CIRRELT

Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport

Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation

Proactive Order Consolidation in Global Sourcing

Teodor Gabriel Crainic
Suzanne Marcotte
Walter Rei
Pawoumodom Matthias Takouda

July 2011

CIRRELT-2011-41

Bureaux de Montréal :
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal (Québec)
Canada H3C 3J7
Téléphone : 514 343-7575
Télécopie : 514 343-7121

Bureaux de Québec :
Université Laval
2325, de la Terrasse, bureau 2642
Québec (Québec)
Canada G1V 0A6
Téléphone : 418 656-2073
Télécopie : 418 656-2624

www.cirrelt.ca

Université Laval · UQÀM · HEC Montréal · École Polytechnique Montréal · Université de Montréal

Proactive Order Consolidation in Global Sourcing

Teodor Gabriel Crainic[1,*], Suzanne Marcotte[1], Walter Rei[1], Pawoumodom Matthias Takouda[2]

[1] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT) and Department of Management and Technology, Université du Québec à Montréal, P.O. Box 8888, Station Centre-Ville, Montréal, Canada H3C 3P8

[2] School of Commerce & Administration, Laurentian University, 935 Ramsey Lake Road, Sudbury, Canada P3E 2C6

Abstract. This paper discusses Proactive Order Consolidation (POC), a recently-proposed strategy for wholesalers acquiring goods according to global supply policies. The strategy aims to group orders before they are communicated to suppliers in such a way that the total cost of transportation and inventory of the firm is minimized. We briefly review processes and practices relative to procurement and order management, as well as consolidation activities in logistics. We then detail the POC concept and issues focusing on the associated information and decision systems and processes. Experimental results on data from an actual case study illustrate the interest of the POC strategy.

Keywords. Proactive order consolidation, global sourcing, bin packing, small order management.

Acknowledgements. While working on this project, T.G. Crainic was the Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research Chair in Logistics Management, ESG UQAM, and Adjunct Professor with the Department of Computer Science and Operations Research, Université de Montréal, and the Department of Economics and Business Administration, Molde University College, Norway. P.M. Takouda was post-doctoral fellow with the Chair. Partial funding for this project has been provided by the Natural Sciences and Engineering Council of Canada (NSERC), through its Industrial Research Chair and Discovery Grants programs, by the partners of the Chair, CN, Rona, Alimentation Couche-Tard and the Ministry of Transportation of Québec.

---

* Corresponding author: TeodorGabriel.Crainic@cirrelt.ca

Dépôt légal – Bibliothèque et Archives nationales du Québec
Bibliothèque et Archives Canada, 2011

1 Introduction

The retail industry the world over is engaged in selling consumer goods and related services through stores to the general public, goods being typically obtained from another industry sector, the wholesale industry. The two sectors account for a significant part of the economy. To illustrate, the Canadian retail industry accounted for 415 billion CND (Canadian dollars) of sales in 2008, while the figure was 532.5 billion CND for the wholesale industry (Statistics Canada, 2009). The corresponding figures for the United States in 2008 were 4 417 and 6 116 billion USD, respectively (US Census Bureau, 2010a,b).

The differentiation between the two sectors is not always clear, however. Wholesalers, whose main activities consist in acquiring large quantities of consumer goods, may also operate their own networks of physical or virtual retail stores. Simultaneously, large retail firms tend to trade directly with suppliers and acquire important quantities of goods "wholesale" (or even to engage in manufacturing operations for the production of private-label goods) to be distributed to stores through their own network of warehousing facilities. In this paper, we focus on the wholesale procurement activities of both types of firms, which, for the sake of simplicity of exposition, we identify as *wholesalers*.

The procurement function of a wholesaler is charged with acquiring and delivering to its warehousing facilities the goods to be distributed and sold through retail stores or any other channel. These activities come under a lot of pressure from different sources. Clearly, the price and quality of the goods must be adequate for the targeted consumer groups, generally, low and high, respectively. Transportation costs must also be controlled, particularly for firms bringing in goods from distant sources and operating over broad geographic areas. Inventory levels must be sufficiently high to satisfy demand, but not too much so in order to control inventory costs.

Good procurement policies supported by efficient supply chains are required to address these challenges and achieve the profitability goals of the firm. The policies and practices implemented by each firm may differ, however, according to the type of consumer goods distributed and the market targeted. *Global sourcing* has emerged, however, as a strong common trend for the wholesale industry.

Global procurement sourcing consists in acquiring part or all of the goods sold by the firm from suppliers from countries all over the world. Global sourcing progressed continuously and strongly in the last decades with the setup of broad free-trade economic zones, the liberalization of the economies of several countries (sometimes, but not always, accompanied by changes in the political regime toward a more democratic rule), the introduction of information, communications, and decision technologies, and more liberalized trade rules. The various rounds of multilateral negotiations of the General Agreement on Tariffs and Trade (GATT), the creation of the World Trade Organization following the Uruguay round of the GATT, and the free-trade agreements resulting from bilateral negotiations aim to define rules and somewhat control the international trade and the exchanges of goods, services, labor, and capital.

Cost control is the main motivation for global sourcing. Acquiring goods from countries with low manufacturing costs became the usual practice for most of the wholesale industry. Countries like Mexico, the Philippines, Brazil, India, Vietnam, and of course China, have thus become major players in the international trade, resulting in a dramatic increase in the number, variety, and volume of products traded, as well as in the distances over which they are moved. Longer supply lines translate into higher total delivery times, while costs fluctuate with the price of oil in an upward trend. Longer supply lines also translated into a significant role for container-based intermodal transportation, both on the seas and on land, which has become the backbone of international trade.

One of the main challenges of logistics and supply chain management in the 21st century is therefore to create innovative processes, practices, and tools to assist firms to efficiently manage their supply chains and, in particular, their global-sourcing procurement processes. Our goal is to provide such processes and tools. We focus primarily in this paper on wholesalers carrying durable or non-perishable consumer goods, for which the ratio of goods acquired overseas relative to "local" procurement is increasing steadily. Those wholesalers often deal with suppliers located far away, e.g., in Asia or South America, and thus display extended supply chains and complex procurement decisions.

The main goal of procurement for such firms is to replenish inventories. Advanced inventory-management methods and tools have been developed to help decide when and how much to order, and those methods generally account for the lead time. When long transportation distances are involved, however, one faces a more complex decision problem involving the choice of the appropriate mix of containers (selected from a restricted set of standardized types and dimensions), the quantities to order, and the total cost of long-haul transportation and inventory in storage facilities until products are sold to customers. These decisions are particularly central to the overall profitability of the firm when large volumes of relatively small orders are considered.

"Small" in this context is defined as larger than the size normally moved by small-package delivery services, but much smaller than the volume of a container. Indeed, decisions are relatively simple when they concern few orders with volumes appropriate for small-package delivery services, or when order volumes are relatively close to the capacity of one of the standard-sized containers and *Full-Container-Load* (*FCL*) transportation is appropriate. For all other numerous cases, one must trade off the cost of using a *Less-than-Container-Load* (*LCL*) policy or using only a small part of a full container, both choices resulting in high unit transportation costs not agreeable to most managers. This induces a tendency to order more than indicated by the inventory-management system, to take advantage of the full capacity of low-unit-cost large containers, to the detriment of an increase in inventory costs.

The *Proactive Order Consolidation* (*POC*) strategy aims to avoid these pitfalls. Its goals is to support an integrated and demand-driven supply chain by providing the means to achieve a profitable trade-off between procurement, transportation, and inventory management. POC is inspired by the consolidation idea that has long been successfully applied to transportation and physical distribution. Different from these areas, where consolidation concerns physical flows once movements are already decided, POC aims to group orders **before** they are communicated to suppliers, in such a way that the total cost of transportation and inventory of the firm is minimized. It is in this sense that we describe POC as a *proactive* order-consolidation strategy. According to our best knowledge, this idea has been little, if at all, explored in the literature. We hope this paper will contribute to increase interest and foster research efforts.

The paper presents the methodological, technological, and managerial aspects of proactive order consolidation and illustrates some of them through a case study in the hardware-wholesale industry (Béliveau, 2008; Crainic et al., 2009, 2011a). The paper is organized as follows. Section 2 reviews a number of processes and practices relative to procurement and order management, while Section 3 discusses consolidation in logistics. Section 4 then introduces the proactive order consolidation concept and discusses a number of related issues focusing, in particular, on the associated information and decision-support system and the processes that have to be set up or modified. The case study is detailed in Section 5 and we conclude in Section 6.

2 The Procurement Process and Players

Procurement is charged with acquiring the materials required for a firm's operations and delivering those materials to the appropriate facilities. The procurement function is often mistakenly identified as "purchasing". In traditional logistics, the objective of a purchasing manager was to simply find the lowest-cost supplier. In today's modern integrated logistics era, successful organizations follow a different approach and develop partnerships with their suppliers of goods and services. They rely on suppliers to improve quality, reduce costs and assist with product design and development. They learn to trust their suppliers. Therefore, other activities, as important as purchasing, are part of procurement. Thus, in general, procurement management groups five main activities: purchasing, consumption management, supplier selection, contract negotiation, and contract management. These activities are inter-related, and coordinated through what is called the order-management process. Figure 1 illustrates the main information flows associated with these processes, and identifies the corresponding functions and players involved.

