SUPPLY CHAIN STRATEGIES

"All this will not be finished in the first 100 days. Nor will it be finished in the first 1000 days, nor in the life of this Administration, nor even perhaps in our lifetime on this planet. But let us begin." – J.F. Kennedy

To integrate freight system planning with logistics and supply chain activities is a long shot. A satisfying integration will not happen within a foreseeable future. However, to position freight activities in the context of logistics management is rewarding to public freight planners. From this section, additional supply chain practices will be introduced while trying to illustrate the implications of freight on logistics wherever possible.

Supply chain management mainly involves the coordination of inventory/distribution management and other associated activities between all interested parties in the system. The primary objective is to reduce the inventory redundancy and increase system wide efficiency while maintaining the same level of service. As explained in Section 1, the entire supply chain cost includes costs in warehousing and distribution as well as associated management and service activities. Many strategies to reduce the supply chain cost have been developed in recent decades. These developments have been motivated by the fact that supply chain cost accounts for a significant portion of the national GDP. The improvements have had a significant impact on economic efficiency in enhancing the global competitiveness of the US products.

Before talking about logistics strategies, let's take a look at the logistics cost break down and see the impact of transportation on the cost of the logistics process.

In the US, supply chain costs account for about 10.5% of the national GDP, in which transportation costs contribute a significant portion of this 10.5%. Table 2.1 below illustrates the breakdown in the USA (Financial Times, 1998).

Cost Item	Percentage of The Total Logistics Cost
Transport	46
Storage/Warehousing	22
Inventory Carrying	22
Administration	10
TOTAL	**100**

Table 2.1 Logistics cost breakdown in the US

Table 2.1 is believed to be comparable to today's situation. It is easily seen that transportation represents a large component of the overall logistics cost.

However, the role of transportation varies with different commodities. These different commodities have different cost breakdowns which can vary greatly as seen in Table 2.2.

Main Business	Transport Cost	Warehousing/Depot	Inventory Holding	Administration	Overall (% of total cost)
Office Equipment	3.2	10.7	0.87		14.77
Health Supply	1.36	9.77	0.66	0.19	11.98
Beer	8.16	2.82	0.56	2.19	13.74
Fashion	0.38	1.31	0.33		2.02
Cement	25.2	9.1	7.1	4.6	46
Auto Parts	2.07	6.35	1.53		9.96
Computer Supply	0.65	0.78	0.09		1.52

Table 2.2 Logistics cost breakdown for different commodities.

In Table 2.2, the last column represents the logistics cost as percent of total final product cost (total retail cost). This variation across sectors generally determines the difference in logistics strategy among different commodities and across different industry sectors. As seen in Table 2.2, transportation cost is a very significant portion of the total logistics cost for bulk commodities such as cement. Understandably, bulk commodities rely on economies of scale in transportation. The higher the value, the less significant the transportation cost. For commodities such as fashion items, transportation cost represents a very low percentage. Transit time duration and reliability of ground shipping would definitely prove to be critical. Interestingly, among the shelf items in chain stores, such as Wal-Mart, logistics managers attempt to differentiate the fast moving items from the rest. Obviously, different shelf items deserve different attention and therefore possibly different ordering and sorting strategies at distribution and warehousing.

This chapter will briefly review some popular strategies and tactics that have had impact in practice. First of all, we will cover inventory management, which will demonstrate how a shift of inventory along the supply chain is made. We will also demonstrate the impact of transportation on inventory cost. Next, we will introduce the vendor managed inventory (VMI), assemble-to-order system (ATO), just-in-time (JIT) system, and pull/push system. Finally, this will be followed by a brief introduction to the multi-echelon system.

Inventory Management

The movement of inventory along the supply chain generates freight on the transportation system of highways, railways, airways, pipelines, and waterways. One may view the logistics system as a system of inventory holding points (warehouses, distribution centers and vendors) with inventory flows between these points. Inventory management policies decide how much to order and when to order from, and for, these holding points. The inventory policy directly relates freight traffic to supply chain management. There are numerous inventory policies and models. In what follows, we will introduce the EOQ model that is generally considered the most basic and considered to have had greatest impact in practice.

Economic Order Quantity (EOQ) model

The EOQ model tries to make a balance between ordering cost and inventory holding cost. If less is ordered each time and orders are placed more frequently, the average inventory will be lower. One might think this would decrease the average inventory carrying cost and would be most preferable. However, there is a trade-off here with the administrative cost, called ordering cost. The ordering cost is a fixed cost associated with placing an order. It includes direct labor time/cost for paperwork, equipment leasing (e.g. for shipping), documentation of ordered items, and unloading.

The EOQ model is the most basic model for deciding the optimal order quantity that balances these costs.

$$Q^* = \sqrt{\frac{2KD}{h}}$$

Where D = Demand; K = fixed ordering cost; h = inventory carrying cost per unit; Q = optimal order quantity.

Example A distribution center (DC) manages distribution of a product. The unit value of this product (purchase cost) is $50.00. The annual demand for this product that goes through the distribution center is 4000 units. A cost of placing the order each time is $400. If the inventory carrying cost is 20% of the tied inventory value, how many units shall be ordered each time?

Solution

Here D=4000; K=400; h=$50x20%=$10.00. Therefore,

$$Q^* = \sqrt{\frac{2KD}{h}} \quad = \sqrt{\frac{2*400*4000}{10}} \approx 566 \text{ (units)}.$$

To conclude, the optimal ordering size is 566 units each time. The order frequency is determined by the total annual demand and order size.

At first glance, the EOQ model does not appear to capture the effect of transportation. In fact, transportation does not affect the quantity ordered each time. The EOQ model introduced might leave readers with an impression that logistics activities are independent of transportation. Since transportation cost is not considered in the EOQ model, one might suspect that the shipping behavior has been driven by other factors than transportation. This is true in that transportation is only one component of a very large supply chain system. Shipping decisions are often not affected by transportation cost. However, if the shipping volume dramatically changes the freight rate so that the

shipping cost could differ significantly, say from 5% to 15% of the total product value, then EOQ model might not apply and a different model might need to be developed. If it is only a difference of between 5% to 7% of the total cost, application of the EOQ model should be fairly accurate.

Transportation cost might not affect the ordering policy in the application of the EOQ model. However, it affects the constantly carried inventory, the safety stock. This is obvious as a longer transit time would increase the risk of running out of stock (stockout) and necessitate the need for a larger safety stock. Therefore, transportation affects the total logistical costs in a very fundamental way.

We have an example to demonstrate this point based on the optimal inventory policies.

Example Suppose that an inventory policy is needed for a consumer product (e.g. TV set). Assume that whenever an order is placed for replenishment, the ordering cost is $4,500, which is independent of the order size. Each unit of product has a cost of $250, and the annual inventory cost is 18% of the product cost. Lead time (from order placing to order arrival) is about two weeks. The support data and optimal decision are given below.

Before we present the optimal policy for the example above, we should introduce more about the inventory policy with uncertain lead time and demand.

(s, S) Policy for Inventory Management

An effective policy for inventory management is referred to as (*s*, *S*) policy. Whenever the inventory drops to below s, an order is placed to make the inventory position to *S*. Here *S=s+Q*, where *s* is called re-order point, *Q* order quantity and *S* order-up-to level.

Note that *s* is composed of two parts: safety stock to prevent stockout and average demand during lead time. If everything is 'normal', the inventory level shall be equal to the safety stock at the arrival of an order. If the demand is not as 'regular' as expected during the lead time, the safety stock is used to prevent stockout.

Freight impacts inventory costs primarily through affecting the safety stock. Safety stock is determined by the uncertainty of demand during lead time. Obviously, the uncertainty of demand during a longer lead time is larger. As a result, a longer lead time is associated with a higher safety stock. Of course, the nature of demand itself (variation of demand within a unit time, or predictability of demand) affects the overall demand during the lead time. In addition, a practical factor in determining the safety stock is the ability of the vendor to accept a stockout. The vendor may refer the customer to another store close by, or to satisfy the demand with substitutable products. Measuring all the outcomes, the stockout cost could be quantified to deciding the inventory policy.

The following paragraphs will illustrate how the lead time, demand, and their associated uncertainty affect inventory cost through affecting the safety stock.

Systems with a fixed lead time and a stochastic demand

Safety stock = $z \times STD \times \sqrt{L}$; (*z* is the safety factor, and is decided by a preset service level, or tolerable stockout risk, α; *L* is the lead time; STD is the standard deviation of demand)

Re-order point = $L \times AVG + z \times STD \times \sqrt{L}$ (where *AVG* is the average demand per unit time period)

An implicit rule here is observed.
Probability {demand during lead time > $L \times AVG + z \times STD \times \sqrt{L}$ }=1- α.

Order quantity *Q* is calculated with the EOQ model (economic lot size method).

Table 2.3 shows the relationship between desired service level α and safety factor z.

Service level	90%	95%	99%	99.90%
z	1.29	1.65	2.33	3.08

Table 2.3 Service level factors

Systems with variable lead time and stochastic demand

$s = AVG \times AVGL + z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$ (The first term accounts for the average demand during lead time and the second safety stock)

Here, AVGL is the average lead time, STDL standard deviation of the lead time.

The order up-to level is *S=s+Q* as before.

Solution to Example Exercise

Using the equations above, we have the following optimal inventory policy.

Average weekly demand	Standard deviation of weekly demand	average demand during lead time	reorder point	Safety stock	order quantity
44.58	32.08	89.16	176	86.2	679

Table 2.4 Demand information and optimal order.

However, if we associate a variance to the lead time, the inventory will have to increase to hedge against the risk of stockout. The average inventory increase in relation to the lead time variance is tabulated in the following.

Standard Deviation (in days)	Re-order Point (units)	Inventory increase (percentage)
2	179	0.78%
3	183	1.72%
4	188	2.97%
5	194	4.49%
6	202	6.23%
7	210	8.14%
8	219	10.20%
9	228	12.38%

Table 2.5 Inventory increase with variance of lead times.

