors noted, CMT can be beneficial to

the suppliers, as they “may combine routes from multiple origins, delay stock assignments, consolidate shipments to two or more customers, or postpone a decision on the quantity destined for each of them”. To study CMT, we apply a research methodology similar to that of Gumus et al. and Bookbinder et al.

Çetinkaya and Lee (2000) considered a vendor realizing a sequence of random demands from a group of retailers located in a given geographical region, and presented an analytical model for coordinating inventory and transportation decisions in VMI systems, which can be viewed as a special case of CMT.

To enjoy economies of scale in shipments, Cheung and Lee (2002) used information on the retailer’s inventory position to coordinate shipments from the supplier, and analyzed the drivers of the relative benefits to both parties.

With the initiative of making shipment decisions, the carrier can take advantages of those economies of scale by improving the optimization of its distribution operations under CMT. Thus it is necessary to take into account previous work in the field of transportation and distribution. Some research considered transportation cost. Aucamp (1982) treated a modification of the standard EOQ problem in which total freight cost depends at least partially on the number of carloads required to fill the order. Burns et al. (1985) developed and evaluated an analytic method that aids in minimizing the sum of transportation and inventory costs for a supplier who distributes items to many customers. Higginson (1993) discussed the modeling of shipper costs through an

examination of cost expressions relating to distribution activities and their relevance to actual costs. Kuzdrall (2002) explored lot size issues when a supplier's prices include shipping charges that are not explicitly stated. The extended EOQ model is worth referring to and is applied in later chapters.

There are several policies considering how the consolidation could be organized. Under a *quantity policy*, orders should be dispatched as soon as the consolidated weight available exceeds the designated level. If shipments are scheduled every constant cycle length, then this is a *time policy*. A *time-and-quantity policy* is the combination of the previous two policies, and the dispatch is triggered once one of the criteria reaches the predetermined point. Çetinkaya and Bookbinder (2003) obtained the optimal target weight before dispatch for a *quantity policy*, and the optimal maximum holding time of any order under a *time policy*, for both private carriage and common carriage. Bookbinder and Higginson (2002) employed probabilistic modeling to choose the maximum holding time and desired dispatch quantity for a *time-and-quantity policy*. The probability of accumulating the preceding target weight within a given time frame is also applicable in the analysis of CMT.

Shippers and consignees may also benefit from CMT by requiring lead time reduction, an advance shipping notice, flexibility in receiving, and a quantity discount. Weng (1995) analyzed the impact of joint decision policies on channel coordination in a system consisting of a supplier and a group of homogeneous

buyers, in which both demand is price-sensitive and transaction costs are functions of order quantities. According to that author, quantity discounts in channel coordination aim to ensure that the joint order quantity selected by both the supplier and the buyer minimizes the joint operating costs; and the role of a “franchise fee” in channel coordination is to enforce the joint profit maximization for both the supplier and the buyer.

Similar to in VMI, we can expect less information distortion, according to Lee et al. (1997) and Chen et al. (2000), in CMT as well. Although in this thesis, we do not stress the sharing of information between the parties, it is worth noticing that information sharing would also play an important part in the *implementation* of CMT.

1.6 Problem definition and research scope

1.6.1 Conceptual framework

The FOB term used in the contract determines which party in the supply chain is responsible for transportation; either this party operates a private fleet (i.e. moves the goods in its own truck) or hires a common carrier. Distinct frameworks are needed to cover different contracts. Thus, our models can be roughly divided into two categories. To allow the chances for consolidation, we include more than one seller or buyer in each category.

For the contract under FOB Destination, the seller is going to be the one in charge of transportation. Models of this category will contain one seller, two buyers, and a common carrier, if the seller chooses to hire one. A conceptual framework of the problem is depicted in Figure 1-2.

The buyers are located in the same geographical region, and face their own constant, deterministic demands which are known in advance. They choose to manage their inventory through an EOQ model. Based on his demand rate, inventory holding cost, and ordering cost, each buyer establishes an economic order quantity and passes an order to the seller. The seller then replenishes the buyers according to the quantities required and the agreed-upon timings.

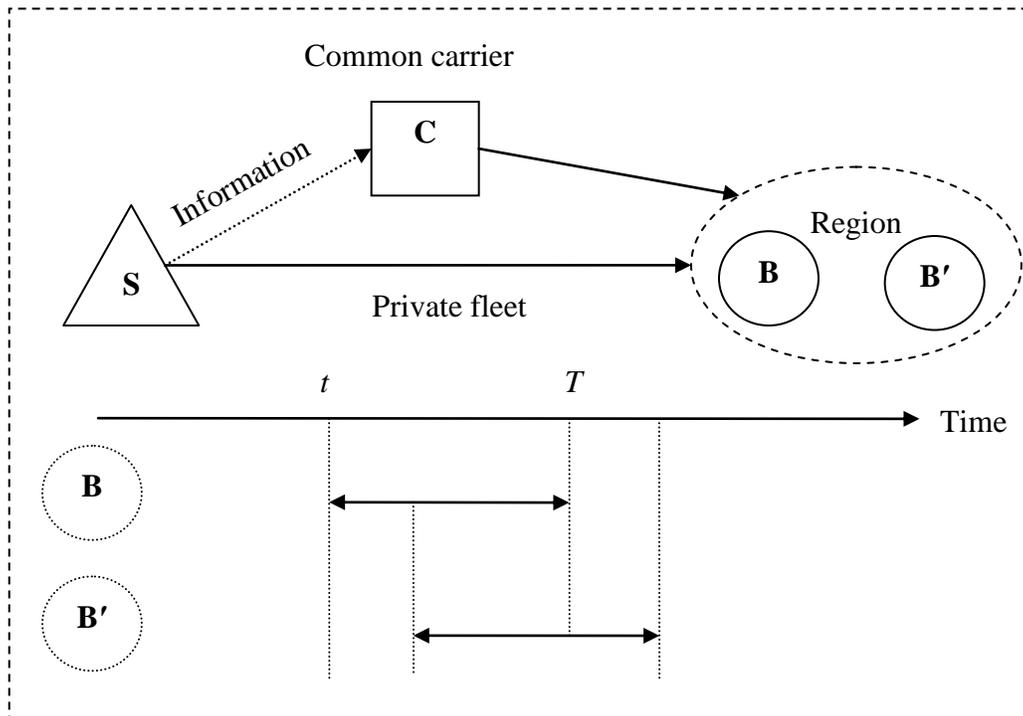


Figure 1-2: Model framework for FOB destination

We assume that the seller always has sufficient goods ready for release. This eliminates backorders to the buyers. The seller dispatches only one truck per shipment. Capacity of the truck is set to be large enough that there is no need to break orders into smaller loads. In addition, there is no extra stop on the way from the seller to the region where the buyers are. Therefore, given the distance between the seller and the region of buyers, we can obtain the in-transit time, as it is proportional to the line-haul distance. But we ignore any distances between the two buyers. In other words, delivery within a region is assumed to require minimal extra time.

In industry, a usual way to guarantee that the buyer gets replenished on schedule, and not late, is by applying a *time window*. Here we introduce a time window (t, T) , in which t is the point at which buyer places an order (e.g. 10AM on Tuesday); and T is the point when his inventory would hit zero, indicating the latest allowable arrival time of the replenishment (e.g. 4PM on Thursday). Time windows are established by buyers and passed to the seller.

For the contract under FOB Origin, the buyer is the one in charge of transportation. Models of this category will contain one buyer, two sellers, and a common carrier, if the buyer chooses to hire one. A conceptual framework of that problem is depicted in Figure 1-3, where B is the buyer and S and S' are sellers.

The buyer faces constant, deterministic demands for two different products from his clients, and uses EOQ models to manage the inventory of those items. Based on demand rate, inventory holding cost, and ordering cost of each product, the buyer establishes an economic order quantity for it and passes an order to the corresponding seller. The sellers then prepare the goods according to the quantities required and timings agreed upon. Since the buyer is responsible for transportation, he picks up products at the sellers, which are located in the same geographical region, to complete the replenishments.

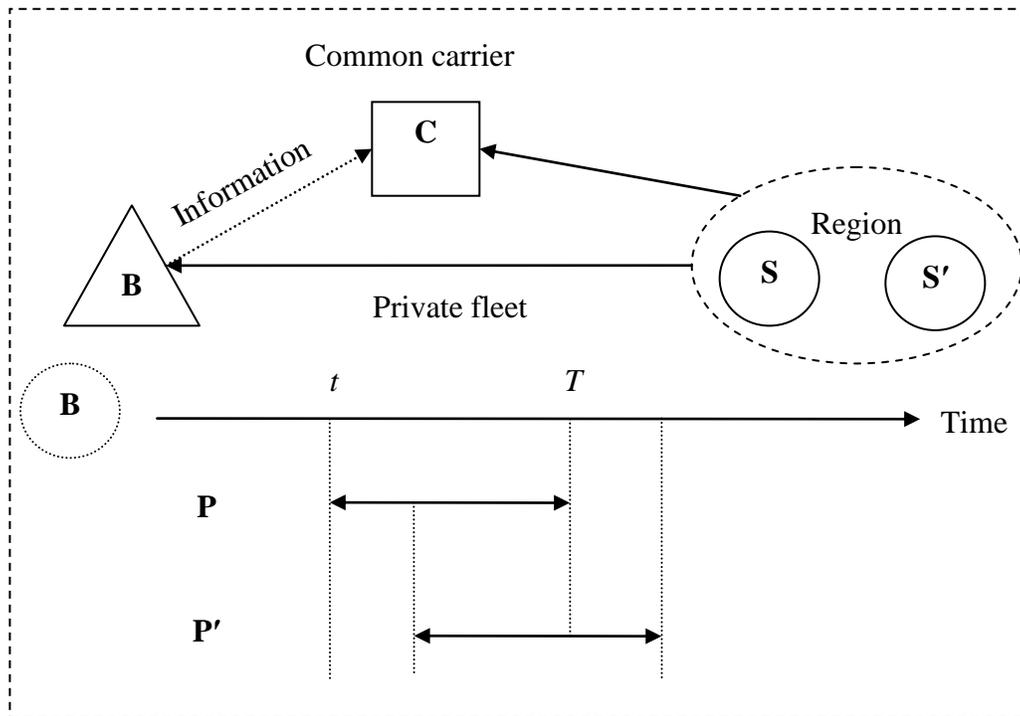


Figure 1-3: Model framework for FOB destination, for products P and P'

Similar to the previous contract, we assume that the sellers always have sufficient goods ready for release. The buyer uses only one truck per replenishment. Capacity of that vehicle is set to be large enough that there is no need to break orders into smaller loads. In addition, there is no extra stop on the way from the buyer to the region where the sellers are located. Therefore, given the distance between the buyer and the region of the sellers, we again calculate the time in transit, proportional to that distance. As before, travelling within a region is assumed to require minimal extra time, hence we ignore any distances between the two sellers.

The definition of time window is basically the same as stated above. A subtle difference is that the time windows here are generated by the one buyer, but for different products.

1.6.2 Research Scope

To clearly indentify the pros and cons of CMT, we introduce another distribution policy for comparison. That is “independent decision making”, which is the traditional way of doing business between the carrier and shipper/consignee. When there is no coordination between the parties, the shipper, carrier and consignee each act separately. The shipper or consignee makes distribution decisions on the premise of minimizing her total cost. She may choose to operate a private fleet or hire a common carrier. Then the

decisions are passed to the logistics department of the given firm or to the common carrier. In either case, the latter will make decisions on distribution practices to minimize his total cost, based on requirements from the shipper/consignee.

Unlike independent decision making, under CMT, the carrier establishes and manages the distribution decisions on behalf of the shipper or consignee, through the sharing of information on the timing and quantities of planned dispatches or replenishments. The carrier merges those decisions with his own transportation operations, i.e. through consolidation of shipments. The shipper or consignee is exempt from related expenses by giving up some rights in decision making, e.g. chances to get a lower total cost on their own.

The parties involved in the partnership are governed by a CMT contract. Although that contract covers all those parties, the essence of it is between two specific parties under various settings. We will discuss it later in Chapters 2 and 3.

Our aim is to develop and analyze quantitative cost models under independent decision making and CMT, as well as to measure the savings on total cost of the seller(s), buyer(s), common carrier, and the whole supply chain. The following cost factors will be included in our models: the costs of on-site inventory holding, those of pipeline inventory, transportation, shipment dispatch, costs of receiving goods and of order preparation. The cost of shipment dispatch

relates to writing up the dispatch request and determining the time of shipment. Note that the buyer is responsible for on-site inventory holding costs and the cost of receiving goods; the seller is responsible for on-site inventory holding costs there, and for the cost of order preparation. The remainder of the above costs may be incurred by different parties, depending on the distribution policy applied.

1.7 Introduction to the cases

Table 1-3 would contain eight cases if we simply combined the carrier choices and FOB terms. However, due to lack of practicality, half the combinations are not used in industry. For example, if the buyer owns private transportation, she will tend to pick up the products herself instead of entrusting the seller. Hence, she will sign a contract featuring FOB origin in this situation. The reasoning is similar when the buyer has the advantage of hiring common carriage.

Now consider the seller's perspective. If he is to organize the transportation, he will avoid the usage of FOB origin because, under FOB origin, expenses on transportation will be paid by the buyer. No matter whether the seller chose to use private or common carriage, he would need to add an additional charge to the invoice for the products shipped. His cost structure would thus be exposed to the buyer; usually a company will try to avoid this.

As a result, there are only four cases left (Table 1-3): Private fleet belongs to the seller, FOB destination (Case 1); Private fleet belongs to the buyer, FOB origin (Case 2); Common carrier, FOB destination (Case 3); and Common carrier, FOB origin (Case 4).

Table 1-3: Classification of cases

FOB terms	Destination Origin	Carrier			
		Private fleet belongs to		Common carrier hired by	
		Seller	Buyer	Seller	Buyer
		Case 1	×	Case 3	×
		×	Case 2	×	Case 4

*The symbol × indicates situations that do not occur in industry

We will introduce the four cases one by one, following the sequence above. Costs will be assigned to the seller and buyer under both distribution policies, while focusing on the contractual relationship under CMT. That relationship may involve the carrier, and even an additional buyer or seller, depending upon the case. We will discuss those cases, based on the type of carriage, in Chapters 2 and 3, respectively.

1.8 Notation

A simple mathematical model will be used to illustrate the changes in cost of each party and of the whole supply chain, with and without CMT. We now define some variables and parameters that are compositions of different cost expressions.

Table 1-4: Notation

Symbol	Meaning
a_c	Fixed cost of shipment dispatch (\$)
a_s	Seller's cost of order preparation (\$ per shipment)
a_b	Buyer's cost of receiving goods (\$ per shipment)
h_s	Cost to hold a unit in inventory at the seller (\$ per day)
h_b	Cost to hold a unit in inventory at the buyer (\$ per day)
h_p	Cost to carry a unit in inventory in-transit (\$ per day)
K	Carrier's cost of initiating a dispatch (\$ per shipment)
δ	Transportation cost (\$ per unit distance)
Q	Quantity ordered by the buyer (units per shipment)
t_p	In-transit time (day)
D	Distance between the seller and the buyer

Table 1-4 lists the complete set of notation. With those symbols, the cost of each party is clearly expressed. But it will be demonstrated in later chapters that some parameters have no impact on the results in which we are interested. We begin in Chapter 2 by using this notation to build our models and analyze the two cases featuring private fleet.

Chapter 2 Private Fleet

In this chapter we discuss the two cases with only two parties involved. Either the seller or the buyer operates a private fleet to fulfill the transportation needs. Two distribution policies are considered: Independent decision making (IDM) and CMT. We build models to analyze the cost structure of each party under both policies. By calculating the savings on the total cost of each party and the whole supply chain, we verify the potential benefits of CMT using private fleet, as introduced in Chapter 1. Some numerical examples are applied to illustrate the significance of the savings. At the end of this chapter, we perform a comparison between the two cases.

We use the subscripts s and b to refer to seller and buyer. In addition, subscripts 1 and 2, used both for variable parameters and total costs, denote independent decision making and CMT, respectively.

2.1 Private fleet belongs to the seller, FOB destination (Case 1)

Responsibility of the seller is determined by FOB destination. The seller operates a private fleet to fulfill his duty of shipping the products. Ownership of the products is transferred to the buyer when the seller's truck arrives at the buyer's location. Thus, it is the seller that bears the pipeline inventory holding cost.

In Case 1, the carrier and the shipper are actually one entity – the seller, and the consignee is the buyer. We apply the framework of the first model in Section 1.6.1, without common carrier.

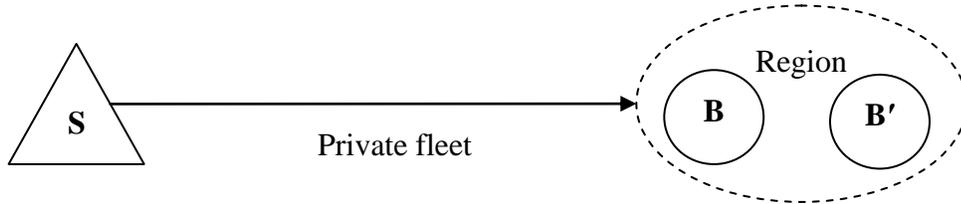


Figure 2-1: Parties involved in Case 1

In order to distinguish the two buyers, they will be denoted as subscripts b and b' , respectively. In addition, their time windows vary, with a difference of Δt (i.e. $T' - T = t_1' - t_1 = \Delta t$). See Figure 2-2 for the details about time windows under both distribution policies). For independent decision making, the time windows produced by the buyers according to EOQ models are very stringent. The buyer orders at t_1 (or t_1'), and expects to receive the goods at T (or T'). Thus, $T - t_1 = T' - t_1' = t_p$ (in-transit time), and the consolidation option is not possible.

Under CMT, both buyers are willing to extend their time windows. Each of them also agrees that replenishment can arrive at any time between the intervals, (t_2, T) or (t_2', T') . The seller can take advantage of the extended time window and wait for additional new orders, instead of replenish the buyer immediately when her order comes. However, the seller still needs to send his truck no later than t_1 . Both time windows contain the time interval $[t_2', t_1]$, indicating that consolidation is feasible.

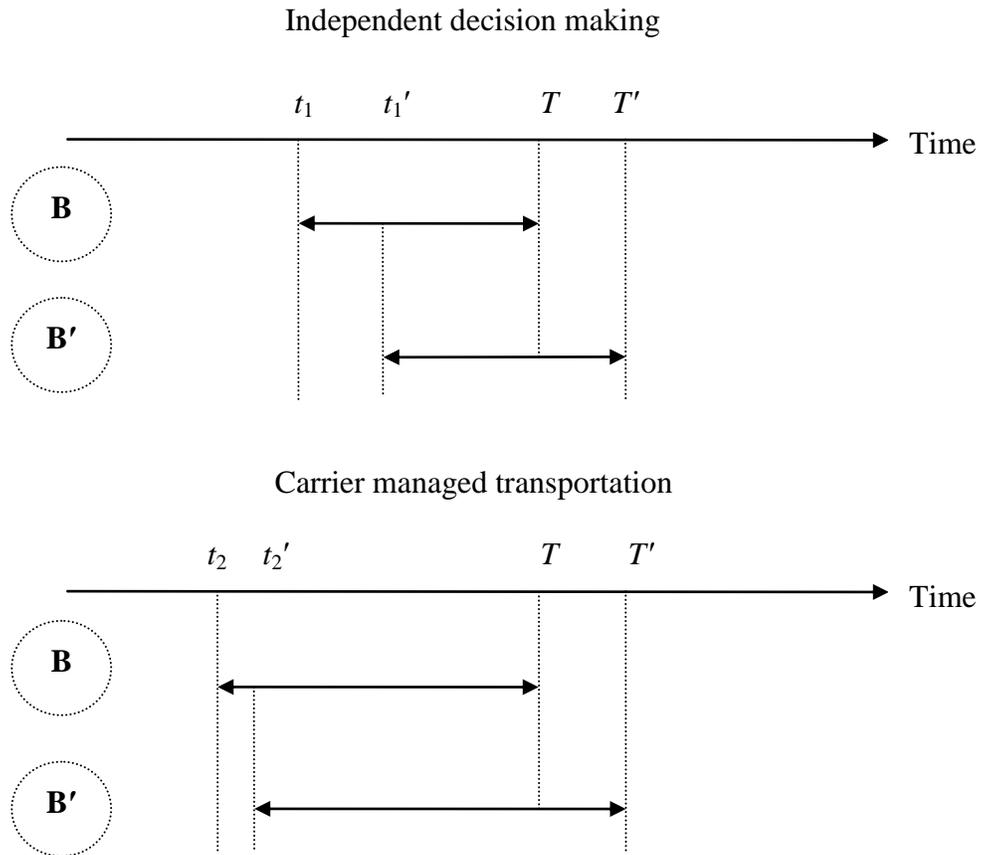


Figure 2-2: Time window in Case 1

In more detail, Figure 2-2: Time window in Case 1 indicates that the time t_1' could be extended to t_2' , and the time t_1 could be as early as t_2 . With either or both of these changes, it would still be possible to consolidate the shipments to B and B'.

Now we divide the costs under independent decision making and CMT, respectively.

2.1.1 Independent decision making

Under independent decision making, the seller/buyer acts on his/her own. The buyer places an order, passes it to the seller. The seller prepares the goods and sends them to the buyer on the delivery day agreed upon.

Costs of the seller = the costs of (1) Order preparation + (2) On-site inventory holding + (3) Pipeline + (4) Shipment dispatch + (5) Transportation

Cost for the buyer = (6) On-site inventory holding + (7) Receiving

Among all costs, (1) and (2) are bound to the seller, and (6) and (7) are tied up with the buyer, as indicated in Section 1.6.2. The seller is responsible for (3) and (5) because of FOB destination. (4) is generated by the customer service department of the seller, and (5) is the operation cost of his logistics department.

Generally, pipeline cost is a part of inventory cost. However, based on different cases, the on-site inventory holding cost and pipeline cost may be generated by different parties. Thus, we split pipeline cost and on-site inventory holding cost.

We assume that inventory holding cost starts to apply after t_1 for the seller and buyer b , and after t_1' for the seller and buyer b' . This also applies in the following sections and Chapter 3. Although we do not consider the inventory holding costs before t_1 and t_1' , those costs still exist, but will be cancelled out in the later calculations. That is, those costs are common to both the CMT and IDM cases.

Let us rewrite the above equations by the notation in Section 1.8.

$$TC_{s1} = a_s(Q + Q') + h_p(Q + Q')t_p + 2a_c + 2(K + \delta D)$$

(1) (3) (4) (5)

$$TC_{b1} = a_b \qquad \qquad \qquad TC_{b'1} = a_{b'}$$

(7) (7)

Below each term, we have indicated the number that corresponds to the verbal description of that cost. Note that not every term (1) – (7) will appear in a particular case.

The cost of the whole supply chain is the summation of the above costs.

$$TC_1 = a_s(Q + Q') + h_p(Q + Q')t_p + 2a_c + 2(K + \delta D) + a_b + a_{b'}$$

Note that, throughout this thesis, Q and Q' are *given parameters*, not decision variables. We will come back to this point in Section 4.3.

2.1.2 CMT

CMT in Case 1 enables the seller to make shipment decisions on behalf of the buyer, given the buyer's time window. Usually, the buyer is willing to extend her time window if the seller provides an Advance Shipping Notice (ASN). The seller can take advantage of the extended time window to better perform his distribution operations.

Cost of the seller = those due to (1) Order preparation + (2) On-site inventory holding + (3) Pipeline + (4) Shipment dispatch + (5) Transportation

Costs of the buyer = (6) On-site inventory holding + (7) Receiving

previous relationship becomes less interesting. Hence, we focus on the relationship between seller and buyer. However, we can still use CMT to enhance the coordination between two different departments of the seller.

2.1.3 Effects of CMT

Comparing the cost functions in Sections 2.1.1 and 2.1.2, we get the following results:

$$TC_{s1} - TC_{s2} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + a_c + K + \delta D > 0$$

The seller saves money mainly from consolidation, and saves a small part on inventory holding.

$$TC_{b1} - TC_{b2} = -(t_1 - t)Qh_b \leq 0$$

$$\text{and } TC_{b'1} - TC_{b'2} = -(t_1 + \Delta t - t)Q'h_b' \leq 0, \text{ since } (t_1 - t) \geq 0.$$

The buyers need to pay extra inventory holding cost, as the goods arrive in advance.

$$TC_1 - TC_2 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s - h_b') + a_c + K + \delta D$$

If the buyer spends less money than the seller in storing the products, the savings of the whole supply chain is even bigger.