Order management in the retail and wholesale industries typically starts, at the tactical level of planning, with consumption management. This consists in understanding how much of each category of products is being bought both centrally and within particular units (e.g., regional distribution centers). These quantities are strongly related to the expected level of sales, and are regularly compared to actual consumption and sales, and updated. The firm then sets up

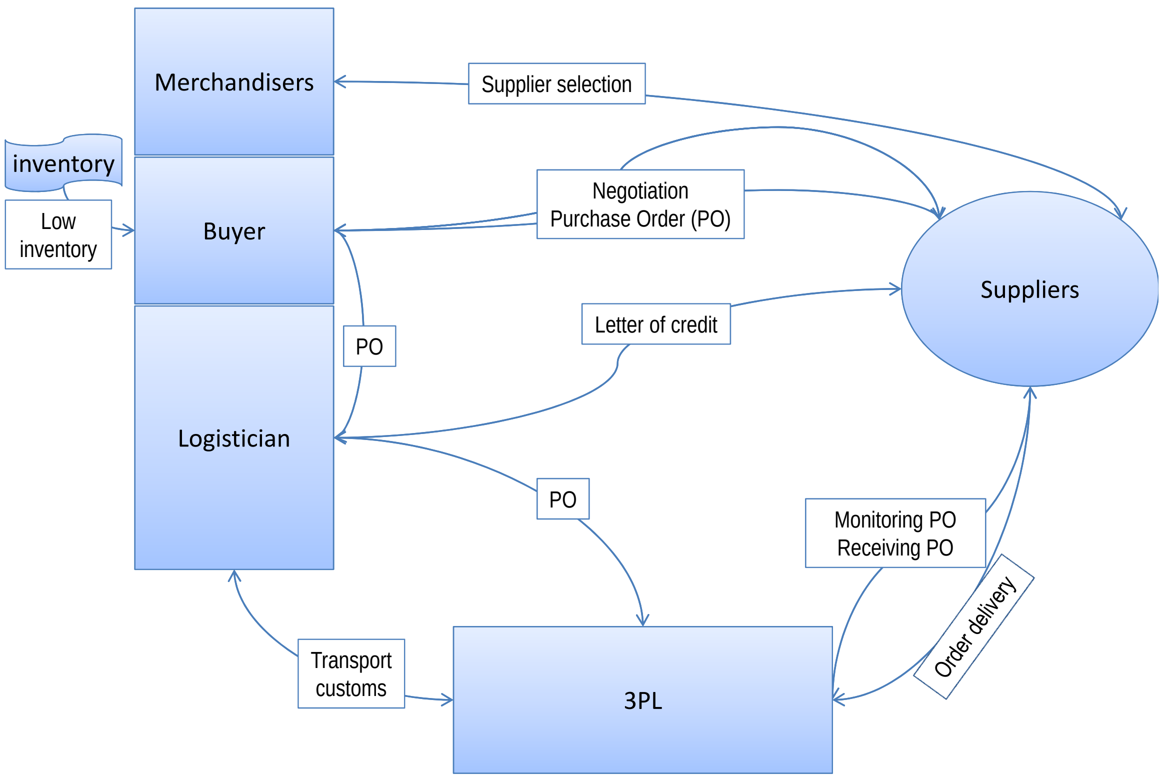

Figure 1: Wholesale procurement process - Main players and information flows

proper inventory-management policies for each product or category of products, and the corresponding order strategies. Supplier selection is also generally associated with the tactical level of planning, the people performing this function being identified as *Merchandisers* in Figure 1. Given the inventory and order policies for each category of products (or individual product), the merchandiser aims to select the appropriate supplier(s) for the next planning period (e.g., the next year). Decisions are made based on several factors such as price, product quality, supplier service level, just-in-time delivery, value added services, etc., and also concern strategic considerations, such as single or multiple sourcing and the geographical balance between local and global sourcing. More than one supplier may be selected to hedge the risks associated with lead time constraints and other uncertainty sources proper to the industrial sector considered. The output of this process is a preferred-supplier list specifying for each product or category of products, the subset of suppliers to be used during the next planning period, as well as a number of conditions associated with each particular contract (e.g., minimum and maximum values for the total product volume to be purchased over the next planning period, prices ranges, discounts, etc.).

Purchasing occurs at the operational level within the framework set by the order and inventory policies and the preferred-supplier list, and is triggered by a low inventory of a given product (the Inventory form in Figure 1). The *buyer* then determines the quantity of product to be acquired and when it should be received (due date) for the firm to maintain its service level. The buyer also determines whether multiple suppliers should be used if it appears improbable that a single supplier will meet the specifics of the required purchase (i.e., the specified quantity delivered for the defined due date). One or several contract "negotiation" activities then start with the chosen suppliers.

The scope of these negotiations depends on the type of understanding the firm and the supplier have agreed on at the tactical (merchandiser) level (Monczka et al., 2009). In many cases, particularly when orders are repetitively issued to the same supplier, this understanding takes the form of a blanket purchase order, i.e., an open order valid for the length of the planning period that specifies the terms of the purchase contract. The buyer then simply communicates with the supplier and engages in a routine order release. In many other cases, however, negotiations must be undertaken for each purchase to specify the particular order details, items, prices, deadlines, service levels and so on. Performance targets may be set at this point, as well as bonuses or penalties for meeting or not the targets. The buyer contacts the first company in the preferred-supplier list and undertakes such a negotiation within the framework of the general understanding. If successful, a *purchase order* (*PO*) is issued. Otherwise, the next supplier on the list in contacted, until the desired items are secured. This second case is particularly present in global sourcing, when suppliers are sited in emerging-economy countries and the confidence of the buying firm in their reliability is weak. To simplify the presentation, we use PO to indicate the output of this process for both "negotiation" cases.

Management approves the PO and the finance department arranges for payments, which are usually made using letters of credit. The supplier then produces the order (make-to-order strategy), assembles the order from pre-produced modules (assemble-to-order), or picks it from its inventories (make-to-stock strategy). Depending on how responsibilities are assigned, transportation arrangements for the goods to be delivered to the wholesaler facilities are undertaken by the supplier, the firm or both. The *Logistician* box in Figure 1 represents the people within the firm in charge of organizing and supervising these transportation activities. The same people also monitor the progress of the order from the time the PO is issued until the goods are in the firm's warehouses. Monitoring provides the firm with the ability to react to delays or other unexpected events, as well as track the performance of its suppliers and hold them accountable relative to the service level agreed upon. Part of these activities may be outsourced and be performed by a Third Party Logistics company - the 3PL box in Figure 1 - either independently or in close collaboration with the logistician.

The previous description emphasizes the flows of money (financial flow), goods (physical flow), and information between the buyer and its suppliers. These flows are largely determined by the flow of decisions made by each of the players involved, reflecting the practices and strategies of each firm, including continuous supply, inventory-investment minimization, quality improvement, supplier development, lowest total cost of ownership, gradual volume consolidation (i.e., reduction of the number of suppliers to a rigorously screened supply base), supplier operational integration (regarding processes and activities for substantial performance improvement), and value management (advanced planning and operational integration, adding value at each step of the process and resulting in a comprehensive and sustainable relationship) (Bowersox et al., 2005). Modern information and decision technologies, including Enterprise Resource Planning (ERP), Electronic Data Interchange (EDI), and Xnet technologies, usually support procurement practices and strategies.

Not all these policies may be contemplated when global sourcing is involved, however, particularly when suppliers are located far from the territory where the wholesaler conducts its business. In this context, suppliers are generally sited in less-developed, low-cost manufacturing countries, where the level of penetration of information technology is lower than in developed countries, and where legal and cultural differences induce a number of additional risks and increase uncertainty and logistical challenges (Bowersox et al., 2005; Simchi-Levi et al., 2002). Of particular interest in this section are issues related to transportation management and the relations among the various elements that make up the total procurement cost of a given product.

Consider the logistics network corresponding to the global sourcing activities of a wholesaler, very schematically illustrated in Figure 2. Products shipped by suppliers sited in a far-away region, identified as "overseas" in the figure, are transported by means of consolidation-based carriers (Crainic and Kim, 2007). Goods are first gathered at a "port of origin" (which may be an actual maritime port or an inland rail or trucking terminal) to be loaded into containers (if not already packed by the supplier), Those, in turn, are loaded onto a long-haul transportation vehicle, a deep-sea container ship, a train or a truck, to be delivered to a "port of destination" in the area serviced by the wholesale firm. At the destination port, containers

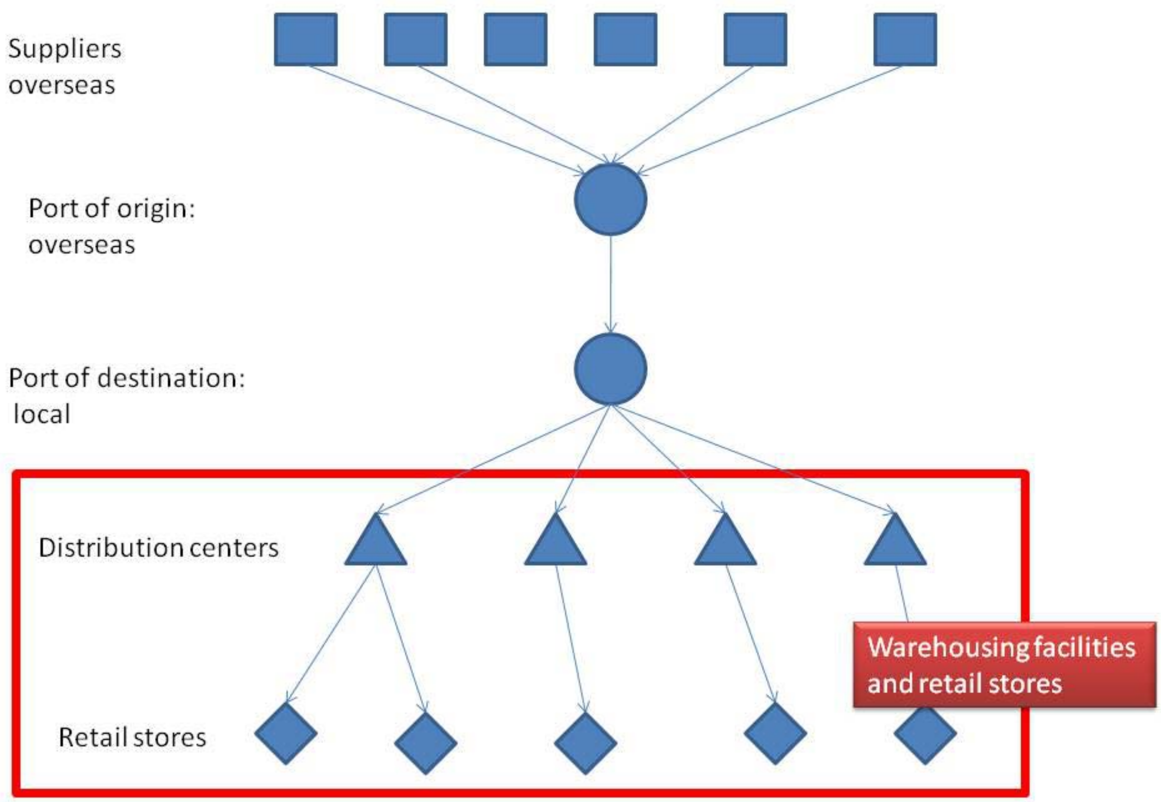

Figure 2: Logistics network for global sourcing

are unloaded and sent to the appropriate warehousing facilities for distribution to stores and customers. Notice that the long-haul transportation link may actually represent an intermodal chain, e.g., a sea-rail combination, which we do not detail for the sake of simplicity of presentation. As for the containers used to move the freight, they belong to different types defined by their dimensions (standard maritime containers are 20 or 40 feet long, while on land they may reach 53 feet), the particular environment they offer (e.g., regular, thermal, or refrigerated box), their form and type of loading, and so on. For our purposes, each type of container offers a fixed volume for shipping goods, and a fixed cost is charged for its utilization on a given trip, regardless of how filled it is.