This roughly means that within one standard deviation of the given lead time (two weeks), e.g. from one standard deviation below to one standard deviation above, the chance of delivering the order is about 70%.

Lead time duration also has an impact on the optimal inventory carried. After calculation using the equations introduced above, Table 2.6 illustrates the average inventory change according to the average lead time change. One can easily see the inventory increase with longer lead times.

Lead Time (days)	Demand During Lead Time	Safety Stock	Re-order Point	Average Inventory Change
24	153	113	266	6.26%
23	146	110	257	5.70%
22	140	108	248	5.13%
21	134	106	239	4.55%
20	127	103	230	3.95%
19	121	100	221	3.34%
18	115	98	212	2.71%
17	108	95	203	2.06%
16	102	92	194	1.40%
15	96	89	185	0.71%
14	89	86	175	0.00%
13	83	83	166	-0.74%
12	76	80	156	-1.50%
11	70	76	146	-2.30%
10	64	73	137	-3.14%

Table 2.6 Inventory increase with lead time changes.

It appears that lead time variance has a larger impact than the average duration on the carried inventory[1].

Pull/Push System

The supply chain management revolves around efficient integration of suppliers, manufacturers, warehouses and stores. The challenge in supply chain integration is in coordination of activities across the supply chain to: reduce cost, increase service level, reduce the bullwhip effect (explain later), better utilize resources, and effectively respond to changes in the market place (e.g. resilience).

Traditional supply chain strategies may be categorized along the line of push or pull. A push based supply chain makes production and distribution decisions based on long term forecasts. Typically the manufacturer makes demand forecasts based on previous orders received from retailer's warehouses or distribution centers. A pre-scheduled manufacturing plan is carried out and products are 'pushed' down the supply chain into its vendors' inventories, often times irrespective of its up-to-date demand information. The disadvantages of this push system include:
- The inability to meet changing demand patterns
- The likely obsolescence of supply chain inventory as demand for certain products disappears.

The so-called bullwhip effect often occurs in the push system. Backward along the supply chain, the suppliers place larger and larger orders to account for the uncertainty of its down stream demand in order to meet their service requirements, making the entire system unstable. In such a system, service levels are low as the system is not responsive to market changes, inventories are excessive, and often products become obsolete.

In a pull based supply chain system, the production and distribution decisions are driven by customer demand. In an ideal pull system, no inventory is held until an order comes. This is enabled by fast information flow mechanisms to transfer information about customer demand to the various supply chain participants. Pull systems are intuitively attractive since they lead to many advantages such as:
- Low inventory
- Stable supply chain system

In practice, no perfect push or pull systems exist. Often times, a supply chain is operated as a combination of both. The following diagram illustrates different products that fit different strategies (Simchi-levi, Kaminsky and Simchi-Levi, 2003), where demand uncertainty and economy of scale constitute the two axes. As indicated in the figure below, high demand uncertainty encourages a high level of pull strategy while a high economy of scale gives incentive to a high degree of push system.

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[1] Formulas for the calculation are from Simichi-Levi, et al. (2000), and are not required in this course.

Demand uncertainty

pull

H

Computer   Furniture
Automobile

Book and CD   **Grocery**

L

push   Economies of scale

L   H
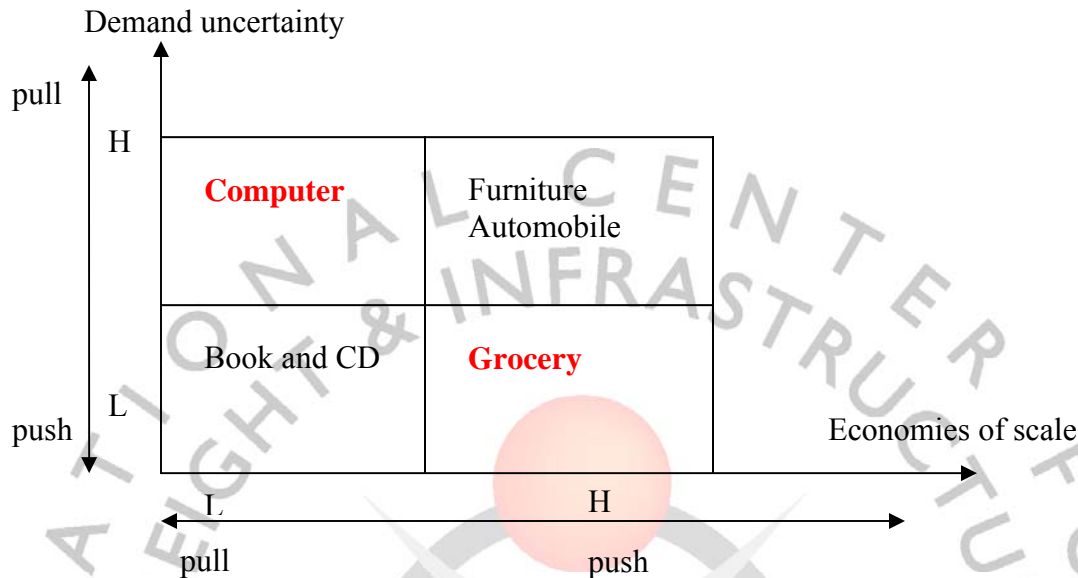
pull   push

Figure 2.1 Commodities on a push-pull scale.

It is clear that a pull strategy fits the computer industry while grocery welcomes a typical push strategy. In addition, the automobile uses a mix of push and pull strategies. As the quote below suggests, it may be moving more toward the pull model.

> A typical auto manufacturer offers a large number of similar products distinguished by functionality, motor power, shape, color, number of doors, sports wheels and so on. In addition, the demand uncertainty for a particular model is very high. Delivery cost is high as well. Traditionally, the industry has employed a push based supply chain strategy, building inventory for the dealer distribution systems. Recently however, GM announced a dramatic vision for restructuring the way it designs, builds and sells its products. The goal is to allow customers to customize and order cars on-line and have the cars delivered to the customer's door within 10 days. GM is moving exactly towards a build-to-order strategy. (pp 125, Simchi-levi, Kaminsky and Simchi-Levi, 2003)

Demand driven production and distribution is also seen in the airline industry. In the airline industry, supply refers to the aircraft capacity on a flight while demand represents the passenger/cargo flow. As demand is uncertain in the market, early fleet assignment onto flights may lose revenue opportunities as the expectedly smaller market could turn out to have a larger demand. Therefore, airlines purposely leave aircraft assignments on the flight network as undecided until the total demand is known. In a typical demand driven practice, two aircraft of different seating capacities are tied together for a potential swap in order to better accommodate market demand.

A pull system, or demand driven system, heavily depends on information and automatic computing power for system optimization and decision making in real time. Development of information technology and availability of rich market and production information has allowed the pull system to work effectively. A demand driven manufacturing or distribution system emphasizes the value of flexibility for future changes in production planning. The value of flexibility is often key to a successful operation of a pull system.

Vendor Managed Inventory

Traditionally inventory management is divided based on ownership across the supply chain. Manufacturers, distributors, and vendors each manage their own inventory and develop their own inventory policy. Isolation of these operations and their myopic decisions cause excessive production and supply. Distributor and vendor collaboration in terms of information sharing and inventory management has been a rewarding area and has motivated profitable practices in the past decade. Some suppliers have developed policies with their retailers such as buy-back-at-a-discount, in which unsold products by a certain time will be allowed to return at a discount price. In this way, suppliers assume partial responsibility of assisting inventory management for the retailers. The following paragraphs will introduce a special type of vendor-retailer relationship: Vendor-Managed-Inventory (VMI).

Vendor-Managed Inventory (VMI) is a planning and management system that is not directly tied to inventory ownership. Under VMI, instead of the retailer monitoring its sales and inventory for the purpose of replenishment order placement, its vendor (e.g. supplier) assumes responsibility for these activities. Note that retailers are referred to as customers of the vendor in paragraphs to come. In the past, many suppliers operated vendor-stocking programs where a representative of the vendor visited a customer a few times a month and restocked their supplies to an agreed-upon level. Popularized by Wal-Mart, VMI replaces these visits with information gathered from cash registers and transmitted directly to a supplier's computer system via Electronic Data Interchange (EDI). Now, suppliers can monitor sales of their products and decide when to initiate the re-supply procedure. This is not an inexpensive proposition for suppliers. Investments must be made in new systems, software, and employee training.

What are the advantages of VMI to customers?

In the article "Integrating Vendor-Managed Inventory into Supply Chain Decision Making" (Fox, 1996), Mary Lou Fox outlines four advantages of VMI:

1. Improved customer service. By receiving timely information directly from cash registers, suppliers can better respond to customers' inventory needs in terms of both quantity and location.
2. Reduced demand uncertainty. By constantly monitoring customers' inventory and demand stream, vendors are not challenged by large, unexpected customer

orders. By watching over several retailers, the aggregate demand becomes smoother.

3. Reduced inventory requirements. By knowing exactly how much inventory the customer is carrying, a supplier's own inventory requirements are reduced since the need for excess stock to buffer against uncertainty is reduced or eliminated.

While these are all potential benefits of VMI, the most important ones were not cited.

4. Improved customer retention. Once a VMI system is developed and installed, it becomes very costly for a customer to change suppliers.
5. Reduced customers' reliance on forecasting. With customers for whom a supplier runs VMI programs, the need to forecast their demand is eliminated, or at least reduced.

Vendor managed inventory implies that the replenishment of inventory is timely, and that excessive supply of inventory is not likely. Here, the agreed upon inventory level plays an important role in deciding the delivery frequency. In addition, retailers/vendors have the capability of differentiating fast moving items from slow ones. Vendors have to take into account the differences in sales volume in deciding delivery frequencies for the different items. Means of delivery in terms of truckload or less-than-truckload then could be well related to this delivery frequency.

