CHAPTER 80

Restructuring a Warehouse Network: Strategies and Models

Hokey Min
University of Louisville

Emanuel Melachrinoudis
Northeastern University

1. BACKGROUND

With the advent of the supply chain concept and the growing popularity of electronic commerce (EC), which transcend geographic and business functional boundaries, the traditional roles of warehouses are changing. Traditionally, warehouses have played three main roles in supporting logistics systems: a storage role, which makes long production runs more economical and bridges temporal gaps between demand and supply by making products available for customers on a timely basis; a consolidation role, which reduces total transportation cost by aggregating small orders into large shipments; and a customization (postponement) role, which reduces inventory carrying cost and enhances customer services by delaying the final stage of production and distribution until customers actually demand specific types of products (see, e.g., Maltz 1998). The relative importance or focus of warehousing roles to the entire supply chain network may vary from one warehouse to another due to dynamic shifts in the firm's business environments and strategic priorities. Such shifts include changes in supplier and customer bases, distribution networks, economic outlooks, corporate mergers/acquisition, downsizing, and government legislation.

For instance, many e-businesses (dot-com ventures) are concerned with filling their customers' orders and keeping customers' deliveries up to speed. Consequently, they tend to decentralize ware-

 Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.
Edited by Gavriel Salvendy

housing operations and increase the number of regional warehouses, which enhances the firms' responsiveness to their online customers. Amazon.com, for example, recently has increased the number and capacity of its warehouses from 2 to a total of 15 facilities. The decentralization of a warehouse network, however, can be costly due to the duplication of safety stocks, reduced freight consolidation opportunities and greater warehousing costs. In an effort to control cost, some companies may downsize or reengineer their corporate structures that involve the consolidation and phase-out of some existing warehouses. According to Ballou and Masters' survey (1993) of 200 logistics executives, 65% of the respondents indicated that they intended to review their current warehouse network and consider restructuring it in the near future. The strategy of consolidating and centralizing warehouses can help the firm save transportation, inventory, and warehousing cost due to economies of scale. Indeed, Ballou (1999) observes that restructuring a warehouse network could generate annual savings of 5–10% of total logistics costs. In the next section, we will elaborate on the pros and cons of different warehouse-restructuring strategies.

2. WAREHOUSE-RESTRUCTURING STRATEGIES

2.1. Warehouse-Centralization Strategy

One of the most noticeable trends in today's warehousing operations is increased inventory velocity. According to the recent study conducted by Speh (1999), the surveyed firms showed the average increase of inventory turns by 30% from 1995 to 1998 and expected to improve inventory turns by 27% between 1998 and 2000. A vast improvement in inventory turns can be attributed to increasing adaptation of more effective inventory management practices such as cross-docking, cycle counting, improved forecast, radio frequency, automated ID systems, and warehouse management systems. Due to significant strides in increasing inventory turns, many firms no longer require a large number of stocking points and consequently allow them to consolidate existing stocking points into fewer locations. In general, warehouse-centralization strategy involves consolidation of regional warehouses into a smaller number of master stocking points and the subsequent phase-out of redundant warehouses. Along with better capacity (or asset) utilization and higher throughput of centralized warehouses, such a strategy often brings substantial amount of savings in warehousing and inventory carrying costs due to the reduced number of warehouses and aggregated inventory. For instance, the square-root rule of inventory consolidation allows the company to estimate the amount of savings in inventory investment as a result of warehouse consolidation. Assuming that the firm relies on economic order quantity (EOQ) rules for inventory management and all stocking points of the firm carry the same amount of inventory, the simplest form of the square-root rule can be mathematically expressed as (Ballou 1999, pp. 352–354):

$$I_T = I_i \sqrt{n}$$

where I_T = the optimal amount of inventory to stock, if consolidated into one location in dollars, pounds, cases, or other units of measurement
I_i = the amount of inventory in each of n locations in the same units of measurement as I_T
n = the number of stocking locations before consolidation

Another benefit includes reduced material-handling costs resulted from bulk storage and picking at centralized locations. Similarly, transportation cost can be reduced due to increased opportunities of large-volume shipments and the subsequent negotiation leverage for better freight rates. In addition, central administrative costs can be reduced through less effort being spent in managing fewer warehouses. On the other hand, warehouse-centralization strategy lengthens lead time and consequently causes deterioration of customer services. With fewer warehouses to serve markets, the accessibility of centralized warehouses to large segments of customer bases and major distribution hubs is critically important. Also, to offset increased distances between centralized warehouses and customers, this strategy may necessitate the more direct shipment of products from master stocking locations to end customers.

2.2. Warehouse-Decentralization Strategy

Forrester Research, Inc. expects that business-to-consumer online sales will reach $184.5 billion in 2004 and business-to-business e-commerce will grow to $1.33 trillion by 2003 (see, e.g., Massie 2000). The explosion of e-commerce will change the way the company distributes its products due to an increasing number of small, unpredictable orders for individual customers. E-commerce requires that warehouses deal with unit quantities of inventories rather than pallet loads of inventories and subsequently accommodate high frequency of small parcel delivery services. Because the role of warehouses has become more of flow-through transshipment facilities intended for quick order fulfillment and product return than traditional storage facilities, their locations need to be dispersed in wider geographical areas. In other words, warehouses that support e-commerce transactions are likely to be decentralized and located in proximity to each segmented market.

In general, warehouse-decentralization strategy aims to shorten customer response time and improve order-fill rates by positioning inventory locations at the lowest downstream of the supply chain (i.e., end customers). Such a strategy may make sense, particularly when online sales require direct-to-home or store delivery services on a quick-response basis. Despite its merits, the warehouse-decentralization strategy leads to increases in inventory carrying cost and warehousing cost due to a larger number of stocking locations. It can also increase transportation cost due to smaller, more frequent shipping requirements.