From a system-wide perspective, CMT reduces the cost of the supply chain, and shifts part of the seller's inventory holding cost to the buyers, especially the one with the latest arrival time T' . The greater opportunity for consolidation is the major cause of cost savings.

In order to compensate the buyers, the seller can share part of his interest in the form of price discount. That is, he can lower the price by a certain percentage of the original price.

If $h_b < h_s$ and $h_b' < h_s$, then to some extent, CMT reduced the seller's cost on inventory, as originally, he has to pay $(t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s$. However for now, even though he has to compensate the buyer, he only needs to pay $(t_1 - t)Qh_b + (t_1 + \Delta t - t)Q'h_b'$.

2.1.4 Numerical example

We assign the following initial values to the base case parameters involved:

Fixed cost of issuing a shipment, $a_c = \$10$ /order

Buyer's cost of receiving the products, $a_b = \$20$ /order

Transportation cost, $\delta = \$2$ /mile

Annual cost to hold a unit in inventory at the seller, $h_s = \$1.2$ /unit/year

Annual cost to hold a unit in inventory at the buyer, $h_b = \$1.5$ /unit/year

Carrier's cost of initiating a dispatch, $K = \$15$ /dispatch

Distance between region of seller(s) and region of buyer(s), $D = 200$ miles

Quantity ordered by the buyer, $Q = 100$ units

Difference of order time, $\Delta t = 2$ days

Other than the parameters listed before, in Case 1, there are three more parameters to be added; their initial values are as follows:

Quantity ordered by the other buyer $Q' = 80$ units

Annual cost to hold a unit in inventory at buyer b' , $h_b' = \$1.8$ /unit/year

Original difference between the order time of buyer b (under independent decision making) and order time of buyer b' (under CMT), $t_1 - t = 3$ days.

Let Δt vary between values of 0 and 7, in steps of 1. The trend of the four cost savings is shown below.

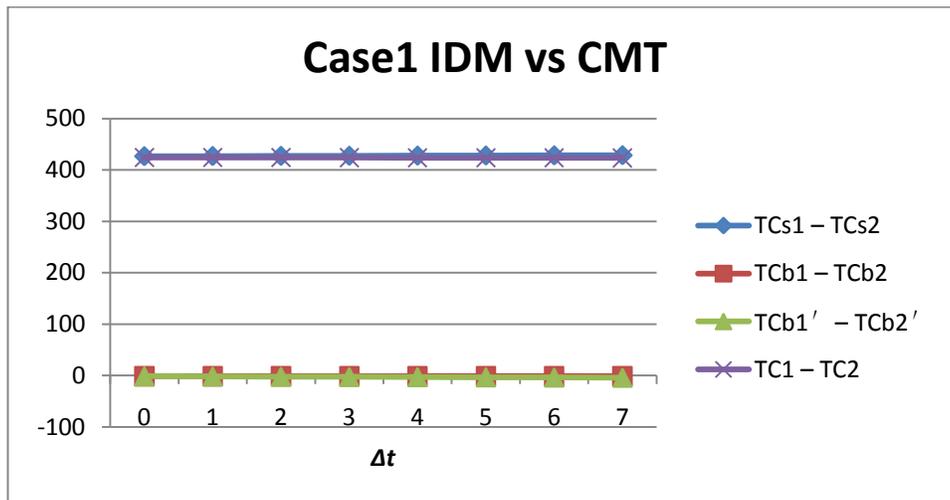


Figure 2-3: Case 1 - Cost savings from CMT with the variation of Δt

Figure 2-3 provides an overview of the cost distribution among all three parties, The savings of the seller is at the same height with the savings of the supply chain, while the buyers are around zero cost saving. Although the value of Δt slightly changed the cost savings, the impact is negligible.

More examples are in Appendix A. All these examples show that:

(1) Most of the savings of the whole supply chain come from savings of the seller, i.e. the owner of the truck.

(2) Fixed cost of issuing a shipment, a_c ; transportation cost, δ ; carrier's cost of initiating a dispatch, K ; distance between the region of seller and the region of buyers, D ; and order quantities of both buyers have greater impact on the savings. Changes of the rest of the parameters may slightly vary the savings for parties, thus are trivial.

(3) The mathematical expressions of the buyers' savings are negative, indicating that the buyers are actually losing money under CMT. However, the numerical examples show that their loss is not significant. When they order about 100 units, the maximum amount of loss is \$5. Even if they order up to 1000 units, their loss will be no greater than \$20. In real life, buyers will not refuse to get involved in CMT because of such tiny loss. A buyer benefits from CMT through the Advance Shipping Notice (ASN) and a more stable relationship with the seller.

2.2 Private fleet belongs to the buyer, FOB origin (Case 2)

Responsibility of the buyer is determined by FOB origin. The buyer operates a private fleet to fulfill her duty of picking up the products. Ownership of the products is transferred to the buyer when the goods are loaded on the

buyer's truck at the seller's location. Thus, it is the buyer that bears the pipeline inventory holding cost.

In Case 2, the carrier and the consignee are actually one entity – the buyer, and the shipper is the seller. We apply the second model framework in Section 1.6.1, without common carrier.

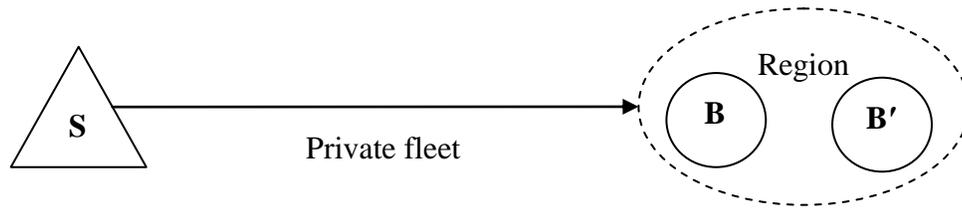


Figure 2-4: Parties involved in Case 2

In order to distinguish the two sellers, we refer to them as s and s' . The buyer buys two products P and P' , respectively from s and s' , with a difference of Δt (i.e. $T' - T = t_1' - t_1 = \Delta t$) in the order timing. See Figure 2-5 for the details about time windows under both distribution policies. For independent decision making, the time windows of the two products are very stringent, according to the EOQ model with lead time. The buyer orders at t_1 (or t_1'), and expects to get replenished at T (or T'). Thus, $T - t_1 = T' - t_1' = t_p$ (in-transit time); consolidation is not possible.

Under CMT, the sellers are willing to coordinate their production cycles with the buyer. As a result, the buyer can extend her time windows for both products, and also allows replenishment to arrive at any time during the new interval between t_2 (or t_2') and the scheduled arrival time T (or T'). She can

combine the pickup process of the two products into one. It is necessary to make sure that a truck is sent to pick up the products no later than t_1 . Both time windows start from t_1 , indicating that consolidation is available.

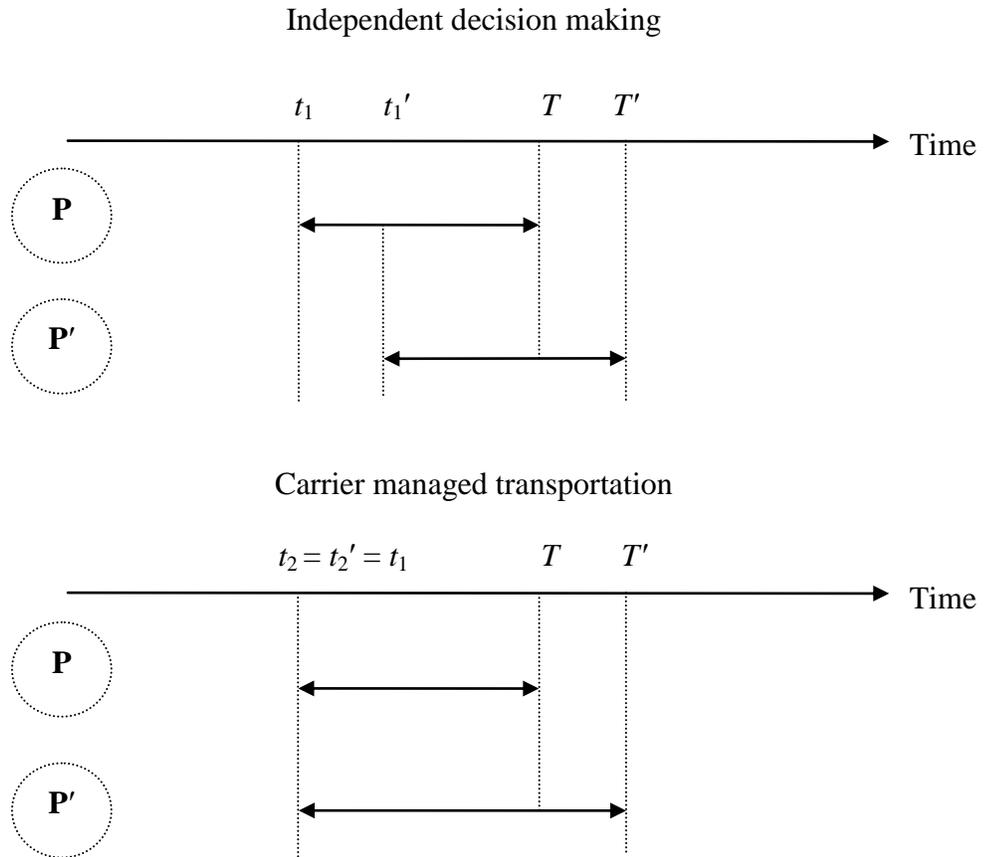


Figure 2-5: Time windows in Case 2

Now we divide the costs under independent decision making and CMT, respectively.

2.2.1 Independent decision making

Under independent decision making, the seller/buyer acts on his/her own. The buyer places an order, passes it to the seller. The seller prepares the goods and notifies the buyer to pick them up on the day specified by him.

Cost of the seller = (1) Order preparation + (2) On-site inventory holding

Cost of the buyer = (3) Pipeline + (4) Shipment dispatch + (5) Transportation + (6) On-site inventory holding + (7) Receiving

The buyer is responsible for (3) and (5) because of FOB origin. (4) is generated by the purchasing department of the buyer, and (5) is the operation cost of her distribution/logistics department.

Rewriting the above equations by the notation in Section 1.8, we have

$$\begin{array}{cccccc} \text{TC}_{s1} = a_s Q; & \text{TC}_{s'1} = a_s' Q'; & \text{and } \text{TC}_{b1} = & h_p(Q + Q')t_p & + & 2a_c + 2(K + \delta D) + 2a_b \\ (1) & (1) & (3) & (4) & (5) & (6) \end{array}$$

The cost of the whole supply chain is then

$$\text{TC}_1 = a_s Q + a_s' Q' + h_p(Q + Q')t_p + 2a_c + 2(K + \delta D) + 2a_b$$

2.2.2 CMT

With or without CMT, the buyer is flexible to extend her own time windows. However, she may get the seller to extend the time limit on picking up the goods (e.g. from one day to three days) under CMT. The buyer can then take the chance to conduct consolidations.

Cost of the seller = (1) Order preparation + (2) On-site inventory holding

Cost of the buyer = (3) Pipeline + (4) Shipment dispatch + (5) Transportation + (6) On-site inventory holding + (7) Receiving

It seems that there is no variation in the costs of either party. However, the cost (4) actually shifts from the purchasing department, which functions as the consignee, to the logistics department, which is the carrier. It happens because CMT allows the carrier to establish and manage the distribution decisions on behalf of the consignee; the latter is thus exempt from related expenses.

Under CMT, the buyer tends to combine the pickup of two products together into one truck. That is, when she places an order for P at t_1 , she also places an order for P'.

$$TC_{s2} = a_s Q \quad (1) \quad TC_{s'2} = a_s' Q' - h_s' Q' \Delta t \quad (1) \quad (2)$$

$$TC_{b2} = h_p(Q + Q')t_p + a_c + K + \delta D + h_b Q' \Delta t + a_b \quad (3) \quad (4) \quad (5) \quad (6) \quad (7)$$

The cost of the whole supply chain is:

$$TC_2 = a_s Q + a_s' Q' + (h_b - h_s') Q' \Delta t + h_p(Q + Q')t_p + a_c + K + \delta D + a_b$$

The actual focus of the contractual relationship under FOB origin should be between consignee and carrier. As the buyer plays both roles now, the previous relationship becomes less interesting. However, we can still use CMT to enhance the coordination between two different departments of the buyer. Note that the relationship between seller and buyer is not as tight as in Case 1.

2.2.3 Effects of CMT

Comparing the cost functions in Sections 2.2.1 and 2.2.2, we get the following results: $TC_{s1} - TC_{s2} = 0$; $TC_{s'1} - TC_{s'2} = h_s'Q'\Delta t$

It seems that the sellers are no worse off. However, since the seller does not have a clear expectation on when the buyer will come, he needs to prepare the products beforehand. This may cause inconvenience to the seller.

$$TC_{b1} - TC_{b2} = a_c + K + \delta D - h_b Q' \Delta t + a_b$$

The buyer's motivation of using CMT is to reduce her total cost, so the previous difference must be greater than 0. Based on the parameters, we can get a range of Δt . This helps the buyer decide whether to combine P' into the consolidation process. Thus, we have:

$$\Delta t < (K + \delta D + a_b + a_c) / h_b Q'$$

This equation implies that:

If the sellers are far away, the buyer can wait for a longer time to perform consolidation; and if the quantity she needs to purchase is large, it is better to consider the sellers with the smaller time difference first.

$$TC_1 - TC_2 = a_c + K + \delta D + a_b + (h_s' - h_b)Q'\Delta t$$

From system-wide perspective, CMT reduced the cost of the supply chain, and shifted part of the sellers' inventory holding cost to the buyer. The increment in the chance of consolidation is the major cause of cost savings.

2.2.4 Numerical example

Other than the parameters listed in Section 2.1.4, in Case 2, there are two more parameters to be added, and their initial values are as follow:

Quantity ordered by the buyer for product P', $Q' = 80$ units

Annual cost to hold a unit in inventory at the seller s' , $h_s' = \$1.8$ /unit/year

Again we observe the trend of the four cost savings when Δt varies between values of 0 and 7, in steps of 1.

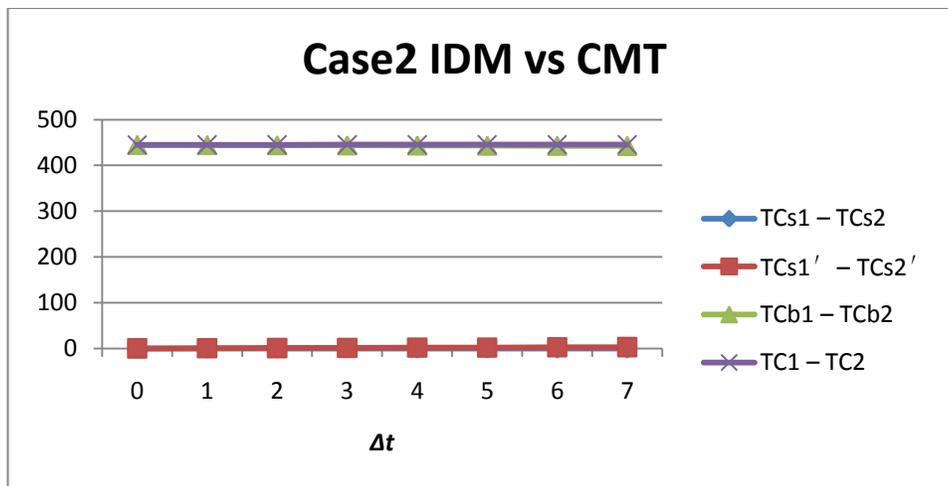


Figure 2-6: Case 2 - Cost savings from CMT with the variation of Δt

The cost saving distribution among all parties looks similar to that in Figure 2-3 . However, in Case 2, it is the buyer that takes most of the savings, and the two sellers have about zero cost savings. Again, the changes in Δt has little effect on the cost savings for all parties involved.

More numerical examples can be found in Appendix A, the part for Case 2.

All these results show that:

(1) Most of the savings of the whole supply chain now come from savings of the *buyer*, the owner of the truck in this case.

(2) Fixed cost of receiving the products, a_b , along with δ , K , D , and a_c have greater impact on the savings. Changes of the rest of the parameters may slightly vary the savings for parties, thus are trivial.

(3) It is worth noticing that quantity ordered by the buyer for product P' , Q' , has less impact on savings of the relevant party and the whole supply chain than it has in Case 1.

Combine the findings in Sections 2.1.4 and 2.2.4, we can get a **strong result**: Whoever owns the truck gets most of the savings. And those savings in turn, result from having consolidated shipments.

Another fact worth noticing is that CMT always transfer inventory holding cost of the seller to the buyer. This seems to be contrary to JIT (Just-in-time), under which the inventory holding cost is shifted to the seller, and ideally, the buyer can achieve zero inventory.

In the next chapter we will continue the exploration of Carrier Managed Transportation, focusing on the cases in which common carrier gets involved.

Chapter 3 Common Carrier

In this chapter we discuss the two cases with three parties involved. Either the seller or the buyer hires a common carrier to fulfill the transportation needs. The distribution policies, research methodologies and sequences of discussion are the same as in Chapter 2. We start from the case of FOB destination.

We use the subscripts s , b , and c to refer to seller, buyer and common carrier. Subscripts 1 and 2, used both for parameters and total costs, denote independent decision making and CMT, respectively.

3.1 Common carrier, FOB destination (Case 3)

Responsibility of the seller is determined by FOB destination. The seller hires a common carrier to fulfill his duty of shipping the products. Ownership of the products is transferred to the buyer when the common carrier's truck arrives at the buyer's location. Thus, it is the seller that bears the pipeline inventory holding cost. The common carrier has no ownership of the goods in the whole process.

Compared to the cases of private fleet, one more party is engaged in Case 3, making the contract more complicated, as each of the parties needs to deal with the other two. We apply the framework of the first model in Section 1.6.1. The relationships between parties are shown in Figure 3-1.

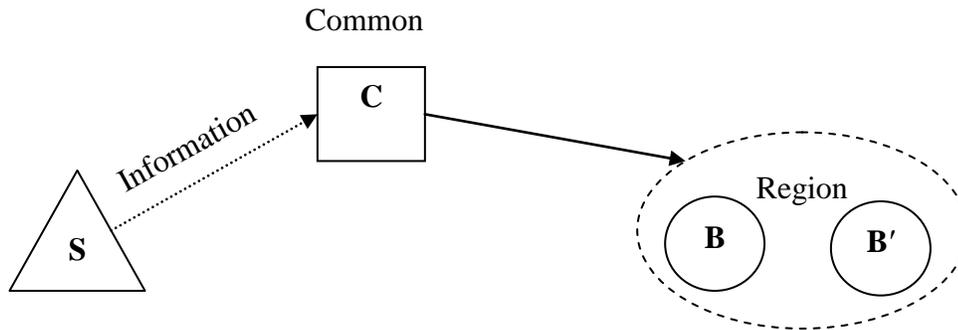


Figure 3-1: Parties involved in Case 3

We continue to use the subscripts and time windows (see Figure 2-2) of the two buyers in Section 2.1 for the two buyers in Case 3. Notice that when using common carrier under independent decision making, the lead time will be longer since the information interchange between seller and carrier will take some time. That is, the t_p under common carrier is longer than it is in 0.

Now we divide the costs under independent decision making and CMT, respectively.

3.1.1 Independent decision making

Under independent decision making, each party acts on his own. The buyer places an order, passes it to the seller. The seller prepares the goods and requires the common carrier to pick them up and send them to the buyer on the delivery day agreed upon.

Costs of the seller = the cost of (1) Order preparation + (2) On-site inventory holding + (3) Pipeline + (4) Shipment dispatch

Cost for the buyer = (6) On-site inventory holding + (7) Receiving

Cost of the common carrier = (5) Transportation

Among all costs, (1) and (2) are bound to the seller, and (6) and (7) are tied up with the buyer, as indicated in Section 1.6.2. The seller is responsible for (3) because of FOB destination. (4) is generated by the customer service department of the seller. Now (5) is the operation cost of the common carrier.

Let us rewrite the above equations by the notation in Section 1.8.

$$TC_{s1} = a_s(Q + Q') + h_p(Q + Q')t_p + 2a_c$$

(1) (3) (4)

$$TC_{b1} = a_b \quad TC_{b'1} = a_{b'} \quad TC_{c1} = 2(K + \delta D)$$

(7) (7) (5)

The cost of the whole supply chain is then

$$TC_1 = a_s(Q + Q') + h_p(Q + Q')t_p + 2a_c + a_b + a_{b'} + 2(K + \delta D)$$

3.1.2 CMT

CMT in Case 3 enables the carrier to make shipment decisions on behalf of the seller, through sharing the buyer's time window. Usually, the buyer is willing to extend her time window if the seller and common carrier provide an Advance Shipping Notice (ASN). The common carrier can take advantage of the extended time window to better perform distribution operations.

Costs of the seller = those due to (1) Order preparation + (2) On-site inventory holding + (3) Pipeline

Cost of the buyer = (6) On-site inventory holding + (7) Receiving

Cost of the common carrier = (4) Shipment dispatch + (5) Transportation

As we can see, (4) shifts from the seller to the common carrier. It happens because CMT allows the carrier to establish and manage the distribution decisions on behalf of the shipper; the latter is thus exempt from related expenses.

The common carrier can dispatch the truck during the interval between t_2' and t_1 . Assume the common carrier chooses to dispatch at time $t \in [t_2', t_1]$. Compared to independent decision making, the buyer b gets replenished prior to t_1 , and the buyer b' gets replenished prior to $t_1 + \Delta t$. There is thus a *saving* in inventory holding cost (relative to independent decision making) of $(t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s$.

$$\text{TC}_{s2} = a_s(Q + Q') - \underset{(1)}{(t_1 - t)Qh_s} - \underset{(2)}{(t_1 + \Delta t - t)Q'h_s} + \underset{(3)}{h_p(Q + Q')t_p}$$

$$\text{TC}_{b2} = \underset{(6)}{(t_1 - t)Qh_b} + \underset{(7)}{a_b}; \quad \text{TC}_{b'2} = \underset{(6)}{(t_1 + \Delta t - t)Q'h_{b'}} + \underset{(7)}{a_{b'}}; \quad \text{TC}_{c2} = \underset{(4)}{a_c} + \underset{(5)}{K} + \delta D$$

The cost of the whole supply chain is:

$$\text{TC}_2 = a_s(Q + Q') + (t_1 - t)Q(h_b - h_s) + (t_1 + \Delta t - t)Q'(h_{b'} - h_s) + h_p(Q + Q')t_p + a_c + K + \delta D + a_b + a_{b'}$$

The focus of the contractual relationship in Case 3 is between shipper and carrier. However, although the common carrier is more involved in the business with the seller, it still needs to deal with the buyer.

3.1.3 Effects of CMT

Comparing the cost functions in Sections 3.1.1 and 3.1.2, we get the following results:

$$TC_{s1} - TC_{s2} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + 2a_c > 0$$

The seller does not need to pay a shipment-issuing fee under CMT, and saves a small part on inventory holding.

$$TC_{b1} - TC_{b2} = -(t_1 - t)Qh_b \leq 0$$

$$TC_{b'1} - TC_{b'2} = -(t_1 + \Delta t - t)Q'h_b' \leq 0$$

The buyers need to pay extra inventory holding cost, as the goods arrive in advance.

$$TC_{c1} - TC_{c2} = K + \delta D - a_c$$

Although the carrier has to pay the shipment-issuing fee, the majority of his savings are from consolidation.

$$TC_1 - TC_2 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s - h_b') + a_c + K + \delta D$$

From a system-wide perspective, CMT with a common carrier involved will not make much difference compared to private fleet. However, under CMT, the information sharing between carrier and seller enhances the dispatching process; hence this reduces the replenishment lead time. Meanwhile, the carrier has more flexibility in timing than the seller and buyer, and he does not bear any inventory holding cost. As a result, there is no incentive that urges him to ship the products

to the buyers as early as possible. Thus, the buyer might be willing to provide a wider time window to the common carrier.

3.1.4 Numerical example

We assign the following initial values to the base case parameters involved:

Fixed cost of issuing a shipment, $a_c = \$10$ /order

Buyer's cost of receiving the products, $a_b = \$20$ /order

Transportation cost, $\delta = \$2$ /mile

Annual cost to hold a unit in inventory at the seller, $h_s = \$5$ /unit/year

Annual cost to hold a unit in inventory at the buyer, $h_b = \$5$ /unit/year

Carrier's cost of initiating a dispatch, $K = \$15$ /dispatch

Distance between region of seller(s) and region of buyer(s), $D = 200$ miles

Quantity ordered by the buyer, $Q = 100$ units

Difference of order time, $\Delta t = 2$ days

Before we start numerical testing, we need to assign initial values to three extra parameters for Case 3:

Quantity ordered by the other buyer $Q' = 80$ units

Annual cost to hold a unit in inventory at buyer b' , $h_{b'} = \$5$ /unit/year

Original difference between the order time of buyer b (under independent decision making) and order time of buyer b' (under CMT), $t_1 - t = 3$ days.