Assemble to Order System

When excessive inventory is costly as in the PC industry, where new models replace current ones very quickly, a special demand driven manufacture-distribution system has been widely adopted in order to reduce the high inventory cost. This special system is called assemble-to-order. In this system, multiple products share the same inventory of components. For instance, PCs of different configurations use the same set of components such as hard drives, memory chips, monitors, keyboards, etc. Customers have various specifications on the products that they demand. Some may need a hard drive of 50GB, some 120GB; some a 29 inch flat panel, and some 21 inch. An assemble-to-order system has all these components in inventory. PCs are assembled according to customer specifications in their orders. In this way, inventory cost is significantly reduced.

Assemble-to-order systems involve value-added activities in the warehouses such as assembling, labeling, and packaging. The following graph illustrates the process of an assemble-to-order system.
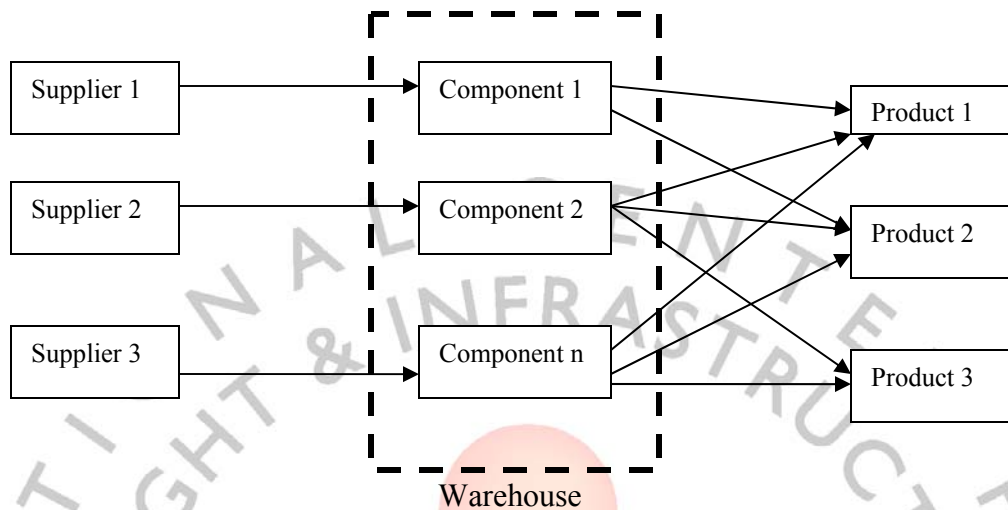
Figure 2.2 An illustrative assemble to order system.

The assemble-to-order system is not a conceptually new invention. In many large hardware stores such as Home Depot, sales of paint and stain offer an assemble-to-order system. Mix of the elementary inputs generates paints or stains of different colors as specified by customers. Imagine the inventory to carry all those paint colors premixed in every possible finish!

Multi-Echelon System

The multi-echelon system represents a perspective towards the structure of the supply chain system. Take a look at a distribution system as demonstrated in Figure 2.3. The product is manufactured at a plant. The manufacturer is considered as the most upstream echelon. The product is then supplied to its immediate next *echelon*, a distribution center, from where the product is further distributed to its vendors, after which the most downstream echelon, retailers receive the product for sale.

Retail products imported from the East Asian countries go through a multi-echelon system. First, the products are manufactured in the East Asian countries. Secondly, they are shipped to large warehouses/distribution centers in the US via ocean liners through major West Coast ports. The products are further shipped to regional distribution centers from where they are distributed to retail stores.

The multi-echelon system of assembly represents another example as shown below. Components are assembled into semi-products which are further shipped to assembly plants to create a final product.
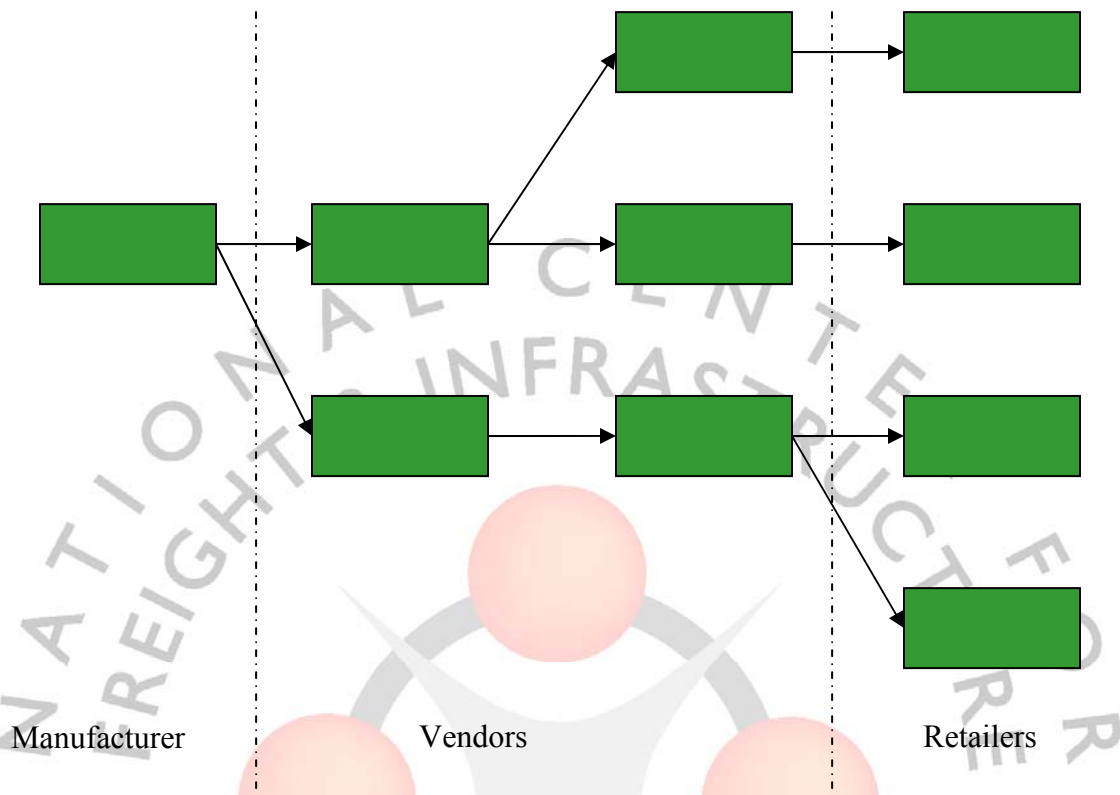
Figure 2.3 A multi-echelon system of distribution

The multi-echelon system point of view towards supply chain management represents a systems approach. It mainly deals with supply chain integration and smooth flow of inventory for system efficiency. Here, if we extend the echelon system of assembly to beyond the final product, we will have an echelon system of distribution. By extending the graph in this way, we will be able to find that the supply chains are in fact intertwined. One might want to consider links between echelons as shipping lines and nodes as major freight terminals. The links and nodes at different levels of echelon have different significance in terms of its network effect. For example, the links from East Asia to the West Coast prove more important than those to the final retailers. Delay/cost during ocean transport or at the West Coast ports has an impact on product distribution in the entire national market of the US. To freight planners, it is clear that achieving reliable and efficient performance on trunk freight lines has strategic value to the efficiency of the distribution network. This is an intuitive justification to the special focus on arterial network or arterial freight corridors and major freight terminals.

Supply Chain Integration

Supply chain integration is a broad concept dealing with strategies that bring vendors and suppliers closer together (by risk sharing or binding contracts) in order to make the production/distribution responsive to market changes. The pull system we introduced before represents an integration strategy. Here, we introduce two additional types of integration strategies: distributional and centralized/decentralized control based on different perspectives to the logistics and supply chain systems (Simchi-Levi et al. 2003).
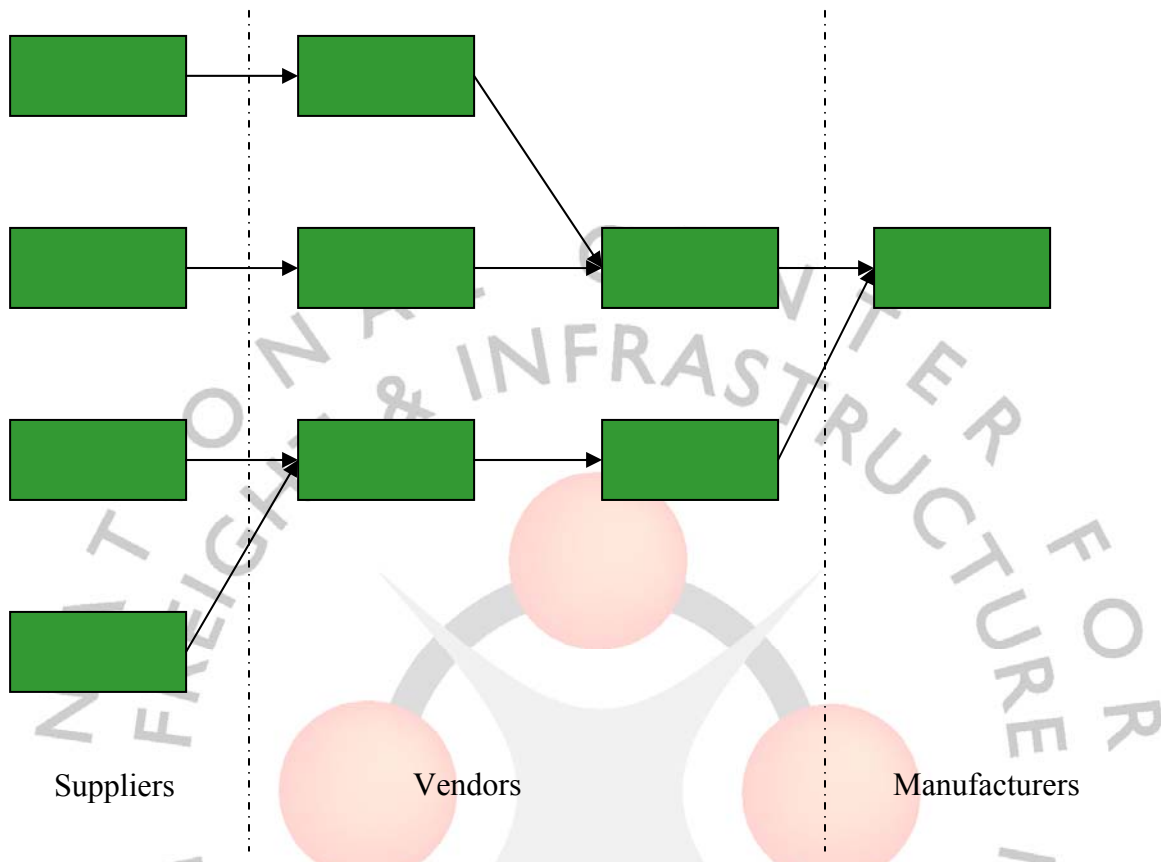
National Center for Freight and Infrastructure Research and Education (CFIRE)
University of Wisconsin – Madison. Instructor: Bruce X. Wang and Ernie Wittwer.   - 12 -