2.3. Profile Analysis for a Strategic Choice

To choose a warehouse-restructuring strategy properly between centralization and decentralization, the company may conduct a profile analysis. The profile analysis is intended to provide the management team with a tool to identify the supply chain needs and the degree of fit between the company's network-restructuring decision attributes (e.g., level of investment, time scales, market positioning) and the available restructuring strategy. The profile analysis is composed of four steps (Hill 1994):

1. Select the appropriate aspects of products (e.g., types of product, product range, life cycles) and markets (e.g., sales/promotional tools, delivery service requirements), logistics (e.g., volume shipment via consolidation), investment and cost (e.g., level of investment, level of inventory, shipping cost), and infrastructure (e.g., corporate culture and management styles).
2. Display the trade-offs of strategic choices (centralization vs. decentralization).
3. Develop the profiles of products and targeted market segments to see alignment between those profiles and the strategic choice.
4. Illustrate the degree of consistency between the characteristics of products/markets and the strategic choice. The straighter the profile, the more consistent the chosen strategy is with the characteristics of products/markets.

The excellent example of the profile analysis for the choice of logistics strategy can be found in the recent study conducted by Pagh and Cooper (1998).

3. MODEL DEVELOPMENT

3.1. A Case Scenario of Warehouse Network Restructuring

This section describes a case study of a firm that plans to restructure its warehouse network and reduce total logistics costs. The firm (called Beta hereafter) plans to consolidate 23 warehouses across the United States and Canada into a smaller number of warehouses, while offering a majority of its customers next-day delivery services. Considering hours-of-service regulations stipulated by the Federal Highway Administration (FHA), a majority of Beta's customers should be within 10 hours of driving time from nearest warehouses. Beta's primary mode of transportation is either less-than-truckload (LTL) or truckload (TL) carriers, and consequently compliance with such regulations is important for Beta's distribution operations. However, since Beta's restructuring plan entails the phase-out of some existing warehouses, truck delivery time to a group of isolated customers will likely increase. Therefore, the restructuring plan must smooth away transition to the centralized warehouses in such a fashion that it minimizes the total length of out-of-service dates and any potential disruption of supply chain activities during transition.

Beta has its main manufacturing plant in Terre Haute, Indiana, and currently operates 23 regional public warehouses to serve a total of 281 customers scattered around the United States and Canada (see Figure 1). Beta primarily manufactures and distributes rolls of films and related materials used for packaging such as clear wrappers on the outside of cigarette packages throughout North America. Beta's outbound distribution activities are supported by a single-echelon (or one-tier) warehouse network where all products move from a manufacturing plant through regional warehouses to end customers. To avoid any duplicated distribution efforts and redundant inventory investment with the preexisting warehouses in 14 different U.S. states and 3 Canadian provinces, Beta prefers to maintain a total of less than 15 regional warehouses. The rationale may be that some warehouse locations are within 100 miles of each other and a large number of volume customers are heavily concentrated in certain states and provinces such as Ohio, Wisconsin, Georgia, Illinois, Texas, North Carolina, New Jersey, California, and Manitoba (see Figure 2). Each state or province generates more than 1.2 million pounds of outbound shipping volume. Customers there account for more than 56.6% of the current outbound shipping volume. Seizing increasing market expansion opportunities on the West Coast and the Mexican and Canadian borders, Beta prefers to keep at least one regional warehouse for each of California, Texas, Winnipeg, and Montreal. Beta hopes that its restructuring plan can be

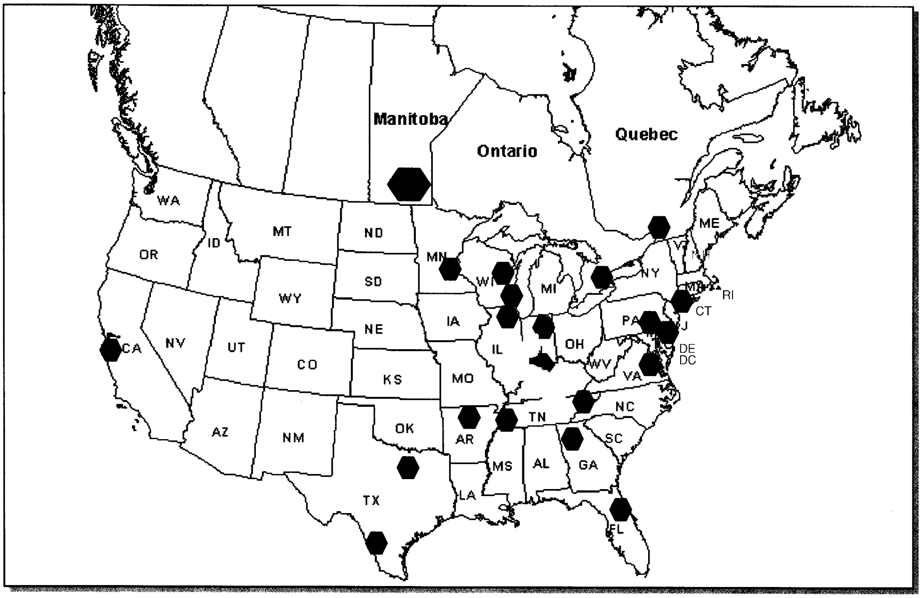

Figure 1 Existing Locations of Regional Warehouses.