In this context, when the replenishment quantity issued by the inventory-management system would fill one or several containers, the FCL transportation mode is appropriate. Otherwise, when the replenishment volume is really small and may be handled by regular or express package mail services, the utilization of such services is the way to go. In both cases, the order volume equals the suggested replenishment quantity, and the procurement cycle continues as described previously.

Frequently, in non-perishable goods wholesale and retail procurement, the replenishment quantity falls in between these two extremes. Ordering this quantity means that either one pays for LCL transportation or for a full container that one cannot use fully. Both choices result in a high transportation cost per unit of product volume going against the cost-reducing objective that motivated global sourcing in the first place. One then observes that buyers tend to boost the order volume to fill up a container.

Yet, from a global system point of view, this *boosted-FCL* strategy displays several shortcomings. First, larger quantities mean greater warehousing space taken up for longer periods. Second, even not counting that some products may go out of fashion with customers during this time, inventory costs increase, both in money frozen in the goods bought and in warehousing expenses. The "gain" made on transportation may thus generate a deterioration of the profitability of the firm or, at least, of the respective product.

To illustrate, consider the example of a decorative item with annual sales of 2642 units. The inventory-management software takes into account the buying pattern and suggests an order quantity of 432 units, which represents a volume of 2.1 cubic-meters (cbm) and an average demand of about 8.5 weeks. According to the boosted-FCL strategy, this quantity is increased to fill a container. The smallest container available, a twenty-foot box, has a capacity of approximately 33 cbm and, thus, a boosted order would result in some 6788 units. The resulting per-unit shipping cost would be low, but the ordered quantity is more than 10 times larger than the one suggested by the inventory-management software. Actually, this boosted-FCL quantity represents the equivalent of more than 2 years of sales, with huge consequences on the annual inventory costs, which represent a significant part of the value of the goods. Moreover, it is very probable that more than half of the items will become obsolete (out of fashion) by the second year.

From a supply chain management point of view, the boosted-FCL strategy evaluates alternatives from a transportation perspective only, ignoring inventory activities and the finance function of the company. It thus goes against best inventory-management principles and the paradigm of coordination of logistic activities and functional areas of the firm in order to achieve an efficient and sustainable overall supply chain. Moreover, such a strategy may also result in setting up the supplier as the driver of the supply chain, the supplier being able to push its products via low-pricing strategies, leaving the retail chain to deal with inventories.

The Proactive Order Consolidation strategy aims to address these shortcomings by consolidating orders before they are communicated to suppliers, in such a way that full containers are used and the total cost of transportation and inventory of the firm is minimized. This strategy is described in Section 4. But, first, the next section presents an overview of the more traditional way of using consolidation in logistics activities.

3 Classical Consolidation in Logistics and Transportation

Consolidation in logistics is often defined as the accumulation of several loads to be grouped either in a vehicle (container, truck, plane, ship, rail car) or at a location (warehouse) (Bowersox et al., 2005). It denotes an active effort to use more efficiently the available transportation and storage resources.

Thus, a program (or policy) of freight consolidation associated with the planning of shipments is defined in Bookbinder and Higginson (2002) as a systematic attempt to decrease the total transportation cost between a given origin and destination. In this context, Çentinkaya (2004) distinguishes *pure* policies, specifically providing dispatching and consolidation rules whenever orders are processed, from *integrated* policies, which combine both inventory and shipping decisions when applying the consolidation strategies.

To implement such policies, an accumulation process is needed to group loads for consolidation. Three strategies have traditionally been used to define such a process: *temporal*, where loads are accumulated during a given fixed-length period, *spatial*, where attaining volume or weight limits stops the process, or *mixed*, the latter being a combination of the first two, accumulation being stopped as soon as one or the other limit is reached (Bookbinder and Higginson, 2002; Ford, 2001; Tyan et al., 2003). These processes are also referred to in the literature as *time-based*, *quantity-based*, and *hybrid* dispatch/consolidation policies, respectively (Çentinkaya, 2004).

Selecting an accumulation process very much depends on the criteria used to evaluate it (Mütlü et al., 2010). Thus, a temporal policy is preferable when trying to perform timely shipments to customers within quoted lead times as opposed to a spatial policy, which minimizes costs. A mixed strategy is useful when trying to strike a balance between the two criteria. It is thus generally acknowledged that the performance of a given accumulation-consolidation strategy depends on the desired customer service level and the order arrival rates (Higginson and Bookbinder, 1994). Yet, the particular characteristics of the transportation mode and service used may also influence performance. Thus, for example, a consolidated shipment may be released at any time when road transportation is used, provided that vehicles are available. When either maritime or rail services are involved, however, the release of a consolidated shipment must match the scheduled departure times of the ships or trains being used. Capacity restrictions also differ according to the type of transportation service considered. In the case of road transportation, capacity is usually less restricted given that vehicles are more readily available. The same cannot be said for maritime and rail transportation, where the number of available container spaces on ships and trains is limited. These transportation considerations are particularly important within global sourcing.

Consolidation may be performed by producers of goods shipping their products to their respective warehousing or distribution facilities or directly to customers, as well as by wholesalers and retailers shipping bought products from their distribution centers to stores. Transportation may be performed by a firm's private fleet, by vehicles hired from a full-load carrier (trucks or ships), or through the services of less-than-vehicle-load consolidation-based carriers such as railroads, LCL, or less-than-truckload motor carriers. See Crainic and Kim (2007) for consolidation in freight transportation. It is noteworthy that integrated consolidation policies require the coordination of several functions within the supply chain. Thus, selection of suppliers (Aissaoui et al., 2007), order and lot sizing (Aissaoui et al., 2007; Rizk et al., 2008), inventory policies (Bertazzi and Speranza, 2005; Bertazzi et al., 2007) and inventory-routing decisions (Bertazzi et al., 2008), all impact consolidation strategies.

Consolidation may also be "outsourced", that is, an external firm may take charge of the loads to be shipped or brought. This intermediary, usually a long-haul consolidation-based carrier or a third-party logistics firm, brings the loads into its own terminals, where they are sorted and consolidated with other loads, possibly from different origins and with different destinations, for long-haul transportation (of course, the initial pick up and final delivery is generally performed by dedicated vehicles). Notice that most 3PL firms use the services of consolidation-based carriers for this part of the journey, which may take the form of an intermodal path. This business and operation model has proved very successful for 3PL firms (Çetinkaya and Bookbinder, 2003; Chen et al., 2001; Min and Cooper, 1990; Wong et al., 2009; Krajewska and Kopfer, 2009).

The broad utilization of consolidation is explained by its benefits (Ford, 2001). It provides the means to take advantage of long-haul transportation pricing schemes, where freight rates decrease as the shipment size increases, and may further decrease transportation costs by reducing the total number of shipments. It also improves speed and reliability by reducing the handling of the products at intermediate terminals. Without any surprise, load consolidation also comes with some disadvantages. Thus, for example, temporal consolidation imposes additional delays to some loads, which must wait for the entire shipment to be ready, possibly translating into higher inventories and associated costs. Consolidation also requires more sophisticated procedures, processes, and methods for planning, monitoring, and control of operations and deliveries.

Advantages generally outweigh inconveniences, provided the appropriate consolidation strategy is selected (Bookbinder and Higginson, 2002). It is noteworthy that all these strategies are concerned with the consolidation of physical flows, once goods are produced and sold and distribution channels are selected. Such load-consolidation strategies do not address the issues identified in the previous section, relative to procurement of large numbers of low-volume products through global sourcing. Addressing these issues is the object of the proactive order consolidation strategies presented in the next section.

4 Proactive Order Consolidation

As previously mentioned, we consider the case of companies that, while using global sourcing, face the problem of managing the procurement of large volumes of relatively small orders placed to a variety of international suppliers. In such a case, companies must manage regular shipments emanating from a series of origin points located in different geographical zones. Each shipment is composed of a container or a set of containers carrying the orders and traveling long distances through intermodal transportation. How to efficiently manage such shipments, while minimizing overall costs, is at the heart of the POC strategy that is proposed.

The concept of proactivity refers here to the role played by a given firm in its own procurement process. Given the functions traditionally played by the 3PL in the organization of shipments in the context of global sourcing, a firm usually assumes a somewhat passive role in this respect. A POC strategy provides the necessary tools for the firm to play a more active role in the planning and management of shipments. In turn, this facilitates and improves the negotiations and interactions with the 3PL that provide the necessary transportation and storage services. By evaluating the capacity requirements to perform the necessary shipments earlier within the procurement process, a firm can benefit from better rates with respect to the logistic services provided by the 3PL and can better manage its own operations.

In this section, we present this general strategy and discuss some important factors to consider when applying it in practice. The section is divided as follows. We define the POC strategy in subsection 4.1, discuss some of the expected benefits that justify it, and enumerate important issues to be addressed when applying it. Subsection 4.2 discusses the information and decision support system (IDSS) required to support a POC strategy. We address issues related to the possible reorganization of the the general procurement process in Subsection 4.3.

4.1 Defining the POC Strategy

Within a properly integrated enterprise information system, relevant data concerning quantities of products to buy and the corresponding orders can be accessed at an earlier stage to gain proactivity in the supply chain. In turn, optimization models can be used to extract from this data meaningful and decisive information that will improve the overall procurement process. In the context of global sourcing, Proactive Order Consolidation can be defined as a strategy used to group LCL orders that are made through the procurement process and that share the same origin point for the long haul intermodal transportation. These groups are created to efficiently fill appropriate transportation containers with the objective of minimizing the overall total costs. Described as such, when using the POC approach, orders are assembled within containers to produce desirable shipments. Given the fact that different orders imply possibly different due dates, consolidation is applied here on subsets of orders that can be grouped and dispatched together in the same load. To identify such subsets, a consolidation window is associated with each order. Such a window defines the time period in which an order is available for consolidation. These windows are set according to the maximum amount of time the shipment of the associated order can be delayed, without causing a stockout or any other disturbance in the activities of the supply chain.