The differences in each total cost as a function of Δt is in the following figure. Δt varies between values of 0 and 7, in steps of 1.

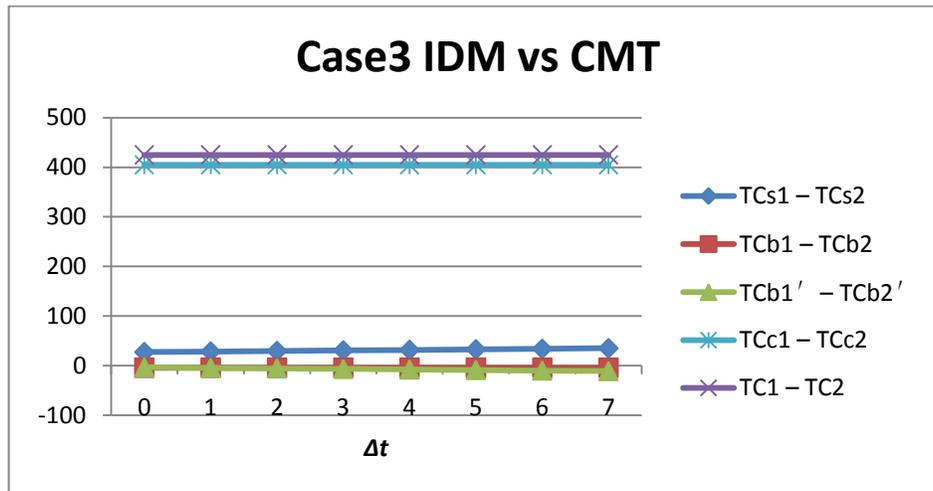


Figure 3-2: Case 3 - Cost savings from CMT with the variation of Δt

From Figure 3-2 we can see that the carrier shares most of the savings of the supply chain. The seller takes a small portion. It seems there is no remarkable change in all cost savings when Δt takes different values. Similar to in Case 1, the buyers are around zero cost saving.

More examples are in Appendix B. All these examples show that:

(1) Most of the savings of the whole supply chain come from savings of the carrier. The rest of the savings is from the seller.

(2) Similar to Case 1, a_c , δ , K and D have greater impact on the savings, while impacts of the remaining parameters are trivial. It is worth noticing that a_c has a positive impact on the cost savings of the seller. However, in terms of the

carrier, the effect of a_c is negative. In addition, if the buyer orders more, the seller can save more on his total cost.

(3) The mathematical expressions indicates that the buyers may not like to get involved in CMT, as their savings are negative, especially with the increment in order quantity. However, the numerical examples show that their loss is not significant. When they order about 100 units, the maximum amount of loss is almost zero. Even if they order up to 1000 units, their loss will be no greater than \$50. The carrier can compensate the buyers for their loss by sharing some of the savings and providing better service. It is in the carrier's best interest to have stable, long-term relationships.

3.2 Common carrier, FOB origin (Case 4)

Responsibility of the buyer is determined by FOB origin. The buyer hires a common carrier to fulfill her duty of picking up the products. Ownership of the products is transferred to the buyer when the goods are loaded on the common carrier's truck at the seller's location. Recall that there are two sellers, S and S'. Thus, it is the buyer that bears the pipeline inventory holding cost. Same as in Case 3, the common carrier has no propriety of the goods in the whole process.

In Case 4, as in case 3, the CMT contract involves an additional party compared to cases under private fleet. As each of the parties needs to coordinate

with the other two, the situation becomes more complicated. We apply the framework of the second model in Section 1.6.1.

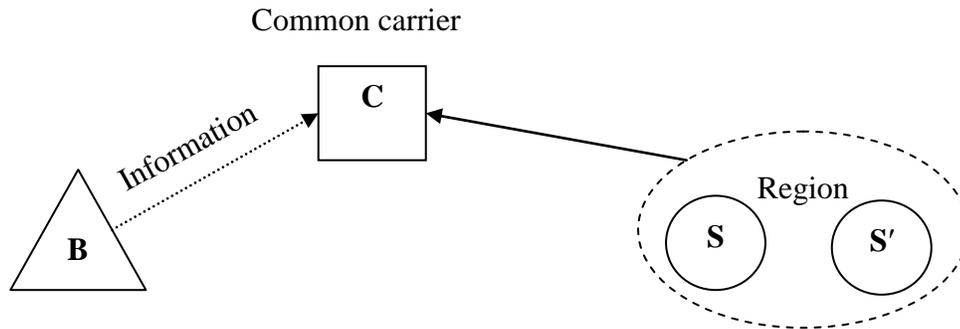


Figure 3-3: Parties involved in Case 4

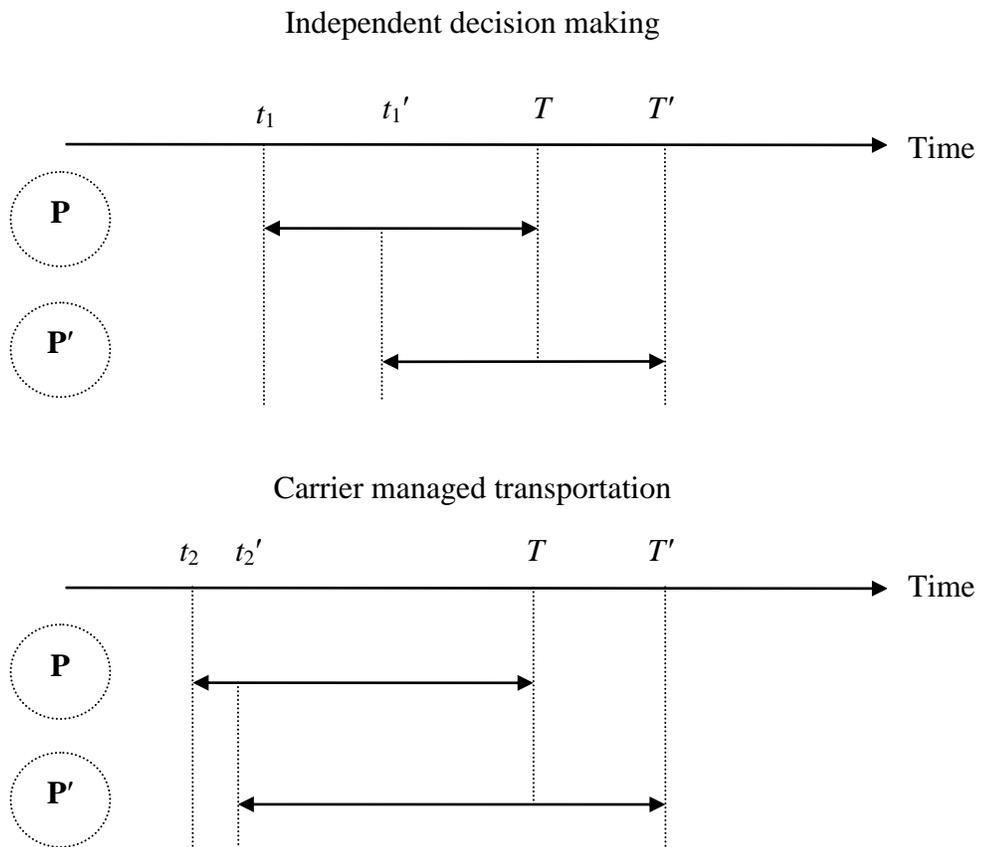


Figure 3-4: Time windows in Case 4, for the products P and P'

The subscripts and time windows of the two sellers are almost the same as defined in Section 2.2. However, there is a slight difference. That is, $t_2 = t_2' = t_1$ no longer holds, due to the fact that transportation is performed by the common carrier. The common carrier can combine orders according to his own convenience, as long as he is sure that the buyer gets replenished before T .

Now we divide the costs under independent decision making and CMT, respectively.

3.2.1 Independent decision making

Under independent decision making, each party acts on his own. The buyer places an order, passes it to the seller. The seller prepares the goods and notifies the buyer. The buyer then requires the common carrier to pick them up on the day specified by the seller.

Cost of the seller = (1) Order preparation + (2) On-site inventory holding

Cost of the buyer = (3) Pipeline + (4) Shipment dispatch + (6) On-site inventory holding + (7) Receiving

Cost of the common carrier = (5) Transportation

The buyer is responsible for (3) because of FOB origin. (4) is generated by the purchasing department of the buyer. As in Section 3.1.1, (5) is the operation cost of the common carrier.

Again express the preceding equations in the notation of Section 1.8.

$$\begin{array}{ccccccc} \text{TC}_{s1} = a_s Q; & \text{TC}_{s'1} = a_s' Q'; & \text{TC}_{b1} = h_p(Q + Q')t_p + 2a_c + 2a_b; & \text{TC}_{c1} = 2(K + \delta D) \\ (1) & (1) & (3) & (4) & (7) & (5) \end{array}$$

The cost of the whole supply chain is:

$$\text{TC}_1 = a_s Q + a_s' Q' + h_p(Q + Q')t_p + 2a_c + 2a_b + 2(K + \delta D)$$

3.2.2 CMT

CMT in Case 4 enables the carrier to make shipment replenishment decisions on behalf of the buyer. With or without CMT, the buyer is flexible to extend her own time windows. However, the common carrier also needs to get the seller's permission to extend the time limit on picking up the goods. The common carrier can take the chance to conduct consolidations, but still must respect the buyer's time window.

Cost of the seller = (1) Order preparation + (2) On-site inventory holding

Cost of the buyer = (3) Pipeline + (6) On-site inventory holding + (7)

Receiving

Cost of the common carrier = (4) Shipment dispatch + (5) Transportation

As we can see, (4) shifts from the buyer to the common carrier. It happens because CMT allows the carrier to establish and manage the distribution decisions on behalf of the consignee; the latter is thus exempt from related expenses.

The common carrier can dispatch the truck between the points in time t_2' and t_1 . Assume the common carrier will choose to dispatch at t , $t \in [t_2', t_1]$.

Compared to independent decision making, the buyer would receive both products P and P' before the latest arrival time points T and T' . The buyer's extra inventory holding cost (based on t_1 and t_1') is $(t_1 - t)Qh_b + (t_1 + \Delta t - t)Q'h_b$.

$$\begin{array}{l} \text{TC}_{s2} = a_s Q - (t_1 - t)Qh_s \quad \text{TC}'_{s2} = a_s' Q' - (t_1 + \Delta t - t)Q'h_s' \\ (1) \quad (2) \quad (1) \quad (2) \end{array}$$

$$\text{TC}_{b2} = h_p(Q + Q')t_p + (t_1 - t)Qh_b + (t_1 + \Delta t - t)Q'h_b + a_b \quad (3) \quad (6) \quad (7)$$

$$\text{TC}_{c2} = a_c + K + \delta D \quad (4) \quad (5)$$

Thus, the cost of the whole supply chain is:

$$\begin{aligned} \text{TC}_2 = & a_s Q + a_s' Q' + (t_1 - t)Q(h_b - h_s) + (t_1 + \Delta t - t) Q'(h_b - h_s') + h_p(Q + Q')t_p \\ & + a_c + a_b + K + \delta D \end{aligned}$$

The focus of the contractual relationship in Case 4 is between consignee and carrier. However, although the common carrier is more involved in the business with the buyer, it cannot avoid the interactions with the seller.

3.2.3 Effects of CMT

Comparing the cost functions in Section 3.2.1 and Section 3.2.2, we get the following results:

$$\text{TC}_{s1} - \text{TC}_{s2} = (t_1 - t)Qh_s \geq 0$$

$$\text{TC}'_{s1} - \text{TC}'_{s2} = (t_1 + \Delta t - t)Q'h_s' > 0$$

It seems that the sellers are no worse off. Although neither seller knows exactly when the common carrier will come, each knows it will be within a

given time interval. The products will have to be prepared before that. This is only a minor inconvenience.

$$TC_{b1} - TC_{b2} = 2a_c - (t_1 - t)Qh_b - (t_1 + \Delta t - t)Q'h_b + a_b$$

The buyer can save on the receiving cost and shipment-issuing cost, but may have to bear more inventory holding cost.

$$TC_{c1} - TC_{c2} = K + \delta D - a_c$$

Although the carrier has to pay the shipment-issuing fee, he saved majority from consolidation.

$$TC_1 - TC_2 = a_c + a_b + K + \delta D + (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s' - h_b)$$

The system wide cost is the same as when the private fleet belongs to the buyer, FOB origin. However, the sellers have a disutility of not knowing when the common carrier will arrive. Hence, the products might be sorted and prepared several days before the truck arrives, although it is sometimes unnecessary.

3.2.4 Numerical example

We continue to use the base values in Section 3.1.4, but with two more parameters added for Case 4:

Quantity ordered by the buyer for product P', $Q' = 80$ units

Annual cost to hold a unit in inventory at the seller s' , $h_s' = \$5$ /unit/year

The cost savings will be like in Figure 3-5 if Δt varies between values of 0 and 7, in steps of 1.

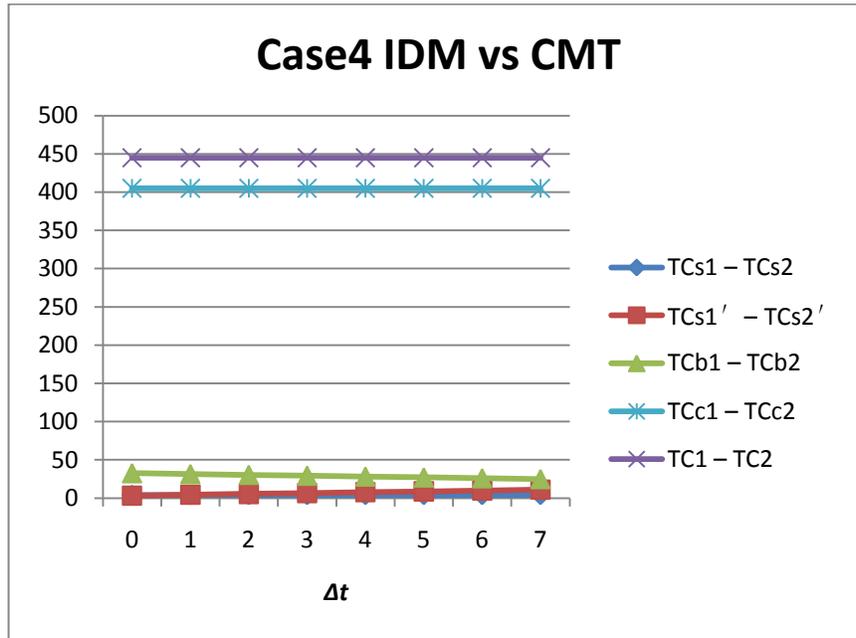


Figure 3-5: Case 4 - Cost savings from CMT with the variation of Δt

Again the carrier shares most of the savings of the supply chain. This time, the buyer gets the rest. There is a trend that savings of the buyer tends to decrease when Δt grows bigger, but the effect is still minor. Similar to in Case 2, the sellers are around zero cost saving.

The numerical examples in Appendix B for Case 4 illustrate that:

- (1) Same as in Case 3, most of the savings of the whole supply chain comes from savings of the carrier.

(2) Parameters related to shipping and receiving and the transportation cost have greater impact on the savings. Changes to the rest of the parameters may slightly vary the savings for parties, thus are trivial.

(3) In Case 4, quantity ordered by the buyer for product P, Q , has more impact on savings of the relevant party and the whole supply chain, comparing to Case 2.

The findings in Sections 3.1.4 and 3.2.4 still supports the strong result at the end of Chapter 2: **Whoever owns the truck gets most of the savings**. When common carrier is involved in CMT, the owner of the products still can share a small part of the total savings.

Therefore, compared to the private fleet owners, the common carriers have greater incentives to implement CMT, as their core business and objective is to provide transportation service to the public, possibly with less operation cost. CMT also encourages the owner of the products (specified by the FOB term used) to use common carriage.

Chapter 4 Computational Testing and Extended Comparisons

In Chapters 2 and 3, we showed the composition of cost savings for each party and the total cost savings with numerical examples. To thoroughly study the nature of CMT, in this chapter, we enumerate more examples to compare the savings through different perspectives. Next, given CMT, we focus on the FOB terms and try to understand the impacts on the cost of each party as well as on the total cost. We thus capture the preferences of each party, on choosing both the FOB terms and their cooperative partners when signing contracts.

In our previous studies, we treated the order quantity as fixed, that is, it is given by the buyer. However, some of the cost parameters may vary under different contractual relationships. Therefore, they may affect the order quantity. In this chapter, we will also discuss why and how the changes happen.

4.1 Impacts of cost savings components

Under different cases in the earlier chapters, we viewed the seller(s), buyer(s), and carrier (if any) each as a group. It was then easy to see that the cost savings of each group have several common components. Also, a few cost-saving expressions have a unique composition that differentiates them from others. This section analyzes to what extent these components will affect the cost savings of each group under the four CMT cases.

Recall that in Table 1-3:

Case 1: Private fleet belongs to the seller, FOB destination

Case 2: Private fleet belongs to the buyer, FOB origin

Case 3: Common carrier, FOB destination

Case 4: Common carrier, FOB origin

4.1.1 Savings of the seller

First we start from the cost savings of the seller(s). For Cases 2 and 4, the cost savings expression below is the sum of the savings of both sellers. We continue to use the subscript s to refer to the seller. Now, subscripts 1, 2, 3, and 4 represent the four cases, respectively.

The cost savings for the four seller groups are thus:

$$TC_{s1} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + a_c + K + \delta D$$

$$TC_{s2} = h_s'Q'\Delta t \quad TC_{s3} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + 2a_c$$

$$TC_{s4} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s'$$

The components listed below have appeared in the previous expressions, and are assigned the following initial values:

$$K + \delta D = \$50 \quad a_c = \$10 / \text{order} \quad h_s = h_s' = \$5 / \text{unit/year}$$

$$t_1 - t = 3 \text{ days} \quad \Delta t = 2 \text{ days} \quad Q = 100 \text{ units} \quad Q' = 80 \text{ units}$$

Now we start by varying one of the above components at a time, keeping the remaining parameters at a fixed level.

(1) Transportation cost $K + \delta D$ varies in the interval [1, 71].

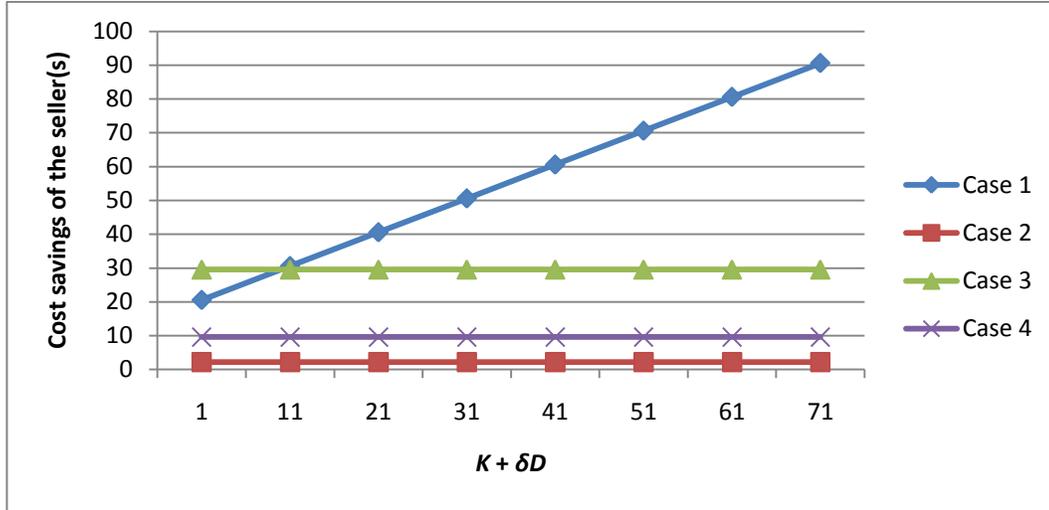


Figure 4-1: Change in the transportation costs. Cases 2 and 4 indicate the total cost savings for the sellers combined; Case 1 and 3 have only a single seller. This applies for all figures in Section 4.1.1.

Component $K + \delta D$ only influences the cost savings of the seller in Case 1, and has no effect on sellers in other cases. While $K + \delta D$ increases, the seller in Case 1 saves more due to applying CMT. As show in the figure, the cost savings of seller in Case 1 start to surpass that in Case 3 when $K + \delta D$ reaches \$11. This means that under FOB destination, the seller tends to use CMT when the expense on transportation dominates, which could be the result of long distance.

(2) Cost of issuing a shipment, a_c , varies from 1 to 8, in steps of 1.

The savings of sellers in Cases 2 and 4 remain the same while the parameter a_c takes different values. On the contrary, the increment in a_c helps sellers in Case 1 and Case 3 spend less under CMT. In addition, the positive impact on

seller in Case 3 is even greater. This is because the seller is fully exempt of such cost by using common carriage.

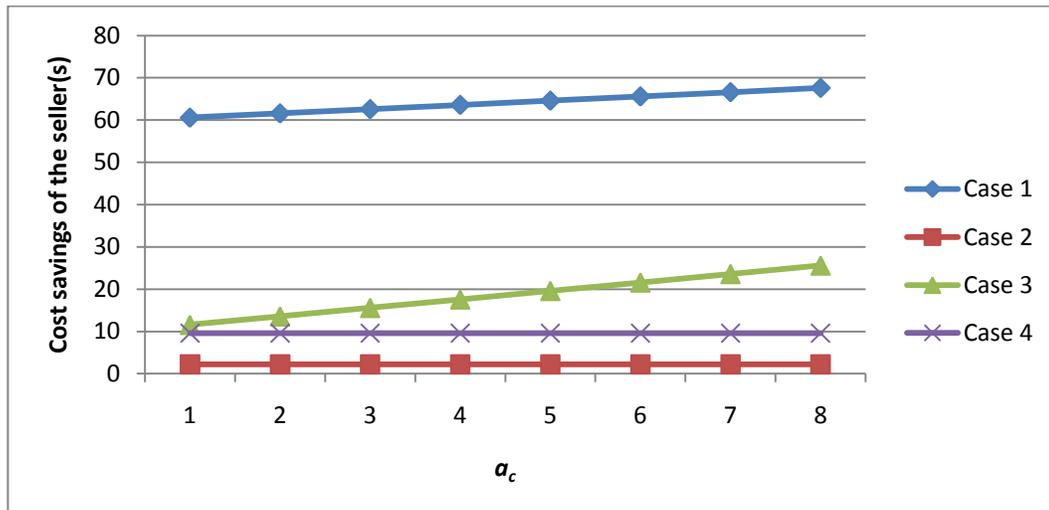


Figure 4-2: Change in shipment issuing cost for all sellers

(3) Annual costs to hold a unit in inventory at the seller (the paired seller), h_s (h_s'), between values of 5 and 40, in steps of 5.

Sellers in Cases 1, 3, and 4 all gain extra savings with the raise in the annual unit inventory holding cost. The cost savings of seller in Case 4 is a bit lower as he is only a part of the seller group. The sellers in Case 2 are indifferent to the change in that holding cost.

Similar to h_s , h_s' is able to affect the cost savings of sellers for only two of the cases, as Case 1 3 do not include a paired seller. Compared to the sellers in Case 2, cost savings of those in Case 4 are more responsive to h_s' due to the use of common carriage.