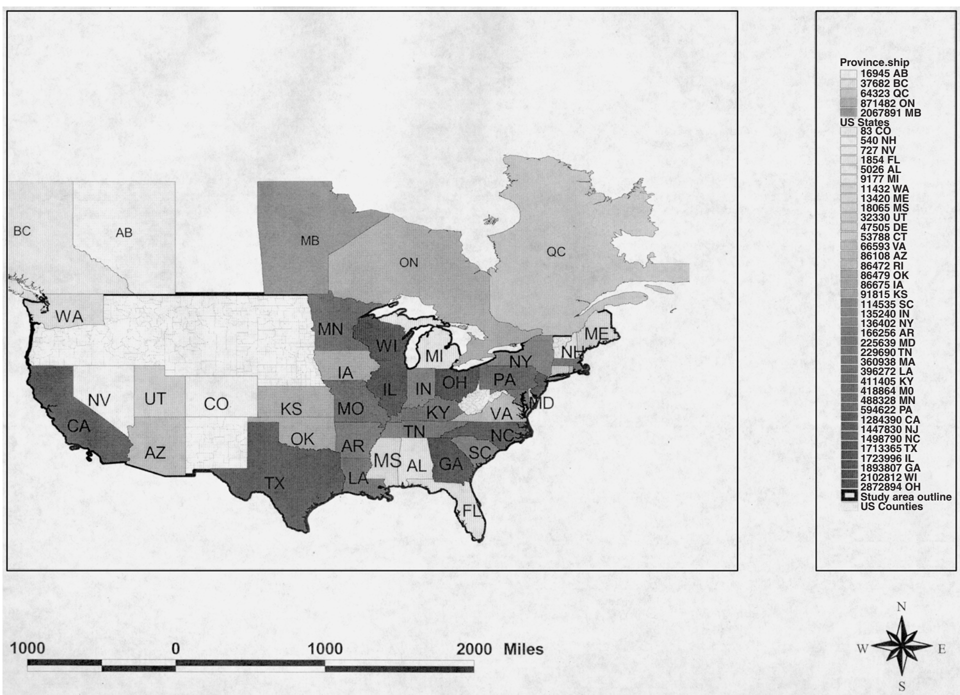

Figure 2 Customer Demand in Shipping Volume.

consistent with the corporate goals of increasing inventory turns and reducing transportation and warehousing costs.

The warehouse network-restructuring problem (WNRP) facing Beta differs from the classical warehouse-location problem in that the former is primarily concerned with determining which warehouses to retain and which warehouses to phase-out among the *existing* locations, whereas the latter is primarily concerned with selecting the optimal site among the alternatives of *new* locations. For excellent discussions of the classical warehouse-location problem, see Baumol and Wolfe (1958), Khumawala (1972), and Meidan (1978). On the other hand, the problems are similar in that both are influenced by the same attributes (or factors), such as warehouse operating cost, transportation cost, delivery access time, and proximity to major customer bases and transportation infrastructure.

In WNRP, each of Beta's consolidated facilities is expected to meet the current demand of all the existing customers and serve its customers within 10 hours of truck-driving time. Some of the existing warehouses, such as two in Terre Haute and one in Indianapolis, Indiana, that Beta considers eliminating may be redundant with their nearest warehouses due to close geographical proximity. But there is no guarantee that elimination of those sites will bring the substantial logistics cost savings without disrupting Beta's supply chain operations. For example, a regional warehouse that gives faster delivery advantages may turn out to be most costly because of its higher inventory taxes. Indeed, the local tax on inventories may vary significantly from one state to another. On the other hand, a warehouse that incurs the lowest cost and provides the best tax incentive packages may be distant from Beta's major customer bases and transportation infrastructure such as break-bulk terminals and major highways.

To deal with this dilemma, systematic decision-aid tools are needed that consider a multitude of conflicting factors affecting the restructuring plan and analyze trade-offs among them. Such decision-aid tools include various mathematical programming techniques such as integer programming (see, e.g., Bradley et al. 1977) and scoring methods such as the analytic hierarchy process (see Cohon 1978; Hwang and Masud 1979; Saaty 1980; Steuer 1986; Harker 1989; Vargas 1990 for excellent discussions of scoring methods). There are comparative advantages and disadvantages associated with the aforementioned decision-aid tools in terms of ease of use, data requirements, computational difficulty, and sensitivity analysis capability.

Considering that Beta's main objective of its restructuring plan is the maximization of a potential cost saving accrued from centralization of warehouses, we propose a single-objective, mixed-integer programming model as our decision-aid tool. The proposed model is designed to find the optimal number of warehouses in the restructured network under capacity limits and service requirements.

3.2. Model Formulation

Under the above scenario, the WNRP addresses the following issues:

1. Which warehouses to retain and which warehouses to eliminate in such a way that Beta's restructured warehouse network minimizes total cost associated with Beta's distribution operations while meeting current customers' demand and delivery service requirements
2. Which customers (or markets) to be served by which consolidated warehouses
3. How to evaluate the sensitivity of restructuring decisions with regard to changing priorities of Beta's restructuring plans

To address the above issues systematically, we develop a mixed-integer programming model that is formulated as follows.

3.2.1. Indices

k = index for manufacturing plants
i = index for warehouses
j = index for customers

3.2.2. Model Parameters

c_{ki} = cost of shipping unit product from manufacturing plant k to warehouse i
s_{ij} = cost of shipping unit product from warehouse i to customer j
v_i = variable cost of operating warehouse i
f_i = fixed cost of maintaining warehouse i
q_i = capacity of warehouse i
d_j = demand of customer j
t_{ij} = truck delivery time (in minutes) from warehouse i to customer j
τ = maximum daily hours of service regulated by FHA
$C(i) = \{j \mid t_{ij} \le \tau\}$

$D(j) = \{i \mid t_{ij} \leq \tau\}$
M = is a large number

3.2.3. *Decision Variables*

x_{ij} = amount of products shipped from warehouse i to customer j
y_{ki} = amount of product supplied by plant k to warehouse i

$$z_i = \begin{cases} 1 & \text{if warehouse } i \text{ remains open} \\ 0 & \text{if warehouse } i \text{ is phased out} \end{cases}$$

3.2.4. *Mathematical Formulation*

$$\text{Minimize} \sum_k \sum_i c_{ki} y_{ki} + \sum_i v_i \sum_{j \in C(i)} x_{ij} + \sum_i \sum_{j \in C(i)} s_{ij} x_{ij} + \sum_i f_i x_i - \sum_i f_i (1 - z_i) \quad (1)$$

