Chapter 3

DISTRIBUTION CENTRES IN SUPPLY CHAIN OPERATIONS

James K. Higginson
James H. Bookbinder

Abstract A *supply chain* consists of all flows and transformations from simple raw materials to purchase of end-items by consumers. Various network nodes perform component fabrication, product assembly or sales. These activities, however, require logistical support, e.g., storage of intermediate or finished goods; consolidation of orders; and transportation. The term, *Distribution Centre* (DC) denotes a supply-chain node that furnishes coordination of that sort.

This chapter highlights seven roles played by a DC. We discuss the measurement of distribution-centre performance, and the information required to manage a DC. These need to be approached differently, depending on the facility's function or role.

1. Introduction

Quinn (2000) has suggested that Transportation is a "forgotten area of supply chain management." That is, analysts have put all their attention into designing the perfect network, and have worried too little about managing the flows of products between nodes. It could be argued that Distribution Centres (DCs) are another forgotten area. A review of supply chain management books published from the late 1990s onward reveals that many do not discuss, nor even include in the index, material on distribution centres or warehouses. Researchers seem to take them for granted, assuming that a DC will be there when needed, offering exactly the services required.

This chapter attempts to fill the gap. A distribution centre can play a number of major roles in a supply chain. Beginning in Section 3, we will examine each of them, and the corresponding issues and decisions required. But let us first consider the "big picture."

2. What is a distribution centre?

Warehouses and DCs are important nodes in a supply network; they perform valuable functions that support the movement of materials. Storing goods (temporarily or longer), processing products, de-aggregating vehicle loads, creating SKU assortments, and assembling shipments are all activities commonly performed in these facilities. (OR applications to warehousing are discussed by Cormier (2005) elsewhere in this volume.)

With the increase in the number and types of services offered by a warehouse, the distinction between it and a distribution centre has become cloudy and ignored by many authors and researchers. A DC is, in fact, a *specific* type of warehouse. Coyle et al. (2003), for example, define a distribution centre to be "a post-production warehouse for finished goods held for distribution." Frazelle (2002) refers to distribution centres as distribution *warehouses* (as does Ballou, 2004), and defines them as facilities that "accumulate and consolidate products from various points of manufacture within a single firm, or from several firms, for combined shipment to common customers."

This chapter adopts the common definition of a DC to be a type of warehouse where the storage of goods is limited or non-existent. As a result, distribution centres focus on product movement and throughput (receiving, putaway, order picking, order assembly, and shipping), and information collection and reporting (throughput and utilization, transportation documentation, loss and damage claim support), rather than storage. Daww (1995) lists several other differences between warehouses and DCs. Two fit the definition we will use in this chapter: "Warehouses store all products; distribution centres hold minimum inventories, and of predominantly high-demand items. Warehouses handle most products in four cycles (receive, store, pick, and ship); DCs handle most products in two (receive and ship)." (Bancroft, 1991, discusses changes required in a facility to move its operations away from a warehouse and towards a distribution centre.) Nonetheless, many of the works cited in this chapter use interchangeably the two terms, warehouse and DC.

Since the 1980s, three supply-chain trends have had a major impact on these facilities:

- reduction in the number of warehouses
- greater emphasis on the *flow* of goods, rather than their storage
- increased outsourcing of warehouse/distribution centre activities.

Early supply-chain initiatives changed the emphasis of logistics operations from productivity improvement to inventory reduction. Delaney (1991), for example, reported a $200 billion decrease in inventory investment in the United States between 1980 and 1989. Others (e.g., Ackerman and Brewer 2001) have noted that the largest saving in logistics costs during the last thirty years has been due to reduced stock. Diminished inventories allow for the closing of facilities, which encourages inventory centralization, closer control of safety stocks, and elimination of obsolete and slow-moving items. This further lessens the need to maintain inventory at so many locations, which changes the role of some facilities from storage to product flow; that is, from warehouse to distribution centre.

The impact on overall inventory of fewer stock-keeping locations has been analysed by a number of researchers, including Caron and Marchet (1996); Bordley et al. (1999); Teo et al. (2001); Kim (2002); and Simchi-Levi et al. (2003). Enhanced communication and transportation have further reduced the need for DCs and warehouses. Ackerman and Brewer (2001) note that many of the distribution centres established in the latter part of the 20th century were aimed at strengthening customer service, but "the substantial improvements in delivery capabilities... have made it possible for some distributors substantially to reduce the number of distribution centres without compromising customer service."

A second factor leading to fewer warehouses and DCs is the outsourcing of logistics activities. During the late 1980s and the 1990s, many North American manufacturers spun off their in-house logistics activities to concentrate on core business operations. Warehousing typically is at or near the top of the list of logistics functions commonly outsourced (e.g., Coyle et al., 2003). This allows third-party logistics providers to consolidate the warehousing/distribution centre operations of several clients in a small number of facilities. Each client benefits from the third party's economies of scale in DC and transportation activities.

It is not clear whether the number of DCs or warehouses required by an organization will continue to decrease. The last few years have seen enhanced demand for warehouse and distribution-centre space, due in part to the greater range of services being carried out in modern DCs, and the shift to smaller customer orders (especially those from e-commerce). Activities traditionally performed in factories (such as packaging and labelling, light assembly, and product localization), and services required by e-business (such as invoicing, billing credit cards, arranging transportation, and handling customer returns), which previously were performed by wholesalers and distributors, are now common in DCs.

According to Planeta (2001), the modern Canadian distribution centre is "usually located within close proximity to highway access, has a ceiling height clearance of 28 feet or more, and contains only a small amount of office space... These facilities are typically designed to have one shipping door per 10,000 square feet of warehouse space and a maximum depth (dock to wall) of 350 feet.... [and] bay sizes in the range of 36 feet by 40 feet, which generally produce the most efficient 'generic' warehouse layout."

The distribution centre of the future will be larger, with a greater emphasis on reducing activity times, again as noted by Planeta (2001):

> Facilities are being built to allow for shipping on two sides, effectively turning them into large cross-docks with significant warehouse capacity. These facilities allow ample room for outside storage of trailer equipment and a higher shipping door ratio. Today's buildings are getting higher, have better shipping capacity, and more efficient mechanical systems.... Unless the product flow rate is extremely high, this type of facility may not be the most efficient for the typical user.

One consideration in determining the feasibility of larger distribution centres is discussed by Footlik (1999). An organization often will operate DCs of different sizes; Lee (1996) has incorporated this fact in a mathematical model for facility location. The distribution centre of the future most likely will be owned and operated by a third party (Ackerman and Brewer, 2001). And although modern DCs tend to be highly automated, many activities remain quite labour-dependent.

Reports indicate that in the future, it will not be uncommon for 50 percent of distribution centre employees to be temporary (Reynolds, 2003). If so, the outbound portion of the supply chain will already be set to follow a "chase strategy," in the sense of aggregate production planning. Thus, the major challenge to warehouses and DCs, both today and tomorrow, will relate to workforce issues such as staffing, training, scheduling, and job design (Ackerman and Brewer, 2001).