It should be noted that, as is defined here, the POC strategy is different from the classical load consolidation presented in the logistics literature. First, the wholesaler becomes responsible for implementing and controlling the consolidation strategy used to manage its own shipments. This is an important difference when compared to the situation where either the supplier or the 3PL are in control of the load-consolidation policy. However, this does not necessarily mean that the wholesaler is able to efficiently run such a policy on its own. For example, the lack of infrastructure (terminals in the supply regions or adequate information systems and decision support tools) or inadequate organizational structures may prevent the company from properly applying the consolidation policy. In such a case, the infrastructure and technical expertise provided by a 3PL may be necessary. Secondly, consolidation is applied on the information flow of the supply chain, not only to the physical flow. Finally, consolidation influences the outbound activities of the company (i.e., purchasing and contract negotiation), in addition to the inbound activities (i.e., freight transportation).

As expected benefits from such a strategy, we first note the economies of scale that can still be obtained even when placing LCL orders. By applying consolidation early in the procurement process, a company can organize shipments that batch orders to be made to a particular supplier. Therefore, this type of batching maintains a high volume of goods ordered from a particular supplier, which enables the economies of scale. The POC strategy also allows for more efficient transportation operations. As mentioned previously, in the case of global sourcing, freight travels long distances packed in appropriate containers. By using the proposed strategy, a company obtains an early plan that specifies the numbers and types of containers that are required to perform the shipments, as well as a list of specific orders and their assignment to the chosen containers. In turn, this information can be used by the wholesaler in different ways, either to improve the deployment of the transportation capacity that is internally available. Alternatively, the information can be used in the negotiations with the 3PL firms. A detailed plan, provided to the 3PL in advance of the shipping date makes for more efficient transportation operations. In turn, this may reduce the costs that are paid by the wholesaler for the logistics services provided by the 3PL. Finally, the POC strategy helps in maintaining normal levels of stock. Indeed, because orders are made based on the replenishment needs of the company (as opposed to the FCL strategy), the procurement process follows more closely customer demands, which helps maintain the levels of stock under control.

When applying this type of strategy, a series of important issues have to be addressed. A first such question is: how should the subsets of orders used in the POC strategy be defined? Subsets can be constructed by collecting orders either one-by-one, as they are issued by the procurement process, or in groups. The latter case may be implemented when a wholesaler is interested in accumulating orders for a particular supplier before applying POC (i.e., batch the orders).

The question of **when** should orders be considered for consolidation, is also very important. As soon as a reordering signal is issued by the inventory-management system of the firm, an order can be prepared and becomes available to consolidation. This defines the beginning of the consolidation window for the order, at which point negotiations with suppliers have not yet taken place and the firm is still free to impose lead-time requirements (i.e., the order may be delayed according to the operational policies in use). This point in time may even be forestalled if a company wishes to consider, within the POC approach, orders that are forthcoming in an effort to anticipate shipments. In this case, forecasting is applied to predict both the volumes of the orders and the due dates used. Also, orders that are considered for POC will be so for a given period of time. As such, to what extent should a consolidation plan be revisited whenever new orders appear? This also relates to the definition of the subsets used within POC. They either include exclusively new orders, or, they take into account orders that have already been consolidated but for which the associated shipment as not yet been made. In all cases, when adjusting consolidation plans, it should be noted that due dates may not be changed once the POs are issued.

The issue of **how** to decide on what and how to consolidate is also important. As will be explained within the next subsection, Bin Packing models (Martello and Toth, 1990b; Wäscher et al., 2007) provide the methodology of choice when addressing the considered problem. However, the choice of the particular model to use will depend on the specific use of the POC strategy.

Finally, issues related to the overall uncertainty associated with the procurement process must also be addressed. Uncertainty involving either the suppliers (change in due dates, transportation arrangements, etc.) or the transportation activities (containers not available, logistic operation times at the points of origin, etc.) justify the need for both monitoring and control throughout the process. How should this monitoring be applied and what type of controls to use, to ensure that both the consolidated orders and the chosen containers are available on the day of shipment, are important points to cover when implementing the POC. Also, uncertainty entails the need for adjusting the established consolidation plans as new information becomes available. For example, to what extent can the wholesaler company change the consolidation plans to account for delays in delivery to the origin port of a number of orders? That is an important point to address, since it may impact the efficiency of the procurement process. Treatment may be impaired by the availability of information, however. Thus, there is a time limit defining the moment when a planned and filled container (i.e., given the assignment of orders to the container) can no longer be changed given the shipping date. Until that time is reached, admissible adjustments should reflect the operational policies of the particular company implementing the POC.

4.2 Information and Decision Support System

We now turn to the issue of the information and decision support system (IDSS) that is needed to support a POC strategy. We first assume that the general operational processes of the wholesaler are supported by proper information technology tools. Ideally, an integrated ERP system is available or, at the very least, an appropriate logistics information system exists. In addition to the existing tools, the IDSS required for the POC should be able to perform the following general functions:

- Preprocessing: process orders according to their characteristics;
- Consolidation: assign subsets of orders to appropriate containers;
- Monitoring: perform the necessary follow up to ensure efficient procurement operations;
- Business analytics: perform necessary forecasts, reliability analysis and evaluation of the procurement process.

The preprocessing function is used to efficiently filter, sort and group orders that are made through the procurement process. Orders must first be filtered according to their volume. This will distinguish the orders that will be shipped using either the FCL transportation mode, the regular or express package mail services, or using the POC strategy. Only those orders that would fall in the LCL category are considered for POC. Preprocessing is also used to sort orders according to the origin and destination points, the supplier, and the consolidation window. Overall, this function serves to produce the subsets of orders used in the POC strategy.

Consolidation constitutes the main POC-related function of the IDSS. It aims to establish for each shipment the number and types of containers that are needed, as well as an assignment of available orders to the containers. This is done with the overall objective of minimizing costs, based upon the number of containers to be used, or the total fixed (transportation) cost that is paid to use them. This type of problem is well-known in the operations research community, and is referred to as *Bin Packing* (*BP*) problem (Martello and Toth, 1990b; Wäscher et al., 2007).

Different BP problems are defined in the literature according to a number of criteria, including bin (i.e., containers) and item (i.e., orders) dimensionality, how items may be placed within bins, the assortment of bins and items available, the shape of items, the optimization objectives, and so on. The dimensionality criterion refers here to the characteristics of items and bins used to define a feasible item-to-bin assignment (corresponding to constraints in the mathematical BP formulation). These characteristics may simply represent physical attributes, e.g., volume, length, height, etc.. They may also include placement (e.g., the load weight should be uniformly distributed within the container), or item-to-bin compatibility requirements. The choice of packing model, and associated solution approach, to be included in the IDSS, should therefore reflect the problem specifics faced by the firm implementing the POC strategy.

In addition to the physical packing characteristics considered, the model should also represent the planning context in which the IDSS is used. As such, should the model be *deterministic*, possibly using forecasts to account for upcoming orders, if such orders are considered? Or, should it be *stochastic*, in which case uncertainty is explicitly accounted for in the model formulation. Also, should a static model be used (consolidation is applied to different subsets of orders at different moments in time), or should it be *dynamic* (orders are consolidated one by one as they are made through the procurement process and the consolidation plans are adjusted accordingly)?

The monitoring function within the IDSS is used to perform all follow-up activities and controls that are defined by the firm to ensure that the consolidation plans are followed. Therefore, such a function is used to follow the groups of consolidated orders, flagging delayed orders and adjusting the plan, if necessary. Monitoring also includes verifying with the 3PLs that containers will be available as planned.

Finally, the business analytics function relates to the capacity of the IDSS to both access historical data and to perform certain specific tasks, e.g., forecasting upcoming replenishment needs, measuring the reliability of suppliers and 3PLs, and evaluating the procurement process.

4.3 Reorganizing the Procurement Process

Implementing a POC strategy and incorporating the corresponding IDSS into the procurement process requires revisiting its organization. It calls for, in particular, specifying the people in the firm who will be in charge of deciding on the consolidation, and when to apply POC during the procurement process.

We have identified five possible positions within the procurement process for POC. These five, not necessarily exclusive, positions lead to different versions of the procurement process. Thus, the IDSS can be used, for a given time window and origin-destination pair, every time a new order is being planned, released, paid, or received at the port of origin (POO), according to the option selected among those proposed in this subsection. Each of these events could involve a complete revision or a small adjustment of the consolidation plans already decided upon. Therefore, a deadline can be set on when the consolidation decision is to be reached for the filtered orders that have been assigned to a given group until then. Afterward, a monitoring mechanism (discussed in the next subsection) reacts to the occurrence of various events and eventually adjusts the consolidation plan.

The five positions of the IDSS within the procurement process are indicated by triangles in Figure 3. The position called Option 0 is for comparison with the other options proposed; there is no POC associated with it. The four other locations refer to different steps of the procurement process. It must be noted that when consolidation is performed after the PO has been released, it is rather a *load* consolidation, not an order consolidation. The intended proactivity within the supply chain is then lost. In all cases, the BP optimization methodology provides the packing of orders within the chosen containers that will be used to prepare the shipment, with the goal of minimizing the total cost.

Option 0: IDSS just before load consolidation of orders. In this setting, the consolidation is to be performed with the orders that are in hand at the POO at the time containers must be loaded. This consolidation approach is very similar to standard load consolidation, particularly when it is outsourced to the 3PL. As indicated, with this option, the intended proactivity within the supply chain is lost.

Option 1: IDSS after confirmation of orders. Similar to Option 0, the IDSS, according to this option, is called upon just before the packing due dates at the POO. The advantage of this option, compared to Option 0, is that one can consider not only the orders of the given group, but also those for which an on-time delivery “confirmation” was received from the suppliers, even though they are not yet at the POO. Of course, there is uncertainty about those latter orders, and they should be monitored carefully. It might even be appropriate to consider only the orders provided by trusted suppliers. If some orders are not received by the due date, an Option 0 consolidation might be required. Similar to option 0, Option 1 does not support proactivity within the supply chain.