Subject to:

$$\sum_{j \in C(j)} x_{ij} \leq q_i \qquad \forall i \quad (2)$$

$$\sum_k y_{ki} = \sum_{j \in C(i)} x_{ij} \qquad \forall i \quad (3)$$

$$\sum_{i \in D(j)} x_{ij} = d_j \qquad \forall j \quad (4)$$

$$x_{ij} + y_{ki} \leq M z_i \qquad \forall k, i, j \in C(i) \quad (5)$$

$$x_{ij}, y_{ki} \geq 0 \qquad \forall k, i, j \in C(i) \quad (6)$$

$$z_i = (0, 1) \qquad \forall i \quad (7)$$

The objective function (1) minimizes total logistics costs composed of shipping costs and warehousing costs while maximizing cost savings resulted from the closure of redundant warehouses. Constraint (2) ensures that the total amount of products shipped to a group of customers does not exceed the capacity of a warehouse serving them. Constraint (3) ensures that the total amount of products supplied by all the manufacturing plants to each warehouse matches the total amount of products shipped from that warehouse to its customers. In other words, inbound shipping volume for each warehouse should be equivalent to its outbound shipping volume. Constraint (4) requires that customer demand be satisfied. Constraint (5) states that unless the warehouse remains open, it cannot serve its customers. Constraint (6) ensures the nonnegativity of decision variables x_{ij}, y_{ki}. Constraint (7) ensures the binary integrality of decision variables z_i.

3.3. Model Application

To demonstrate how the proposed WNRP model works and verify its usefulness, the model was applied to the real-world problem facing Beta. As explained earlier, the Beta management team intended to reduce the number of regional warehouses it was currently operating but had no idea of the ideal number of warehouses to retain. They considered keeping in the range of 7 to 14 warehouses. Although the smaller number of warehouses will reduce Beta's total logistics costs, Beta's management team would like to know the optimal number of warehouses sufficient accommodate current customer demand. Furthermore, Beta would like to offer consistent delivery services to geographically dispersed customers. Therefore, heavy concentration of consolidated warehouses in certain regions is not desirable for Beta's commitment to next-day delivery services. Regardless of cost-saving opportunities, Beta would like to maintain at least one regional warehouse in California and one in Canada.

Given the current warehouse network, however, we (analysts) discover that 11 customers isolated from other clusters of customers cannot be served within 10 hours of delivery time by existing locations of regional warehouses. Herein, we estimated delivery time using actual driving distance between different locations as opposed to Euclidean (straight-line) distance. Most of these isolated customers are located on the West Coast, such as Colorado, Utah, Arizona, Washington, and British Columbia. Since Beta currently has no plan either to relocate its warehouses or to open new warehouses, our task is to find the optimal number and geographic locations of consolidated warehouses that can best serve the remaining customers. In so doing, we run the model specified in Section 3.2

using LINGO's modeling language (LINGO 1995). LINGO is nonprocedural mathematical programming software that provides an environment where analysts can develop, run, and modify mathematical models interactively. Unlike other conventional software, it requires only *what* the modeler wants, rather than *how* it should find the solution (LINGO 1995). The model was run on a TD- 260 personal computer (PC). The total number of feasible warehouse–customer pairs considered by LINGO was 3625. The baseline LINGO model resulted in 23 binary integer variables, 3648 noninteger variables, and 3952 constraints. The execution time of the baseline model and the subsequent runs ranged from 50 seconds to approximately 3 minutes.

The optimal baseline solution suggests to retain consolidated warehouses in four different locations: Paterson, New Jersey; Winnipeg, Manitoba; Memphis, Tennessee; and San Leandro, California (see Figure 3). This solution makes sense in that it covers geographically dispersed areas while preventing any warehousing locations from being too close to each other. It is also congruent with the Beta's management team's wish that the restructured warehouse network include at least one Canadian and one West Coast location. However, in reality, a dramatic reduction in the number of warehouses from 23 to 4 may create confusion among Beta's common carriers, employees, and utility companies (e.g., phone companies) during transition. In addition, such an attempt will likely disrupt customer services during transition because it entails suspension of delivery services, reroutes of shipping, reorganization of load plans, and transfer of some inventory items from phased-out warehouses to consolidated warehouses.

To provide Beta's management team with greater sets of alternatives that allow them to keep the disruption risk to a minimum, we added a constraint that sets the total number of consolidated warehouses prior to running the model. This constraint is mathematically expressed as:

$$\sum_i z_i = p \tag{8}$$

where p = the desired number of consolidated warehouses. The above constraint is common in the prototypical p-median problem (see, e.g., Church 1974; Krarup and Pruzan 1983 for a detailed discussion of the p-median problem). For instance, by setting p = 5, we identified five locations of

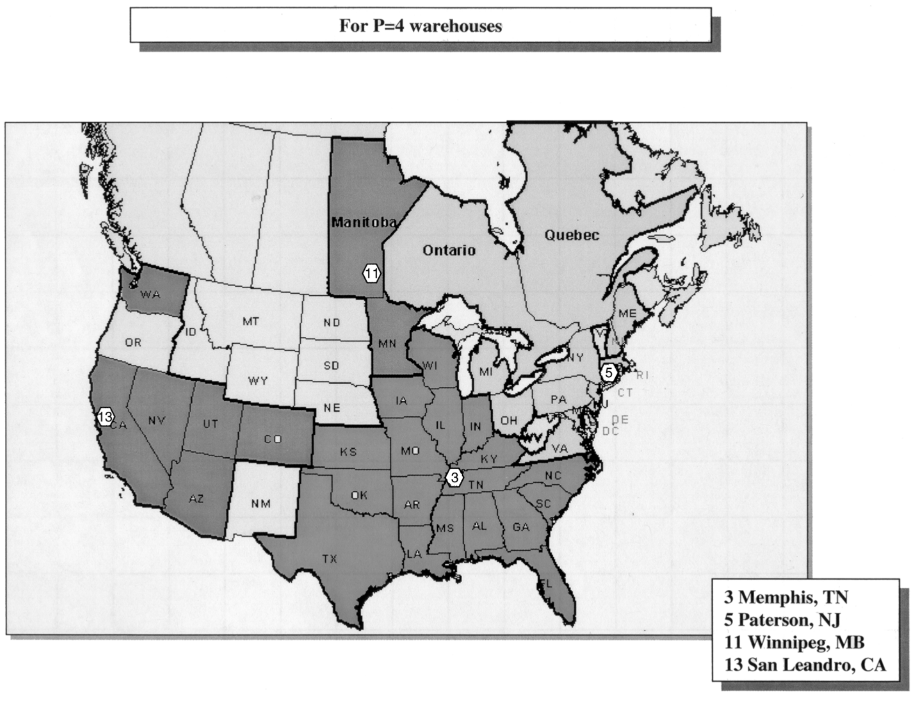

Figure 3 Locations of Consolidated Warehouses and Their Market Boundaries.