Trappey and Ho (2002) present an approach to managing employees in distribution centres. They discuss an information system add-on that assigns pick lists to employees, and goods to trucks, in a DC. The assignment routines, based on simple heuristics, are designed to integrate with the human-resource and order-management modules of an ERP system (See Section 5).

We have seen in this section a number of ways to define a DC. Let us now turn attention to the activities there.

3. Roles of a distribution centre in the supply chain

The article of Min and Melachrinoudis (1999) is concerned with a "hybrid" facility, one that performs both manufacturing and distribution. Attention is mostly on *location*, and use of the Analytic Hierarchy

Process (AHP) to assess various site-selection factors. But it is clear, right from the start, that this facility has a dual function.

The present section examines more precisely the various roles that a DC might take on in a supply chain. Specifically, we discuss the issues and literature related to the distribution centre that may act as a make-bulk/break-bulk consolidation terminal, a cross-dock operation, a transshipment node, an assembly facility, a product fulfilment centre, or a returned goods depot. Our definitions of these roles are misleadingly clear. In reality, a distribution centre often performs several of these simultaneously, as will be seen below.

3.1 The DC as a make-bulk/break-bulk consolidation centre

Breaking bulk and making bulk are traditional functions of a distribution centre. In a break-bulk facility, large incoming loads are deaggregated, often for product mixing and to create consolidated outbound shipments. A make-bulk facility, or consolidation centre, combines small quantities of several products in fewer, larger assortments.

Higginson and Bookbinder (1994) note that a program of freight consolidation involves determining those products to be dispatched together; which customer orders will be combined; and when consolidated orders will be released. Also, who will perform these activities, which specific consolidation techniques will be used, and will these activities be carried out at a DC or elsewhere? Hall (1987) provides a good introduction to the impact of consolidation performed at a terminal. Gray et al. (1992) discuss the design and operation of an order-consolidation warehouse.

Ketzenberg et al. (2002) examine the benefits of breaking bulk in retail operations. They suggest the major advantage is better use of retail space, rather than reduced inventory. Diks and de Kok (1996) discuss the allocation to multiple retailers, of inventory incoming to a single distribution centre. Klincewicz and Rosenwein (1997) present a heuristic, based on set partitioning, to determine the shipments that should be made from a warehouse or distribution centre each day.

Daganzo (1988) addresses the case of many origins shipping to one destination through a single consolidation centre. He develops an algorithm for use when vehicles can haul multiple items, and presents an example applying the concepts discussed to the transport of automobiles. Daganzo (1987) looks at the role of terminals in a network of several origins shipping to a number of destinations. He notes that, with certain assumptions, the benefits of consolidation can be achieved in one-to-many networks (or many-to-one networks) without the use of terminals, by having vehicles make multiple stops. Daganzo (1999) combines much of his earlier work, and is discussed later in this chapter.

Baudin (2001) lists a few activities that a consolidation centre should *not* perform:

- Kitting. To do so, consolidation-centre employees would require up-to-date information about pick lists, bills-of-material, and engineering -change notices. Kitting should be performed in the factory; the consolidation centre should deal only with individual items.
- Quality assurance of incoming products. That would require consolidation-centre employees to be trained in the characteristics of parts and the customer's quality assurance methods and requirements.
- Sorting of empty crates and other shipping materials. This "creates work that otherwise wouldn't need to be done. It is more economical to organize the pickup of empties by item."

A common example of the use of DCs as consolidation centres for the inbound-to-factory movement can be found in the automobile manufacturing supply chain. Here, the consolidation centre is a facility located close to a production plant, that "receives large shipments of components and parts from many suppliers, breaks them down into the smaller quantities that the plant needs, disposes of the supplier's shipping materials, places the parts in the plant's reusable containers, and delivers them either to plant receiving or directly to the point of use" (Baudin, 2001). Thus, the consolidation centre acts like a supplier to the manufacturer, making frequent deliveries of components and relieving the factory from having to accept large, less regular deliveries of inappropriately packaged items. This requires the consolidation centre to hold substantial inventory, while facility management must have the ability to influence suppliers to improve deliveries and reduce costs.

Baudin notes that consolidation centres in the automobile industry often "are operated by separate companies, in which the manufacturer may or may not own equity. A consolidation centre can recruit warehouse personnel for half or even one third of a car assembler's wages. It cannot do all the material handling for the manufacturing plant, but what it does, it can make a profit while saving money for the plant."

3.2 The distribution centre as cross-dock (CD)

Another function of a DC, i.e., the *cross-docking* of a product through a distribution centre, is recognized as one of the basic distribution strategies (e.g., Chopra, 2003; Chopra and Meindl, 2004). "Cross docking refers to a process where the product is received in a facility, occasionally married with product going to the same destination, then shipped at the earliest opportunity, without going into long-term storage." (Napolitano, 2001) Forty-eight hours is the often-quoted time limit for a cross-docked item to remain in the facility (resulting in an annual inventory turnover greater than 100), but time limits ranging from one to three days appear in various sources. Some sorting and product consolidation also may occur before shipping.

There is a fundamental difference between the use of a CD and traditional warehousing. Customer orders can be filled from goods stored at the warehouse, whereas with cross-docking, customer orders are filled from some other facility (such as a manufacturing plant) and just pass through the distribution centre or CD.

Cross-docking is a form of transshipment, the two differing in terms of objectives. The former strategy is *customer*-focussed, and attempts to move a product through a facility as quickly as possible. Transshipment (discussed next in this chapter) is a *carrier* strategy that aims to improve truck utilization, typically by better matching the size of the load to that of the vehicle. Transshipment is not new (after all, less-than-truckload or LTL transportation is dominated by transshipment operations), while it is only in the last two decades that use of a CD has received widespread attention.

Cross-docking produces many benefits, including:

- Elimination of activities associated with storage of products, such as incoming inspection, putaway, storage, pick-location replenishment, and order picking. Doing away with the latter is especially beneficial: Order picking is the most labour-intensive, time-consuming, costly, and error-prone of all activities in a typical warehouse.
- Faster product flow and improved customer service. Having eliminated storage, products move directly from receiving to shipping (or at worst sit in a staging area for short periods of time).
- Reduced product handling. The results are decreased probability of product damage, less wear on material handling equipment, and diminished labour.
- Cuts in inventory. Cross-docking avoids the holding of stock at multiple locations.
- Lower costs due to elimination of the above-mentioned activities; smaller inventories; less investment in racking, floor storage, or other equipment; and encouragement of consolidation of products for the same destination.

There are several disadvantages to cross-docking. The major one is the very complex planning and coordination needed to make it work effectively. Heaver and Chow (2003) note that because of this difficulty, many retailers have not been able to achieve anything close to true cross-docking. A major impediment, they add, is that most manufacturers are not equipped to efficiently create store-order quantities. As well, because cross-docks do not hold inventory, some managers feel uneasy that customer requirements must be satisfied from more distant facilities, rather than from local warehouses that carry stock (Jones, 2001).