Figure 2.4: Multi-echelon system of assembly

Suppliers   Vendors   Manufacturers

Distributional Strategies

Typically, three distinct outbound distributional strategies are used: direct shipping, warehousing and cross-docking.

- **Direct shipping** means shipping directly from manufacturers to retailers bypassing DCs. It is common when a retail store requires fully loaded trucks. It is most often mandated where lead time is critical. Sometimes, the manufacturer is reluctant to be involved in direct shipping but may have no choice in order to keep the business. Direct shipping is also prevalent in the grocery industry, where lead time is of greatest importance because of perishable goods. (Simchi-Levi et al., 2003).

- **Warehousing** is the classic strategy in which warehouses keep stock and provide customers with items as required. Typical functions of warehousing are sorting and storage. Value added activities include labeling, packaging and sometimes assembling.

- **Cross docking** is a strategy that Wal-Mart made famous. In this strategy, warehouses function as inventory coordination points rather than as inventory storage points. In typical cross-docking systems, goods arrive at warehouses from the manufacturer and are transferred to vehicles serving the retailers as rapidly as possible. Goods spend very little time in storage at the warehouse – often less than 12 hours. This system limits inventory costs and decreases lead time by decreasing storage time. The down side of cross-docking is its difficulty to manage. It requires the transportation, dock operations and information sharing all to be efficient.

Centralized vs. decentralized control

This represents another unique way of looking at the logistics system.
In a centralized system, decisions are made at a central location for the entire supply network. Typically the objective is to minimize the total cost of the system while satisfying service level requirements. This is true when the network is owned by a single entity. It may also be true in situations that involve multiple organizations provided that savings and profit are distributed among the interested parties with some contractual mechanism. Some typical strategies include buy-back strategy, VMI, etc.

Summary

In recent years, many supply chain strategies have been developed. These strategies largely focus on the system efficiency by information sharing, centralizing decision making, profit/risk sharing, bypassing distribution centers wherever possible, and manufacturing postponement (assemble to order system/demand driven distribution, etc.)

The freight system plays an important role in supply chain integration. It may be deemed as a connector of these inventory holding points. Inherent connection of these points in terms of distance, time, cost, and (reliable) responsiveness to each other depends on transportation system performance to a great degree. As an example, an efficient and reliable freight system helps make strategies such as cross-docking and assemble-to-order possible. In addition to the direct savings in freight, the supply chain benefits include a significant reduction in inventory cost.

According to some statistics, in year 2000 the supply chain in the US remained comparable or better than its global competitors. According to Financial Times (December, 2000), the logistics cost accounts for over 10% of the US national GDP and a slightly higher percentage for other countries. Table 2.1 shows logistics cost as a percentage of national GDP for some countries.

Country	GDP %
USA	10.5
Canada	12
UK	10.63
Denmark	12.88
Ireland	14.26
Spain	11.52
Hong Kong	13.71
Japan	11.37

Table 2.7 Logistics cost as a percentage of national GDP.

The figures above remain true in terms of the general percentage of GDP. We do not have statistics in the most recent years for all countries. However, according to some sources, the logistics cost in percentage of GDP for the States has been below 10% for years, and that this percentage has been rising towards 10% due to the increasing energy cost. For example, the 9.4% of US GDP in 2005 changed to 9.9% in 2006.

However, the logistics cost across sectors varies, as explained in this chapter. The difference in logistics costs are accompanied by different logistics strategies developed in their corresponding sectors. Note that Table 2.7 represents the overall performance only. It does not mean that every sector of the US economy remains equally competitive. In addition, logistics cost in international trade might be different in some particular sectors.

Literature

1. Fox, Mary Lou, *Integrating Vendor-Managed Inventory into Supply Chain Decision Making*, APICS 39th International Conference Proceedings, 1996
2. **http://vendormanagedinventory.com/article7.htm, by** Mark K. Williams. Accessed on May 19, 2007.
3. David Simchi-Levi, Philip Kaminsky and Edith Simichi-Levi. 2003. Designing and managing the supply chain: concepts, strategies and case studies. 2nd edition. McGraw Hill Irwin Publication.

Logistics Network Design and Facility Location

By now, we have introduced inventory management as a key area in logistics management. However, inventory management is generally on the tactical level. At the strategic level, logistics network design lays the ground for the entire system efficiency and determines the general cost structure. Logistics network design is about where to put the production plants, warehouses and distribution centers, and how to coordinate their activities to make an efficient and natural supply network.

Logistics network planning in the private sector influences freight traffic on the transportation system such as at major freight terminals and on freight corridors. The location of a distribution center could give rise to serious congestion on the local street network. For instance, it may be interesting to know how much freight traffic on major interstate corridors is originated at Wal-Mart distribution centers.

In the following section, the location decisions in the private sector will be introduced. A basic decision is warehouse location.

Warehouse Location

There are several major factors in warehouse decisions: the number of warehouses, the locations, and their sizes. These decisions are interrelated. As the number of warehouses increases, their sizes decrease. There is always an optimal operational plan for each established network of warehouses and DCs. The major costs are inventory, warehousing, and transportation.

Figure 2.5 shows an illustrative relationship between the number of warehouses and the total logistical cost. This is an example showing how private firms depend on their logistics network design to control total cost. The overall system wide inventory cost increases with the number of warehouses. This is due to the lack of pooling effect for having more warehouses.

Total Cost

Inventory
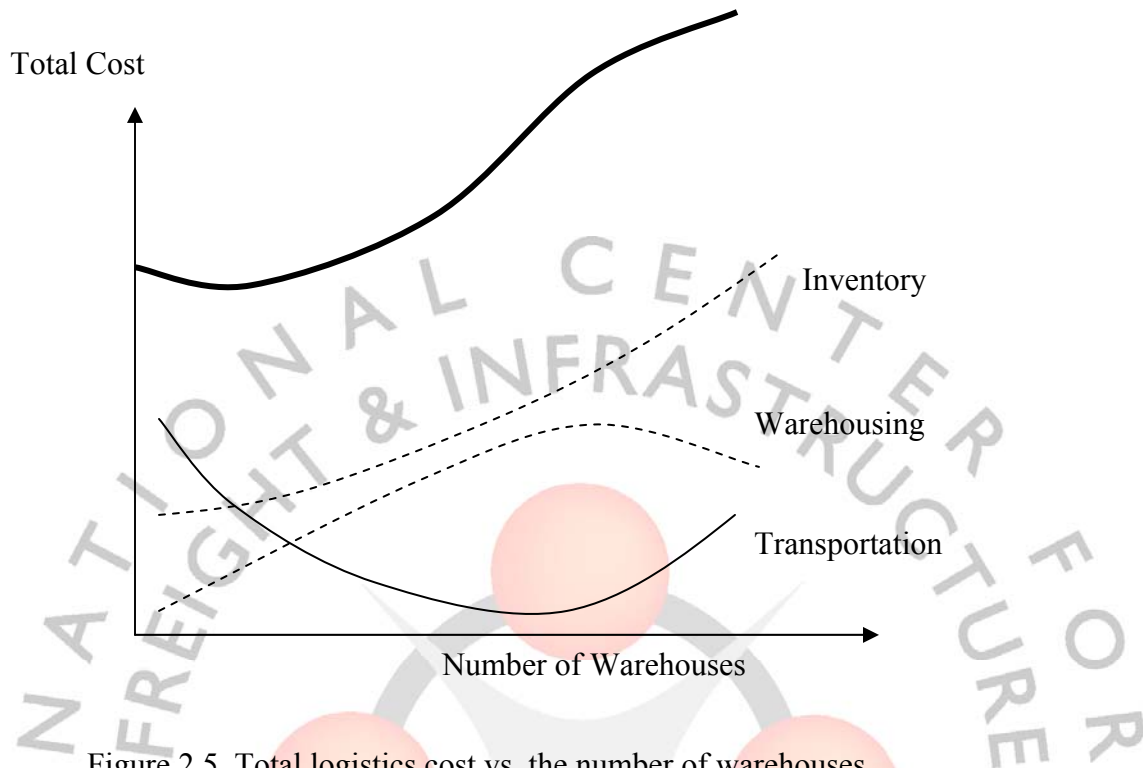
Warehousing

Transportation

Number of Warehouses

Figure 2.5. Total logistics cost vs. the number of warehouses.
(Source: Strategic Logistics Management. Stock and Lambert, 2001)

State of the art network design for facility number and locations often dictates large scale, complex mathematical modeling that considers various operational strategies in different scenarios to balance the trade-offs between factors. The advancing computational power proves to be of great help to put millions of constraints into consideration in order to balance the nuances between different considerations. However, oftentimes, mathematical modeling is not feasible due to the scale of the problem, where computer simulation is adopted to see effects of the what-if scenarios.