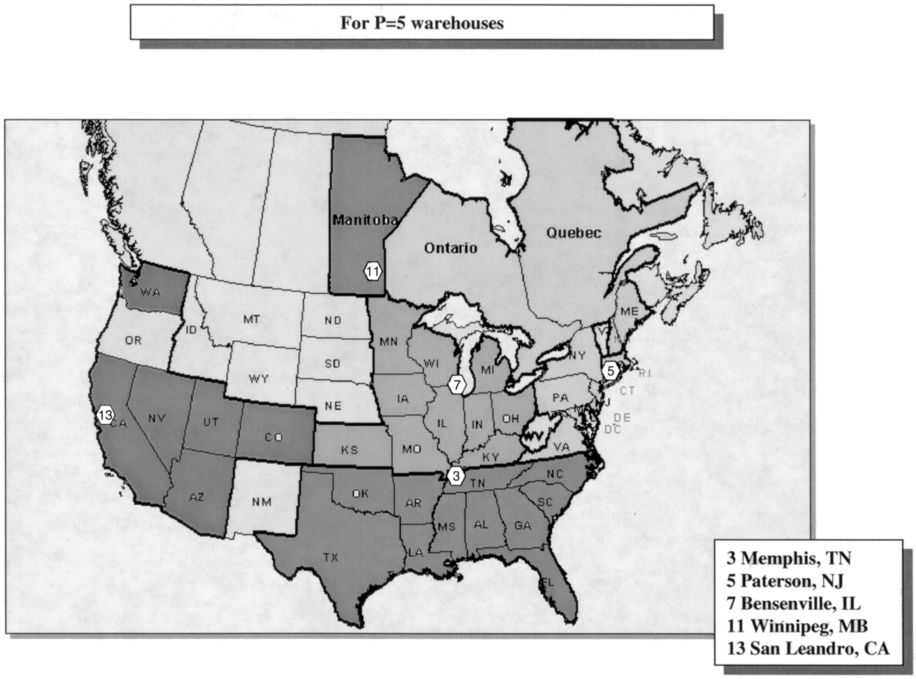

Figure 4 Locations of Consolidated Warehouses and Their Market Boundaries.

consolidated warehouses: Paterson, New Jersey; Winnipeg, Manitoba; Bensenville, Illinois; Memphis, Tennessee; and San Leandro, California (see Figure 4). When we set $p = 6$, the optimal solution suggested retaining six locations: Paterson, New Jersey; Winnipeg, Manitoba; Bensenville, Illinois; Atlanta, Georgia; Dallas, Texas; and San Leandro, California (see Figure 5). Finally, when $p = 7$ was set, we identified seven locations of consolidated warehouses: Paterson, New Jersey; Winnipeg, Manitoba; Toronto, Ontario; Bensenville, Illinois; Atlanta, Georgia; Dallas, Texas; and San Leandro, California (see Figure 6). It is interesting to note that these locations are either at the center or in the vicinity of the center of concentrated customer demand locations. As shown in Figures 3, 4, 5, and 6, among the eight states that originate customer shipping volume in excess of 1.2 million pounds, only three (Ohio, Wisconsin, and North Carolina) do not have consolidated warehouses. However, these states are still within next-day delivery areas from nearest consolidated warehouses such as the ones in Paterson, New Jersey; Atlanta, Georgia; Toronto, Ontario; and Winnipeg, Manitoba.

More interestingly, with the exception of warehouses located in Atlanta, Georgia, and Paterson, New Jersey, all the other warehouses to be retained for consolidation (i.e., Winnipeg, Manitoba; Toronto, Ontario; Bensenville, Illinois; Dallas, Texas; San Leandro, California) were substantially underutilized under the current warehouse network. According to the warehouse-utilization ratio (the number of pallets in the warehouse at the end of a year divided by the theoretical capacity of the warehouse) used by Beta, the Atlanta-based warehouse and the Paterson-based warehouse have an 11% and a 9% utilization ratio, respectively. On the other hand, those in Winnipeg, Toronto, Bensenville, Dallas, and San Leandro have 5% or less utilization ratios. Despite the sustained growth of customer demand in Texas and Mexican border areas, the Dallas-based warehouse has been virtually unused, as evidenced by a less than 1% utilization ratio. Such underutilization may have resulted from redundant warehouses located in Laredo, Texas, and Little Rock, Arkansas, which are within a 500-mile radius from Dallas. If Beta decided to reduce the number of warehouses to 7 from 23, each of the 7 consolidated warehouses would enjoy the average of an approximately 14% utilization ratio, which is a 10% increase from the current average utilization ratio of slightly over 4%.