In general, the best potential for effective cross-docking is for those SKUs where a sense of urgency exists. Examples are fast-selling products, time-sensitive components, and sale and promotional items. Special orders and goods that are backlogged also should be cross-docked: These often arrive at the CD pre-packaged and labelled for delivery to the consignee, and do not have to be combined with additional items to complete the customer's order (Frazelle, 2002).

Cross-docking can provide greater control over delivery schedules. Use of a CD is thus well suited to the Just-In-Time manufacturing environment (Luton, 2003), and also to the make-to-order environment (Copacino, 1997). Other conditions under which cross-docking should be considered are given in *Modern Materials Handling* (1995). These include SKUs that arrive at the warehouse already labelled or priced; receipt of large numbers of individual items; products whose destination is known when received; and goods for customers who are prepared to receive them immediately.

The major prerequisite for successful cross-docking is a system to ensure the efficient exchange of products between supply chain entities. Emphasis should be given to the scheduling and coordination of shipments inbound and outbound at a given node (Bookbinder and Barkhouse, 1993; Jones, 2001). This requires a timely and accurate flow of information between supply chain members. Such an information system should support advanced shipment notifications (ASN), electronic data interchange (EDI), and automatic identification (auto ID) technologies, such as bar codes and radio-frequency tags.

Frazelle (2002) notes that advance knowledge of inbound goods and their destinations allows the CD "to route the product to the proper outbound vehicle, to schedule inbound loads to match outbound requirements on a daily or even hourly basis, and to better balance the use of receiving resources (dock doors, personnel, staging space, and material handling equipment) and, if necessary, shift time-consuming receipts to off-peak hours."

Other requirements of cross-docking include (e.g., Napolitano, 2001):

- Suppliers who can consistently provide the correct quantity of the right product, at the precise time when needed.
- Capital to sustain a cost-justified CD system and personnel who recognize the importance of moving, not storing, products.

- Adequate space for staging, and appropriate docks and material handling equipment (Jones, 2001).
- Inbound shipments consisting of pallets or cases that contain a single SKU or a set of SKUs going to the same destination, so as to minimize sorting (Frazelle, 2002).

As well as information requirements, the physical design of the CD (Bartholdi and Gue , 2001) must be considered. The ideal cross-dock should be rectangular, long and narrow, with loading docks on each side to smooth the product flow and inhibit product storage (Murphy and Wood, 2004). Although the facility should be as small as possible to minimize travel distances between vehicles (Luton, 2003), the cross-dock staging area must be large enough to allow the direct flow of products between receiving and shipping (Jones (2001)). There also must be a sufficient number of doors to avoid backlogs and delays for carriers. Luton (2003) notes that a conventional warehouse can encourage direct-flow operations by having both shipping and receiving docks on the same face of the building.

3.3 The DC as a transshipment facility

Along with breaking bulk and making bulk, a traditional function of a distribution centre is *transshipment.* This refers to the process of taking an item or shipment out of one vehicle and loading it onto another (Daganzo, 1999). Transshipment may or may not include consolidation or de-consolidation. If no items are added or removed during the transshipment, the process is sometimes referred to as *transloading.* Beuthe and Kreutzberger (2001) provide a detailed discussion of transshipment in logistics networks of various designs.

Transshipment occurs when there is good reason to change transportation modes or vehicle type. Transshipment centres "decouple the linehaul transportation and local delivery operations, enabling us to use larger trucks for linehaul than for delivery; they also increase the number of delivery stops that can be made without violating route length limitations." (Daganzo, 1999). Transshipment can be used as well during the final delivery stage to handle time-of-day constraints at customers, or weight restrictions on truck-delivery routes. Vehicles operating out of a transshipment centre are dedicated to specific links of the supply chain; they can thus be optimally sized and configured for the services and routes they handle. Conversely, transshipment does imply greater cost: Less-direct truck routes are employed, transshipment facilities are required, and terminal operations increase transit time and potential for damage.

Transshipment is the main focus of a hub-and-spoke transportation system, aspects of which have been examined by a number of researchers. Examples include Taylor et al. (1995); Pirkul and Schilling (1998); Bryan and O'Kelly (1999); Cheung and Muralidharan (1999); and Campbell et al. (2002).

Pleschberger and Hitomi (1994) and others have noted the negative impacts (noise, air pollution, ...) of frequent JIT deliveries. In Europe, transshipment centres have thus been suggested as a way to reduce environmental problems created by truck traffic in urban areas. Whiteing et al. (2003) observe, however, that such centres have had problems related to insufficient product volumes, relatively high operating costs, and feelings of loss of control by shippers of the goods. Since the major drawback of transshipment facilities is inadequate throughput, proposals for transshipment centres often *require* carriers to consolidate products for delivery or collection in city centres (or include penalties for not doing so). Many carriers, however, have requested exemption from consolidation, claiming that their products are highly perishable, may contaminate other goods, or need intense levels of security (Whiteing et al., 2003).

Similar environmental concerns were part of the discussion by Taniguchi et al. (1999) of the experience in Japan with a *public logistics terminal*. This is a multi-company DC; it may be viewed as the supply-chain generalization of a public warehouse. Those authors employ queuing theory and nonlinear programming in a model to determine the optimal sizes and locations of public logistics terminals. Traffic congestion and energy-environmental issues were accounted for in an application in the Kyoto – Osaka area.

Bendel (1996) describes transshipment centres as key to a concept called *city logistics*. During the 1990s, carriers in several German cities agreed to divide loads (and revenue) so as to improve efficiency and avoid duplication of travel. These schemes sometimes included, with financial assistance of local government, the establishment of a transshipment centre to handle collections and deliveries for the urban area concerned. Kohler and Straub (1997) discuss a city logistics program in Kassel, whereby five German carriers tranship freight to a sixth. The latter delivers to retailers in the city centre. This arrangement improved the vehicle load factors by more than 50 percent. It was found, however, that environmental benefits were partly offset by increases in total operating costs. Short case studies of other city logistics schemes are given in Thompson and Taniguchi (2001). Wider issues, i.e., advanced methods to manage urban freight transport, are considered by Taniguchi et al. (2001) and Crainic et al. (2004).

Lee's (1996) facility location/allocation model recognizes that an organization will use distribution centres with differing capacities. This integer linear programming model implicitly treats all DCs as transshipment centres. Bhaskaran (1992) presents a case study from the automobile manufacturing industry. She develops a heuristic to determine the number and location of transshipment centres; here those centres are *CDs*, with no possibility of storage. The paper discusses a good sequential strategy for adding new transshipment centres, one at a time, as demand grows in the network.

Daganzo (1999) provides a comprehensive mathematical examination of different logistics systems, both with and without transshipment centres. (We remark that his work considers the breaking of bulk as included in a transshipment.) He begins by studying loads moving from an origin to a single destination, through one transshipment centre. Daganzo notes that this problem is similar to the classical model for facility location and sizing, with an additional decision related to vehicle scheduling. Thus, the critical step in design of such a system is to determine ideal locations for transshipment facilities. In this case, when pipeline inventory cost is negligible relative to other logistics costs, he concludes that trucks should be filled to capacity. Hence the largest ones possible should be used, which may require transshipments if truck sizes are restricted in a market area.