To freight planners, it would be helpful to have a big picture of the facility locations in relation to markets. The following gravity model hopefully would serve this purpose.

Center-of-Gravity Model (COG)

Here we introduce a simple model developed early on for warehouse location. It is called the center-of-gravity approach, or gravity model for short.

In this approach, assume there are a set of customers on a grid system, each having an annual demand. The location of each customer is represented by an *x* and *y* coordinate. This method decides the approximate location of a warehouse to serve those customers, assuming a single warehouse is needed. Briefly, the center-of-gravity approach allows the warehouse to be located closer to larger customers.

The following formula is used to calculate the location (x, y) of the warehouse.

$$x = \frac{\sum x_i d_i}{\sum w_i}; \quad y = \frac{\sum y_i d_i}{\sum w_i}$$

Where x_i and y_i are the coordinates of the ith customer, and d_i is annual demand of the ith customer.

Example: The XYZ company would like to set up a distribution center to serve several key supply chain customers in the area. The annual demand and location of these customers are shown in the table. Use COG model to determine the approximate location of the DC.

Customer	x-y-coordinate(of location)	Annual Demand (units)
A	(5,12)	2,000
B	(7,8)	10,000
C	(12,10)	4,000
D	(3,9)	15,000
E	(15,4)	6,000
F	(7,15)	8,000

Table 8 Demand information

Solution

The warehouse location is calculated as follows.

$$\overline{X} = \frac{\sum_{i=1}^{n} d_i x_i}{\sum_{i=1}^{n} d_i} = \frac{5 \times 2000 + 7 \times 10000 + 12 \times 4000 + 3 \times 15000 + 15 \times 6000 + 7 \times 8000}{2000 + 10000 + 4000 + 15000 + 6000 + 8000} = 7.09$$

$$\overline{Y} = \frac{\sum_{i=1}^{n} d_i y_i}{\sum_{i=1}^{n} d_i} = \frac{12 \times 2000 + 8 \times 10000 + 10 \times 4000 + 9 \times 15000 + 4 \times 6000 + 15 \times 8000}{2000 + 10000 + 4000 + 15000 + 6000 + 8000} = 9.4$$

Note that the location site calculated here is approximate. The final decision is subject to examination of zoning requirements, warehouse taxes, labor availability and other factors. However, what is indicated by the above equation is interesting. It shows that the warehouse location is drawn largely by market demand. The reasoning might be that volume shipping is used from the suppliers to the warehouse, whose cost does not change much with the minor shift of warehouse location in a region. And a large number of shipping in smaller packages is done on route from the warehouse to the vendors, which has a higher freight rate and is more related to the regional warehouse location.

Exercise: DryIce is a manufacturer of air conditioners that has seen its demand grow significantly. They anticipate nation wide demand for the year 2011 of 180,000 units in the South, 120,000 units in the Midwest, 110,000 units in the East and 100,000 units in the West. Managers at DryIce are designing the production and distribution network and have selected four potential sites – New York, Atlanta, Chicago and San Diego—for production of air conditioners. Plants could have a capacity of either 200,000 or 400,000 units. The annual fixed costs at the four locations are known, along with the cost of producing and shipping the air conditioners to each of the four markets. Where should DryIce build its facilities and how large shall they be?

Distribution Network

From the logistics and supply chain point of view, it is usually a distribution network instead of a single warehouse that is considered in a location design problem. Regarding the distribution network, an example structure is shown below.
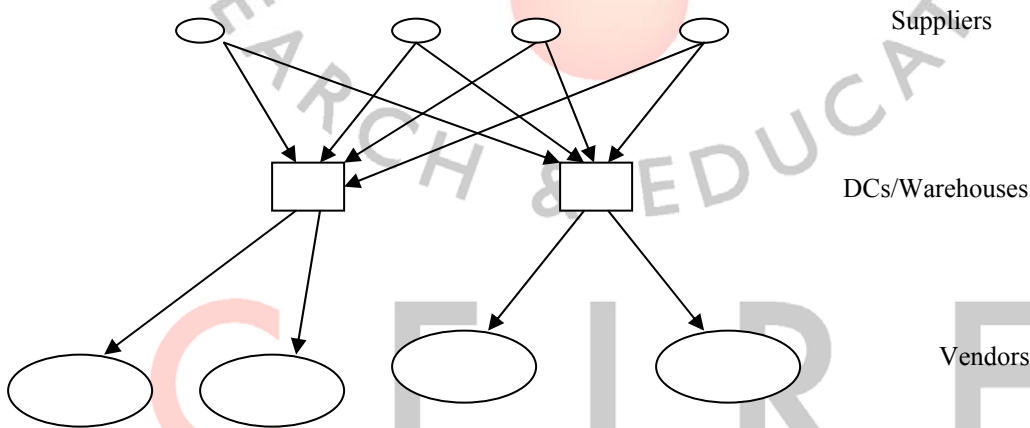

Figure 2.5 An Illustrative Structure of a Distribution Network

Note that from suppliers to DCs, the volume could be high. Each DC could have up to several thousand suppliers. Shipping from suppliers to the DCs might have to go through

a consolidation process. For example, purchases in China by Wal-Mart may be consolidated before being shipped to the DCs in the States.

In a distribution network, there are typically multiple suppliers and distributors (warehouses). It is rarely the case that the network is designed from scratch. Instead, it is often re-designed based on the current distribution network in operation. The decisions are how to efficiently use the existing DCs, which ones to close, and where to add new DCs onto the network if necessary. In this way, the problem is much simpler compared to a complete network design. As is often the case, the network is examined and re-engineered frequently. According to a recent report, Wal-Mart re-engineers its distribution network every six months to adapt to the changing market and minimize its shipping costs. Note that such re-engineering does not necessarily have to do with warehouse re-location. It might just be an adjustment to market division among the DCs as well as adjustment to the dispatching strategies at each DC due to market area changes.

The following table shows the best locations given the number of warehouses needed to cover the market in the United States.

Number of Warehouses in the Network	Shortest Average Distance to US Population	Best Warehouse Locations	Number of Warehouses in the Network	Shortest Average Distance to US Population	Best Warehouse Locations
1	797	Bloomington, IN	8	203	Madison, NJ
2	486	Chillicothe, OH			Pasadena, CA
		Mojave, CA			Chicago, IL
3	376	Allentown, PA			Palestine, TX
		Mojave, CA			Gainesville, GA
		McKenzie, TN			Tacoma, WA
4	315	Hilltown, PA			Lakeland, FL
		Mojave, CA			Denvor, CO
		Chicago, IL	9	188	Newark, NJ
		Meridian, MS			Pasadena, CA
5	265	Madison, NJ			Rockford, IL
		Mojave, CA			Palestine, TX
		Chicago, IL			Gainesville, GA
		Dallas, TX			Tacoma, WA
		Macon, GA			Lakeland, FL
6	237	Madison, NJ			Denvor, CO
		Pasadena, CA			Mansfield, OH
		Chicago, IL	10	174	Newark, NJ
		Dallas, TX			Alhambra, CA
		Macon, GA			Rockford, IL
		Tacoma, WA			Palestine, TX
7	218	Madison, NJ			Gainesville, GA
		Pasadena, CA			Tacoma, WA
		Chicago, IL			Lakeland, FL
		Dallas, TX			Denvor, CO
		Gainesville, GA			Mansfield, OH
		Tacoma, WA			Oakland, CA
		Lakeland, FL			

 Table 2.9 Best locations vs. the number of warehouses.
(Source: Strategic logistics management by Stock and Lambert, 2001)

Table 9 shows the locations of warehouses in order to cover the national market with designs of different warehouses.
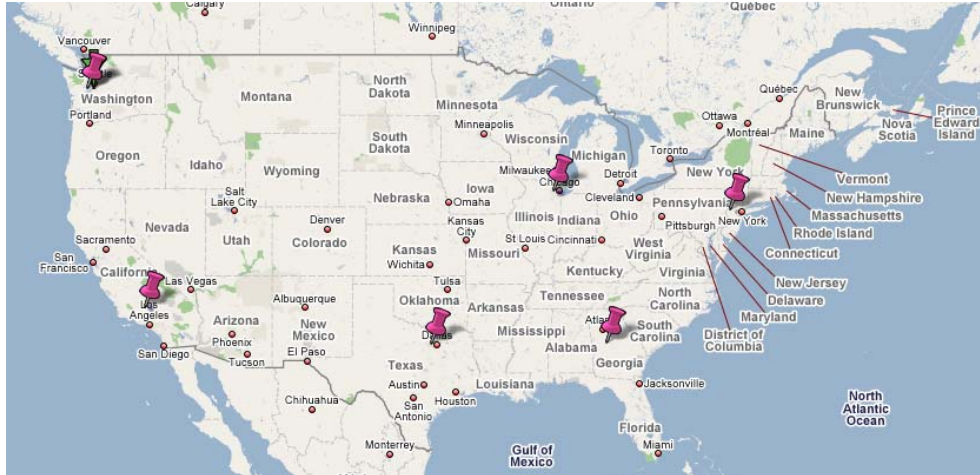
Figure 2.6. Example of six warehouse locations in the States