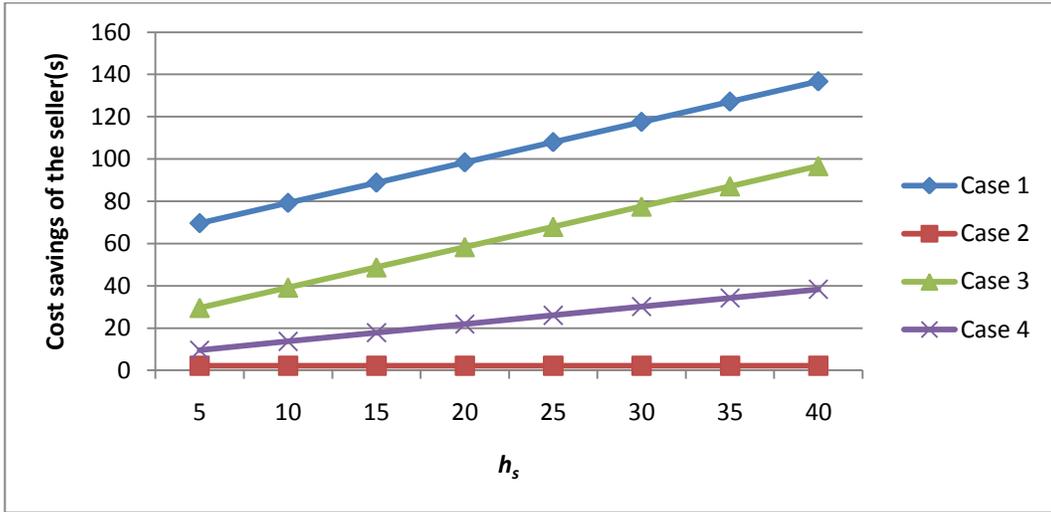


Figure 4-3: Change in h_s for all sellers

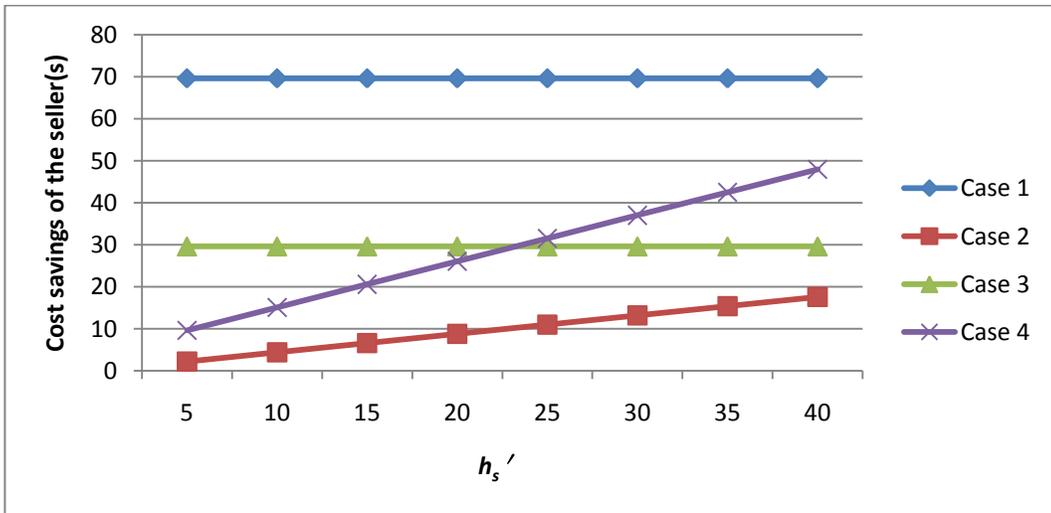


Figure 4-4: Change in h_s' for all sellers

(4) Let us vary $t_1 - t$, between the values of 1 and 8, in steps of 1. That is the difference in time between when the buyer orders under independent decision making and the time when the shipment occurs under CMT.

$t_1 - t$ has the same positive impact on the cost savings of sellers in Case 1, 3, and 4. However, this time difference does not affect the sellers in Case 2. That is a special case because the buyer's option that sets t equal to t_1 , thus $t_1 - t = 0$ is optimal.

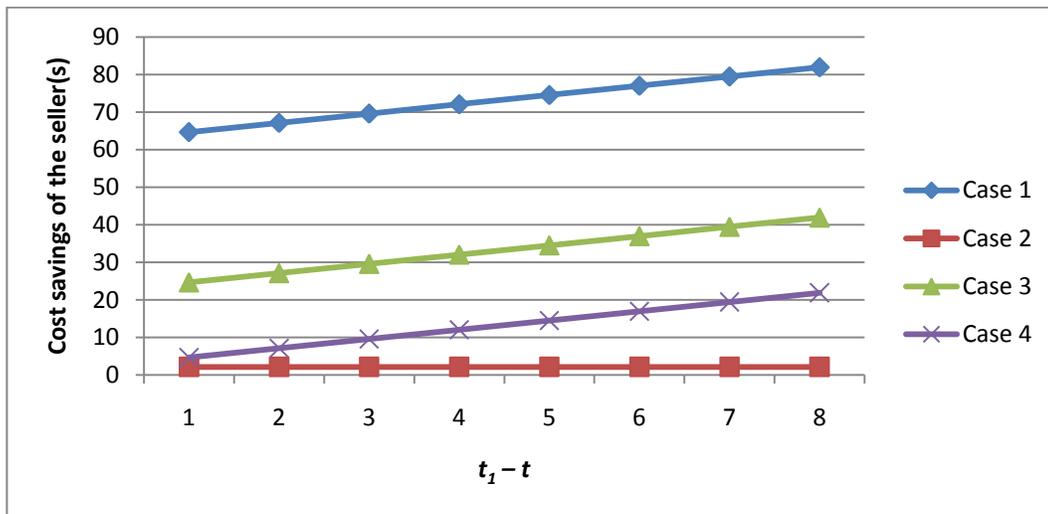


Figure 4-5: Change in difference of buyers order time for all sellers

All the figures indicate that the seller in Case 1 saves the most if CMT is chosen as the contractual relationship. Both Case 1 and Case 3, in which the FOB term gives the seller privilege to arrange transportation, prove that CMT is more preferable from the perspective of the seller, under FOB destination.

4.1.2 Savings of the buyer

We consider the cost savings of the buyer(s) next. The expression for cost savings (see below) includes both buyers for Case 1 and Case 3. Subscript b is

used to refer to the buyer. The use of subscripts 1, 2, 3, and 4 is the same as in Section 4.1.1.

The cost savings for the four buyer groups are thus:

$$TC_{b1} = -(t_1 - t)Qh_b - (t_1 + \Delta t - t)Q'h_b'$$

$$TC_{b2} = a_c + K + \delta D - h_b Q' \Delta t + a_b$$

$$TC_{b3} = -(t_1 - t)Qh_b - (t_1 + \Delta t - t)Q'h_b'$$

$$TC_{b4} = 2a_c - (t_1 - t)Qh_b - (t_1 + \Delta t - t)Q'h_b + a_b$$

The components listed below have appeared in the previous expressions, and are assigned the following initial values:

$$K + \delta D = \$50 \quad a_c = \$10 / \text{order} \quad a_b = \$10 / \text{order} \quad h_b = h_b' = \$5 / \text{unit/year}$$

$$t_1 - t = 3 \text{ days} \quad \Delta t = 2 \text{ days} \quad Q = 100 \text{ units} \quad Q' = 80 \text{ units}$$

Now we start by varying one of the above components at a time, but keep the remaining parameters at a fixed level.

(1) Transportation cost $K + \delta D$ varies in the interval [1, 71].

Other than in Case 2, component $K + \delta D$ has no effect on the cost savings of the buyers in other cases. With $K + \delta D$ increasing, the savings of buyer in Case 2 grow rapidly due to applying CMT. This means that under FOB origin, any factor that would add to the spending on transportation, such as higher cost of initiating a dispatch and longer distance, can be avoided if the buyer chooses CMT.

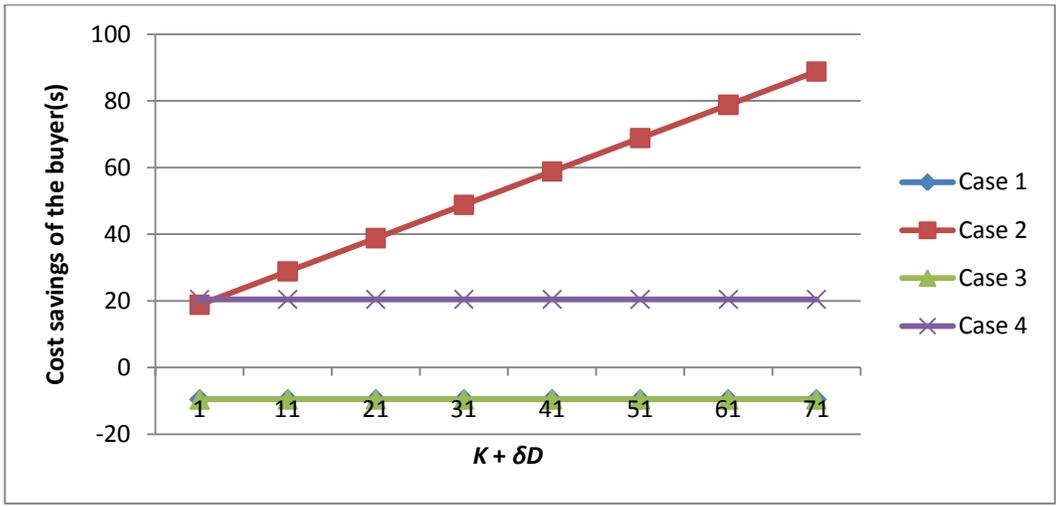


Figure 4-6: Change in the transportation costs. Cases 1 and 3 indicate the total cost savings for the buyers combined; Case 1 and 3 have only a single buyer. This applies for all figures in Section 4.1.2.

(2) Cost of issuing (receiving) a shipment, a_c (a_b), varies from 1 to 8, in steps of 1.

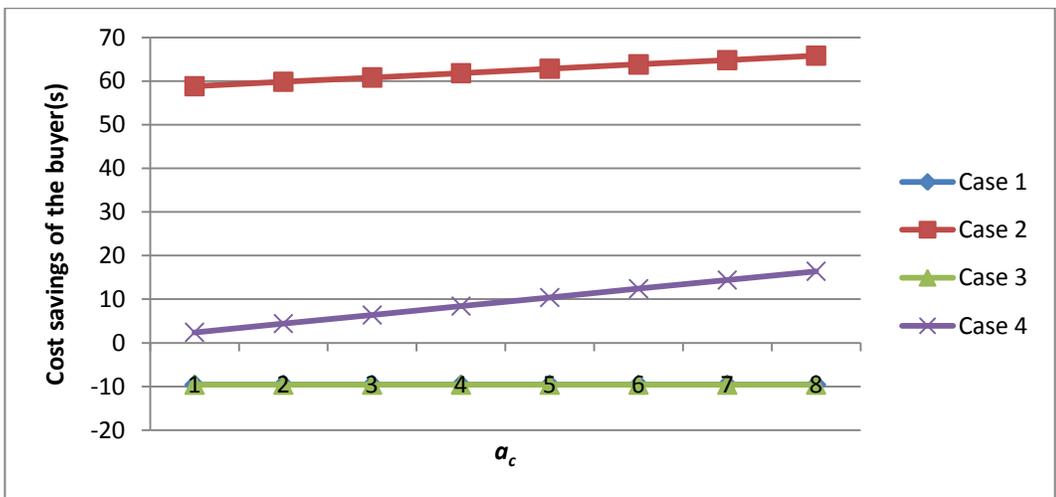


Figure 4-7: Change in shipment-issuing cost for all buyers

Neither a_c nor a_b affect the cost savings in Cases 1 and 3, but can help reduce expenses of the buyers in Case 2 and Case 4 under CMT. This is because

FOB origin requires that the buyers be responsible for transportation and the associated shipment-issuing fee. The impact of a_b on the buyers is the same in Cases 2 and 4, but a_c has greater impact on the buyer in Case 4. The reason is that, by using common carriage, the seller is fully exempt from a_c .

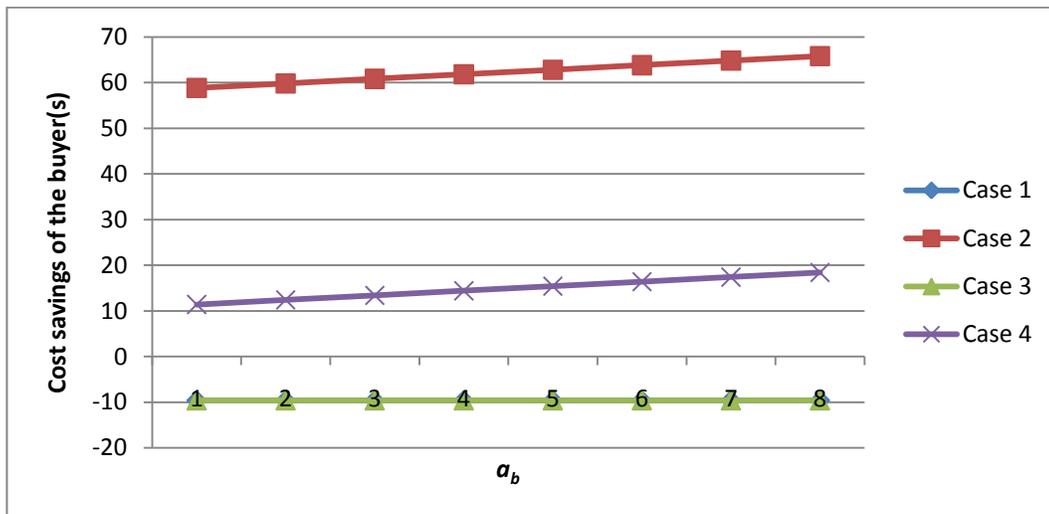


Figure 4-8: Change in shipment receiving

(3) Annual costs to hold a unit in inventory at the buyer (the paired buyer), h_b (h_b'), varies between values of 5 and 40, in steps of 5.

The figures show that h_b and h_b' have equal negative effect on the cost savings in Case 1 and 3. However, the cost savings in Case 2 and Case 4 is irrelevant to h_b' , while h_b causes lower cost savings for the buyers in both cases, especially in Case 4. A reasonable explanation is that the common carrier will not always choose the replenishment plan with lower inventory holding cost to the buyer.

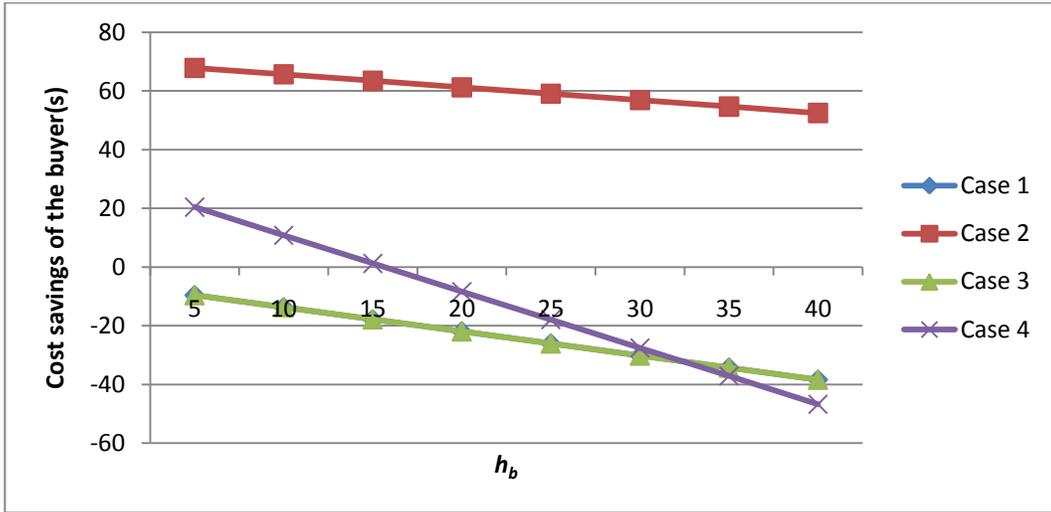


Figure 4-9: Change in h_b

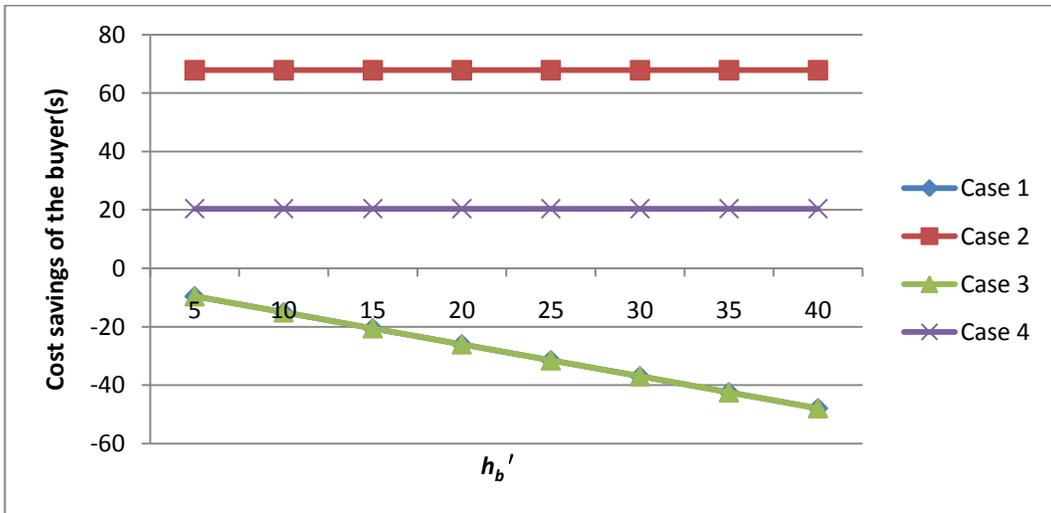


Figure 4-10: Change in h_b'

Similar to the findings in Section 4.1.1, all figures in this part indicate that the buyer in Case 2 saves the most if CMT is chosen as the contractual relationship. FOB origin allows the buyer in both Case 2 and Case 4 to arrange

transportation, making CMT an even better choice for the buyer to gain more savings on her total cost.

Conclusion 1: The party responsible for transportation according to the FOB term prefers to apply CMT with other partners in the supply chain. The cost savings of that party can be maximized, especially when private fleet is used.

4.1.3 Savings of the carrier

Now look at the common carriers. We use the subscript c to refer to the carrier. As there is no common carrier in Cases 1 and 2, we focus on the cost savings in the remaining two cases. Thus, only subscripts 3 and 4 are required.

The cost savings for the two cases with common carrier are thus:

$$TC_{s3} = TC_{s4} = K + \delta D - a_c$$

The expression indicates that the cost savings of the carrier in both cases only consist of the transportation cost and the cost of issuing a shipment. As shown in Chapter 3, these two components have an opposite influence on the savings, while the transportation cost dominates. Therefore, CMT is always a good choice for the carrier to save additional operating cost. However, the common carrier has no preference in choosing the seller or the buyer as the CMT partner, as the cost savings will be the same.

Conclusion 2: The common carrier is indifferent between seller and buyer when choosing the CMT partner.

4.1.4 Savings of the supply chain

We continue to use subscripts 1, 2, 3, and 4 to represent the four cases and study the cost savings for seller(s), buyer(s) and carrier as a whole in each case.

The total cost savings for the four cases are thus:

$$TC_1 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s - h_b') + a_c + K + \delta D$$

$$TC_2 = a_c + K + \delta D + a_b + (h_s' - h_b)Q'\Delta t$$

$$TC_3 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t) Q'(h_s - h_b') + a_c + K + \delta D$$

$$TC_4 = a_c + a_b + K + \delta D + (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t) Q'(h_s' - h_b)$$

The components listed below have appeared in previous expressions, and are assigned the following initial values:

$$a_c + K + \delta D = \$60; \quad a_b = \$10 / \text{order}; \quad h_s - h_b = h_s - h_b' = h_s' - h_b = \$5 / \text{unit/year}$$

$$t_1 - t = 3 \text{ days} \quad \Delta t = 2 \text{ days} \quad Q = 100 \text{ units} \quad Q' = 80 \text{ units}$$

Again we study the impact of the components by varying only one at a time, keeping the others at a fixed level.

(1) Cost regarding the shipment, $a_c + K + \delta D$, varies in interval [1, 71].

When $(a_c + K + \delta D)$ increases, the cost savings for all four cases grow steadily with the same slope. Figure 4-11 shows a strong incentive to use CMT: to reduce the relevant transportation cost of the entire chain. Among the four cases, Case 4 has the greatest cost savings for the whole supply chain.

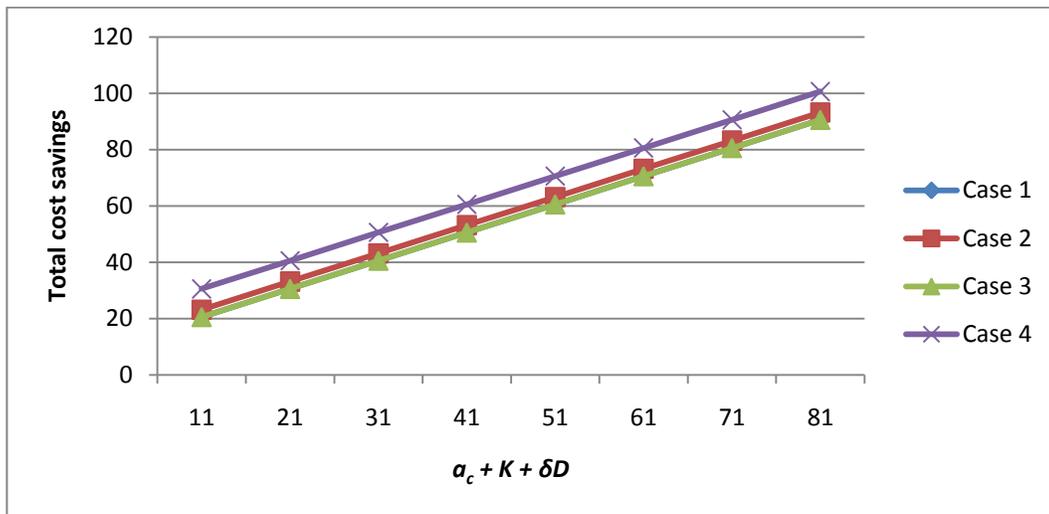


Figure 4-11: Change in shipment cost for all four cases

(2) Differences in annual costs to hold a unit in inventory at the seller and at the buyer, $h_s - h_b$, $h_s - h_b'$, and $h_s' - h_b$. Each is varied between values of 5 and 40, in steps of 5, respectively.

Figure 4-12 indicates that the total cost savings of Cases 1, 3, and 4 are proportional to the differences in the unit holding cost. Results of the computational testing are thus in accordance with the fact that the paired buyer appears only in Cases 1 and 3.

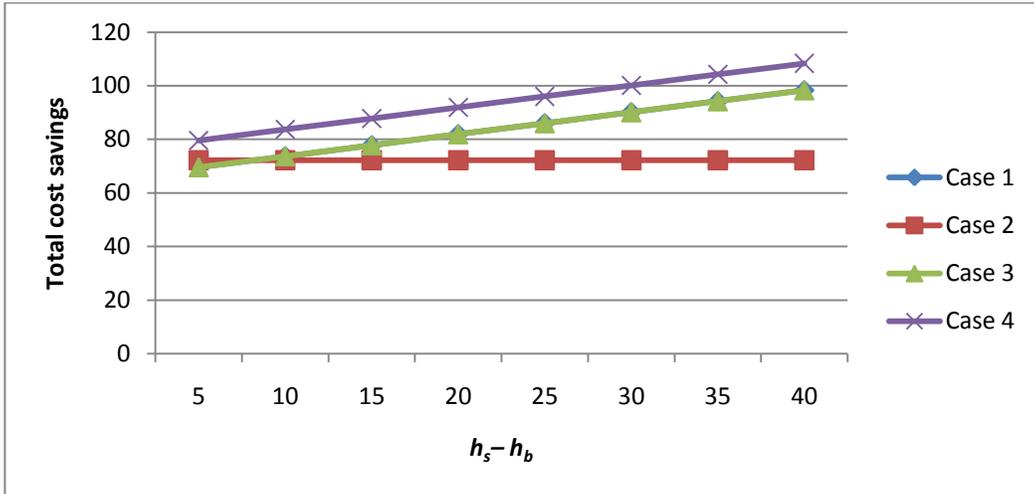


Figure 4-12: Change in $h_s - h_b$ for all four cases

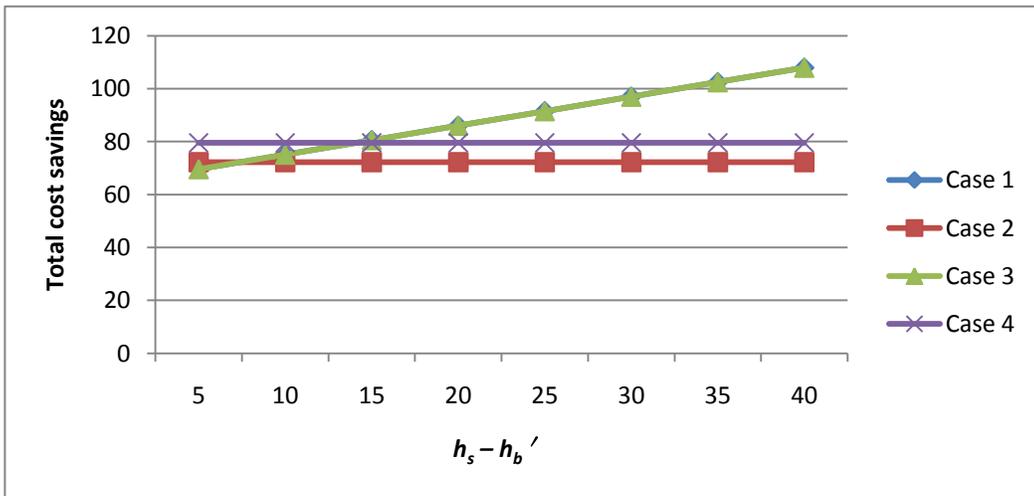


Figure 4-13 Change in $h_s - h_b'$ for all four cases

As the paired seller is excluded from Cases 1 and 3, a change in $h_s' - h_b$ has no impact on the cost savings in those two cases. The reason that its impact on Case 4 is greater is explained when analyzing the influences of h_s' and h_b .