As shown in Figure 6, the Paterson-based warehouse will serve customers located in Maine, Massachusetts, Rhode Island, New Hampshire, Connecticut, New Jersey, New York, Pennsylvania, Delaware, Maryland, and Virginia. The Winnipeg-based warehouse will serve customers located in Minnesota, Manitoba, and Alberta. The Toronto-based warehouse will serve customers located in

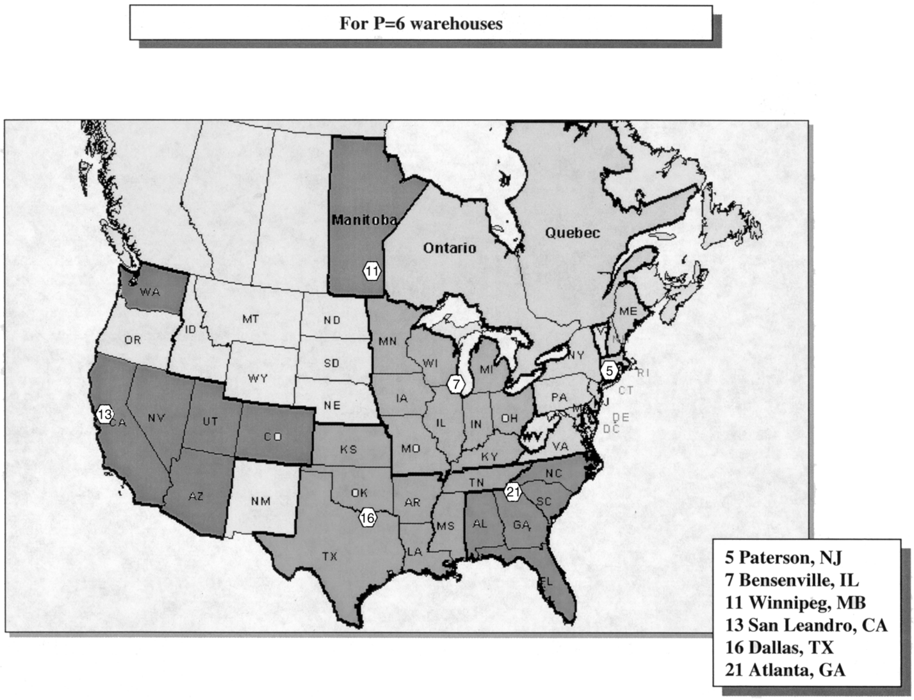

Figure 5 Locations of Consolidated Warehouses and Their Market Boundaries.

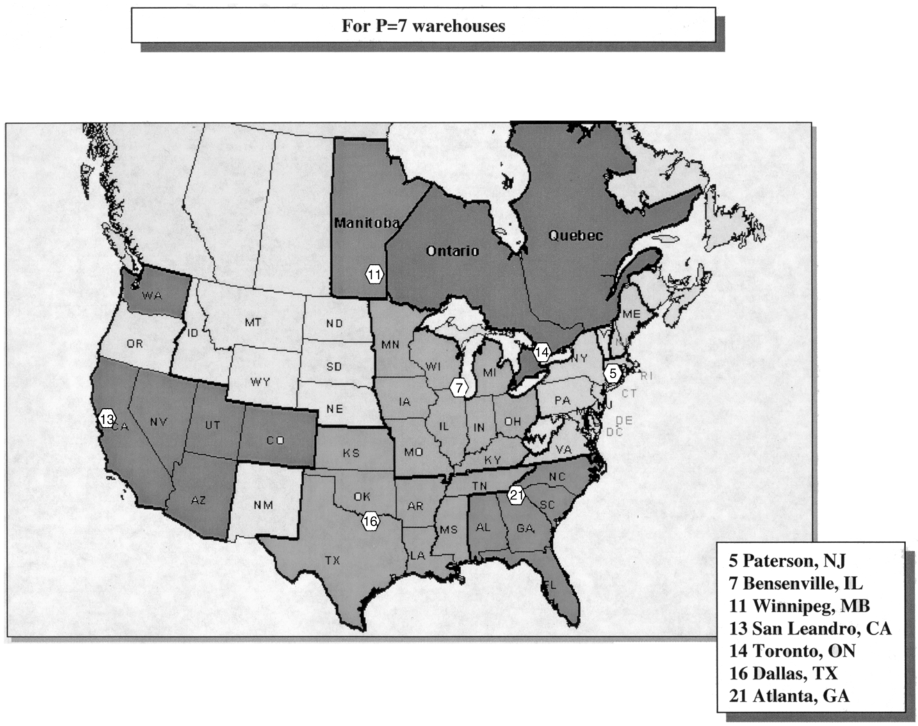

Figure 6 Locations of Consolidated Warehouses and Their Market Boundaries.

upstate New York, Ohio, Michigan, Quebec, and Ontario. The Bensenville-based warehouse will serve customers located in Kentucky, Ohio, Indiana, Michigan, Iowa, Wisconsin, Minnesota, Illinois, Missouri, and Kansas. The Atlanta-based warehouse will serve customers located in North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Kentucky, and Louisiana. The Dallas-based warehouse will serve customers located in Tennessee, Mississippi, Missouri, Kansas, Louisiana, Arkansas, Oklahoma, and Texas. The San Leandro-based warehouse will serve customers located in Colorado, Utah, Arizona, Nevada, California, Washington, and British Columbia. Notice that some warehouses cover overlapped states such as New York, Kentucky, Tennessee, and Louisiana due to heavy geographical concentration of customers in those states. Another thing to note is that, unlike other consolidated warehouses serving at least 30 different customers, the Winnipeg-based warehouse is allocated to serve only three customers. The possible explanation for such an aberration is that it has a huge customer in Winnipeg with its annual order volume in excess of 2 million pounds. That is to say, the Winnipeg-based warehouse is mainly dedicated to the one major customer and consequently its location is contingent upon the continuation of a business relationship with that customer.

4. DECISION SUPPORT SYSTEM FRAMEWORK

Even though the proposed model described in the previous section was designed to help Beta's management team find the minimum cost solution to the problem of determining which warehouses to retain and which warehouses to eliminate, it cannot capture all the complexities and dynamics of the WNRP facing Beta. As such, the proposed model should be embedded within the decision support system (DSS) framework, where the decision maker (e.g., Beta's management team) can freely add, delete, update, and modify the model objective functions, parameters, and constraints. Following three paradigms suggested by Sprague and Carlson (1982), this DSS framework has three components: data-management, model management, and dialogue management.