The above map shows six best locations if six regional warehouses are decided necessary. By comparing the six locations with the transportation network distribution in rail, highway, air, and waterway, one can easily find the coincidence between DC locations and accessibility of the transportation system.
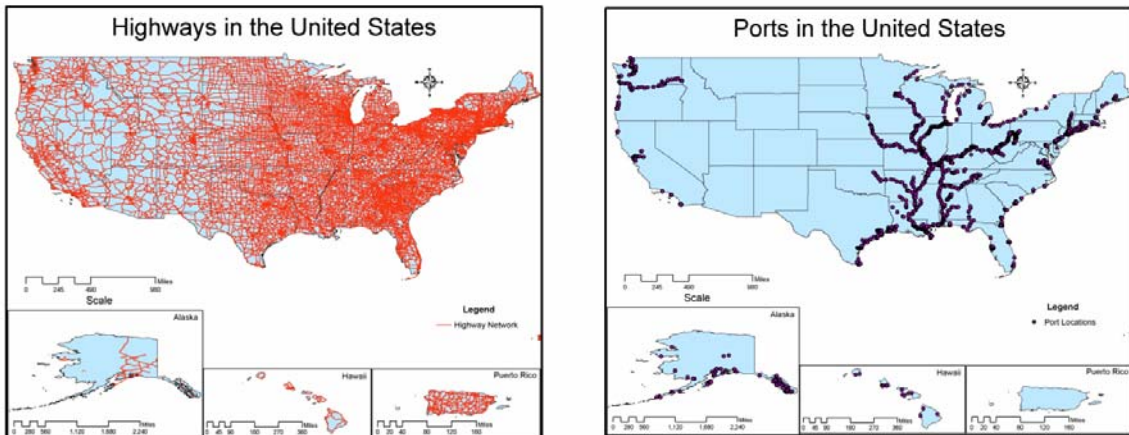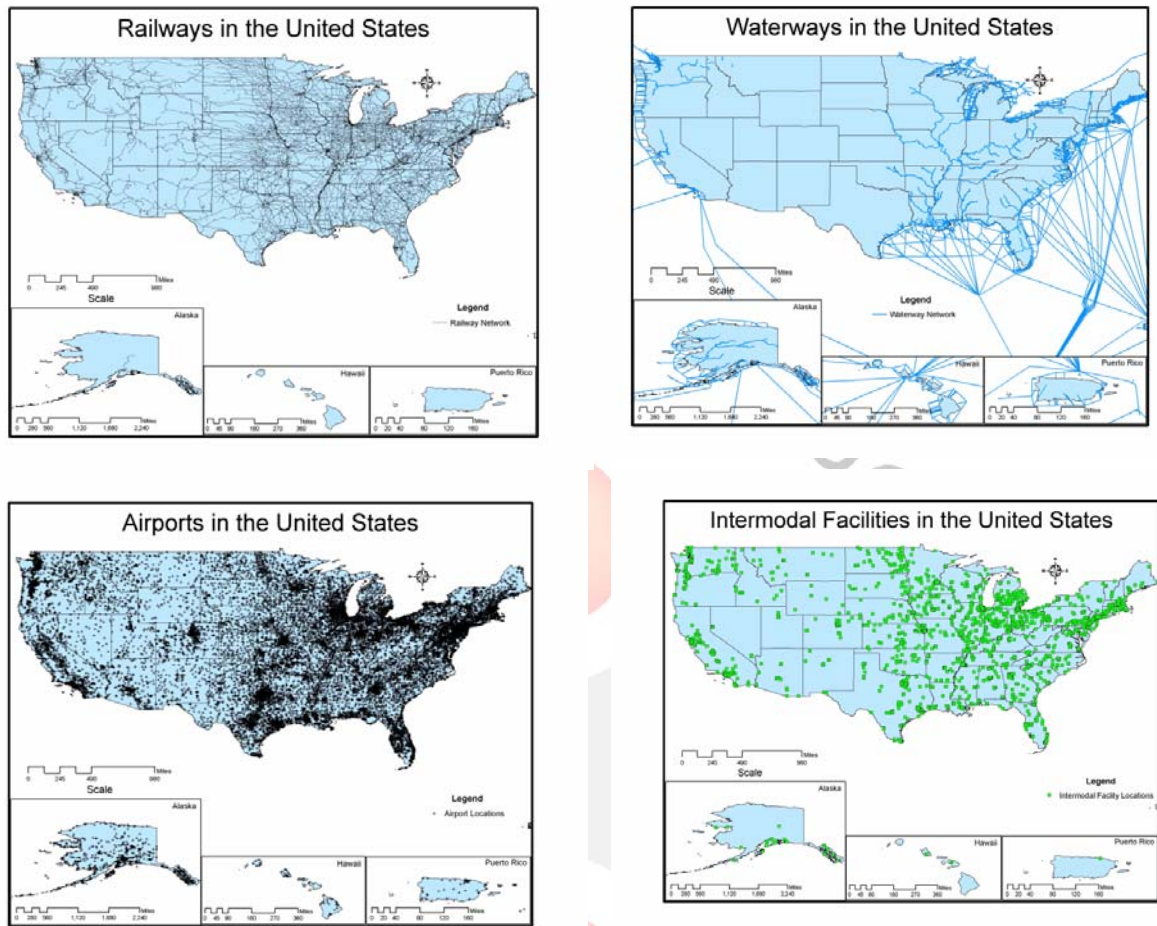
Figure 2.7. Transportation network distribution in the States

The distribution network in the case of six distribution centers coincides with the concentration of the most highway, rail, waterway, airports and intermodal terminals by just an empirical examination of the above distribution maps.
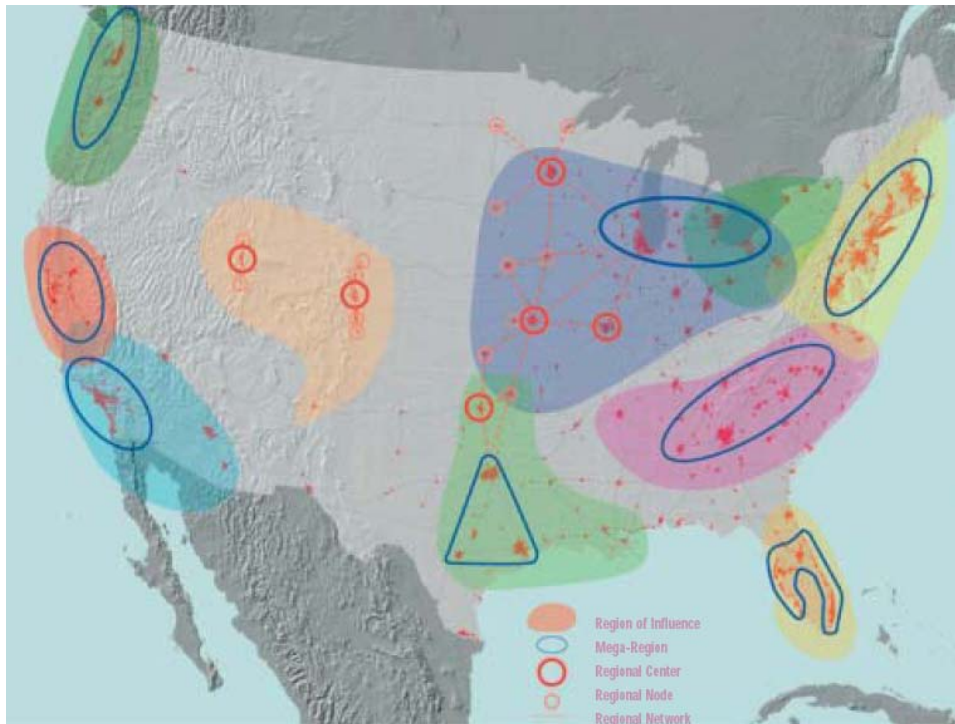
Figure 2.8. Large metro areas in the States

Source: Carbonell et al, Global Gateway Regions, The United States of America's Third Century Strategy, Southern California Association of Governments, Los Angeles, CA, Sept. 2005; based on "Toward an American Spatial Development Perspective," University of Pennsylvania, Department of Planning, Spring 2004.

If we further take a look at the population distribution, we may find this coincidence between locations of distribution centers and the major concentrations of population in the United States. The importance of population distribution to the logistics distribution network is obvious. Therefore, it is important for freight planners to be conscious about potential demographic and geographic shifts of population in the Unites States in order to do a good job that anticipates changes.

Factors Influencing Network Design Decisions

In deciding a warehouse location, there are many factors to consider. These include strategic factors, technological factors, microeconomic factors, exchange rate and demand risk, political factors, infrastructure factors, competitive factors, customer response time and local presence, logistics and facility costs, etc.

We explain these factors in the following.

- Strategic factors

A firm's strategy has a significant impact on its logistics network design. Cost reduction is generally the primary factor. It is suggested to use the following strategic roles for facility classification in a global supply chain.

- o Offshore facility: low cost facility for export production. It serves the role of being a low cost supply source for markets located outside the country.
- o Source facility: low cost facility for global production. It is often a primary source of product for the entire global market.
- o Server facility: regional production facility. Its objective is to supply the market where it is located. A server facility is built because of tax incentives, local content requirement, tariff barriers, and a high logistical cost to supply the region from elsewhere.
- o Contributor facility: regional production facility with development skills. It serves the market where it is located, but also assumes the responsibility for product customization, process improvements, product modifications, or product development.

- • Technological factors

Characteristics of available technologies have a significant impact on network design decisions. If the production technology displays significant economies of scale, then a few large production sites may suffice to supply the market. Otherwise, a larger number of production sites are preferred.

- • Macroeconomic factors

These include taxes, tariffs, exchange rates and other economic factors that are external to an individual firm. There are risks associated with exchange rates and market changes due to the changes in global economy.

- • Political factors

These are related to political stability.

- • Infrastructure factors

Availability of good infrastructure for transportation such as water and power is an important prerequisite to locating a facility in a given area. Poor infrastructure adds to the cost of doing business from a given location.

- • Competitive factors

Companies must consider their competitors' strategy, size, and location when designing their supply chain networks.