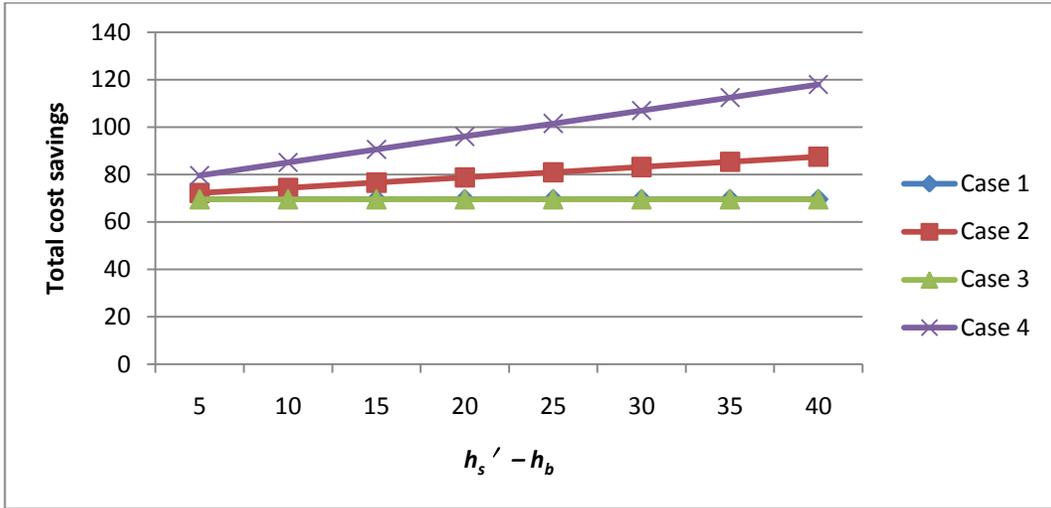


Figure 4-14 Change in $h_s' - h_b'$ for all four cases

(3) Cost of receiving a shipment, a_b , and the difference of the buyer's order time under independent decision making and the time when the shipment occurs under CMT, $t_1 - t$.

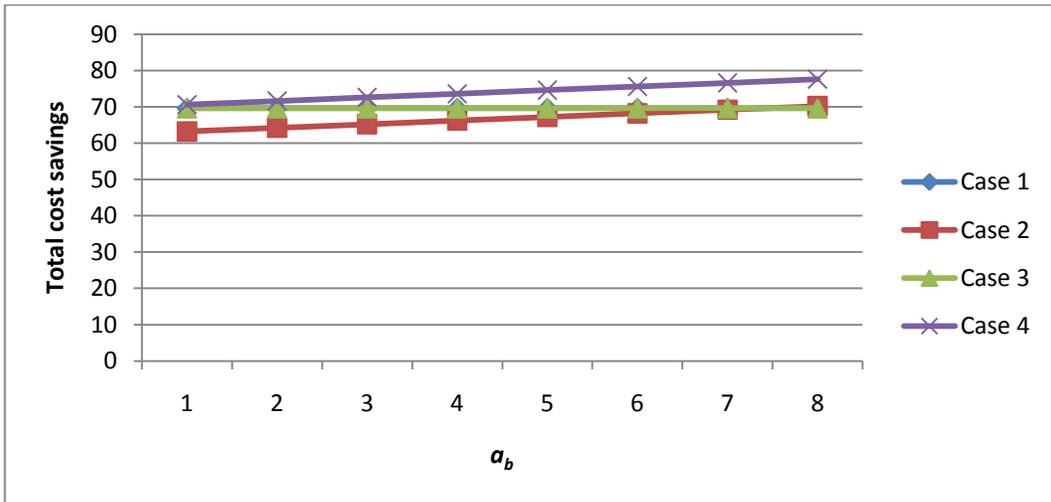


Figure 4-15 Change in shipment receiving cost for all four cases

The effect of $t_1 - t$ and a_b is similar to that described before. It is easy to understand by referring to the analysis of the corresponding parameters in part (4) of Section 4.1.1.

4.2 Private fleet vs. Common Carriage

In this section we look solely at CMT. By comparing the cost of each party under different FOB terms, we will find out which FOB term is more favorable in terms of seller, buyer, common carriers, and the whole supply chain.

We continue to use the cases and subscripts defined in the previous section. Among the four cases, Cases 1 and Case 3 use FOB destination, while Cases 2 and 4 are based on FOB origin. In each pair, the former represents private fleet and the latter includes a common carrier.

4.2.1 Case 1 vs. Case 3

If we exclude the transportation relevant cost of the seller in Case 1, then each of the corresponding parties in the two cases have the same cost expressions. However, as indicated in Section 4.1, the t_p under common carrier is longer than that when using private fleet, that is, $t_{p1} < t_{p3}$ in Table 4-1, as the information interchange between seller and carrier will take more time. The difference in t_p makes it more expensive for the seller to implement CMT by hiring a common carrier. Common carriage is also more expensive from the perspective of the total supply chain. Only the buyer is indifferent to what type

of transportation is used. Therefore, it is more cost effective if the seller uses his own fleet for CMT than uses common carriage.

Table 4-1: Cost comparison under FOB destination

Cost under private fleet – Cost under common carriage	
Seller	$h_p(Q + Q')(t_{p1} - t_{p3}) < 0$
Buyers	Both are 0
Total	$h_p(Q + Q')(t_{p1} - t_{p3}) < 0$

4.2.2 Case 2 vs. Case 4

The cost differences between cases applying FOB Origin are bigger than those of the first pair. The sellers spend less on holding inventory when the common carrier is hired by the buyer. As a result, the sellers may prefer to use common carriage. However, according to Table 4-2, using common carrier actually costs the buyer more. If the buyer does not have a private fleet, then hiring a common carrier works for both herself and the sellers. If the buyer already has access to private carriage, it is more reasonable that she operates the self-managed transportation.

The difference in total cost of the two cases can be positive or negative, depending on whether the buyer has cost-wise advantage over the sellers in inventory management. However, in real life, the pipeline inventory holding cost usually dominates. This is the same as explained in comparison of Cases 1 and 3,

$t_{p2} < t_{p4}$, because of the extra time spent on information interchange between buyer and carrier. Therefore, $h_p(Q + Q')(t_{p2} - t_{p4}) < 0$, i.e. the pipeline inventory holding cost of Case 2 is lower. This means that, when CMT is employed under conditions of FOB origin, the buyer prefers that private fleet be used (Naturally, this is the buyer's own truck).

Table 4-2: Cost comparison under FOB origin

Cost under private fleet – Cost under common carriage	
Sellers	$(t_1 - t)Qh_s > 0$ and $(t_1 - t)Q'h_s' > 0$
Buyer	$h_p(Q + Q')(t_{p2} - t_{p4}) - (t_1 - t)Qh_b - (t_1 - t)Q'h_b < 0$
Total	$h_p(Q + Q')(t_{p2} - t_{p4}) - (t_1 - t)Q(h_b - h_s) - (t_1 - t)Q'(h_b - h_s')$

In general, compared to hiring a common carrier, using a private fleet can help the party in charge of transportation spend less on that operation. This finding corresponds to the statement in **Conclusion 1**. Note that this does not mean that common carriage is not preferable. If there is no available private fleet, common carrier is also a nice choice, yielding cost savings compared to independent decision making.

4.3 The impact on EOQ of different FOB terms

In Chapter 1, we assumed that the buyers apply the EOQ model to decide the order quantity. That order amount is a *parameter* rather than a variable, which means that it is pre-determined and fixed throughout the model. When

discussing and making comparisons, we therefore did not change the order quantity. Instead we used the same order quantity in each case in the numerical examples, in order to make it easier to compare. However, we should point out that the order quantity generated from the EOQ models does depend on the FOB terms used. In this section we discuss why and how this variation occurs.

The EOQ formula is $Q = \sqrt{2DS/IP}$, in which:

P Price of item = Freight charge per item + Product value

I Inventory holding cost (% of the Price of item)

D Demand per period

S Fixed cost incurred to order regardless of quantity

Given a seller and a buyer, we write the following expressions for the order quantities under different FOB scenarios. Subscripts d and o are used to refer to FOB destination and FOB origin, respectively.

EOQ under FOB Destination: $Q_d = \sqrt{2DS_d/IP_d}$, and EOQ under FOB Origin: $Q_o = \sqrt{2DS_o/IP_o}$. Note that $P_d > P_o$, as P_d includes the seller's freight charge, and $S_d < S_o$, as the buyer needs to bear the transportation operating cost. Thus, we can conclude that $Q_o > Q_d$.

Conclusion 3: The order quantity under FOB origin is greater than that under FOB destination.

Define FC as the freight charge per item, then: $S_o = S_d + FC$, and $P_d = P_o + FC$. If CMT is implemented, P_d and S_o will decrease due to the improvement in distribution, through higher chances in consolidation, either accomplished by private fleet or common carrier. That is, FC is going to be smaller, i.e. will move to the left in Figure 4-16. As a result, Q_d is increasing, while Q_o is decreasing. The gap between those two EOQs is getting narrower with the reduction in transportation cost.

Set $D = 100$, $I = 5\%$, $S_d = 3$, $P_o = 10$. The following figure shows the variation in the two EOQs under different FOB terms when FC is changing.

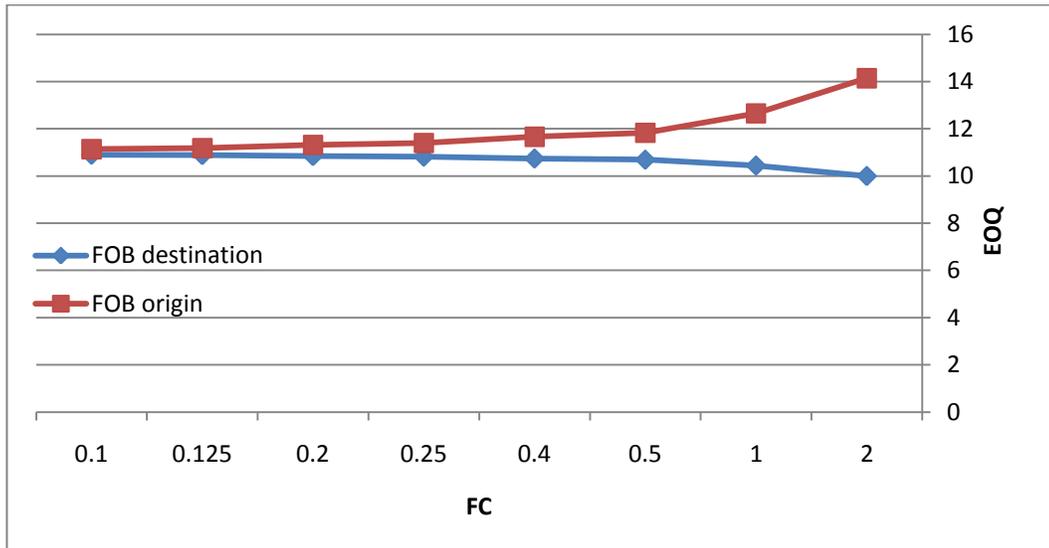


Figure 4-16 The impact of CMT to EOQ under different FOB terms

Conclusion 4: Applying CMT under FOB destination increases the order quantity of the buyer, and correspondingly lowers the rate of ordering. Under FOB origin, CMT leads to more frequent replenishments with a lower quantity per order.

Chapter 5 Summary and Conclusions

5.1 Summary

In this thesis we explored the possibility to apply a supply chain collaboration policy in the field of transportation and distribution. With reference to vendor managed inventory (VMI), we named the new policy “Carrier Managed Transportation” (CMT). As opposed to the traditional approach, where the shipper or consignee decides when to request shipments of the products, in CMT, the carrier will make these decisions on their behalf through the sharing of information on the timing of planned replenishments.

Based on the Incoterms and carrier choices, we divided CMT into four cases that are generally observed in the transportation business. They are: Private fleet belongs to the seller, FOB destination (Case 1); Private fleet belongs to the buyer, FOB origin (Case 2); Common carrier, FOB destination (Case 3); and Common carrier, FOB origin (Case 4).

We then made a few assumptions and applied two main frameworks to analyze the cost of each party and the entire supply chain. In the frameworks, the concept of time window was introduced to provide a basis for information sharing, and to guarantee that the business is processed on schedule. The cost components incorporated in our model include: the costs of on-site inventory holding, those of pipeline inventory, transportation, shipment dispatch, costs of

receiving goods and of order preparation. Depend upon the case, there may be an extra seller or buyer involved in the framework, to provide the chance for consolidation. The analysis was done for both CMT and another distribution policy called “independent decision making”. The results under the two policies were compared to examine the possible benefits of CMT. We further compared the impacts of choosing FOB terms and cooperative partners.

Our findings include one strong result and four conclusions:

A strong result: Whoever owns the truck gets most of the savings.

Conclusion 1: The party responsible for transportation according to the FOB term prefers to apply CMT with other partners in the supply chain. The cost savings of that party can be maximized, especially when private fleet is used.

Conclusion 2: The common carrier is indifferent between seller and buyer when choosing the CMT partner.

Conclusion 3: The order quantity under FOB origin is greater than that under FOB destination.

Conclusion 4: Applying CMT under FOB destination increases the order quantity of the buyer, and correspondingly lowers the rate of ordering. Under FOB origin, CMT leads to more frequent replenishments with a lower quantity per order.

The following subsection gives a more general explanation to these findings.

5.2 Conclusions

From the previous studies we can draw the following conclusions:

(1) Carrier Managed Transportation has great potential in shredding the transportation cost in the supply chain. Thus, any party that has advantages on transportation over the supply chain will tend to use CMT as the collaboration policy.

(2) CMT leads to centralized decision making, especially when common carrier is in the transportation system. Each party can focus on its core business, and the common carrier plays a role of the professional logistics service provider. From the perspective of the shipper and the consignee, other than transportation activities, they outsource part of their decision making power to the carrier as well.

(3) CMT is applicable in industry. Although the examples showed that some parties are worse-off in certain situations, in fact the main disadvantage they face is to bear inventory holding cost for a few days more. In real life, companies does not stress on such trivial extra expenses. Moreover, CMT can provide long-term collaborative relationships and discounts to compensate their loss.

As for the common carrier, we proved that it has no preference choosing business partners. The common carriers can enjoy customer variety, and the industry will remain balanced.

(4) CMT will affect inventory planning of the chain members. If CMT is implemented, the order quantity and frequency will change according to different terms used. As a result, the inventory design needs to be modified to adjust the changes in the previous factors. The change in inventory settings may further influence chain members outside the transportations system. Therefore, it is suggested that the parties choose the FOB terms carefully with their business partners.

(5) Applying CMT tends to transfer the inventory holding cost to the downstream chain members, i.e. from the seller to the buyer, no matter what type of transportation is used.

CMT allows the master of the supply chain to take initiative and gain more benefits. If a company has advantages in managing the supply chain, it could consider CMT to further reduce its spending and enhance the relationships with its partners. Our findings can be a source of reference to help companies decide if CMT works for them.

The above conclusions are based on the assumptions made in Section 1.6.1. However, even if some of the assumptions do not hold, CMT is still beneficial. We give two examples to show how the changes in assumptions will affect the results of CMT.

We assumed that the demand is constant and deterministic. If the market faces a probabilistic demand, the buyer will thus need to keep a safety stock to

prevent a stockout. Therefore, the reorder point will need to increase. In addition, buyer B (facing probabilistic demand) would like the time t_2 to move further to the left (e.g. see Figure 2-2), meaning a consolidated shipment could be dispatched sooner. The relevant time interval now has a greater width, but the carrier will prefer to dispatch a consolidated load at a time closer to the left end point. These variations do not change the basis of our calculations. However, determination of those cost savings under probabilistic demand will not be as easy to obtain as when demand is fixed.

Another assumption is that there is no need to break orders into small loads. However, in real life, splitting orders is often the case, e.g. due to truck capacity. In such circumstances, the buyers will need to have better and more information sharing with the carrier to implement CMT. From the perspective of the carrier, there will be a greater number of orders. Thus, consolidation will become even more important, and if performed well, could bring the carrier additional profits.

5.3 Future Research

In this thesis we used a simple mathematical model to illustrate the concept of Carrier Managed Transportation and how it affects the cost responsibilities of each party in the transportation system. For further research, one can extend this model by adding in multiple sellers and buyers, introducing probability when referring to the chance of consolidation, or relaxing the assumption that demand

is fixed, etc. One can also consider different inventory management policies to handle the changes in demand. For the extensions that are much more complicated, computer simulation can be used to aid the modeling process and output analysis.

Another choice is to evolve in the shipment quantity as a decision variable in CMT. In our model, there is no break bulk of the orders. However, according to our definition of CMT, it is possible that the carrier dispatch the products in several shipments, as long as the clients get replenished on time. In such case, the factors affecting consolidation become more complicated, but the potential of CMT will be explained distinctively.

It is also an interesting topic if CMT is combined with VMI. Among the four cases discussed in this thesis, Private fleet belongs to the seller, FOB destination (Case 1) may be the best fit for combination of the two policies.

Although CMT is a supply chain collaboration policy, the party who makes decisions is still biased. That is, it will maximize its own profit, sometimes sacrificing the interests of other parties. Therefore, joint decisions in CMT could be discussed to show the differences in performance if there is a neutral party that makes decisions from the system-wide perspective. In addition, a method for obtaining the best price discount can be established and applied in CMT to compensate the parties that are worse-off. The price discount could be a part of the joint decisions that helps to balance the interests of all chain members.

Appendix A Numerical Examples for Private Fleet

In Appendices A and B, we include the graphs that compare the various cases when additional parameters are varied.

Private fleet belongs to the seller, FOB destination (Case 1)

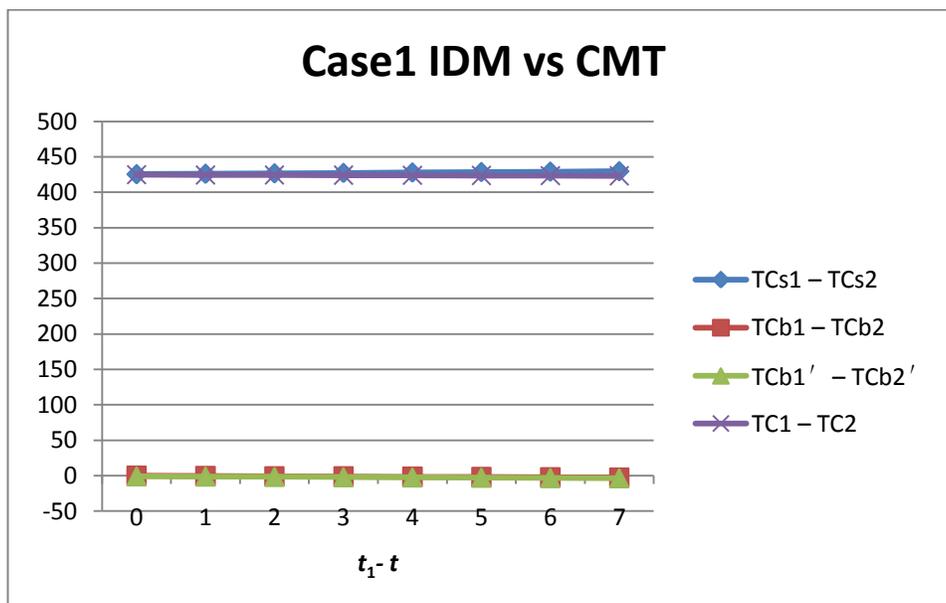
$$TC_{s1} - TC_{s2} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + a_c + K + \delta D > 0$$

$$TC_{b1} - TC_{b2} = -(t_1 - t)Qh_b \leq 0$$

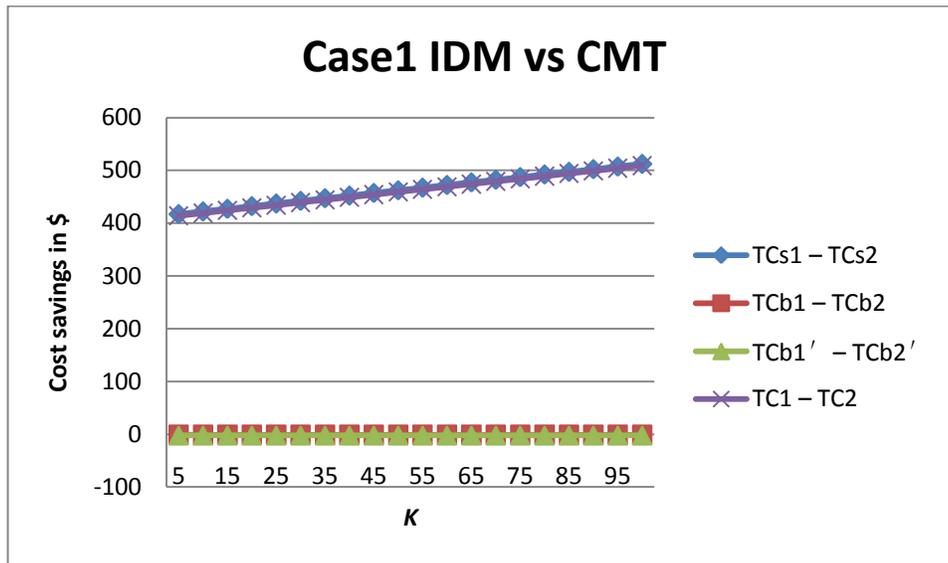
$$TC_{b'1} - TC_{b'2} = -(t_1 + \Delta t - t)Q'h_{b'} \leq 0$$

$$TC_1 - TC_2 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s - h_{b'}) + a_c + K + \delta D$$

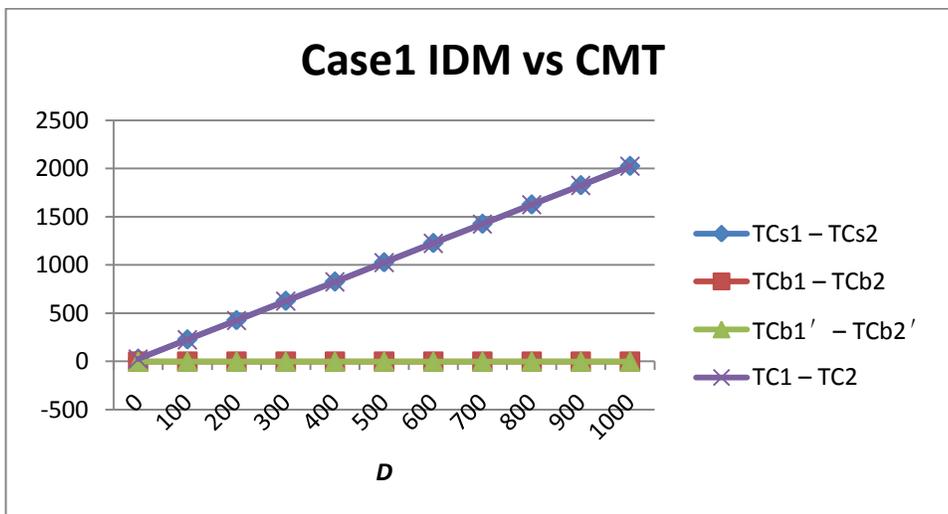
(1) Difference of buyer b 's order time under independent decision making and the order time of buyer b' under CMT, $t_1 - t$, between values of 0 and 7, in steps of 1.