Daganzo's examination of many-to-many distribution treats facilities as makebulk/breakbulk consolidation centres. These are multicommodity problems where each origin supplies a unique product. When there are no restrictions on vehicle capacity or route length, logistics costs per delivered item improve as more routes tranship at the terminal. Logistics systems with one terminal; multiple terminals having a single transshipment per load; and multiple terminals with more than one transshipment per load are discussed. Daganzo shows how, for multiple-terminal systems, determination of truck routes depends on whether the area around a given terminal ships to, or receives from, only that terminal.

A number of researchers have studied the use of transshipments in the management of inventory and its re-allocation. Such models typically employ the term, "transshipment," differently than the transportation-sense adopted in this section. Instead, *transshipment* is defined as a tactic in multi-location inventory control, whereby products can be transferred laterally between stocking-points, as demand requires. (Bertrand and Bookbinder, 1998, term this a *redistribution.*) Thus, contrary to our definition of DC, it is assumed that facilities do hold inventory. Publications in this area include Evers (1996, 2001); Herer et al. (2002); Hong-Minh et al. (2000); and Tagaras and Vlachos (2002).

3.4 The distribution centre as an assembly facility

Having discussed the inventory-transportation interfaces of a DC, let us now consider linkages closer to manufacturing. It is well known that delaying item-differentiation, packaging, and labelling until later stages of the supply chain can improve product allocation. The often-cited case of Hewlett Packard's European distribution centre is a good example of using a DC for minor product assembly (see, for example, Kopczak and Lee, 1994; Simchi-Levi et al., 2003). Prior to moving assembly activities to that facility, HP's DeskJet printer was manufactured in Vancouver, Washington, and shipped by water to the European DC. The latter facility suffered from inaccurate forecasts, serious inventory problems, and poor customer service. HP redesigned the DeskJet so that a single generic model (allowing easy customization) could be produced in Vancouver, then assembled-to-order in one of six ways at the European distribution centre. Simchi-Levi et al. (2003) offer a mathematical illustration of the resulting savings in inventory cost. This hinges on the decreased standard deviation of demand, hence lower safety stock overall, due to generic redesign.

Just as important are the human issues related to HP's decision. Assembly responsibilities were initially resisted by DC employees, who saw their role to be in *distribution*, not manufacturing. As well, the DCs were reluctant to give up some inventory, in light of expectations of high customer service.

A major advantage of using a distribution centre for final assembly activities is "product localization"; that is, the ability to configure an item in a given market area to better reflect the needs and characteristics of that market. Switching to a strategy of performing final assembly at a DC will also change the relative value of an SKU at different stages in the supply chain. Some financial benefits may result. For example, labour often costs less at the distribution centres than in factories. If goods must cross international borders before reaching the DC for final assembly, tariff duties may be lower on the unfinished product than on a finished item.

3.5 The DC as product-fulfilment centre

Let us now consider facilities with stronger links to the end-customer. The term *fulfilment centre* has been used to describe a DC or warehouse whose major function is to respond to product orders from the final consumer, by shipping those items directly there. Usually, customers will have placed those orders via an electronic medium such as the World Wide Web.

Product fulfilment centres differ from traditional warehouses and DCs in a number of ways (Ackerman and Brewer, 2001):

- Because the fulfilment-centre operator deals directly with consumers, customer-service requirements demand greater importance.
- The size of a typical order handled by a product fulfilment centre is smaller, but the number of orders is larger.
- Most or all orders are received electronically (as noted already).
- Fulfilment centres typically must receive customer payments, often by major credit card; some also create customer invoices and handle banking for their clients.
- A large amount of time is spent in dealing with *returns* from customers.
- Computerized information systems and task automation are increasingly critical, and the transportation function (especially residential delivery) is more complex.

Because the role of product-fulfilment centre interacts with several others that the DC may play, there is considerable potential here for further research.

3.6 The distribution centre as depot for returned goods

Although reverse distribution is analysed in greater detail elsewhere in this book, it is useful to briefly examine the role of DCs in the handling of returned items.

Many of the distribution-centre functions discussed previously in this chapter (including consolidation and light assembly) come together in dealing with product returns. The reverse distribution channel typically is more complex than the forward flow. The main objective in many reverse distribution systems is to minimize costs, while quickly getting the returned product back into the forward distribution channel. At the same time, a major management concern in reverse distribution is to avoid the inadvertent mixing of SKUs in the return channel with those in the forward direction. As a result, firms such as Sears Roebuck, Hudson's Bay, Target and K-Mart have outsourced their reverse distribution channel to third parties who operate DCs dedicated to materials returned.

The handling of such items is very labour intensive. All returned products must be inspected, then separated into those that can be repaired or repackaged at the returned-goods depot; others which need go back to the supplier; those that will be sent elsewhere (e.g., donated to charity or sold in a secondary market); and some that must be destroyed or recycled for scrap. Conversely, an organization with a private fleet, and which chooses to manage its own reverse distribution channel, can improve vehicle and driver utilization if returned items are transported on inbound trips back from other facilities.

3.7 The DC in miscellaneous other roles

A distribution centre often performs more than one function simultaneously. We have mentioned transshipment and consolidation (Whiteing et al., 2003); break bulk and light assembly (Kopczak and Lee, 1994); and returned-goods processing at outbound consolidation facilities. In conjunction with material flows, a DC may also act as a depot for trucks or drivers, where the fleet is domiciled or maintained, or where drivers switch vehicles to avoid violating personnel schedules or legal or workforce constraints. Ross and Droge (2002) present an example of this role in the petroleum industry.

Coordination of inbound and outbound vehicles for product distribution has been discussed by several authors (e.g., Daganzo, 1999); restrictions on tour length due to driver issues are common in vehicle routing formulations. Nevertheless, research typically treats the questions of where vehicles or drivers rest as secondary to product decisions.

A distribution centre also can offer customer support. Designing, providing and scheduling services such as installation and repair require operational decisions quite different from those faced by DCs dealing only in goods movement. Similarly, particular SKUs (e.g., repair parts or hazardous items) should be held centrally or in specialized locations. Some distribution centres will thus be assigned these functions.

Lastly, a DC can offer space for retail sales to final customers, i.e., can act as a factory-outlet store. As well as providing a way to dispose of excess, discontinued, returned or slightly soiled items, manufacturers and distributors can retain control over their products while earning the higher revenues associated with retailing (e.g., Berman, 1996).

4. Measuring distribution-centre performance

Section 3 described how a DC can play multiple roles, singly or in combination. We now turn attention to *evaluation* of those activities.