- • Customer response time and local presence

Firms that target customers who value a short response time must locate close to them.

- • Logistics and facility cost

Logistics and facility costs incurred within a supply chain change as the number of facilities, their location, and capacity allocation are changed. Companies must consider inventory, transportation, and facility costs when designing their supply chain network.

A Framework for Network Design

The goal of network design is to create a network that maximizes the firm's profits while satisfying customer needs in terms of demand, service responsiveness and reliability. Global network design decisions are usually made in four phases. Phase I specifies what capacity a firm's supply chain network must have in order to support the firm's competitive strategy. Phase II defines regions in which facilities must be located, their potential roles and approximate capacity. Phase III determines the particular locations of the facilities. Phase IV finalizes the location decision.

The following graph demonstrates this process. (source: Supply Chain Management: Strategy, Planning and Operations. By Chopra and Meindl, 2001.)
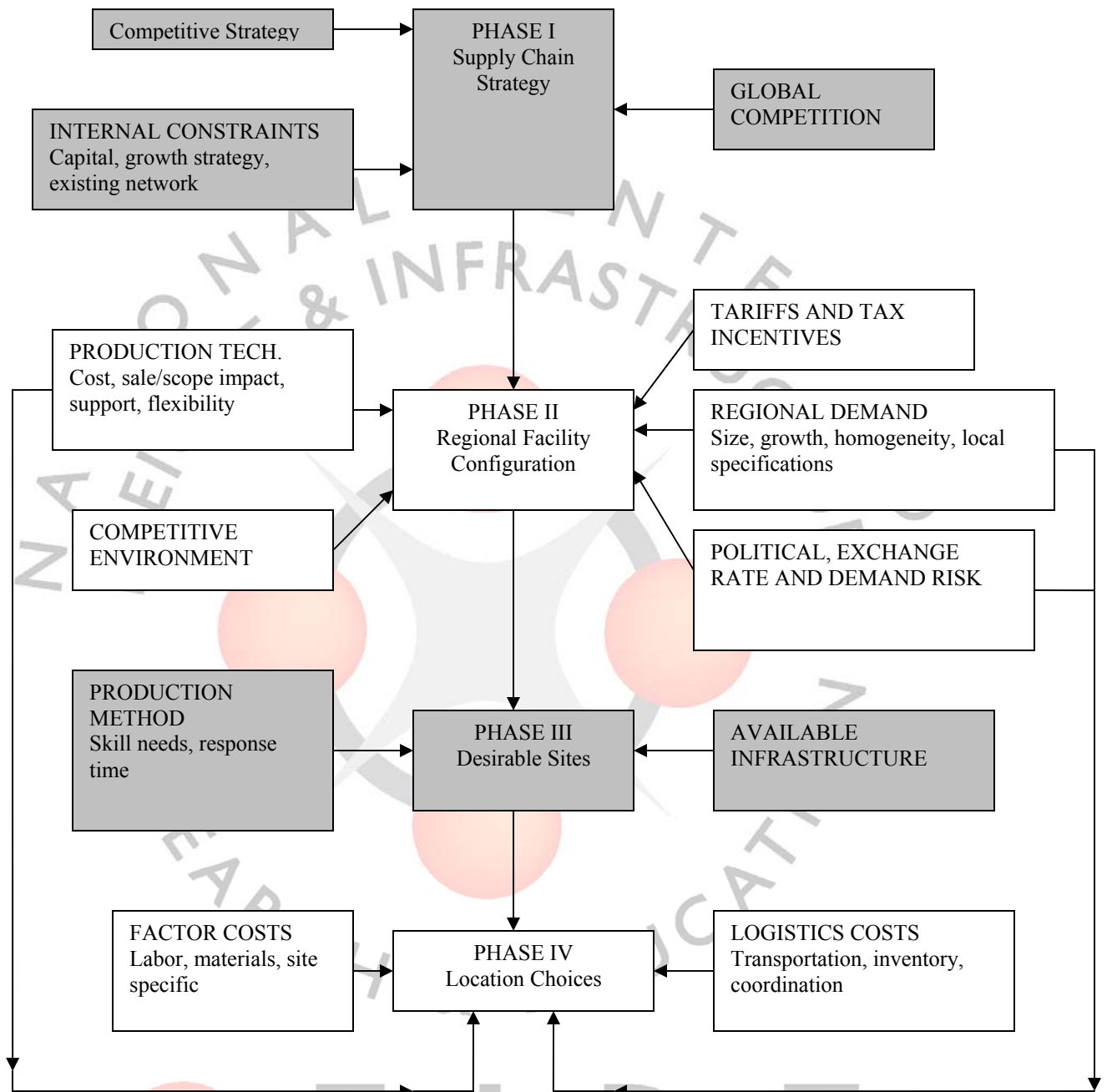
Figure 2.9. A Framework for Network Design.

Remarks

Facility location for a supply chain network is a complex decision process. A large portion of the cost of the system is on freight, inventory and warehousing. Design of a

network also resolves division of markets among distribution centers, and largely defines modal shipping from the suppliers and distribution centers to retailers. Decision support systems employing optimization models are widely adopted to capture the cost tradeoffs between alternative plans.

In practice, the network design problem has more factors to consider than discussed here. For example, the life-cycle cost of facilities, quality of life for employees, and the focus on tariffs and tax incentives when locating facilities are all important to a firm.

Due to economies of scale in distribution, many networks follow a hub-n-spoke pattern. For example, FedEx has large freight terminals for package consolidation. Airlines have their hub airports for passenger transfer. Between hub locations or terminals, volume shipping takes place.

The figure below shows an example distribution network with its market division among the distribution centers.
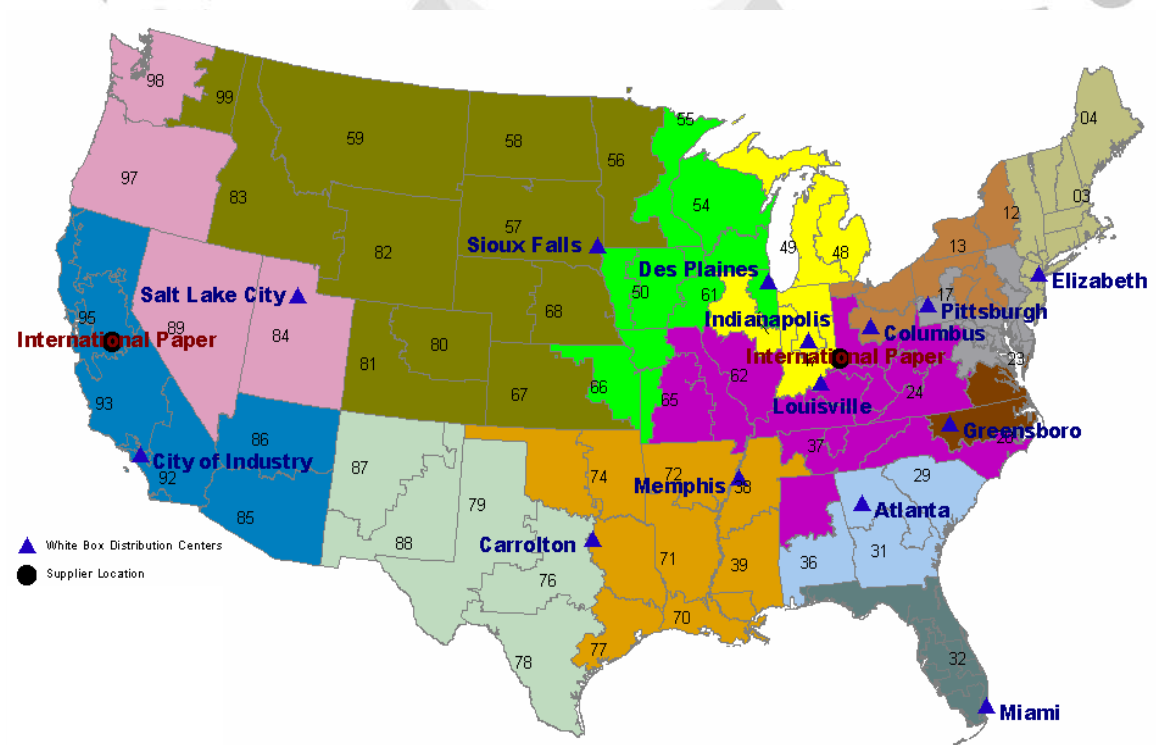

Figure 2.10 International Paper Distribution Network of a Global Carrier

At hub locations or major freight terminals, a significant amount of traffic is expected. The hub locations require heavy capital investment from the carriers. Therefore, they are

relatively stable and cannot be easily changed. These hub locations often cause serious traffic delays that challenge freight planners. From the private sector's network point of view, delays in and around these hub locations have a profound effect on distribution system efficiency.

Literature

1. James R. Stock and Douglas M. Lambert. 2001. Strategic Logistics and Management. 4th Edition. McGraw Hill Publishing. [Chapter 10: Warehousing. Page 405 contains facility development, useful]
2. S. Chopra and P. Meindl. 2004. Supply Chain Management: Strategy, Planning and Operations. 2nd Edition. Pearson Prentice Hall (Page 101-).

Procurement and Outsourcing

An Example Strategic purchasing at medical solutions

Siemens, founded in 1847 and headquartered in the Federal Republic of Germany, is an electronics and electrical engineering company employing more than 450,000 employees in 190 countries. Their annual sales for fiscal year 2001 was €87 billion (€ is the symbol for euro). Approximately 22% of the sales were from Germany, whereas 30% each came from the United States and the rest of Europe. Siemens spent about 47% of the sales for the year, about €41 billion, on purchases of production materials, system components, software, and services. Its diverse business portfolio is segmented into the following areas: information and communications, automation and control, power, transportation, medical, lighting, and financial and real estate. The medical segment, Medical Solutions (Med), provides a broad spectrum of products, solutions, and services for the healthcare industry.