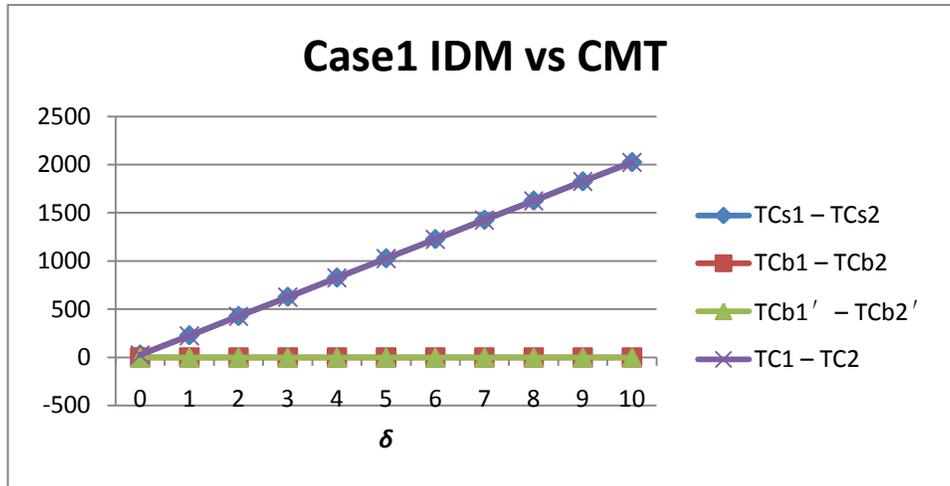
(2) Carrier (seller)'s cost K , of initiating a dispatch. Variation between values of 5 and 100, in steps of 5.



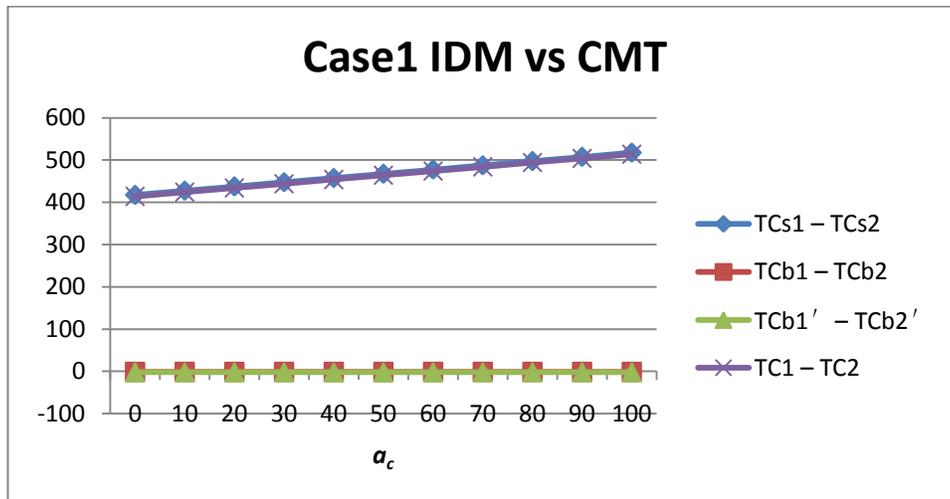
(3) Distance between the region of seller and the region of buyers, D , between values of 0 and 1000, in steps of 100.



(4) Transportation cost, δ , between values of 0 and 10, in steps of 1.

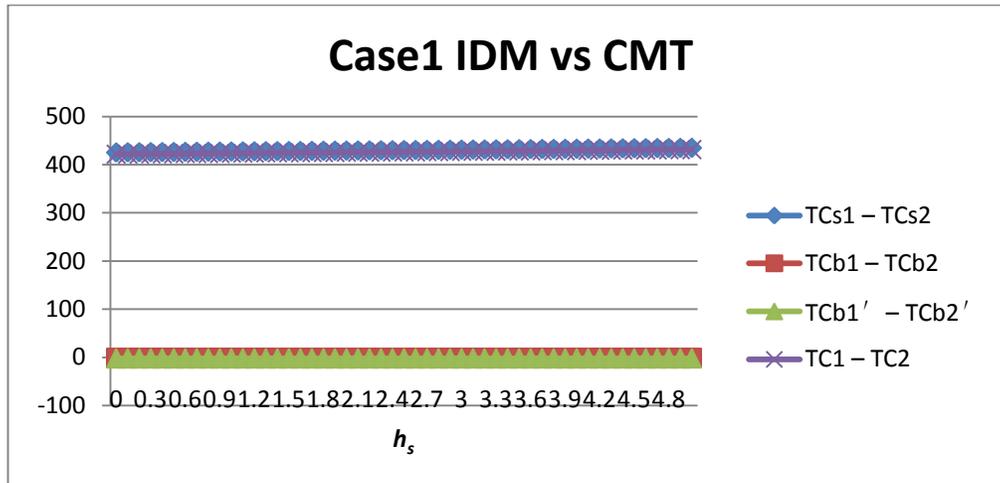


(5) Fixed cost of issuing a shipment, a_c , between values of 0 and 100, in steps of 10.

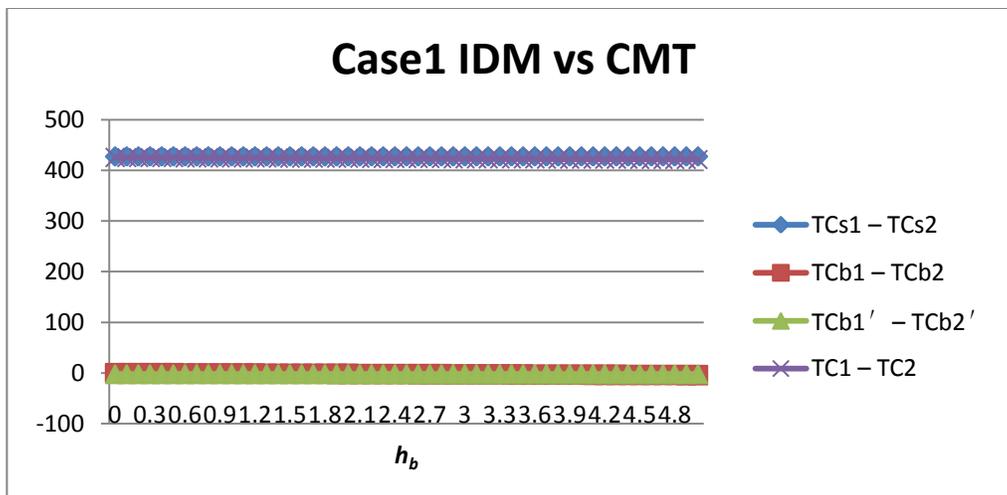


(6) Annual cost to hold a unit in inventory at the seller, h_s , between values of 0 and 5, in steps of 0.1. In such condition, $h_s - h_b \in (-1.5, 3.5)$, $h_s - h_b' \in (-1.8, 3.2)$.

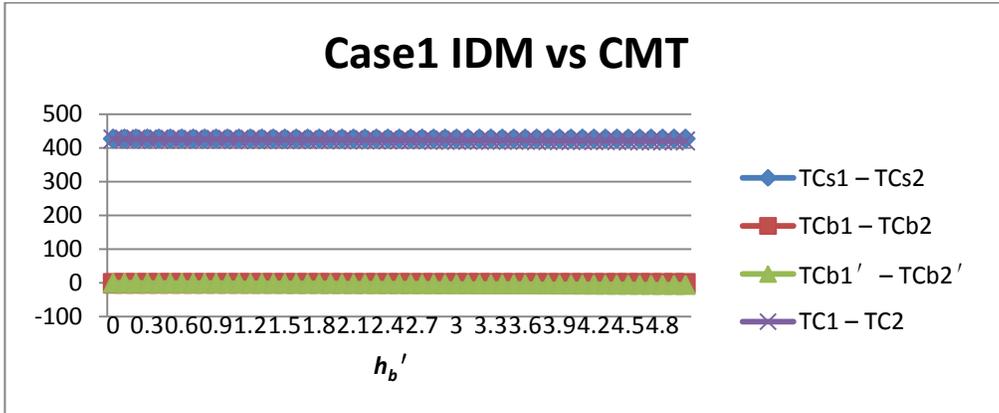
When $h_s < 1.5$, h_s is smaller than both h_b and h_b' ; when $1.5 < h_s < 1.8$, $h_b < h_s < h_b'$; when $h_s > 1.8$, h_s is larger than both h_b and h_b' .



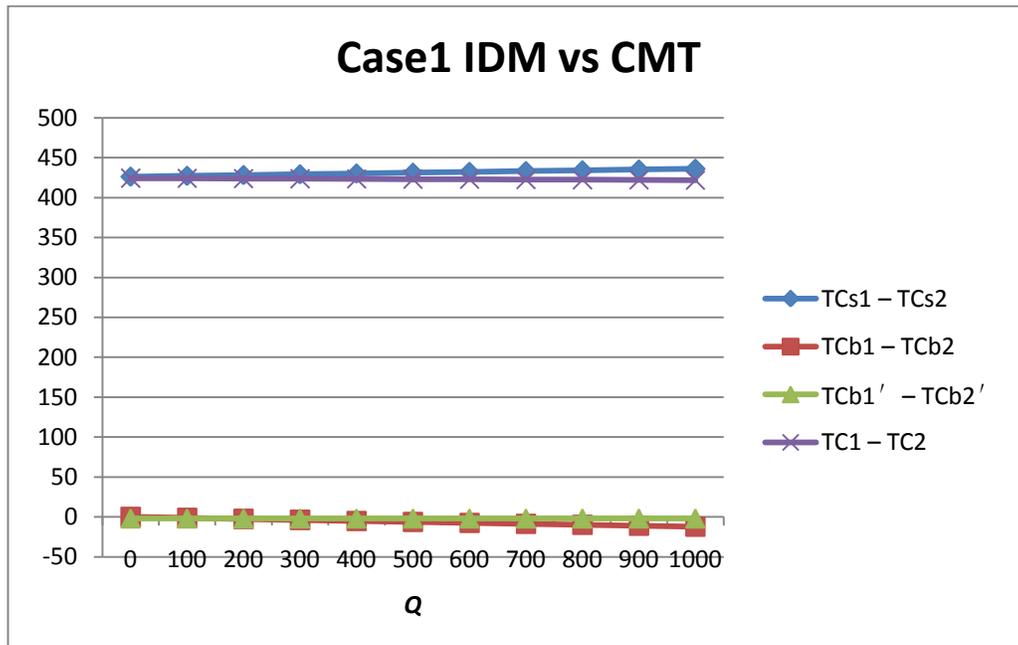
(7) Annual cost to hold a unit in inventory at the buyer, h_b , between values of 0 and 5, in steps of 0.1. In such condition, $h_s - h_b$ will decrease from 1.2 to -3.8. When $h_b < 1.2$, h_b is smaller than h_s ; when $h_b > 1.2$, h_b is larger than h_s .



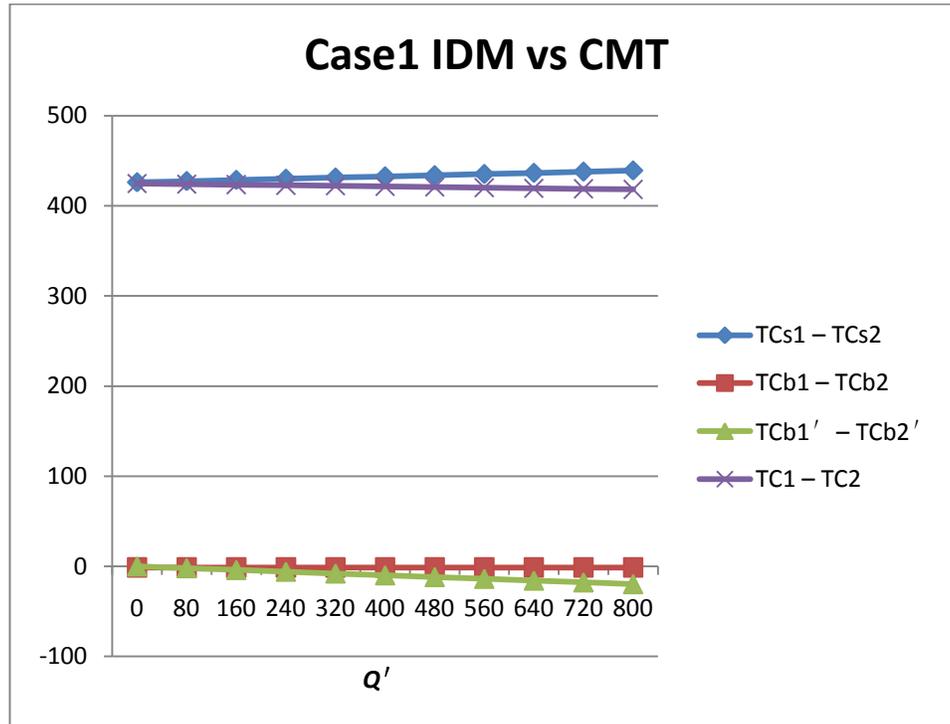
(8) Annual cost to hold a unit in inventory at buyer b' , h_b' , between values of 0 and 5, in steps of 0.1. In such condition, $h_s - h_b'$ will decrease from 1.2 to -3.8. When $h_b' < 1.2$, h_b' is smaller than h_s ; when $h_b' > 1.2$, h_b' is larger than h_s .



(9) Differences in total cost as a function of the quantity Q , ordered by the buyer, between values of 0 and 1000, in steps of 100.



(10) Quantity ordered by the buyer, Q' , between values of 0 and 800, in steps of 80.



Private fleet belongs to the buyer, FOB origin (Case 2)

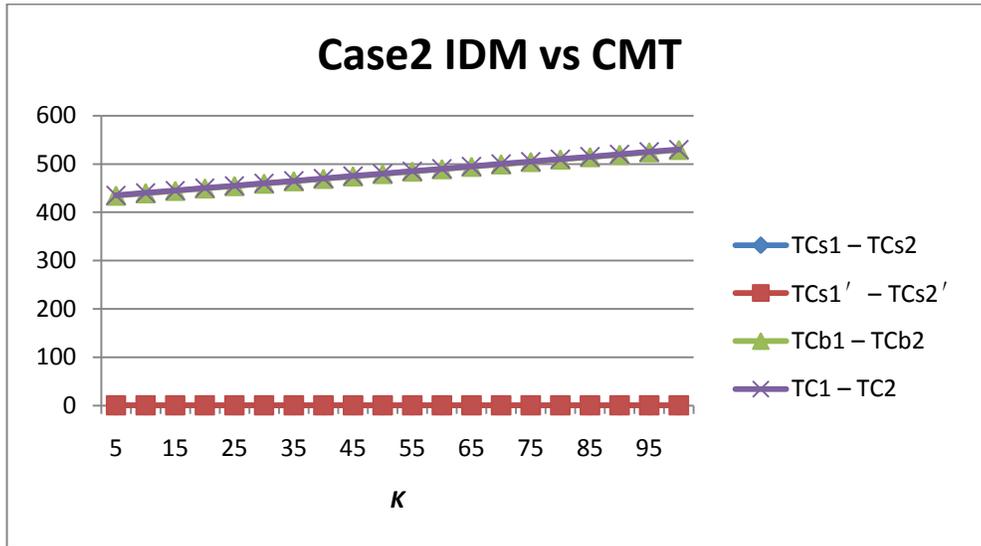
$$TC_{s1} - TC_{s2} = 0$$

$$TC_{s'1} - TC_{s'2} = h_s' Q' \Delta t$$

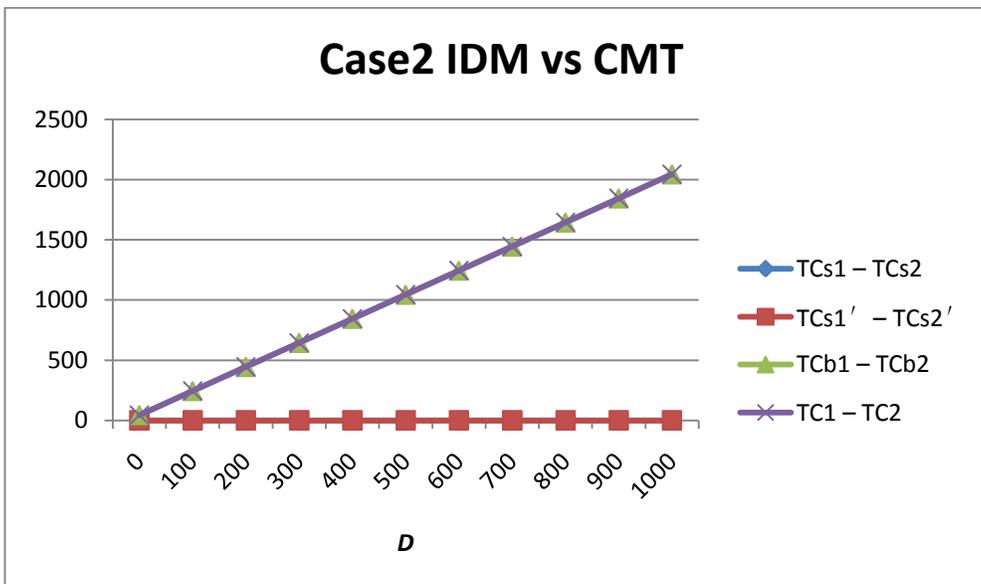
$$TC_{b1} - TC_{b2} = a_c + K + \delta D - h_b Q' \Delta t + a_b > 0$$

$$TC_1 - TC_2 = a_c + K + \delta D + a_b + (h_s' - h_b) Q' \Delta t$$

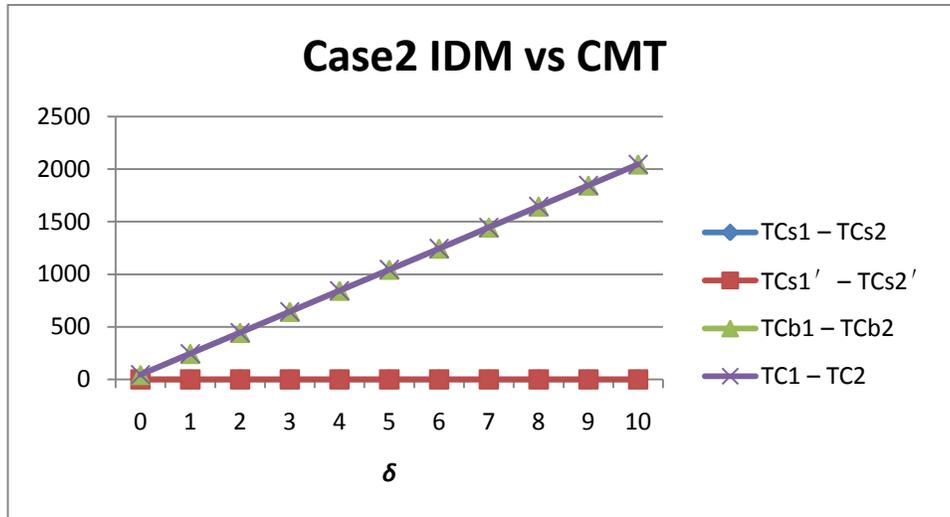
(1) Carrier (buyer)'s cost of initiating a dispatch, K , between values of 5 and 100, in steps of 5.



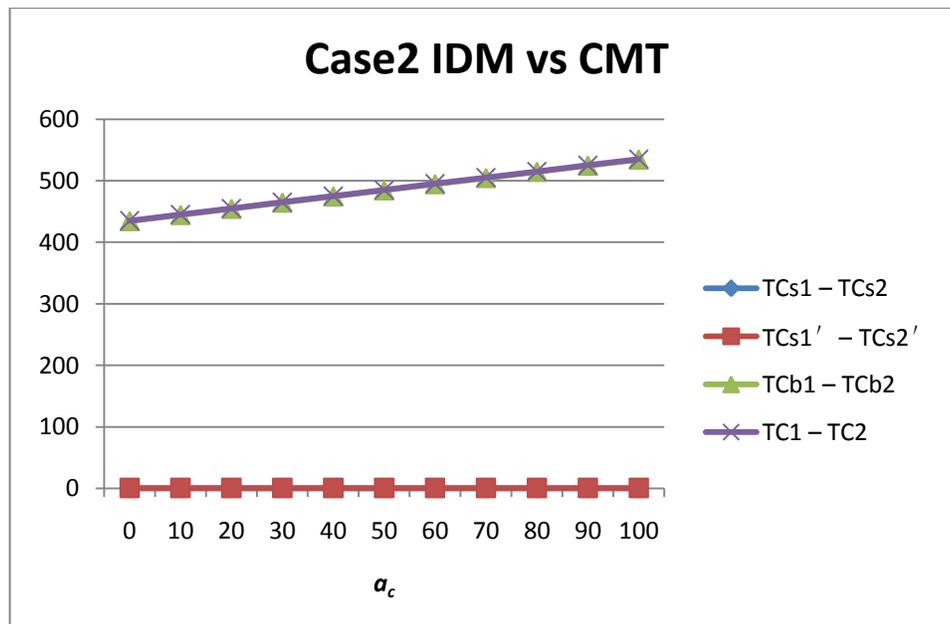
(2) Distance between the region of sellers and the region of buyer, D , between values of 0 and 1000, in steps of 100.



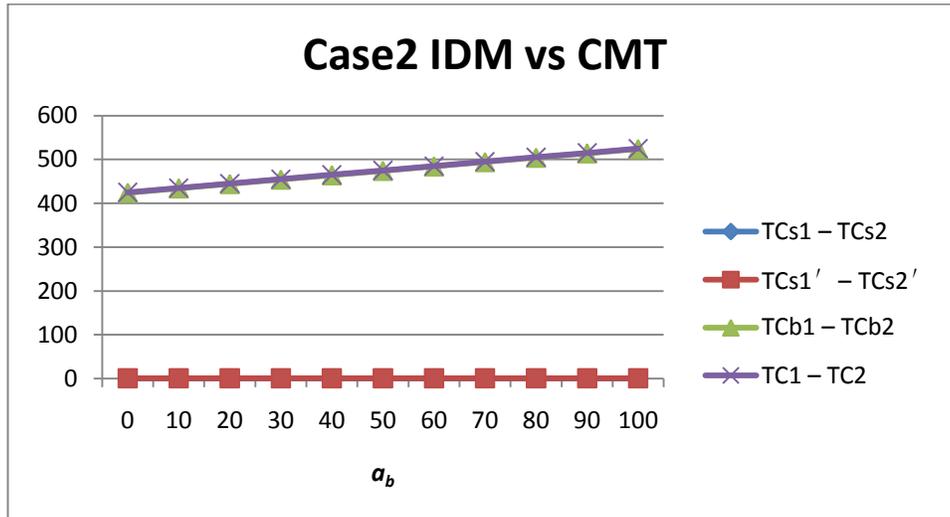
(3) Transportation cost, δ , between values of 0 and 10, in steps of 1.



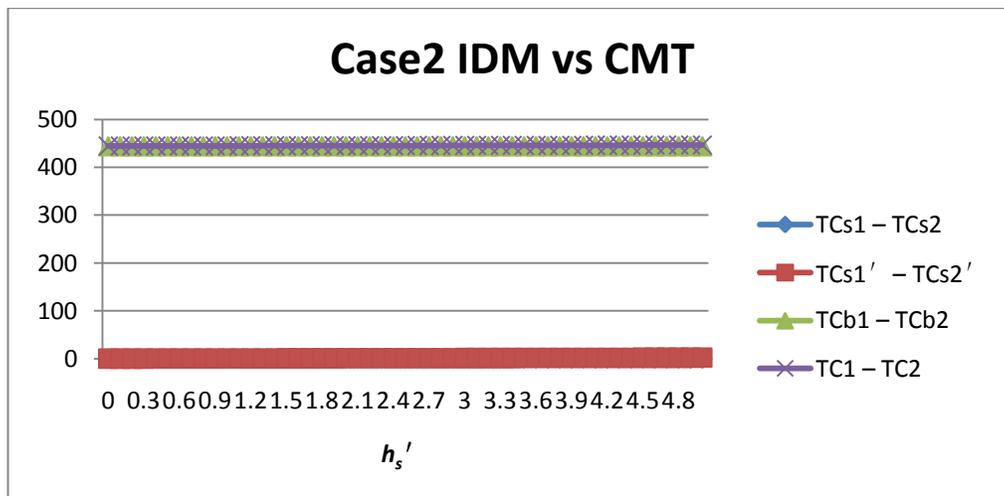
(4) Fixed cost of issuing a shipment, a_c , between values of 0 and 100, in steps of 10.