The measurement of performance of an organization's logistics function or its supply chain is addressed in many works (see, for example, Ross et al., 1999; Keebler, 2001; Ballou, 2004). However, performance assessment is not usually discussed explicitly for a *DC*. Fortunately, a number of the measures used in evaluating performance of traditional warehouses are applicable to distribution centres. Metrics for a DC would thus typically benchmark current actual performance against results achieved in the past, output of comparable operations elsewhere in the company, or achievements by other organizations or best performers and industry standards. This comparison is straightforward. A DC carries out a large number of activities, highly repetitive and easily monitored; that encourages quantitative measures.

In fact, a few methods for evaluating performance of the distribution centre as part of a supply chain have been developed. In addition to benchmarking (above), one has available the analysis of cycle time and integrative-evaluation approaches, such as "balanced scorecard" models and *SCOR*, the Supply Chain Operations Reference model.

As in a warehouse, the per-unit and total costs remain critical measures of DC performance (Higginson, 1993). Daganzo (1999) covers the mathematical modelling of distribution centre costs, discussing the charges for inventory holding, transportation and material handling. Another important indication of the viability of a DC is *throughput*; that is, the total amount (weight, dollar-value, etc.) of goods that pass through the facility during a stated period of time. Inventory turnover and the similar shipments-to-inventory ratio also are employed. Performance measures commonly used in distribution centres include total cost per case, or per pallet, or per employee hour; labour utilization percent; fixed cost per square metre; and the time between receipt and dispatch of an order. Additional metrics for DC productivity are listed in Schary (1984, p. 102). Again, some of these measures assume that the facility carries stock.

Frazelle (2003) states, "The most critical quality indicators for distribution centre operations are inventory accuracy (percentage of inventory storage locations without discrepancies), picking accuracy (percentage of lines picked without errors), shipping accuracy (percentage of lines shipped without errors), and warehouse damage percentage (percentage of dollar-value of damages per dollar-value of items shipped)." Clearly most of these standards relate not to product movement, but rather to SKU storage and picking. Those warehouse-type functions ignore the *time-based* element in a DC.

Yang (2000) identifies, through computer simulation, the major policies and environmental factors that affect the performance of a single-warehouse multiple-retailer distribution system. He remarks that the operating environment (e.g., few vs. many stores; low or high variability of demand) often has a greater effect on performance than does choosing the appropriate system or policy (vehicle routing algorithm; periodic vs. continuous inventory review). Ackerman and Brewer (2001) note that one of the most important measures of distribution centre performance is the perception of customers who work with, or receive deliveries from, the DC. They add that, "In a distribution centre where customer service has top priority, the warehouse management system is judged by its capacity to provide service that is superior to its competition."

Kuo et al. (1999) examined performance measurement in six categories (finance, operations, quality, safety, personnel, and customer satisfaction) for five DCs (technically, warehouses). A cross-case comparison showed that the facilities used fairly similar objective measures for the first four categories, including cost per unit, percentage of errors, and number of employee accidents. However, for all five DCs, evaluation of service to clients was limited to customer feedback.

Less traditional methods for evaluating distribution centre performance have been suggested. Noh and Jeon (1999) employ several methodologies, including AHP and data envelopment analysis (DEA), to compare relative efficiencies for the DCs of a Korean telecommunications company. Ross and Droge (2002) present a benchmarking model, also using DEA. To evaluate a set of 100 DCs in the petroleum business, Ross and Droge optimise an objective related to the aggregate efficiency ratio. Their DEA model has three inputs: Fleet size; labour (average no. years experience of personnel assigned to DC); and mean order-throughput time. Outputs are (transformed) sales volumes of each of four products. The resulting efficient frontier gives the top-performing DCs in any time period.

The model of Ross and Droge (2002) appears useful in evaluating distribution centres whose role (among others) is that of vehicle depot. It could be argued, however, that order-throughput time is an *output*, not an input, and that the marketing mix (beyond the DC's control) has a major effect on sales volume. But Ross and Droge do point a way to evaluate the distribution centres of a given supply chain or of competing chains.

5. Information requirements to manage a DC

An additional input that most distribution centres take for granted is *information*, available in the proper format. A DC must be efficient in the retrieval and transfer of data because of today's greater size of facilities, faster product flow, and increased importance of coordinating inbound and outbound shipments. This section focuses on two common computerized information systems - Enterprise Resource Planning

(ERP) and Warehouse Management Systems (WMS) - employed at distribution centres. A non-technical overview of the evolution of logistics information software is given in Ayers (2001).

An Enterprise Resource Planning system is a computer package that integrates the data of the entire organisation into a single relational or object-oriented database linked to various transaction-processing modules. Such modules typically include applications in distribution and sales, finance and accounting, human resources, inventory control and manufacturing, and purchasing. The functions of warehousing and distribution centre management are typically accessed through one of these modules.

Factors contributing to successful and not-so-successful ERP implementations have been well documented in the literature (e.g., Stratman and Roth, 1999; Nah and Lau, 2001; Umble et al., 2003). It has been recognized by several researchers that many ERP systems unfortunately lack the functionality required to adequately support warehouse/distribution centre planning, and other supply chain processes including transportation. (See, for example, Frazelle, 2002; Handfield and Nichols, 2002; Spiegel, 2003).

ERP systems are designed to integrate, via a "suite" of applications, all of the organization's functions, including warehousing. However, as Frazelle (2002) notes, "Many warehousing systems evolved from applications very far removed from warehousing, including accounting, customer service, general ledger, inventory management, and/or manufacturing. Unfortunately, warehousing is typically an afterthought application for these providers, and the full-suite providers typically have very little expertise in warehousing." As well, ERP systems are "transaction-based;" that is, they are intended to record what the organization *has* done, rather than plan what the organization should do.

This has led to the development of Advanced Planning and Scheduling software (APS), which provide the OR capabilities in optimisation lacking in ERP and MRP packages (e.g., Green, 2001). "Bolt-on systems" is the descriptor given to APS: They extend the functionality of other software by drawing their input data from those packages, including ERP and logistics execution systems such as forecasting, production control, transportation, warehousing and order management (Cauthen, 1999).

Aksoy and Derbez (2003) categorize available software according to OR techniques used and the supply-chain application. Many of these packages have been quite successfully utilised. We remark, however, that some APS designed for logistics planning is purely-executional software which lacks a capability for long term planning. This is perhaps one reason why it was recently reported (Foster, 2003) that many users preferred to purchase single programs to address specific logistics problems, rather than *suites* of supply-chain applications.

Let us turn now to the Warehouse Management System. This denotes computer software that tracks, plans, controls, analyses, and records the flow of product through a warehouse or distribution centre. A WMS (like a Transportation Management System) falls into the category of "logistics execution software." Thus, unlike ERP systems, Warehouse Management Systems are intended as *real-time planning tools*.

Particular functional capabilities are common in a Warehouse Management System (for example, see Frazelle, 2003). Such software:

- automates transaction activities such as verification of product weight and cube, and vendor compliance
- determines product storage locations within a facility
- develops and prints order pick-lists
- prints labels for bar code, storage location, product IDs, etc.
- plans inbound and outbound transportation activities, including container optimization, load planning, and dock and yard management
- performs various activities related to workforce management, such as workload planning and scheduling, labour control, and time standards
- supports electronic communication within the facility (such as via radio frequency) and with supply chain partners (e.g., through EDI and ASN)
- compiles and reports activity information, e.g., detailed summaries of each inbound or outbound movement, item activity profiles, and facility performance measures.