Option 2: IDSS just after payments. This setting and the following options enable proactive consolidation. It is the logistician who is in charge of POC in this case, and the consolidation strategy is to be applied once (most of) the payments of the POs are confirmed for a given group. Because the IDSS is placed earlier in the procurement process, decisions may be made by considering orders already confirmed exclusively, or, including also the possible incoming orders based on forecasts. These forecasts consider regular products but may also take into account special events such as sales promotions or seasonal items. This option yields two

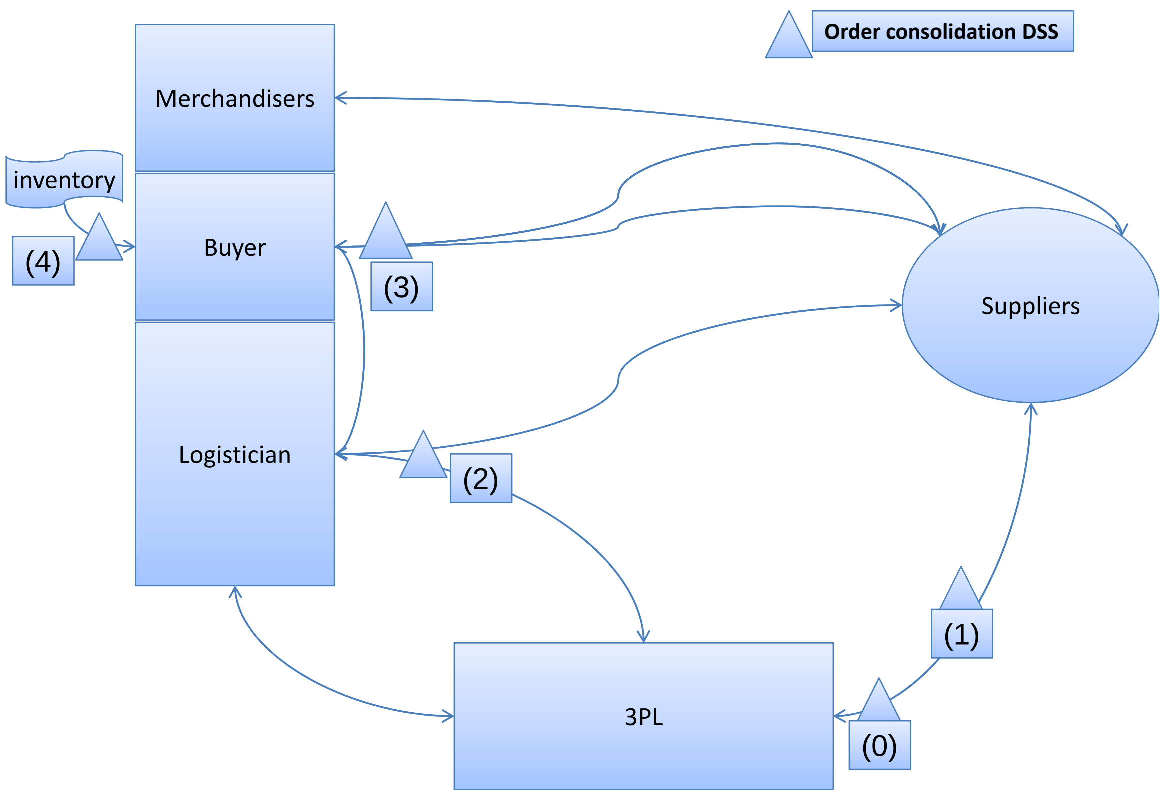

Figure 3: Locating the IDSS within the proactive order consolidation process

information strategies for Option 2, with and without forecasts. The choice, as with the other possible strategies and utilization modes described in this section, must be application-specific, and determined according to the policies of the firm and the level of risk management is ready to accept. Simulation provides the appropriate tools to assist making these decisions.

When using the IDSS at this stage, one ends up with "virtual" containers made up of orders already placed but not yet shipped by suppliers. Several sets of such virtual containers may exist simultaneously for various combinations of order consolidation window, origin, and destination. Then, when a new order is placed within the system, a decision must be made to either consolidate the order immediately, within the appropriate group given the characteristics of the order, or wait for other orders with similar characteristics to be available before applying consolidation. This choice yields at least five possible *packing* strategies that, combined to the two information strategies above, yield ten possible utilization modes.

When orders are processed as they appear within the system, the POC packing strategy may be to:

1. Find the best assignment of the order to one of the virtual containers already defined (if no feasible assignment is possible then a new container is to be used);
2. Undo all the previous virtual containers and pack all available orders, including the new one, into a new set of containers.

On the other hand, when orders are collected in groups before being considered for consolidation, the following three packing strategies may be defined:

1. Consider only the orders within the group, and find the best assignment to new containers;
2. Find the best assignment of the orders to either new or previous virtual containers (without undoing previous decisions);
3. Consider all orders (both old and within the new group), and find the best packing into new containers.

There is an important point to be made if previous decisions are allowed to be changed. In this case, a limit has to be set on which virtual containers can be undone. This limit should reflect the fact that a particular container is less likely to be undone as time passes.

Option 3: IDSS just after reorder flag. According to this third option, consolidation is decided upon at the same time orders are prepared and placed, both tasks being assigned to the buyer. This option is very similar to the previous one. The main difference arises when forecasts are allowed to be considered, when Option 3 appears potentially more efficient than Option 2.

Indeed, it is the buyer who receives the reordering signals from the firm's inventory-management system, and then proceeds to prepare the corresponding orders. It is the buyer, therefore, who is in the best position to query the system regarding products that are expected to be in need of re-ordering within a short period of time, products from a potential supplier, and so on. It is therefore much easier at this level, compared to Option 2, to decide on advancing some buying decisions or on considering potential buying decisions that could happen in the very near future. Leaving these tasks to the logistician (Option 2) would require either a redefinition of the tasks each function must perform, or an increase in the workload of the buyers, or both.

Option 4: Integrating the IDSS to the inventory management system. This is the "fully automatic" version of Option 3, which may facilitate integrating forecasts into POC. Of course, this does not mean the buyer function is eliminated, far from it. The buyer must still decide whether to call on several suppliers for a given product, as well as interact with the inventory-management system to decide on the consolidated groups. The buyer is also still in charge of negotiating and preparing the final orders and associated forms (POs).

To conclude this part, we emphasize that the earlier the proactive consolidation activity is placed within the procurement process, the more global the view one may have on the entire process and system. This may lead toward a more systemic and global optimization of this component of the supply chain. It may also offer the opportunity to negotiate better terms with the various partners and service providers, carriers and 3PLs, in particular.

On the other hand, early decisions on consolidation imply that uncertainty could play a more important role. Forecasting that, in the (near) future, one will need to issue orders for other products generates some of this uncertainty, which may be important for seasonal or in-promotion products, but much less so for regular ones. Uncertainty also comes from the behavior of suppliers and carriers. Orders may arrive late, incomplete (backorders arriving at some later point in time), and with some items damaged in transport. In most cases, one would need to update and adjust the consolidation plan. Monitoring the progress of orders, to enable the system to react to various events, is required in all cases.

Monitoring is not a new function, of course. All industrial processes must be monitored as operations enfold to ensure plans are adjusted (when needed) and followed such that the stated objectives of the firm are attained. Procurement and the proactive consolidation processes described in this paper are no different.

One monitors whether the forecast orders materialize as planned with respect to time and quantity. One also monitors how suppliers take care of the orders received, in particular, if deliveries are expected to be on time. The activities of the other partners, 3PLs in particular, are also monitored to ensure containers are available, and shipments proceed as planned. The particular monitoring processes and actions the firm may implement to react to events and redress the situation are application specific and an in-depth discussion is beyond the scope of this paper. We make only three points.

With respect to POC, modifications in the quantities ordered and late deliveries of ordered items at the POO are the main factors that may require updating the consolidation plans. The “do nothing” response to such events does not perform this updating and ships the containers as they are, the extra loads (if any) being shipped by full container or LCL according to the available item volumes. At best, the “do nothing” approach applies Option 0 to the loads available at the POO. More proactive strategies would modify the existing consolidated groups, according to one of the previously-defined options, provided sufficient time is available. Obviously, too frequent updates may rapidly become cumbersome from a management and operations point of view.

Monitoring can also be very useful to assess the quality of service of suppliers, carriers, and 3PLs, as well as to reassess the required lead time associated with a given supplier. If consolidation plans must be done over and over again because a given supplier is always late in delivering the ordered items, then either the lead time should be adjusted in the inventory management system, or the supplier should be dropped from the preferred list. Similar performance measures may be built for the other partners in the supply chain.

Finally, one should monitor its own performance with respect to, e.g., purchasing, ordering and transportation cost, as well as customer service level (inventory level versus demand). Other interesting performance measures are the amount of back orders, the value of items that became obsolete because ordered quantities were boosted to fill containers, the number of containers booked but not required, the final cost compared to the expected cost, and estimations of the “cost” of uncertainty. Such activities would provide the means to continuously improve the planning capability and operations of the firm.

The design of a proactive order consolidation approach needs to be evaluated before it is implemented. Focus groups help to evaluate qualitative elements such as the applicability of the process. Quantitative elements, such as costs, can be evaluated with computer simulations. Discrete-event, Monte-Carlo, object-oriented simulations, and multi-agent based simulation can be used to assess POC. The next subsection covers a first evaluation of the proposed approach based on a Monte-Carlo simulation.

5 Case Study

We illustrate the proactive order consolidation methodology through a number of analyses performed on a case study strongly inspired by the setting of an important North American hardware and home-improvement wholesale-retail chain (Béliveau, 2008). We start with a brief description of the case with respect to the procurement processes presented in previous sections. The methodology used to group orders is presented next, followed by the description of the data sets and the Monte Carlo simulation built to perform the experiments. The results of the numerical experiments performed and the corresponding analyses follow.

5.1 The Setting

The firm operates as a wholesaler for its nation-wide retail network made up of large and medium-size stores, as well as independent small-size neighborhood shops. It stocks a very large variety of products to serve a numerous and diversified set of customers. Global sourcing is part of the set of strategies the firm deploys to perform within the highly competitive North American market.

The case study concerns the procurement process for a group of products imported from South-East Asia. The logistics network follows the scheme illustrated in Figure 2, while the procurement process involving the firm, its suppliers, and a 3PL service provider is illustrated in Figure 1.

In selecting suppliers, the merchandiser also sets up agreements on a certain number of terms including the buying conditions (incoterms), port-of-loading/origin (POO), price and order-quantity intervals, and so on. Buyers are primarily in charge of maintaining the planned levels of product inventory. Following a signal from the inventory-management software, a buyer negotiates the purchase with a pre-determined supplier. Decisions are made on the order quantity, delivery date, price, incoterms, and POO, the last three being generally only a confirmation of the original contract established by the merchandiser. A PO is then issued, verified, approved by the appropriate services, and transferred to all concerned parties. The logistician is responsible for the payment aspects, and for monitoring the progress of the order to ensure that the purchased items are delivered on time to the firm's warehouses. This activity is performed in partnership with a 3PL service provider. The 3PL is also in charge of receiving the products from suppliers and shipping overseas, to the company's distribution centers, according to the firm's instructions. Products are typically moved in containers. As noted earlier, two transportation options are generally available, LCL and FCL. Pricing is defined per unit of volume in the former case, while in the latter, the usage of a full container is bought at a fixed price, depending on its type, and filled at will. The logistician decides the transportation option to be used for each order.