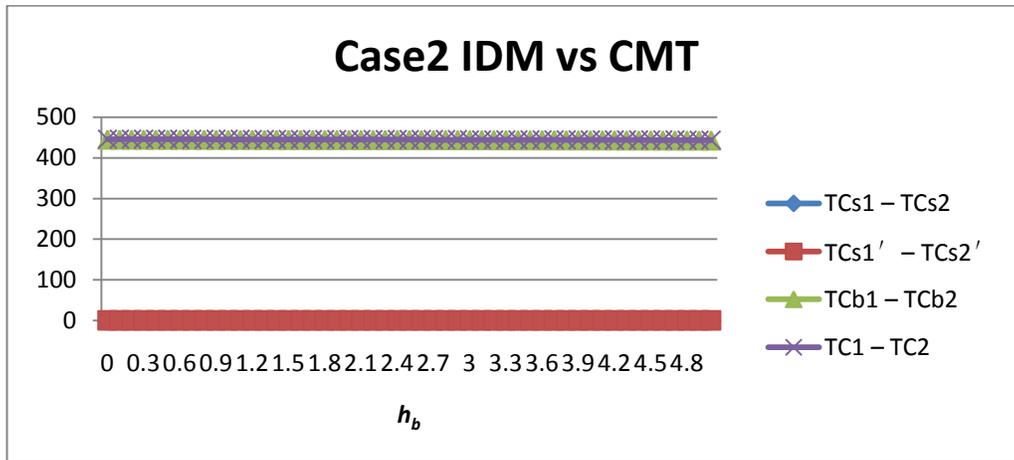
(5) Fixed cost of receiving the products, a_b , between values of 0 and 100, in steps of 10.



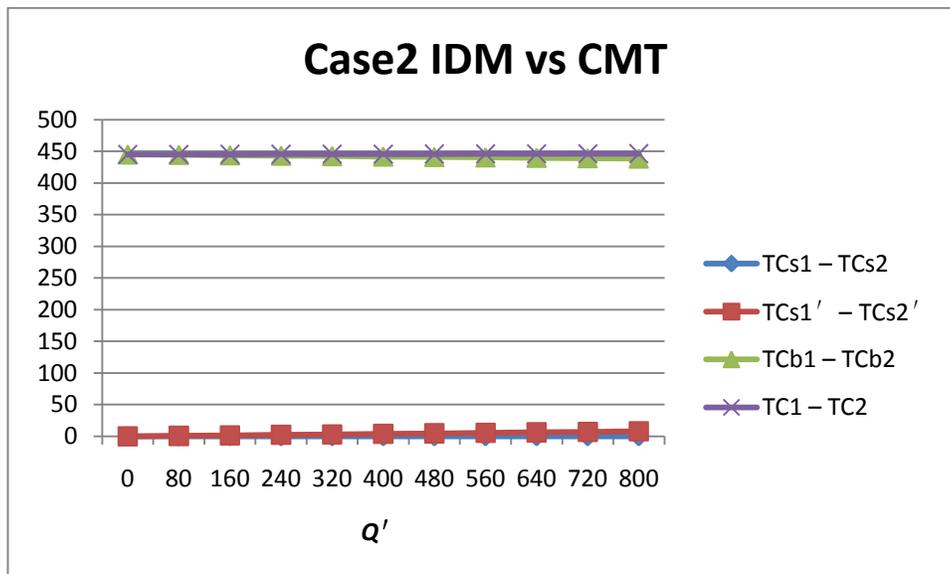
(6) Annual cost to hold a unit in inventory at the seller s' , h_s' , between values of 0 and 5, in steps of 0.1. Thus $h_s' - h_b \in (-1.5, 3.5)$. When $h_s' < 1.5$, h_s' is smaller than h_b ; when $h_s' > 1.5$, h_s' is larger than h_b .



(7) Annual cost to hold a unit in inventory at the buyer, h_b , between values of 0 and 5, in steps of 0.1. In such condition, $h_s' - h_b$ will decrease from 1.8 to -3.2. When $h_b < 1.8$, h_b is smaller than h_s ; when $h_b > 1.8$, h_b is larger than h_s .



(8) Quantity ordered by the buyer for product p' , Q' , between values of 0 and 800, in steps of 80.



Appendix B Numerical Examples for Common Carrier

Common carrier, FOB destination (Case 3)

$$TC_{s1} - TC_{s2} = (t_1 - t)Qh_s + (t_1 + \Delta t - t)Q'h_s + 2a_c > 0$$

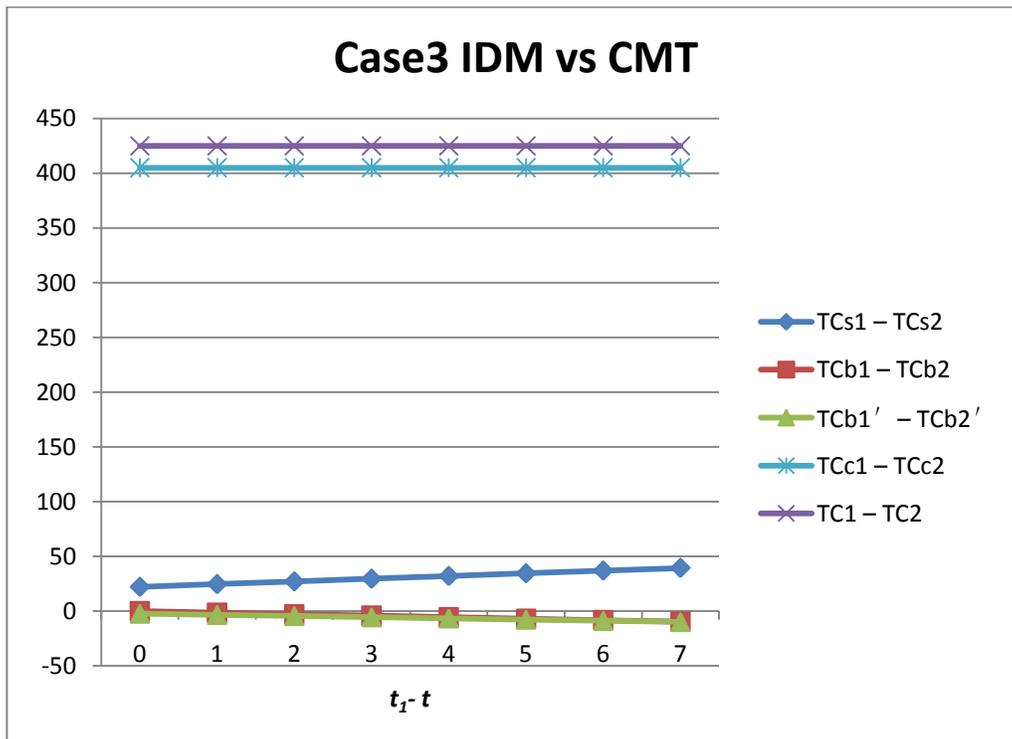
$$TC_{b1} - TC_{b2} = -(t_1 - t)Qh_b \leq 0$$

$$TC_{b'1} - TC_{b'2} = -(t_1 + \Delta t - t)Q'h_b' \leq 0$$

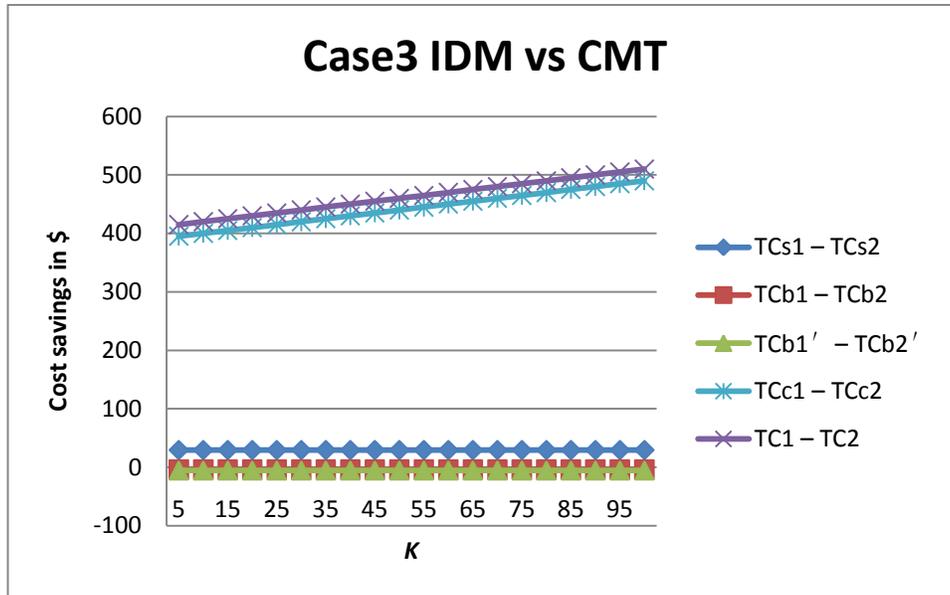
$$TC_{c1} - TC_{c2} = K + \delta D - a_c$$

$$TC_1 - TC_2 = (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s - h_b') + a_c + K + \delta D$$

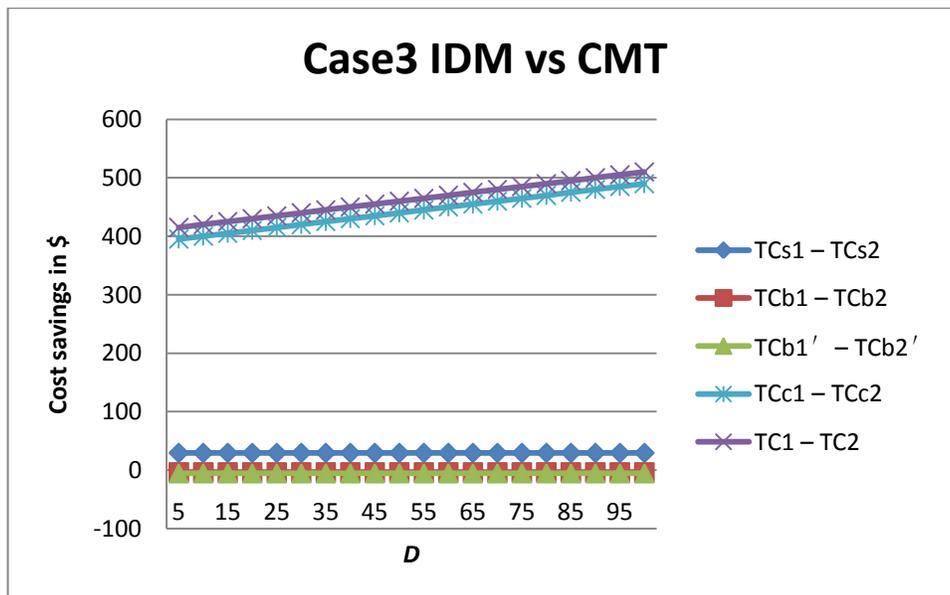
(1) $t_1 - t$, between values of 0 and 7, in steps of 1.



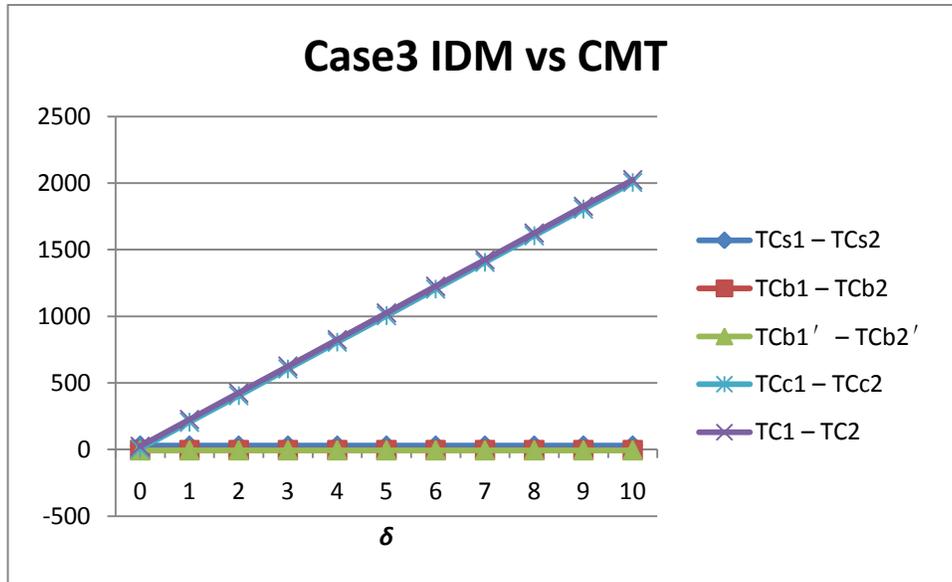
(2) K . Variation between values of 5 and 100, in steps of 5.



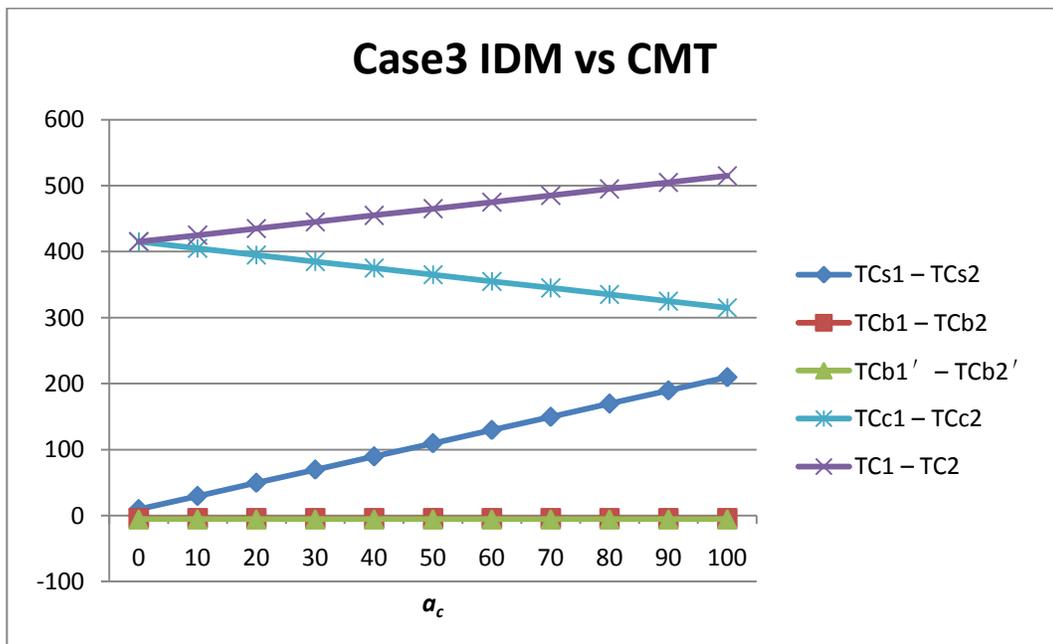
(3) D , between values of 0 and 1000, in steps of 100



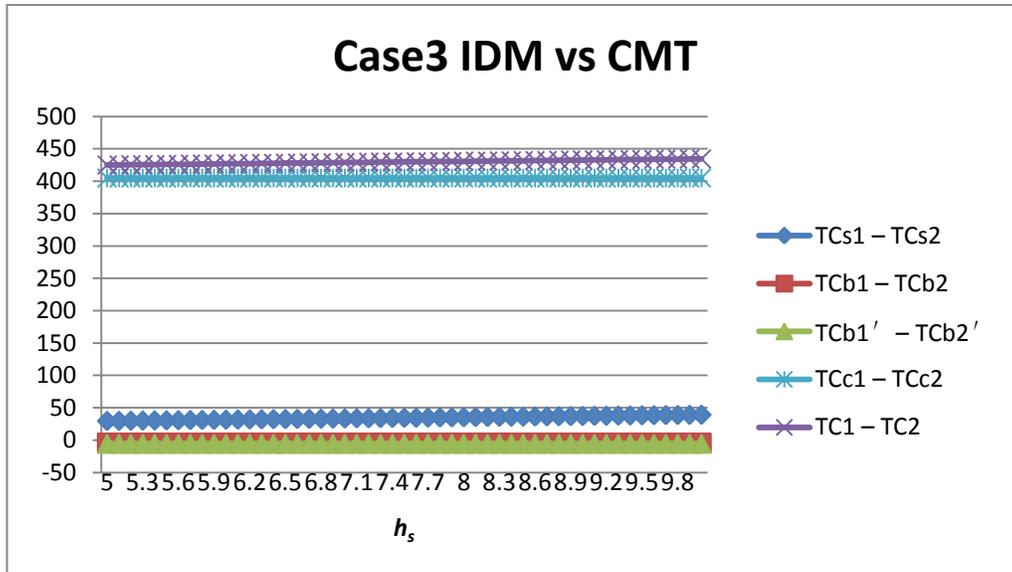
(4) δ , between values of 0 and 10, in steps of 1.



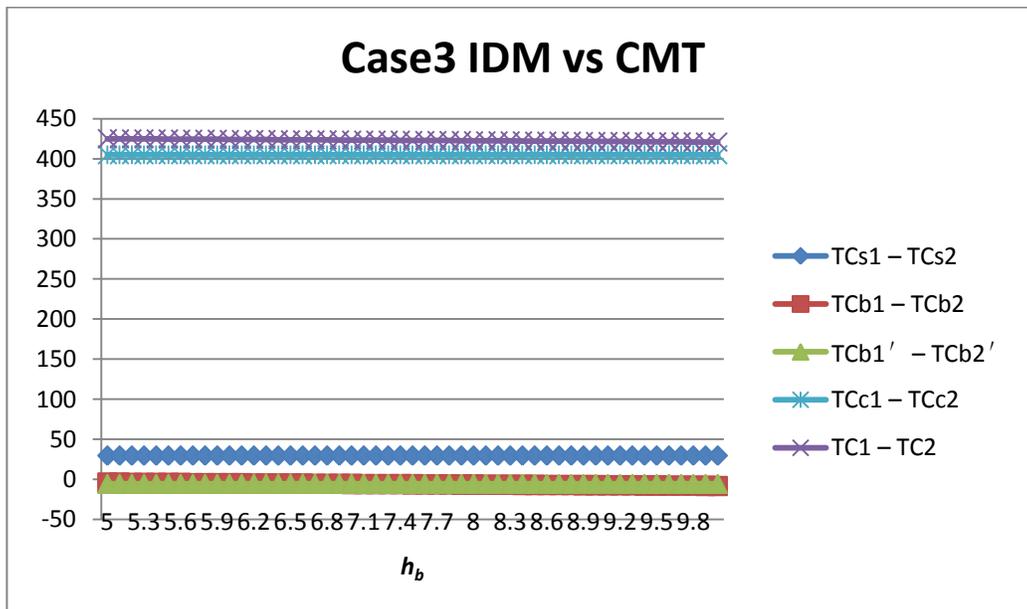
(5) a_c , between values of 0 and 100, in steps of 10.



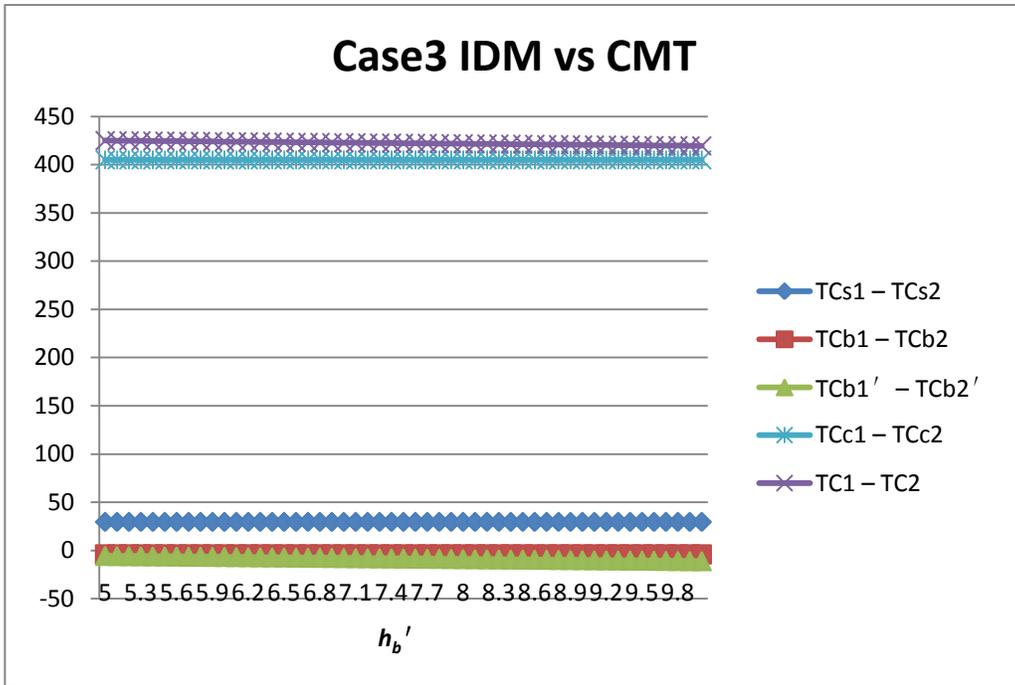
(6) h_s , between values of 5 and 10, in steps of 0.1.



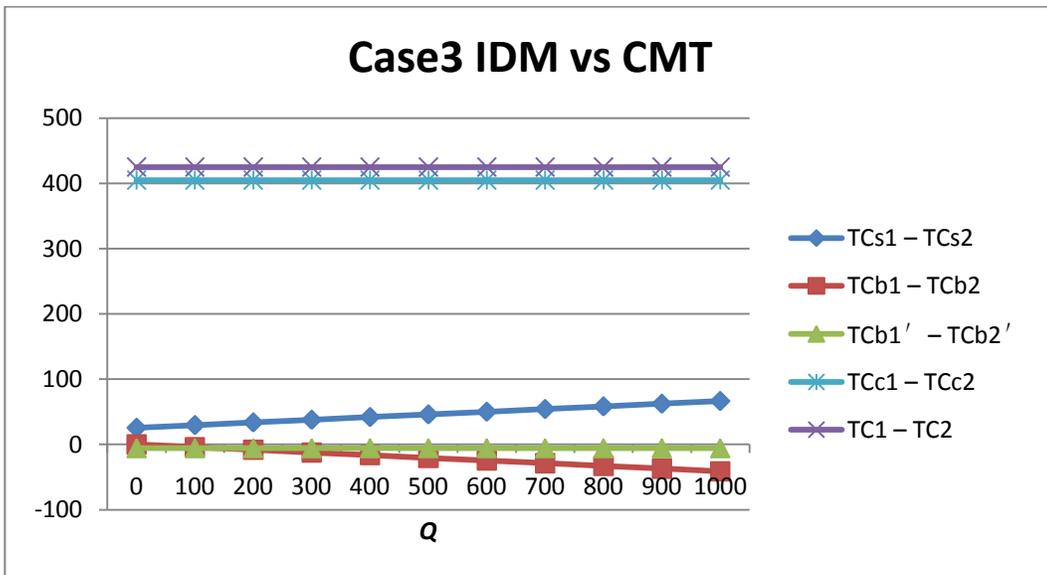
(7) h_b , between values of 5 and 10, in steps of 0.1.



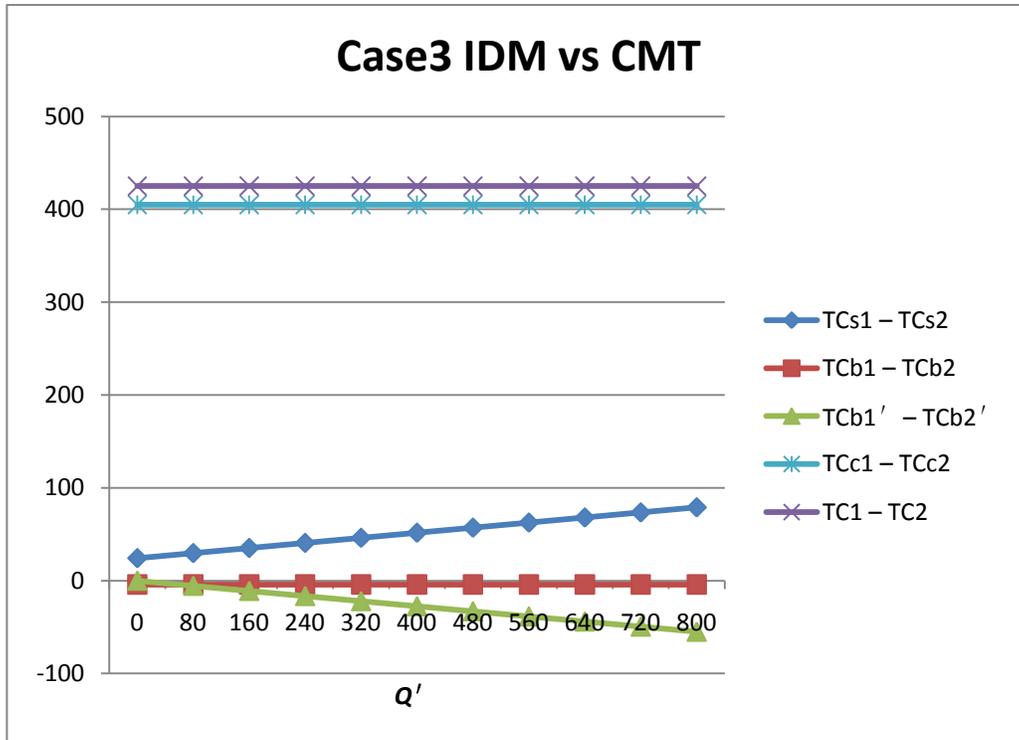
(8) h_b' , between values of 5 and 10, in steps of 0.1.