The above is the good news. However, Warehouse Management Systems have several fundamental problems. Frazelle (2002) observes, "... Most WMS vendors have few highly qualified engineers and analysts. Those few are typically assigned to the largest and most prestigious accounts. If you are not included in that list, you may not be satisfied with the capabilities of the engineers and analysts assigned to your project." He goes on to note that, "Less than half of all warehouse management systems yield the performance and practice improvements promised during the justification phase."

Moreover, integrating a Warehouse Management System with an ERP system is considered to be quite difficult, really time-consuming, and very expensive (Cooke, 1998). Thus, organizations wishing to have warehouse/distribution centre management functionality as part of their ERP system will have to be involved in a major integration project, or purchase an ERP system that, although possessing such capabilities, probably has less than is desired. It remains to be seen if recent attempts by some major ERP vendors to ally themselves with providers of WMS will be successful. At the same time, there has been a similar move toward integrating WMS and Transportation Management Systems; Mason et al. (2003) discuss the benefits of doing so.

Lastly, ERP and WMS focus on logistics activities for one organization or for one facility of that organization. Although many ERP systems allow electronic communication with suppliers and customers, neither WMS nor ERP is well suited for linking supply chain members, and even less so for planning and coordinating movements between facilities throughout the chain. Distribution Resource Planning (DRP) systems may provide assistance in these tasks. (See, e.g. Vollmann et al., 2004). The initial DRP systems of the 1980s promised smaller inventories, higher in-stock availability, and reduced transportation and operating costs. Those systems did not often achieve their potential, partly because DRP is most beneficial for multi-echelon distribution networks. These have become less popular as companies reduced the number of stock-keeping locations. But note that the original concept of DRP pertained to a single organization.

Channel-wide DRP systems attempt today to link all facilities across the supply chain, something not found traditionally in logistics software. In the channel-wide case, "each customer distribution centre is established as a stocking location in the manufacturer's DRP system. The manufacturer's DRP system manages replenishment from plants to both its own distribution centres and the customer's distribution centres as if the manufacturer owned the entire network. Given that supply chains from manufacturers to their customers are multi-echelon systems, a channel-wide DRP replenishment system invariably produces superior results" (Copacino, 1997). This is clearly a challenging research area, since it involves simultaneous scheduling for multiple decision-makers whose databases have varying degrees of integration.

6. Summary and conclusions

This chapter has described the functions that a distribution centre can assume in the operation of a supply chain, as well as discussed some considerations in monitoring and controlling the activities of a DC. Our final section comments on the weaknesses of published articles related to those roles. We suggest some areas in which future research could be carried out, in addition to topics proposed above.

As stated previously, most academic literature does not distinguish between warehouses and distribution centres, therefore ignoring any distinctions in activity. The paper by Lee (1996) is a good example.

Whereas the title does indicate that various types of facilities are being modelled, this difference is only in terms of capacity and fixed costs, not roles. (Of course, it could be claimed that contrasting functions *imply* the differing capacities.) Ignoring the diversity of activities at a DC can result in assumptions that may not be accurate, or are not explicitly stated to the reader. A common example is assuming that the distribution centre will store inventory. Conversely, recognizing the variety of services the facility may offer provides researchers with potential areas for study.

In fairness, some publications have emphasized that facilities may function as distribution centres, not as warehouses. In the classical transshipment problem, for example, the assumption that all items that move into the facility must also leave implies that inventory is not being held, hence the facility is acting as a DC or cross-dock. However, as observed in Section 3.3, some of the more recent papers employ the term "transshipment" to mean transfers between stock-keeping locations.

Among the roles of a distribution centre discussed in this chapter, the OR literature has given greatest attention to transshipment. This is due in part to its close relationship to vehicle routing or decisions on the number and mix of vehicles in the fleet. The key issue that should be captured in a mathematical model that includes transshipment or cross-docking through a DC is the synchronization of trucks inbound and outbound. This is mentioned by Daganzo (1999) and others.

An obvious and interesting question then is, "When should a facility be used for storing inventory and when should it be limited to the flow-through roles described in the previous sections?" The location model of Gümüş and Bookbinder (2004) aims to decide, from a set of potential sites, where *CDs* will be opened. Only cross-docks are considered; consolidated-shipment opportunities are thus important here. A location model could, more generally, consider two types of intermediate facilities: One would act as a stock-keeping warehouse, the other as a distribution centre.

Similarly, little research has been done on issues in using a DC for light assembly. A model of product flows in this situation would have to include considerations of *time*. Although a shorter interval might be required for production at the factory, the period between arrival at the DC and customer-delivery will increase. If there is not a greater frequency of shipment from factory to distribution centre, total lead-time will grow. Even with that enhanced frequency, the customer's wait will be of longer duration.

Other questions exist: What are the characteristics of a supply chain for which light assembly is preferably done at an intermediate DC? What is the best layout of such a facility? Mathematical modelling has potential application in the design and configuration of distribution centres for use in product assembly, e-commerce fulfilment and returned-goods collection. These analyses would correspond to those done on the layout of warehouses (e.g., Gray et al., 1992) or cross-docks (Bartholdi and Gue, 2001).

The role of a distribution centre as a depot for returned items has been touched upon by vehicle routing studies that consider both deliveries and backhauls. In practice, the major qualifying factor is the volume of product to be brought back on a route; this is rarely as great as the quantity moving outward. Fernie (2003) mentions the case of a Scottish DC, designed to act as collection point for reusable items picked up from retail stores. The volume of such materials, however, insufficiently utilized the trucks returning to the facility.

When a third party handles returned goods, items moving in the reverse direction typically do not flow through the seller's forward distribution system at all. Instead, they go directly from the point of customer return to the third party's facility. That can simplify any modelling or analysis: Forward and backward product flows, now independent, can be optimised separately.

Distribution-centre performance measurement and information systems have their roots in warehouse management. Some approaches may therefore be sub-optimal for application in DCs. An examination is warranted to determine the true utility of Warehouse Management Systems, or warehouse-based performance measures, in managing the operations of a distribution centre. For example, it has been noted that many early WMS did not adequately handle cross-docking; improved functionality in this area is appearing only now.

Clearly, a DC in a supply chain can assume roles that go well beyond the traditional functions of transshipment and breaking bulk. This recognition provides a number of areas for potential study. That research will encourage better understanding and utilization of these facilities.

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References

Ackerman, K.B. and Brewer, A.M. (2001). Warehousing: A key link in the supply chain. In: A.M. Brewer, K.J. Button, and D.A. Hensher (eds.), *Handbook of Logistics and Supply-Chain Management*, pp. 225 – 237. Pergamon, New York.