When a boosted-FCL strategy is selected, the supplier fills a container with the order, seals it, performs the export duties with the local authorities, and delivers it to the departure yard of the POO so that the 3PL can ship it (a Free-On-Board, FOB, incoterm agreement is generally used, Bowersox et al., 2005). The POC strategy considered in this study followed Option 3 (buyer based) with an information strategy that did not include forecasts. Orders were considered in groups (by week) according to the first packing strategy (only the orders in the group to be packed into new containers). It was also assumed that the consolidation strategy was not used to modify due dates. Those were computed given historical data and assuming loads corresponding to consolidated orders were shipped on a vessel leaving the port of origin each week on the same day. For all strategies considered in the simulation, orders were supposed to be delivered on time.

5.2 Grouping Orders - Bin Packing Models

The main decision to be made by the IDSS is the efficient grouping of orders of relatively small volumes into lots with total volumes close to the available container capacity. As indicated earlier, this corresponds to the well-known *Bin Packing* (*BP*) problem class (Martello and Toth, 1990b,a; Wäscher et al., 2007). In the case considered in this paper, containers (bins) and orders (items) are characterized by a single attribute, the volume (usable for the former and actual for the latter). An assignment of a group of orders to a container is then feasible if the sum of their volumes is less than the usable container capacity (volume).

We analyze two scenarios in this study, assuming the availability of a single container type or of two types, respectively, and therefore use two BP models. We first address the latter scenario because it is more general than the first. The BP formulation when two (or more) container types are available corresponds to the *Variable Cost and Size Bin Packing* problem of Crainic et al. (2011b). Consider a set $\mathscr{I}$ of $|\mathscr{I}|$ orders. Each order $i \in \mathscr{I}$ has a volume v_i smaller than the maximum container capacity (anything larger is to be split into a number of full containers, and a residue to be considered by the order-consolidation process). Let $\mathscr{J}$ be the set of containers, with capacity and cost V_j and $c_j,\ j = 1, \ldots, |\mathscr{J}|$, respectively. The number of available containers is usually not a constraint, but can be. Moreover, considering an upper bound $|\mathscr{J}|$ tightens the formulation. Define the decisions variables:

- y_j, container-selection variables equal to 1 if container $j = 1, \ldots, |\mathscr{J}|$ is selected, and 0 otherwise;
- x_{ij}, loading-decision variables defined for each pair (order i, container j), equal to 1 if order $i = 1, \ldots, |\mathscr{I}|$ is loaded into container $j = 1, \ldots, |\mathscr{J}|$, and 0 otherwise.

The Order Consolidation Bin Packing model (OCM) may then be written as:

$$\text{Minimize} \quad Z = \sum_{j \in \mathscr{J}} c_j y_j \tag{1}$$

$$\text{s.t.} \quad \sum_{j \in \mathscr{J}} x_{ij} = 1, \forall i \in \mathscr{I}, \tag{2}$$

$$\sum_{i \in \mathscr{I}} v_i x_{ij} \leq V_j y_j, \forall j \in \mathscr{J}, \tag{3}$$

$$y_j \in \{0,1\}, \forall j \in \mathscr{J}, \quad (4)$$
$$x_{ij} \in \{0,1\}, \forall i \in \mathscr{I},\ \forall j \in \mathscr{J}. \quad (5)$$

The objective aims to minimize the total cost of the containers used, while equations 2 make sure each order is transported (assigned to a container) and constraints 3 enforce container-capacity limits. Constraints 4 and 5 enforce the integrality of the decision variables. Notice that, when only one type of container is available, all containers are identical, i.e., $V_j = V,\ j \in \mathscr{J}$, and the container costs may be dropped. The resulting model then corresponds to the classical BP formulation of Martello and Toth (1990b). We use the bounding heuristics proposed by Crainic et al. (2011b), which yield very high-quality solutions, for both formulations.

5.3 Data and the Monte Carlo Simulations

The goal of the experimentation phase is to evaluate the particular proactive order consolidation process defined above, by comparing it to two options:

1. Boosted-FCL policy, where order volumes are increased to fill up a container for full-container load shipment;
2. LCL policy, where orders, corresponding to quantities computed by the inventory-management policy, are shipped using LCL services.

The experimentation is based on a Monte Carlo simulation, which generates orders that are then processed according to each of the three policies. The comparison is then performed by computing the total annual procurement and inventory-holding costs.

Based on information provided by the firm, the data used for the simulation correspond to products (SKUs) that originate from the same region in South-East Asia. Items are shipped through the same port, and display regular selling patterns (i.e., promotional and other similar activities were not taken into account). Based on the expertise of the 3PL, we made sure the selected products may be packed together.

The selection process yielded a sample of 109 products. The data available for these products includes the monthly historical sales for a 13-month span, the packaging information, and the selling prices. The annual and the average monthly demand for each product were computed from this historical data. As for the product packaging information, it was used to compute the order quantity corresponding to a full forty-foot container, which was the type most used by the company.

Forty-foot containers and twenty-foot containers were available to ship orders to North-America. Each type is characterized by its cost (when fully loaded, forty-foot containers represent the most economical alternative), and maximum loading volume when used for a single product or for consolidation (approximately 10% less). The cost per cubic-meter of an order shipped using LCL services was also given. The *transportation-mode break-even point*, defined as the volume for which paying for a full container or shipping LCL yields the same transportation cost, was then computed for each container type as its cost divided by the LCL cubic-meter cost.

We assumed the demand for the 109 regular products to be uniform over the year. Three classes of products were defined corresponding to the total volume ordered, as reflected in the actual data received from the firm. The first class included the 64 SKUs with the highest annual volume. The high rate of sale implied each product in this class had to be ordered each month, the order quantity being equal to the corresponding average monthly demand. The second class grouped the 30 SKUs with a medium annual volume of sales, a requirement to buy every two months, and an order quantity twice the average monthly demand. Half of these 30 SKUs were ordered every odd month (first, third, etc.) and the other 15 every even month. Finally, the 15 SKUs with the lowest annual sales volume made up the third class, with a quantity covering the average demand of 3 months ordered every three months. Five of these products were ordered every first, fourth, seventh, month, etc.; five others every second, fifth month, etc.; and the last five every third, sixth month, etc. This yielded 84 SKUs to be ordered each month. The distribution of these orders within the month is assumed to be random, however. Thus, the total number of orders placed every week was assumed to follow a triangular distribution with parameters 10, 25, and 30, representing the lowest, most-likely (mode), and highest number of orders, respectively. The resulting orders had volumes inferior to the capacity of at least one type of container. By policy, orders could not be split.

Deterministic order lead times were assumed for this series of simulations, meaning the monitoring process is performing well enough to avoid significant delays. Then, each run of the Monte-Carlo simulation consisted in developing a procurement plan to satisfy the demand for a year, selecting the transportation mode for each order or consolidated group of orders. The simulation (one simulation run) worked as follows:

1. Determine, for each month of the simulated time horizon, a list of products to be ordered according to the 1, 2, and 3-month classes defined above.
2. For every week of the month,
   (a) Determine k, the number of orders to be released that week, according to the Triangular(10, 25, 30) distribution;
   (b) Pick k orders randomly from the updated monthly list (except for the last week that ships all the remaining ones); Update the list;

(c) Solve the OCM model to determine the minimum number of containers (of each type, when appropriate) needed to ship all the orders of the week, as well as the orders packed into each container;

(d) Review each container to compare its load, i.e., the total volume of the orders it contains, to the breakeven point of the respective container type. Then, either send the consolidated container if filled over the breakeven point, or send the orders in the container using LCL services, otherwise.

5.4 Numerical Results and Analyses

Results are provided for the three policies: Boosted-FCL, identified as FCL in the following tables and figures; all orders shipped by LCL services; and the POC, with LCL for groups of loads with total volume less than the breakeven point. The total annual cost of the respective procurement plan is used to compare and assess performance. This cost was computed as the sum of the costs of purchasing, ordering, transportation/brokerage, and inventory holding. We computed these costs according to the actual practice of the firm:

***Purchasing* =** Average total quantity ordered for each product, multiplied by its unit cost, and summed over products. Unit costs are negotiated by the merchandiser for the year and are thus fixed. The annual purchasing cost is therefore computed once, and is the same for the three strategies;

***Ordering* =** Average annual number of orders placed, multiplied by the cost of placing an order;

***Transportation/brokerage* =** Sum of the prices paid to ship that average annual number of orders; This includes the cost for transportation and the brokerage fees paid to the 3PL for its services;

Inventory-holding for a given product is computed by multiplying its annual inventory unit cost (viewed as a percentage of the purchase price) and its average inventory level over the year; The total inventory cost is then summed over all products considered.

We performed three sets of experiments, which we identify as

Analysis 1: One type of container, 40 feet, only available for consolidation and no extra costs charged by the 3PL for the potential additional handling caused by consolidation. This corresponds to the actual case studied.

Analysis 2: Two types of containers, 40 and 20 feet, and no extra handling charge.

Analysis 3: One type of container, 40 feet, with additional charges for consolidation. Three cases were considered with an additional 5%, 10%, and 15%, respectively, on the price of the 40-feet container.

The simulation was run over 50 scenarios for each analysis and strategy, a scenario corresponding to one year, 52 weeks, of operations. The Bin Packing method proposed by Crainic et al. (2011b) was run on a Lenovo Thinkpad laptop running a 2.4 GHz core i5 processor. Numerical results are reported as averages over all replications. Costs are reported in thousands of dollars. The entire simulation, 52 runs for each analysis corresponding to 12 000 Bin Packing problems, required approximatively 917 CPU seconds, for an average of 0.07 CPU second per problem.

The results for Analysis 1 are displayed in Table 1. Ordering costs are lower for the FCL strategy because larger volumes (up to the container volume) are ordered less often. On the other hand, the corresponding inventory cost is significantly higher than for the other two strategies that ship smaller orders more often. The number of orders and their volumes being the same for the LCL and POC strategies, the corresponding ordering and inventory costs are also the same. Transportation costs are lower for the POC strategy, which makes it the most cost efficient of the three.