4.1. Data Management Subsystem

A model is only as good as the quality of the data that support it (Napolitano 1998). To enhance data quality and avoid data redundancy, we developed a database that contains three data sources: external, internal, and governmental. External sources include public data files available from local chambers of commerce, regional economic development agencies, *Site Selection Handbook*, *Industrial Development Magazine*, and websites such as Lycos Roadmaps. Internal sources include the Beta's order history files (e.g., sales shipment data, warehouse shipment data, ZIP code data, statistics reports), inventory record files, accounting data files, bills of lading, and internal customer policy manuals. Government sources include legal documents, regulatory guidelines, and reports issued by federal (e.g., Department of Transportation, Federal Highway Administration, Surface Transportation Board) and state agencies. In addition to raw data that can be obtained from the above sources, Beta may create more specific data categories that are relevant to WNRP. These categories are as follows.

4.1.1. Cost Data

Cost is one of the primary concerns of the WNRP decision. The total logistics costs involved in WNRP encompass annual rental fees for public warehousing, administrative expenses for general office personnel, inventory carrying cost (e.g., local inventory property taxes and insurance premiums on inventory), information-processing cost (e.g., maintenance of warehouse management systems), equipment-handling cost, cost of purchased labor, cost of unloading/loading vehicles, cost of palletizing/sorting, inbound/outbound shipping expenses, freight penalty incurred from delivery route changes, inventory transfer cost, cost of moving value-added services (e.g., packaging, labeling), out-of-service cost, and cost of changing service standards. For additional details of warehousing cost elements, see Speh (1990) and Ackerman (2000).

4.1.2. Traffic Data

Since Beta deals primarily with relatively heavy and bulky products using LTL and TL carriers, it needs to look for a warehouse location that can not only handle the large volume of traffic but can also provide easy access to transportation infrastructure and traffic-related services. Important traffic concerns include proximity to major interstate highways, any overhead construction impairing truck movement, curfew restrictions on hours of traffic operations, close distance to break-bulk terminals, and the availability of freight forwarding and brokerage services. In addition, Beta requires that the warehouse be within a one-day delivery range (approximately a 500-mile radius) of most of its major customers, including food packaging companies in the United States.

4.1.3. Market Data

The profitability of Beta depends heavily on the market potential of the area it serves. In a broad sense, the market potential of a chosen trading area is dictated by its business climate and competition level. Since Beta's business efforts are geared toward business-to-business transactions, an explicit measure of the local business climate is not readily available. As an indirect barometer for the local business climate, however, we can consider Beta's customers' customers' (e.g., grocery shoppers) aggregated effective buying power and buying power index in the area (metropolitan city or county) that surrounds the warehouse location. Herein, effective buying power is expressed as net gross personal income (= gross personal income − personal taxes − nontax payments). Buying power index is a measure of market ability to buy, expressed as a percentage of U.S. totals. In addition, Beta's past sales volumes and forecasted future business growth in Mexican, Canadian, and West Coast markets can be taken into consideration.

Under the premise that a majority of customers would gravitate toward the Beta's warehouse closest to their market centers, we used proximity to existing customers as part of a surrogate measure of Beta's competitive position in the trading area. Finally, since short inbound delivery to the warehouse can reduce order cycle time for the entire supply chain and subsequently help serve customers better, proximity to Beta's suppliers' locations can be considered as an indicator of Beta's competitiveness in the trading area. Given that the amount of rates (e.g., class rates) for the transportation of freight increases as mileage scales (e.g., rate basis numbers) increase, proximity to Beta's suppliers' locations affects inbound shipping cost.

4.1.4. Local Incentive Data

To increase the return on investment from the consolidated warehouse, local incentives should be taken into consideration. According to the recent Conway Data global survey of development organizations (Venable 1996), local incentives such as labor availability (e.g., annual unemployment rate), labor quality, tax breaks, and loans were considered one of the five most important location factors by thousands of economic development executives. In particular, the Beta management team is greatly concerned with ongoing labor shortage problems. For the last several years, high employee turnover and the subsequent labor shortage have been a key concern in labor-intensive warehousing operations because labor shortages can disrupt continuous distribution of products to customers. In addition, since Beta's product is an important component of distribution packages, which are regarded as a main source of waste, Beta should carefully review local environmental regulations before determining the consolidated warehouse location. Finally, Beta should look for a broad range of tax incentives (e.g., enterprise zone incentives, job creation tax credits or super tax credits for capital investment and job creation) around the consolidated warehouse.

4.2. Model Management Subsystem

The main focus of the model management subsystem is the incorporation of the WNRP model (problem generator) into the DSS. Although the WNRP model can be regarded as a "black box" whose algorithm and solution procedures need not be understood by the Beta's management team, it should be integrated with a problem solver such as LINGO. LINGO is standard, commercially available software designed to solve the mixed integer programming problem. To further enhance user-friendliness, we also integrated a geographic information system (GIS) into the model management subsystem. GIS simplifies the data display mechanism by separating data presentation from data storage.

Whereas the WNRP model represents esoteric numbers and symbols, GIS creates a wide variety of visual aids in the form of sound, images, and maps, illustrated in Figures 2, 3, 4, 5, and 6. In general, GIS allows Beta's management team to visualize how distinctive geographic information (e.g., customer shipping volume) from one location is from that from another by superimposing the information on a map. By recognizing geographical differences between one location and another, Beta's management team can choose the warehouse network that is most suitable for their needs. One of the most important advantages of combining the WNRP model with GIS is the enrichment of data quality, because GIS helps analysts visualize database errors that may otherwise go undetected. Particularly, GIS is capable of segmenting customer markets and measuring future market shares. Such an ability can aid the Beta's management team in developing the warehouse network that best serves customers.

4.3. Dialogue Management Subsystem

At best, the model is an abstraction of real-world situations. Consequently, it cannot capture reality without running it more than one time (Dyer and Mulvey 1983; Min 1989). Thus, the model should enable Beta's management team to evaluate "what-if" scenarios associated with shifts in Beta's management philosophy (e.g., a shift from cost minimization to quick-response services) and competitive positions (e.g., a shift from domestic to global operations). In other words, the model's successful implementation depends on its flexibility for contingency planning. To enhance the model flexibility, the results of model runs should be reported in user-friendly formats. These formats include standardized reports such as tables summarizing cost-saving opportunities and figures depicting maximum service radius as a function of the number of warehouses.