(9) Q , between values of 0 and 1000, in steps of 100.



(10) Q' , between values of 0 and 800, in steps of 80.



Common carrier, FOB origin (Case 4)

$$TC_{s1} - TC_{s2} = (t_1 - t)Qh_s \geq 0$$

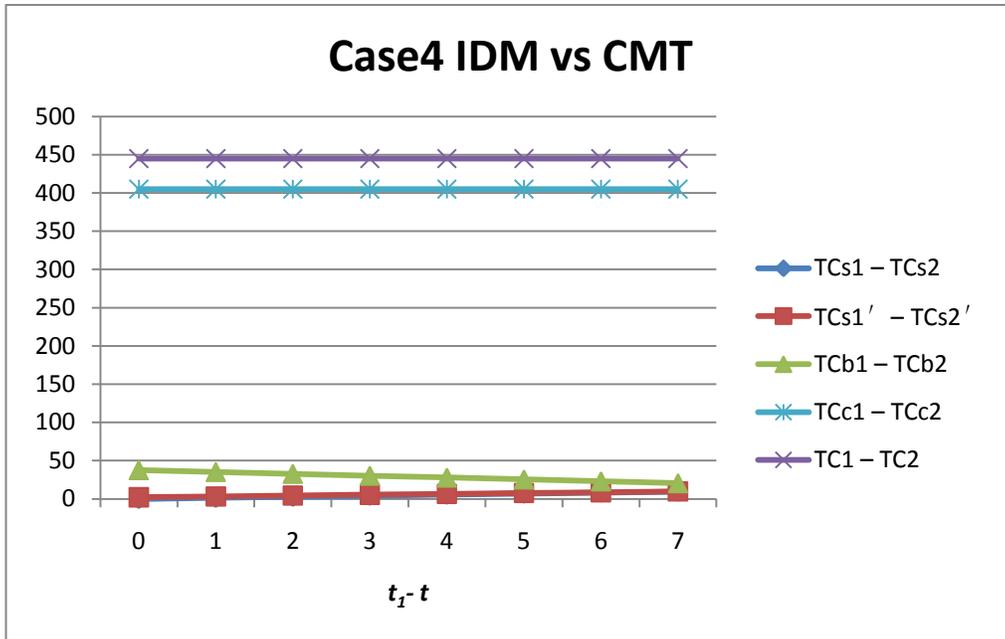
$$TC_{s'1} - TC_{s'2} = (t_1 + \Delta t - t)Q'h_s' > 0$$

$$TC_{b1} - TC_{b2} = 2a_c - (t_1 - t)Qh_b - (t_1 + \Delta t - t)Q'h_b + a_b$$

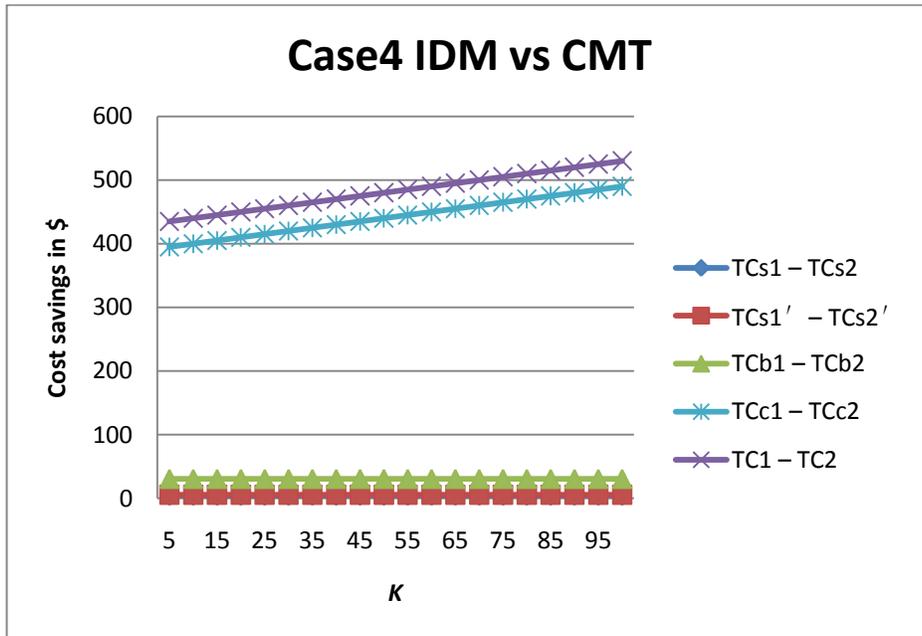
$$TC_{c1} - TC_{c2} = K + \delta D - a_c$$

$$TC_1 - TC_2 = a_c + a_b + K + \delta D + (t_1 - t)Q(h_s - h_b) + (t_1 + \Delta t - t)Q'(h_s' - h_b)$$

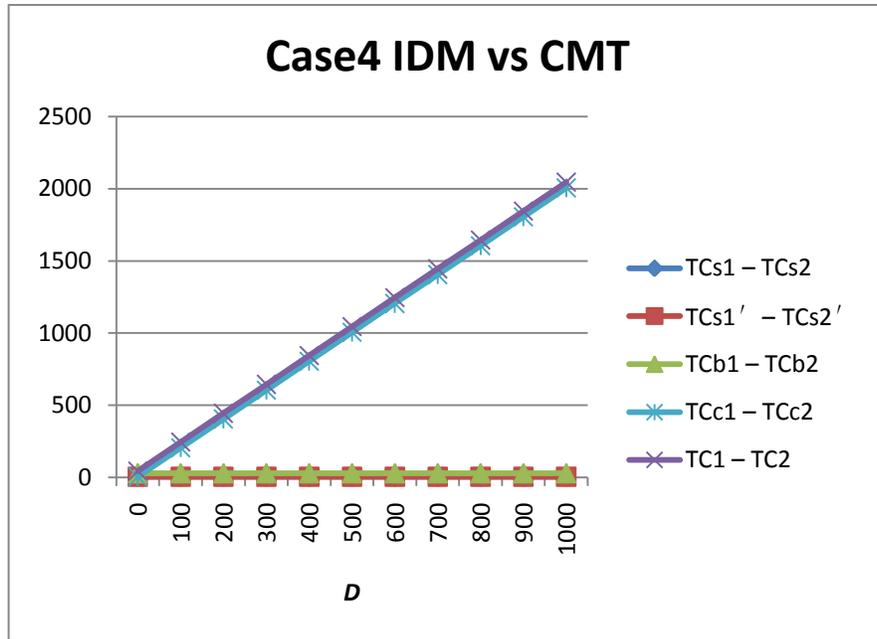
(1) $t_1 - t$, between values of 0 and 7, in steps of 1.



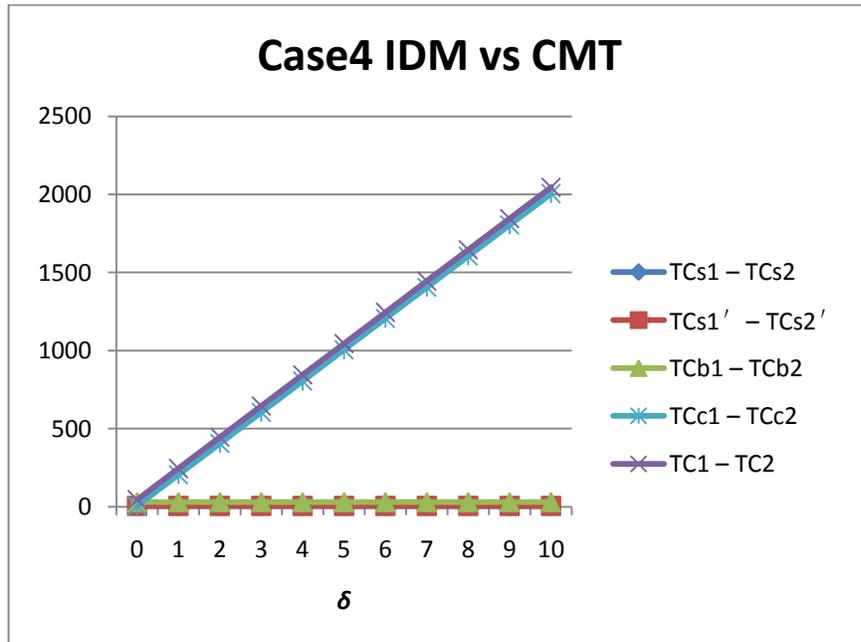
(2) K . Variation between values of 5 and 100, in steps of 5.



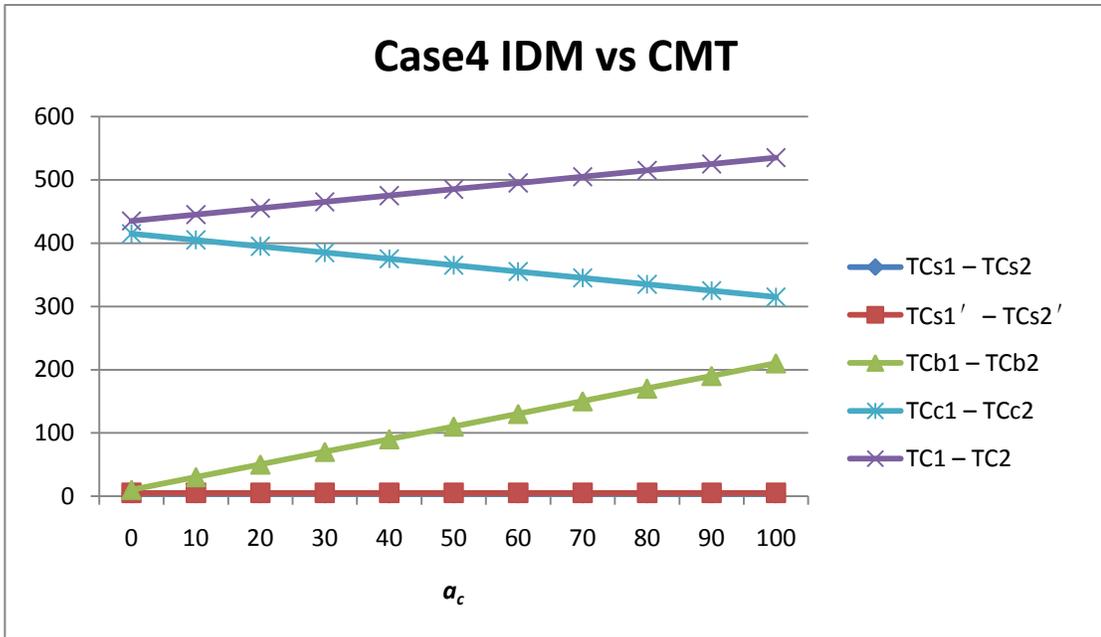
(3) D , between values of 0 and 1000, in steps of 100.



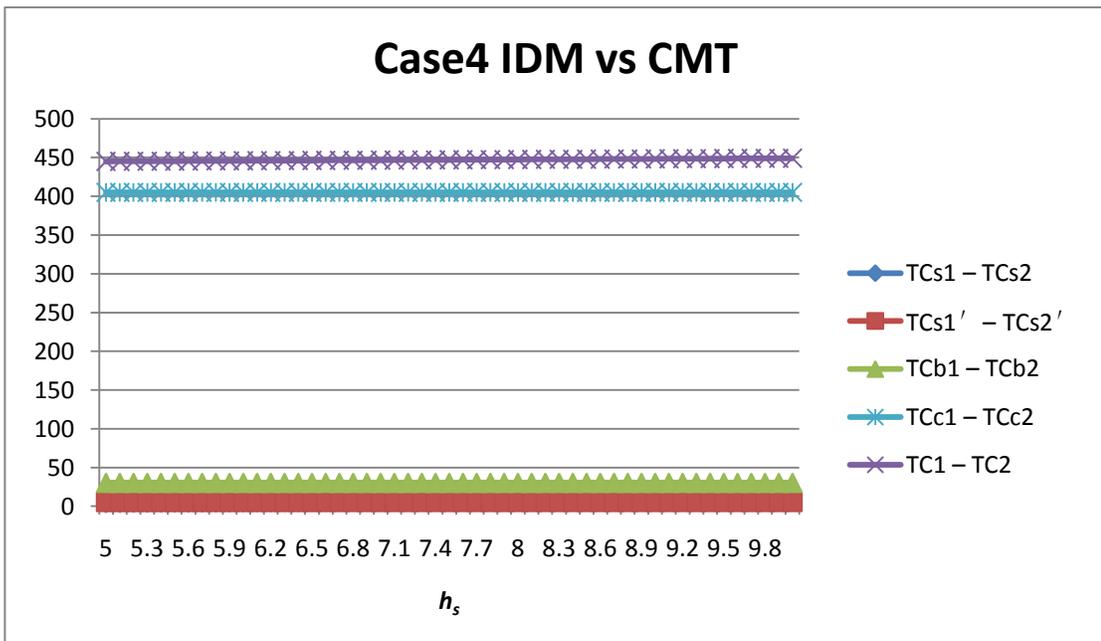
(4) δ , between values of 0 and 10, in steps of 1.



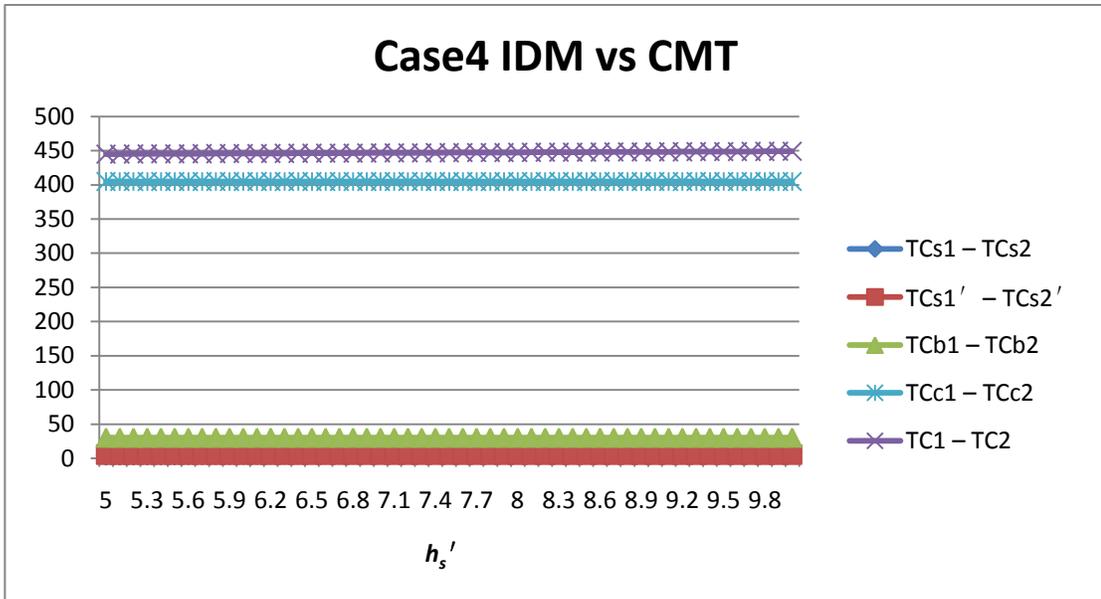
(5) a_c , between values of 0 and 100, in steps of 10.



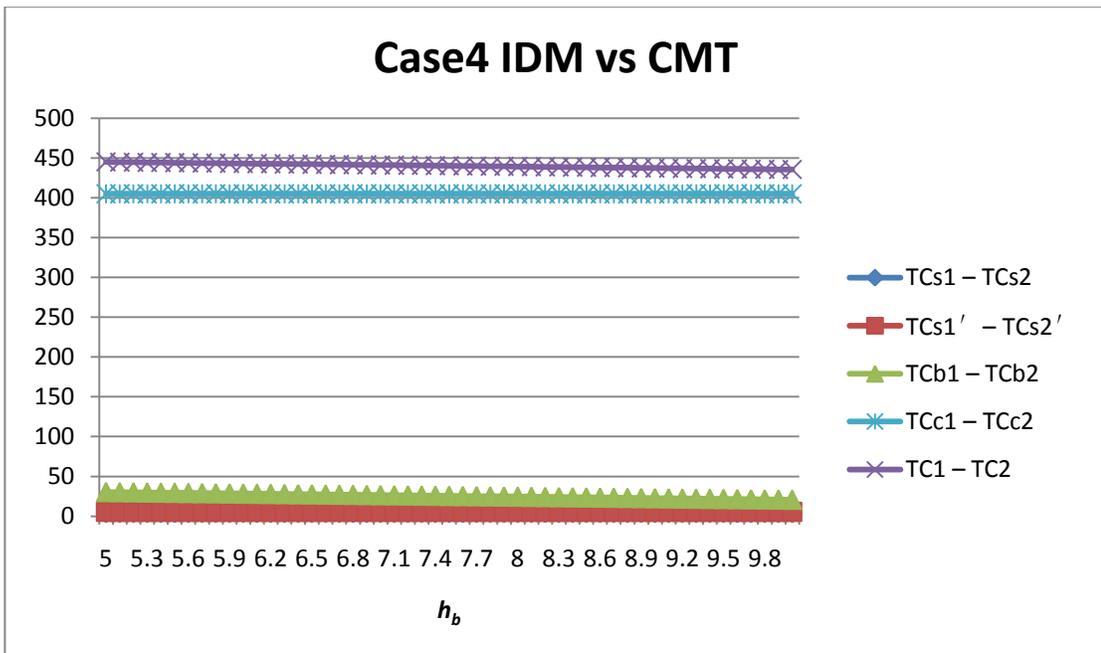
(6) h_s , between values of 5 and 10, in steps of 0.1.



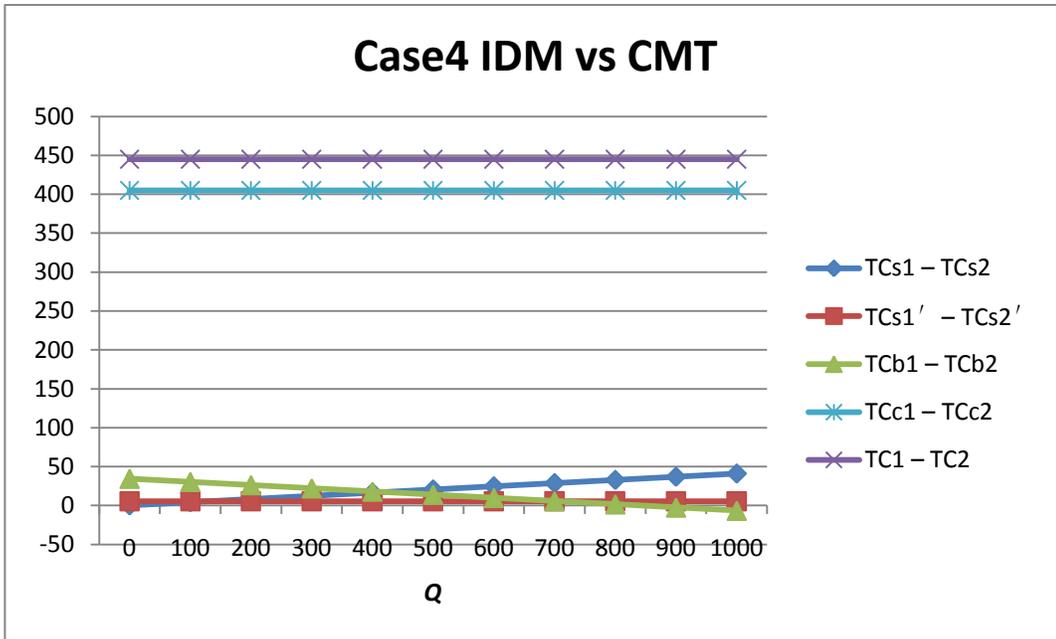
(7) h_s' , between values of 5 and 10, in steps of 0.1.



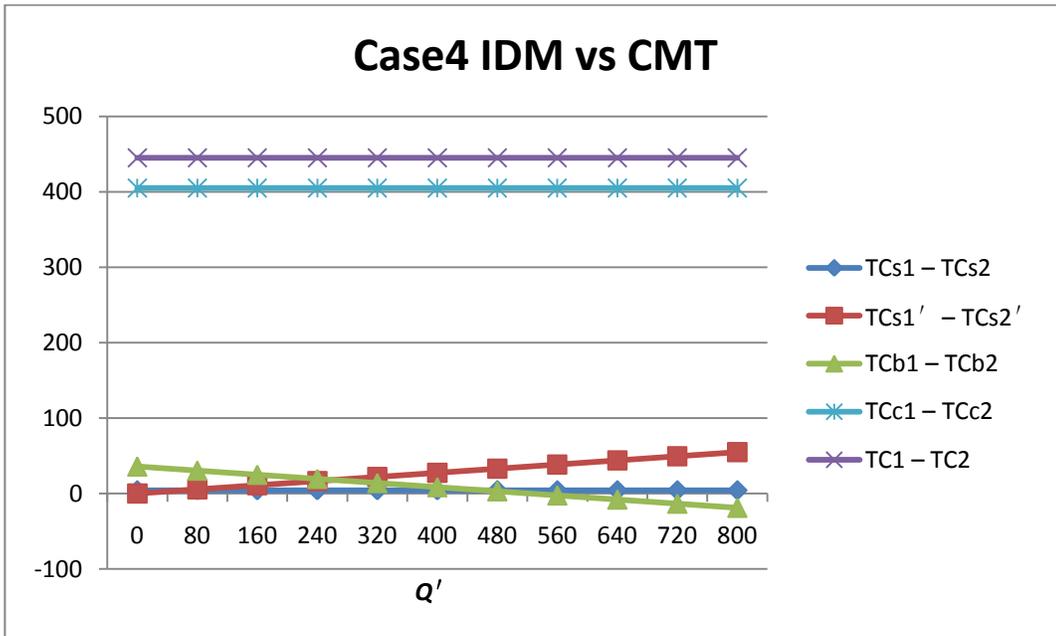
(8) h_b , between values of 5 and 10, in steps of 0.1.



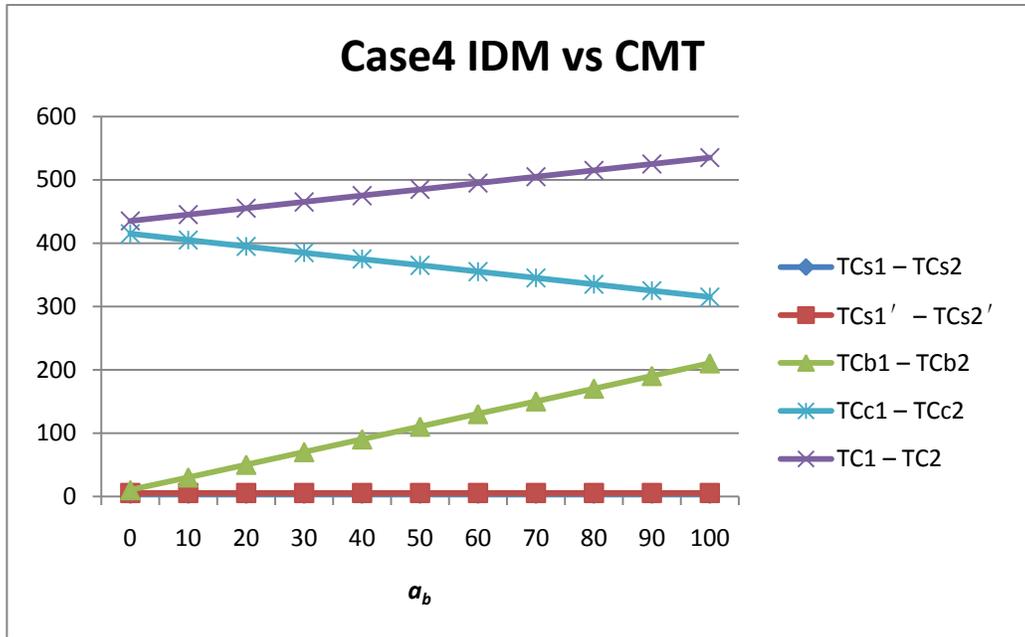
(9) Q , between values of 0 and 1000, in steps of 100.



(10) Q' , between values of 0 and 800, in steps of 80.



(11) a_b , between values of 0 and 100, in steps of 10.



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