Table 1: Average annual costs for the three strategies ($K) - Analysis 1

Costs	FCL	LCL	POC
Purchasing	9,517.2	9,517.2	9,517.2
Ordering	6.4	36.3	36.3
Transportation	616.5	1,282.2	794.0
Inventory	941.5	140.4	140.4
Total	11,081.6	10,976.1	10,487.9

Table 2 displays a two-by-two comparison of the performances of the three strategies. Each column, identified as X vs. Y, displays the reduction, in %, in the cost associated with strategy X relative to that of strategy Y. Thus, reducing the order volumes to the quantities needed increases the ordering cost significantly, but also reduces in a significant manner the inventory-related costs.

Table 2: Annual cost comparisons (% of reduction) - Analysis 1

	LCL vs. FCL	POC vs. FCL	POC vs. LCL
Purchasing	0.0	0.0	0.0
Ordering	-470.6	-470.6	0.0
Transportation	-108.0	-28.8	38.1
Inventory	85.1	85.1	0.0
Total	1.0	5.4	4.4

Figure 4 illustrates the reduction in inventory-holding cost for the products considered. Products are displayed by their designated SKU number on the horizontal axis in increasing order of their average monthly demands (in volume). The reduction is at least 40%, the highest reductions being obtained for the products with low average demands. That confirms the interest of the POC strategy in this respect.

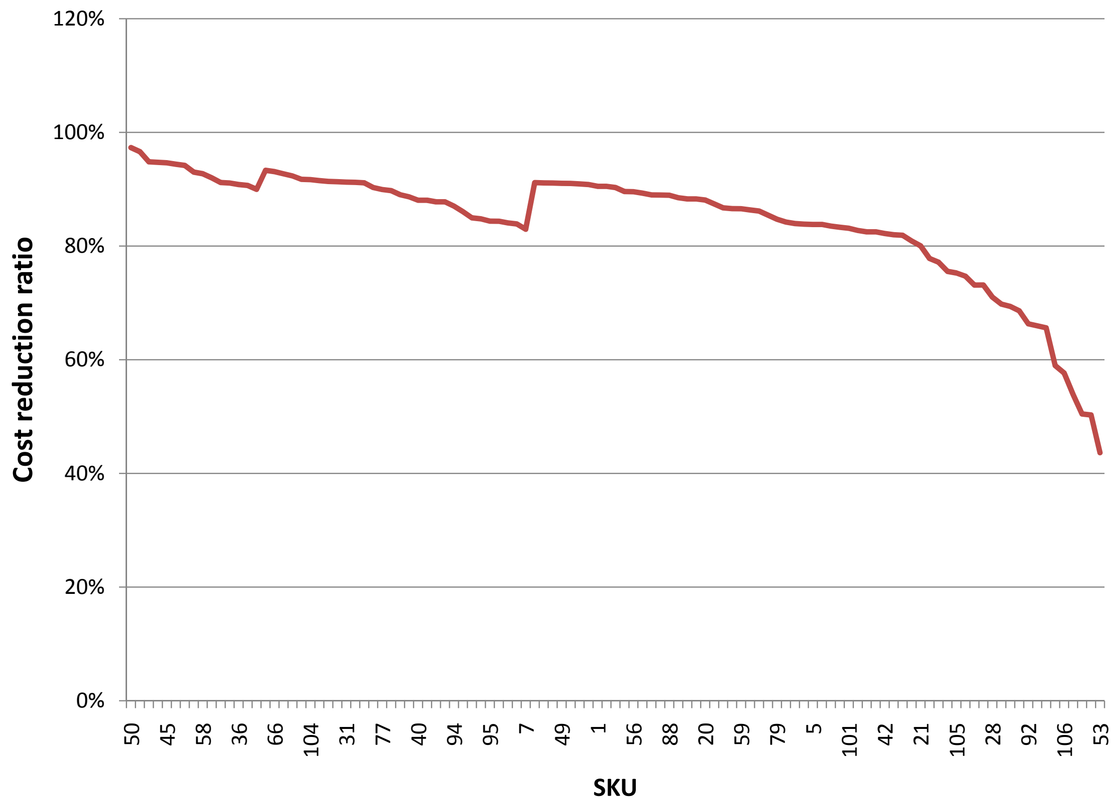

Figure 4: Inventory cost reduction ratio from FCL to POC - Analysis 1

Not surprisingly, the highest transportation cost corresponds to the LCL strategy where single-shipment costs are paid for each order. Due to the slightly lower loading capacity, the POC strategy yields a somewhat higher unit cost (per cubic-meter) than FCL, as illustrated in Figure 5. This is however largely compensated by the large decrease in inventory-holding costs, as indicated by the entries in Tables 1 and 2: a transportation costs increase of \$178K compared to the huge reduction of \$801K in inventory costs. The proactive order consolidation strategy is winning in this respect.

The results for Analysis 2, given in Table 3, further emphasize the superiority of the the POC strategy over the two other strategies, yielding substantial economies of 5.4% and 4.5% compared to FCL and LCL, respectively. This analysis also supports the claim that a choice

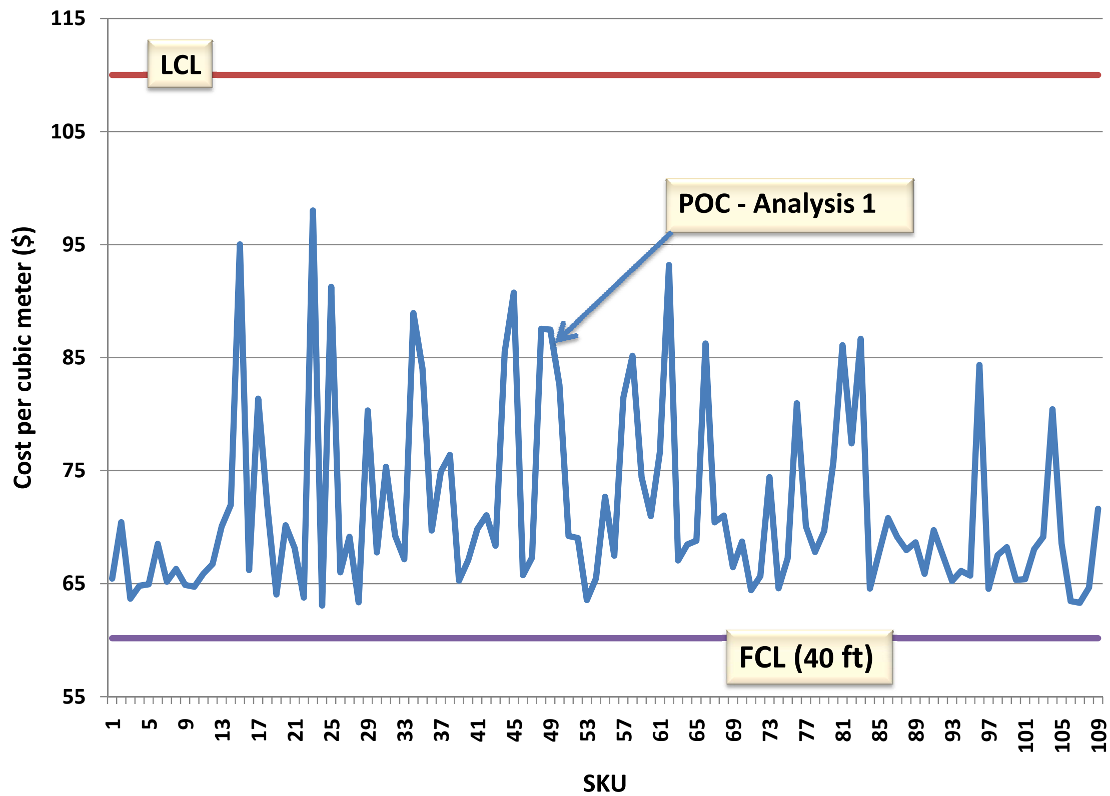

Figure 5: Unit cost per cubic-meter cost for each strategy - Analysis 1

of container types is beneficial. Moving from one to two container types decreases the average transportation cost by $0.6K yearly.

Table 3: Average annual costs for the tree strategies ($K) - Analysis 2

Costs	FCL	LCL	POC
Purchasing	9,517.2	9,517.2	9,517.2
Ordering	6.4	36.3	36.3
Transportation	616.5	1,282.2	793.4
Inventory	941.5	140.4	140.4
Total	11,081.6	10,976.1	10,487.3

Proactive order consolidation allows wholesalers to give better information, earlier, to their 3PL partners regarding the numbers and types of containers required in future periods. One may thus expect 3PL rates to stay the same or to decrease slightly. Yet, to better characterize the interest of a POC strategy, Analysis 3 takes the opposite view and addresses the case of an increase in brokerage fees. A single type of container, the 40 feet one, is considered. The annual costs are displayed in Table 4, while the two-by-two comparison yields Table 5. The corresponding product unit (cubic meter) transportation cost is displayed in Figure 6. The results of this set of experiments show that, even with raises in transportation/brokerage fees, proactive order consolidation still exhibits significant advantages over the other strategies.

Table 4: Average annual total costs ($K) - Analysis 3

	FCL	LCL	POC	POC+5%	POC+10%	POC+15%
Purchasing	9,517.2	9,517.2	9,517.2	9,517.2	9,517.2	9,517.2
Ordering	6.4	36.3	36.3	36.3	36.3	36.3
Transportation	616.5	1,282.2	794.0	831.0	868.0	904.2
Inventory	941.5	140.4	140.4	140.4	140.4	140.4
Total	11,081.6	10,976.1	10,487.9	10,524.9	10,561.9	10,598.1

Table 5: Annual cost comparisons (% of reduction) - Analysis 3

	LCL FCL	POC FCL	POC+5% FCL	POC+10% FCL	POC+15% FCL
Purchasing	0.00	0.00	0.00	0.00	0.00
Ordering	-470.6	-470.6	-470.6	-470.6	-470.6
Transportation	-108.0	-28.8	-34.8	-40.8	-46.7
Inventory	85.1	85.1	85.1	85.1	85.1
Total	1.0	5.4	5.0	4.7	4.4

To sum up, the experimental results show that both LCL and POC strategies are better than FCL. Even though they induce an increase in ordering costs, this increase is largely compensated by major savings in inventory cost. FCL clearly appears particularly inappropriate for slow moving products. Proactive order consolidation appears as the strategy of choice, yielding lower total costs compared to all the other strategies considered.