5. CONCLUDING REMARKS AND FUTURE RESEARCH DIRECTIONS

The warehouse is in the middle of the supply chain and therefore dictates the efficiency and effectiveness of the supply chain. With the increasing importance of a warehousing role in the supply chain, the warehouse network restructuring strategy can all but determine the success and failure of supply chain operations. This chapter introduces two distinctive warehouse network restructuring strategies: warehouse centralization and decentralization. These two strategies have their pros and cons, depending on the company's strategic focus. This chapter also develops a mathematical model that aims to provide a minimum-cost solution for the real-world warehouse restructuring (centralization) problem. Despite numerous merits, the proposed model points to a number of directions for future work:

1. The model can be expanded to include the element of risk and uncertainty involved in the warehouse-restructuring problem and can be tested for the expanded time periods.
2. The future research theme should include multiobjective treatments of the WNRP that explicitly analyze the trade-offs among cost, traffic access, market potential, and local incentives.
3. The multicommodity problem, which considers both slow-moving and fast-moving products, may be studied in the future.
4. The future network-restructuring problem should look into the possibility that the company will not only phase out some of the redundant warehouses but also relocate others to serve customers better.
5. Pure WNRP research can also continue by incorporating the combined usage of private, public, and contract warehouses into the mathematical modeling process.
6. The multiechelon hierarchical network configuration, which considers the options of both direct shipment from manufacturing plants to customers and indirect shipment through either master distribution centers or regional warehouses, may be an intriguing subject for further studies.

Acknowledgments

The authors wish to thank the senior management team and the vice president of the anonymous company for providing them with valuable data and assistance in the case study reported in this paper.

REFERENCES

Ackerman, K. B. (2000), *Warehousing Profitably: A Manager's Guide*, Ackerman, Columbus, OH.

Ballou, R. H. (1999), *Business Logistics Management: Planning, Organizing, and Controlling the Supply Chain*, Prentice Hall, Upper Saddle River, NJ.

Ballou, R. H., and Masters, J. M. (1993), "Commercial Software for Locating Warehouses and Other Facilities," *Journal of Business Logistics,* Vol. 14, No. 2, pp. 71–107.

Baumol, W. J., and Wolfe, P. (1958), "A Warehouse Location Problem," *Operations Research,* Vol. 6, pp. 252–263.

Bradley, S. P., Hax, A. C., and Magnanti, T. L. (1977), *Applied Mathematical Programming*, Addison-Wesley, Reading, MA.

Church, R. L. (1974), *Synthesis of a Class of Public Facilities Location Models*, Ph.D. Dissertation, Johns Hopkins University.

Cohon, J. L. (1978), *Multiobjective Programming and Planning*, Academic Press, New York.

Dyer, J. S., and Mulvey, J. M. (1983), "Integrating Optimization Methods with Information Systems for Decision Support," in *Building Decision Support Systems,* J. L. Bennett Ed., Addison-Wesley, Reading, MA, pp. 89–109.

Harker, P. T. (1989), "The Art and Science of Decision Making: The Analytic Hierarchy Process," in *The Analytic Hierarchy Process: Applications and Studies,* B. L. Golden, E. A. Wasil, and P. T. Harker Eds., pp. 3–36.

Hill, T. (1994), *Manufacturing Strategy: Text and Cases*, Richard D. Irwin, Burr Ridge, IL.

Hwang, C., and Masud, A. (1979), *Multiple Objective Decision Making-Methods Applications*, Springer, New York.

Khumawala, B. M. (1972), "An Efficient Branch and Bound Algorithm for the Warehouse Location Problem," *Management Science,* Vol. 18, No. 12, pp. B718–B733.

Krarup, J., and Pruzan, P. M. (1983), "The Simple Plant Location Problem: Survey and Synthesis," *European Journal of Operational Research,* Vol. 12, pp. 36–81.

LINGO Systems Inc. (1995), *LINGO: The Modeling Language and Optimizer*, Chicago, IL.

Maltz, A. (1998), *The Changing Role of Warehousing*, Warehouse Education Research Council, Oak Brook, IL.

Massie, C. (2000), "Webhousing," *WERC Sheet*, April, pp. 1–5.

Meidan, A. (1978), "The Use of Quantitative Techniques in Warehouse Location," *International Journal of Physical Distribution and Materials Management,* Vol. 8, No. 6, pp. 347–358.

Min, H. (1989), "A Model-Based Decision Support System for Locating Banks," *Information and Management,* Vol. 17, pp. 207–215.

Napolitano, M. (1998), *Using Modeling to Solve Warehousing Problems: A Collection of Decision-Making Tools for Warehouse Planning and Design*, Warehousing Education and Research Council, Oak Brook, IL.

Pagh, J. D., and Cooper, M. C. (1998), "Postponement and Speculation Strategies: How to Choose the Right Strategy," *Journal of Business Logistics*, Vol. 19, No. 2, pp. 13–33.

Saaty, T. L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York.

Speh, T. W. (1990), *A Model for Determining Total Warehousing Costs for Private, Public and Contract Warehouses*, Warehousing Education and Research Council, Oak Brook, IL.

Speh, T. W. (1999), *Warehouse Inventory Turnover*, Warehousing Education and Research Council, Oak Brook, IL.

Sprague, R. H., and Carlson, E. D. (1982), *Building Effective Decision Support Systems*, Prentice Hall, Englewood Cliffs, NJ.

Steuer, R. (1986), *Multiple Criteria Optimization: Theory, Computation, and Application*, John Wiley & Sons, New York.

Vargas, L. G. (1990), "An Overview of the Analytic Hierarchy Process and Its Applications," *European Journal of Operational Research,* Vol. 48, pp. 2–8.

Venable, T. (1996), "The New Business Location Process: Who's Driving, and What's Steering?" *Site Selection,* Vol. 41, No. 2, pp. 436–437.