Aksoy, Y., and Derbez, A. (2003). 2003 software survey: supply chain management. *OR/MS Today*, 30(3):34–41.

Ayers, J.B. (2001). Topography of supply chain applications. In: J.B. Ayers (ed.), *Handbook of Supply Chain Management*, pp. 167–178. St. Lucie Press, Boca Raton, FL.

Ballou, R.H. (2004). *Business Logistics/Supply Chain Management*. Pearson, Upper Saddle River, NJ. 5th edition.

Bancroft, T. (1991). Strategic role of the distribution centre: How to turn your warehouse into a DC. *International Journal of Physical Distribution and Logistics Management*, 21(4):45–47.

Bartholdi, J.J. and Gue, K.R. (2001). The best shape for a cross dock. Under review.

Baudin, M. (2001). Consolidation centers in the lean supply chain. In: J.B. Ayers (ed), *Handbook of Supply Chain Management*, pp. 375–383. St. Lucie Press, Boca Raton, FL.

Bendel, H.J. (1996). City logistics. *Logistics Europe*, pp. 16–23, February.

Berman, B. (1996). *Marketing Channels*. John Wiley & Sons, New York

Bertrand, L.P. and Bookbinder, J.H. (1998). Stock redistribution in two-echelon logistics systems. *Journal of the Operational Research Society*, 49:966–975.

Beuthe, M. and Kreutzberger, E. (2001). Consolidation and trans-shipment. In: A.M. Brewer, K.J. Button, and D.A. Hensher (eds.), *Handbook of Logistics and Supply-Chain Management*, pp. 239–252. Pergamon, New York.

Bhaskaran, S. (1992). Identification of transshipment center locations. *European Journal of Operational Research*, 63:141–150.

Bookbinder, J.H. and Barkhouse, C.I. (1993). An information system for simultaneous consolidation of inbound and outbound shipments. *Transportation Journal*, 32(4):5–20.

Bordley, B., Beltramo, M., and Blumenfeld, D. (1999). Consolidating distribution centres can reduce lost sales. *International Journal of Production Economics*, 58(1):57–61.

Bryan, D.L. and O'Kelly, M.E. (1999). Hub-and-spoke networks in air transportation: An analytical review. *Journal of Regional Science*, 39:275–295.

Campbell, J.F., Ernst, A.T., and Krishnamoorthy, M. (2002). Hub location problems. In: Z. Drezner and H.W. Hamacher (eds.), *Facility Location: Applications and Theory*. Springer-Verlag, Heidelberg.

Caron, F., and Marchet, G. (1996). The impact of inventory centralization/decentralization on safety stock for two-echelon systems. *Journal of Business Logistics*, 17(1):233–257.

Cauthen, R. (1999). APS technology: Powering supply chain management. *Enterprise Systems Journal*, 14(9):41–45.

Cheung, R.K. and Muralidharan, B. (1999). Impact of dynamic decision making on hub-and-spoke freight transportation networks. *Annals of Operations Research*, 87:49–71.

Chopra, S. (2003). Designing the distribution network in a supply chain. *Transportation Research E*, 39(2):123–140.

Chopra, S. and Meindl, P. (2004). *Supply Chain Management: Strategy, Planning, and Operation.* 2nd edition, Upper Saddle River, NJ: Pearson.

Cooke, J.A. (1998). Crossing the great software divide. *Logistics Management*, pp. 72–74, June.

Copacino, W.C. (1997). *Supply Chain Management: The Basics and Beyond*. St. Lucie Press, Boca Raton.

Cormier, G. (2005). Operational research methods for efficient warehousing. In: A. Langevin and D. Riopel (eds.), *Logistics Systems: Design and Optimization*, Kluwer, Norwell, MA.

Coyle, J.J., Bardi, E.J., and Langley, C.J., Jr. (2003). *The Management of Business Logistics: A Supply Chain Perspective*, 7th edition. South-Western, Mason, OH.

Crainic, T.G., Ricciardi, N., and Storchi, G. (2004). Advanced freight transportation systems for congested urban areas. Forthcoming in *Transportation Research C*.

Daganzo, C.F. (1987). The break-bulk role of terminals in many-to-many logistic networks. *Operations Research*, 35:543 – 555.

Daganzo, C.F. (1988). Shipment composition enhancement at a consolidation center. *Transportation Research B*, 22:103 – 124.

Daganzo, C.F. (1999). *Logistics Systems Analysis*, 3rd edition. Springer-Verlag, Heidelberg.

Daww, R.L. (1995). Reengineer warehousing. *Transportation and Distribution*, 36(1):98 – 102.

Delaney, R.V. (1991). Trends in logistics and U.S. world competitiveness. *Transportation Quarterly*, 45(1):19 – 41.

Diks, E.B. and de Kok, A.G. (1996). Controlling a divergent 2-echelon network with transshipments using the consistent appropriate share rationing policy. *International Journal of Production Economics*, 45(1/3):369 – 379.

Evers, P.T. (1996). The impact of transshipments on safety stock requirements. *Journal of Business Logistics*, 17(1):109 – 133.

Evers, P.T. (2001). Heuristics for assessing emergency transshipments. *European Journal of Operational Research*, 129:311 – 316.

Fernie, J. (2003). Retail logistics. In: D. Waters (ed.), *Global Logistics and Distribution Planning*. pp. 249 – 275, 4th edition. Kogan Page, London.

Footlik, R.B. (1999). Property tax trends: Do 30' high distribution centres make sense? *Journal of Property Tax Management*, 10(3):63 – 71.

Foster, T.A. (2003). Supply chain top 100 software vendors. *Logistics Management*, 42(9):S9.

Frazelle, E.H. (2002). *World-Class Warehousing and Materials Handling*. McGraw-Hill, New York.

Frazelle, E.H. (2003). *Supply Chain Strategy*. McGraw-Hill, New York.

Gray, A.E., Karmarker, U.S., and Seidmann, A. (1992). Design and operation of an order-consolidation warehouse: Models and application. *European Journal of Operational Research*, 58:14 – 36.

Green, F.B. (2001). Managing the unmanageable: Integrating the supply chain with new developments in software. *Supply Chain Management*, 6(5):208 – 211.

Gümüş, M. and Bookbinder, J.H. (2004). Cross-docking and its implications in location-distribution systems. Forthcoming in *Journal of Business Logistics*.

Hall, R.W. (1987). Consolidation strategy: Inventory, vehicles and terminals. *Journal of Business Logistics*, 8(2):57 – 73.

Handfield, R.B. and Nichols, E.L., Jr. (2002). *Supply Chain Redesign*. Financial Times Prentice Hall, Upper Saddle River, NJ.

Heaver, T. and Chow, G. (2003). Logistics strategies for North America. In: D. Waters (ed.), *Global Logistics and Distribution Planning*, pp. 413 – 427, 4th edition.Kogan Page, London.

Herer, Y.T., Tzur, M., and Yucesan, E. (2002). Transshipments: Emerging inventory recourse to achieve supply chain legality. *International Journal of Production Economics*, 80:201 – 212.