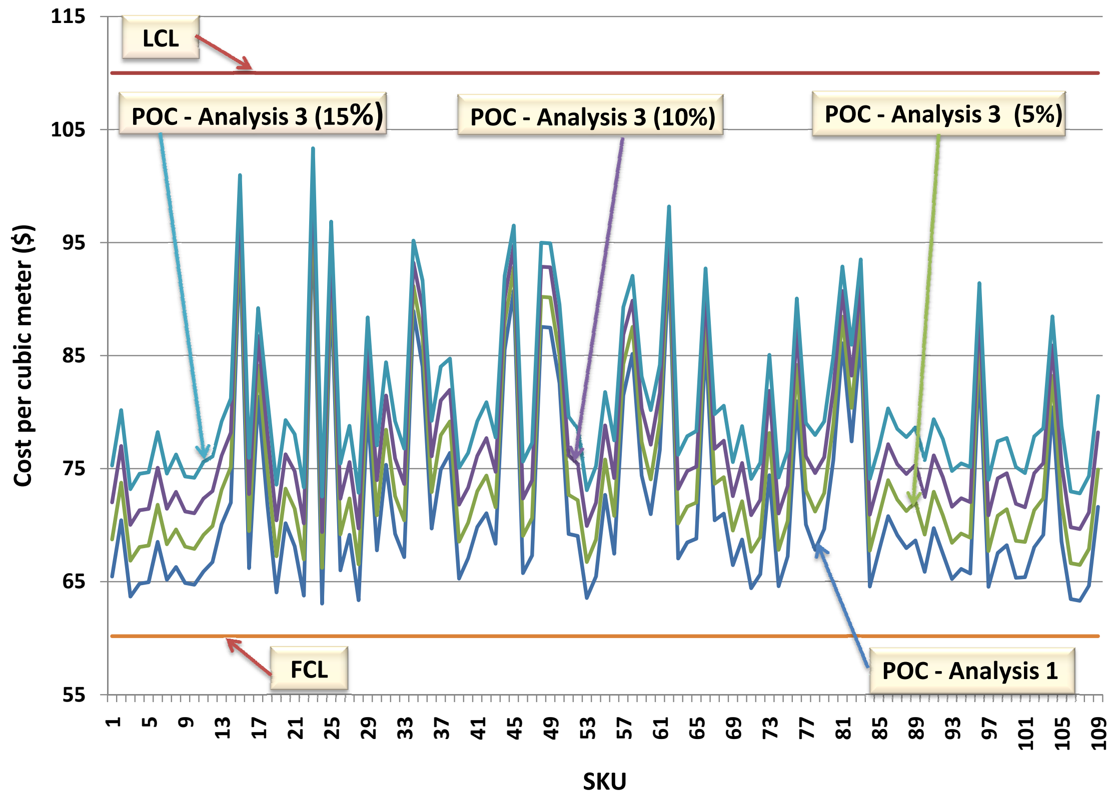

Figure 6: Unit cubic-meter cost for each strategy - Analysis 3

6 Conclusions and Perspectives

We presented the *Proactive Order Consolidation* strategy for wholesalers acquiring goods according to global supply policies. The strategy aims to group orders before they are communicated to suppliers, in such a way that the total cost of transportation and inventory of the firm is minimized. Experimental results showed the interest of this strategy for products with regular but low-demand volumes compared to container capacities. POC provides the means to achieve profitable trade-offs between procurement, transportation, and inventory costs.

Much work and many interesting developments are still ahead. The various alternatives for the POC strategy have to be thoroughly evaluated under a variety of industrial, economic, and partnership settings. Simulation and focus groups with concerned managers appear as the appropriate means to undertake this study. Such comprehensive evaluations are essential in addressing the technology-transfer challenge and building a favorable environment for industry to consider adoption on any large scale.

More advanced POC strategies appear promising and require to be studied and evaluated. A prominent candidate in this respect is to consider an integrated decision process that determines order release times and volumes simultaneously with consolidation, to globally minimize the total logistic cost. Methodological developments are still largely to come for most strategies, particularly those explicitly considering time dependencies and uncertainties. Worthy of interest is also the relations between procurement and the new freight packaging and transportation systems being currently proposed. To give just a small illustration, a transformation of the container from a rigid box to an assembly of smaller boxes of various sizes, adapted to the items transported, which may combine (without lost space) to make large transportation units, would radically change container-based transportation and open very interesting opportunities for proactive order consolidation. We are advancing along some of these research and development paths and plan to report results in the near future.

Acknowledgments

The authors take this opportunity to thank the Editor and referee for their extensive and very enlightening comments. They helped us write a better paper.

While working on this project, the first author was the NSERC Industrial Research Chair in Logistics Management, ESG UQAM, and Adjunct Professor with the Department of Computer Science and Operations Research, Université de Montréal, and the Department of Economics and Business Administration, Molde University College, Norway. The fourth author was post-doctoral fellow with the Chair.

Funding for this project has been provided by the Natural Sciences and Engineering Council of Canada (NSERC), through its Industrial Research Chair and Discovery Grants programs, and by the partners of the Chair, CN, Rona, Alimentation Couche-Tard and the Ministry of Transportation of Québec.

References

N. Aissaoui, M. Haouari, and E. Hassini. Supplier selection and order lot sizing modelling : a review. *Computers and Operations Research*, 34:3516–3540, 2007.

M. Béliveau. Consolidation de commandes dans la grande distribution. MBA Thesis, École des sciences de la gestion, UQAM, Montréal, Canada., 2008.

L. Bertazzi and M. G. Speranza. Worst-case analysis of the full load policy in the single link distribution system. *International Journal of Production Economics*, 93-94:217–224, 2005.

L. Bertazzi, M. A. Chan, and M. G. Speranza. Analysis of practical policies for a single link distribution system. *Naval Research Logistics*, 54:497–509, 2007.

L. Bertazzi, M. W. P. Savelsbergh, and M. G. Speranza. Inventory routing. In Golden, B., Raghavan, S., and Wasil, E., editors, *The Vehicle Routing Problem: Latest Advances and New Challenges*, pages 49–72. Springer, New York, 2008.

J. H. Bookbinder and J. K. Higginson. Probabilistic modeling of freight consolidation by private carriage. *Transportation Research Part E*, 38:305–318, 2002.

D. J. Bowersox, D. J. Closs, and M. B. Cooper. *Supply Chain Logistics Management*. Irwin Professional Pub, 2005.

S. Çentinkaya. Coordination of inventory and shipment consolidation decisions: A review of premises, models, and justification. In J. Guenes, E. Alcah, P. M. Pardalos, H. E. Romeijn, and Z.-J. M. Shen, editors, *Applications of Supply Chain Management and E-Commerce Research in Industry*, pages 3–51. Springer, NY, 2004.

S. Çetinkaya and J. Bookbinder. Stochastic models for the dispatch of consolidated shipments. *Transportation Research Part B*, 38(8):747–768, 2003.

F. Chen, A. Federgruen, and Y.-S. Zheng. Coordination mechanisms for a distribution system with one supplier and multiple retailers. *Management Science*, 47(5):74–76, 2001.

T. G. Crainic and K. H. Kim. Intermodal Transportation. In Barnhart, C. and Laporte, G., editors, *Transportation*, volume 14 of *Handbooks in Operations Research and Management Science*, chapter 8, pages 467–537. North-Holland, Amsterdam, 2007.

T. G. Crainic, S. Marcotte, W. Rei, and P. L. Takouda. Order Consolidation for Global Sourcing. Publication CIRRELT-2009-37, Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport, Université de Montréal, Montréal, QC, Canada, 2009.

T. G. Crainic, S. Marcotte, W. Rei, and P. L. Takouda. A Case Study of Proactive Order Consolidation for Global Sourcing in the Hardware Retail Industry. Publication CIRRELT-2011, Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport, Université de Montréal, Montréal, QC, Canada, 2011a.

T. G. Crainic, G. Perboli, W. Rei, and R. Tadei. Efficient lower bounds and heuristics for the variable cost and size bin packing problem. *Computers & Operations Research*, 38(11): 1474–1482, 2011b.

D. J. Ford. Inbound freight consolidation: a simulation model to evaluate consolidation rules. Master's thesis, Massachusetts Institute of Technology, Master of Engineering in Logistics, 2001.

J. K. Higginson and J. H. Bookbinder. Policy recommendations for a shipment-consolidation program. *Journal of Business Logistics*, 15(1):87–112, 1994.

M. Krajewska and H. Kopfer. Transportation planning in freight forwarding companies: Tabu search algorithm for the integrated operational transportation planning problem. *European Journal of Operations Research*, 197:86–97, 2009.

S. Martello and P. Toth. Lower bounds and reduction procedures for the bin packing problem. *Discrete Applied Mathematics*, 28:59–70, 1990a.

S. Martello and P. Toth. *Knapsack Problems*. Wiley, New York, 1990b.

H. Min and M. Cooper. A comparative review of analytical studies on freight consolidation and backhauling. *Logistics and Transportation Review*, 26(2):149–169, 1990.

R. M. Monczka, R. B. Handfield, L. C. Giunipero, and J. L. Patterson. *Purchasing & Supply Chain Management*. South-Western, part of Cengage Learning, 2009.

F. Mütlü, S. Çetinkaya, and J. H. Bookbinder. An analytical model for computing the optimal time-and-quantity-based policy for consolidated shipments. *IIE Transactions*, 42(5):367–377, 2010.

N. Rizk, A. Martel, and S. D'Amours. Synchronized production-distribution planning in a single-plant multi-destination network. *Journal of the Operational Research Society*, 59: 90–104, 2008.

D. Simchi-Levi, P. Kaminsky, and E. Simchi-Levi. *Designing and Managing the Suppy Chain*. McGraw-Hill Education, 2002.

Statistics Canada. *Canada Year Book, 2009*. Statistics Canada Catalogue no 11-402-X, 2009.

J. C. Tyan, F.-K. Wang, and T. C. Du. An evaluation of freight consolidation policies in global third party logistics. *Omega*, 31:55–62, 2003.

US Census Bureau. Annual Retail Trade Survey-2008. Publication, US Census Bureau, 2010a.

US Census Bureau. Annual Whole Trade Survey-2008. Publication, US Census Bureau, 2010b.

G. Wäscher, H. Haußner, and H. Schumann. An improved typology of cutting and packing problems. *European Journal of Operational Research*, 183:377–389, 2007.

W. Wong, L. Leung, and Y. Hui. Airfreight forwarder shipment planning: A mixed 0-1 model and managerial issues in the integration and consolidation of shipments. *European Journal of Operations Research*, 193:86–97, 2009.