Higginson, J.K. (1993). Modelling shipper costs in physical distribution analysis. *Transportation Research A*, 27:113 – 124.

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

Hong-Minh, S.M., Disney, S.M., and Naim, M.M. (2000). The dynamics of emergency transshipment supply chains. *International Journal of Physical Distribution and Logistics Management*, 30(9):788 - 816.

Jones, A. (2001). Cross docking — is it right for you? *Canadian Transportation & Logistics*, 104(9).

Keebler, J.S. (2001). Measuring performance in the supply chain. In: J.T. Mentzer (ed.), *Supply Chain Management*, pp. 411 – 435. Sage Publications, Thousand Oaks, CA.

Ketzenberg, M., Metters, R., and Vargas, V. (2002). Quantifying the benefits of breaking bulk in retail operations. *International Journal of Production Economics*, 80(3):249 – 263.

Kim, J.-S. (2002). On the benefits of inventory-pooling in production-inventory systems. *Manufacturing and Service Operations Management*, 4(1):112 – 116.

Klincewicz, J.G. and Rosenwein, M.B. (1997). Planning and consolidating shipments from a warehouse. *Journal of the Operational Research Society*, 48(3):241 – 246.

Kohler, U. and Straub, S. (1997). City logistics concept for Kassel. *Proceedings of 25th PTRC European Transport Forum: Seminar B – Freight*, pp. 97 – 103. PTRC Education and Research Services, London.

Kopczak, L. and Lee, H. (1994). *Hewlett-Packard: DeskJet Printer Supply Chain (A)*. Stanford University, Department of Industrial Engineering and Engineering Management.

Kuo, C.-H., Dunn, K.D., and Randhawa, S.U. (1999). A case study assessment of performance measurement in distribution centers. *Industrial Management + Data Systems*, 99(2):54 – 63.

Lee, C.Y. (1996). An algorithm for a two-staged distribution system with various types of distribution centers. *INFOR*, 34(2):105 – 117.

Luton, D. (2003). Keep it moving: A cross-docking primer. *Materials Management & Distribution*, 48(5):29.

Mason, S.J., Ribera, P.M., Faris, J.A., and Kirk, R.G. (2003). Integrating the warehousing and transportation functions of the supply chain. *Transportation Research E*, 39(2):141 – 159.

Min, H. and Melachrinoudis, E. (1999). The relocation of a hybrid manufacturing/distribution facility from supply chain perspectives: a case study. *Omega*, 27(1):75 – 85.

Modern Materials Handling. (1995). Receiving is where efficiency starts. *Modern Materials Handling*, 50(5):9.

Murphy, P.R., Jr. and Wood, D.F. (2004). *Contemporary Logistics*, 8th edition., Pearson, Upper Saddle River, NJ.

Nah, F.F., and Lau, J.L. (2001). Critical factors for successful implementation of enterprise systems. *Business Process Management Journal*, 7(3):285 – 296.

Napolitano, M. (2001). *Making the Move to Cross-Docking* pp. 308 – 320. Warehousing Education and Research Council, Oxford, OH.

Noh, S.-J. and Jeon, S.-H. (1999). A relative efficiency assessment model for logistics systems. *Journal of the Korean Operational Research Society*, 24(4):95 – 109.

Pirkul, H. and Schilling, D.A. (1998). An efficient procedure for designing single allocation hub and spoke systems. *Management Science*, 44:S235 – S232.

Planeta, J. (2001). Real estate logistics: understanding the modern Canadian distribution centre. *Canadian Transportation & Logistics*, 104(9):14.

Pleschberger, T.E. and Hitomi, K. (1994). Just-in-time shipments in a truck-traffic-coordination system. *International Journal of Production Economics*, 33:195 – 205.

Quinn, F.J. (2000). Transportation: The forgotten factor. *Logistics Management*, p. 45, September.

Reynolds, T. (2003). Distribution Center Management. *Annual Trends Report.*

Ross, A., and Droge, C. (2002). An integrated benchmarking approach to distribution center performance using DEA modelling. *Journal of Operations Management*, 20(1):19 – 32.

Ross, A., Venkataramanan, M.A., and Ernstberger, K.W. (1999). Reconfiguring the supply network using current performance data. *Decision Sciences*, 29:707 – 728.

Schary, P.B. (1984). *Logistics Decisions: Text and Cases.* The Dryden Press, Chicago.

Simchi-Levi, D., Kaminsky, P., and Simchi-Levi, E. (2003). *Designing and Managing the Supply Chain.* 2nd edition. McGraw-Hill Irwin, Boston.

Spiegel, R. (2003). ERP vendors muscle into logistics. *Logistics Management*, 6(4):45 – 48.

Stratman, J.K. and Roth, A.V. (1999). Beyond ERP implementation: Critical success factors for North American manufacturing firms. *Supply Chain and Logistics Journal*, 5(1):5.

Tagaras,G., and Vlachos, D. (2002). Effectiveness of stock transshipment under various demand distributions and nonnegligible transshipment times. *Production and Operations Management*, 11:183 – 198.

Taniguchi, E., Noritake, M., Yamada, T., and Izumitani, T. (1999). Optimal size and location planning of public logistics terminals. *Transportation Research E*, 35:207 – 222.

Taniguchi, E., Thompson, R.G., Yamada, T., and van Duin, J.H.R. (2001). *City Logistics: Network Modelling and Intelligent Transportation Systems.* Pergamon, New York.

Taylor, G.D., Harit, S., English, J.R., and Whicker, G. (1995). Hub and spoke networks in truckload trucking: Configuration, testing and operational concerns. *Logistics and Transportation Review*, 31:209 – 237.

Teo, C.P., Ou, J., and Goh, M. (2001). Impact on inventory costs with consolidation of distribution centres. *IIE Transactions*, 33(2):99 – 110.

Thompson, R.G., and Taniguchi, E. (2001). City logistics and freight transport. In: A.M. Brewer, K.J. Button, and D.A. Hensher (eds.), *Handbook of Logistics and Supply-Chain Management*, pp. 393 – 405. Pergamon, New York.

Trappey, A. and Ho, P.-S. (2001). Human resource assignment system for distribution centers. *Industrial Management + Data Systems*, 102(1):64 – 72.

Umble, E.J., Haft, R.R., and Umble, M.M. (2003). Enterprise resource planning: Implementation procedures and critical success factors. *European Journal of Operational Research*, 146:241 – 257.

Vollmann, T.E., Berry, W.L., Whybark, D.C., and Jacobs, F.R. (2004). *Manufacturing Planning and Control Systems*, 5th edition. McGraw Hill-Irwin, New York.

Whiteing, T., Browne, M., and Allen, J. (2003). City logistics: The continuing search for sustainable solutions. In: D. Waters (ed.), *Global Logistics and Distribution Planning*, pp. 308 – 320, 4th edition. Kogan Page, London.

Yang, K.K. (2000). Managing a single warehouse, multiple retailer distribution center. *Journal of Business Logistics*, 21(2):162 – 172.