Prior to 1997, buyers at Medical Solutions' decentralized purchasing system bought components and materials for the individual plants without communicating and considering the needs of other segments or divisions within the same segment. Purchasers and suppliers were rarely involved in new product design and development. Purchasing was considered strictly a tactical supporting function, and there were no synergies with the design and manufacturing facilities. Purchasing's responsibility was simply to ensure that the right materials were available at the right place, at the right time, and at the right price. The decentralized purchasing system missed out on opportunities to leverage purchases of common items among the various business units. It has no long term contracts with strategic suppliers or control over prices.

When Dietmar Dresp, vice president of strategic purchasing, was hired in 1997, he transformed medical solutions purchasing function into a strategic purchasing organization. The goals of the organization were to leverage Medical Solution's material purchases with suppliers, exploit the technical expertise of suppliers, and form long term mutually beneficial relationships with suppliers. Purchasing engineers were hired to work with design engineers and suppliers in product design and development. Eight materials groups, each headed by a manager, were formed to handle strategic sourcing of production materials.

The new centralized strategic purchasing structure reduced medical solutions' materials cost by 25% and cut its supplier base by 50% to 2500 over a three year period. Keys to the strategic efforts included outsourcing, supplier based reduction, strategic alliances, supplier performance evaluation, and supplier involvement in new product design and development. With its new strategic purchasing organization, Medical Solutions drastically reduced its product development and manufacturing cycle times. For example, Medical Solutions' newest ultrasound product, the SONOLINE Antares, is built in hours, whereas previous generations of the equipment took days to manufacture. [Source: Wisner, leong and Tan, 2005]

Procurement is an important function for firms, especially those in manufacturing and retail sectors. The procurement function manages the purchase of raw materials, components, (semi) products, related services and other resources from suppliers. Purchasing can be broadly classified into two categories: merchants and industrial buyers. The former refers to wholesalers and retailers who purchase their merchandise in volume to take advantage of volume discounts and other incentives such as transportation economy and storage efficiency. They create value by consolidating merchandise, breaking bulk, and providing the essential logistics services. The industrial buyers purchase primarily for production. They purchase services, capital equipment, maintenance, repair, and operating supplies.

The primary goal of purchasing is to ensure uninterrupted flow of raw materials at the lowest total cost. Purchasing is the crucial link between the sources of supply and the organization itself. It is considered by many to be essential to involve purchasing and strategic suppliers in concurrent engineering activities in order to collapse the design-to-production cycle time.

The details of the purchasing process such as identification of needs, request for quotation and proposal, and final selection are skipped here for the interest of time. Worthy of a special mention is sourcing, a popular concept in supply chain management in recent years. Sourcing is the entire set of business processes required to purchase goods and services, including selection of suppliers, design of supplier contracts, product design collaboration, procurement of materials, and evaluation of supplier performance.

The benefits from effective sourcing can be partially listed as follows.

- Better economies of scale can be achieved if orders within a firm are aggregated.
- Efficient procurement transactions significantly reduce the overall cost of purchasing. This is most important for items which have a large number of low-value transactions.
- Good procurement processes can facilitate coordination with suppliers and improve forecasting and planning. Better coordination lowers inventories and service levels.
- An appropriate supplier contract can allow for the sharing of risks, resulting in higher profits for both the supplier and the buyer.
- Firms can achieve a lower purchase price by increasing competition through the use of auctions (bidding for businesses).

It is important for a firm to be clear on the factors that have the greatest influence on performance and make improvement in those areas. For example, if most of the spending for a firm is on materials with only a few high-value transactions, improving the efficiency of procurement transactions will provide little value whereas improving design collaboration and coordination with the supplier will provide significant value. In contrast, when sourcing items with many low –value transactions, increasing the efficiency of procurement transactions will be very valuable.

Supplier Scoring and Assessment

Procurement often needs to decide among a number of competing suppliers the ones that best meet their needs. Supplier scoring is an effective means to choose the right supplier(s). The primary factor is usually the quote price. However, there are also other factors that play a significant role in the decision. These factors include:
- Replenish lead time
- On-time delivery performance
- Supply flexibility
- Delivery frequency (minimum lot size)
- Supply quality
- Inbound transportation cost
- Pricing terms
- Information coordination capability
- Design collaboration capability
- Exchange rates, taxes, and duties
- Supplier viability

Detailed explanation of the above factors can be seen in Chapter 13 of Chopra and Meindl (2007).

The following example illustrates how lead time and on-time performance affect the overall cost of a company.

Example Green Thumb, a manufacturer of lawn mowers and snow blowers, has historically purchased a thousand bearings per week from a local supplier who charges $1.00 per bearing. The purchasing manager has identified another potential source willing to supply the bearings at $0.97 per bearing. Before making his decision, the purchasing manager evaluates the performance of the two suppliers. The local supplier has an average lead time of two weeks and has agreed to deliver the bearings in batches of 2000 units. Based on past on-time performance, the purchasing manager estimates that the lead time has a standard deviation of one week. The new source has an average lead time of six weeks and a standard deviation of four weeks. The new source requires a minimum batch size of 8,000 bearings. Which supplier should the purchasing manager go with? Green Thumb has a holding cost of 25 cents per bearing. They currently use a continuous review policy for managing inventory and aim for a cycle service level of 95 percent. (Note: a continuous review policy monitors the inventory continuously and places a replenishment order whenever the inventory falls below a threshold.)

Solution
A supplier's performance on lead time (including its variability) affects the safety stock level, and the minimum batch size affects the cycle inventory held. Thus, the purchasing manager should evaluate the total cost of using each supplier.

First, consider the cost of using the local supplier.

Annual material cost = (annual demand in units) x unit cost = 1000 x 52 x 1 = \$52,000
Average cycle inventory = (order quantity)/(cycle length) = 2,000 / 2 = 1000 (unit)
Annual cost of holding cycle inventory = (average inventory value) x 25%
$$= 1000 \times 1 \times 0.25 = 250 \text{ (UDS)}$$
Safety inventory required with current supplier = $z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$
$$= 1.65 \times 1086 = 1792 \text{ (units)}^2$$
Annual cost of holding safety inventory = 1792 x 1 x 0.25 = 448 (\$)
The total annual cost of using current supplier = material cost + safety inventory cost + cycle inventory cost = 52,000+250+448 = **52,698.00** (\$)

Correspondingly the annual cost for the new supplier is calculated as follows.

Annual material cost = 0.97x1000x52=\$50440
Average cycle inventory = 8,000 / 2 = 4000 (units)
Annual cost of holding cycle inventory = 4000 x 0.97 x 0.25 = \$970
Safety inventory required with new supplier = $z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$

$$= 1.65 \times 4066.94 \text{ units (for 95\% service level)}$$
$$= 6710 \text{ (units)}$$
Annual cost of holding safety inventory = 6710 x 0.97 x 0.25 = \$1627
The total annual cost of using the new supplier = \$53037.00

The conclusion is to use the local supplier since the new supplier incurs a higher overall cost although the latter has a lower purchasing cost. Price advantage can be easily offset by lead time (part of which is shipping time) and inventory cost.

Supplier Selection and Contract

Once the aforementioned scoring analysis has been completed, a list of promising suppliers will emerge. The firm can then select desired suppliers using a variety of mechanisms such as off-line competitive bids, reverse auctions, or direct negotiations. No matter what mechanism is used, supplier selection should be based on total cost of using a supplier and not just the purchase price, as demonstrated in the example above.

The relationship with suppliers may be better appreciated if one realizes the risk associated with the purchasing decision. As an example, when demand changes quickly, the retailer has a significant risk in volume purchasing. The purchasing contract is a binding document between parties. However, properly set up, it may also help mitigate the purchasing risks involved. There are several alternative contracts worth mentioning.

- *Buyback* contracts have been popular in recent years. The supplier buys back the remaining inventory at a discount price within a certain time period of purchase.

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[2] Here we assume that the standard deviation of demand during the lead time is 30% of the average demand. Therefore STD=300 units.

This provides incentives to the buyer to purchase a larger variety and at a larger quantity of products to solicit demand. It is suitable for products with a low variable cost. But it can lead to surplus inventory.

- *Revenue-Sharing* contracts apply in the retail sector. It allows the buyer to pay a minimal amount for each unit purchased, but shares a fraction of the revenue for each unit sold. In this way, there are no product returns.
- *Quantity flexible* contracts allow the buyer to modify the order (within limits agreed to by the supplier) as demand becomes clearer when closer to sales.
- *Contracts to coordinate supply chain costs* apply to supply chain parties with strategic relationships. It aims at reducing the total supply chain cost including manufacturing, distribution, and inventory.
- *Contracts to induce performance improvement* contain the flexibility of rewarding the supplier based on performance such as percentage of on-time delivery and percentage of damage.

Outsourcing

Outsourcing is similar to purchasing. It emphasizes on the choice between keeping in-house and subcontracting. Purchasing as mentioned above is not just about materials but also services such as transportation. Typically, when a firm purchases transportation services, this process is called transportation services outsourcing. Transportation services outsourcing is an important and complex process for large manufacturing firms such as GM and large retail stores.

The outsourcing decision is centered at the company's core competency. The products and services are outsourced to those firms with superior competency in providing related services and products. Related to the concept of outsourcing are 3rd and 4th party logistics service providers. The 3rd party logistics service providers provide services such as transportation, distribution, warehousing, as well as IT services. If the functions outsourced are too complex, they could be outsourced to a 4th party service provider. And the 4th party service provider then serves as the primary contractor to multiple additional 3rd party logistics providers.

Case Study

A critical decision of outsourcing is first about make-or-buy. Should a manufacturing firm make the component by itself, or purchase from outside providers? A break-even analysis is a handy tool for computing the cost effectiveness of sourcing decisions when cost is the most important criterion. The following example is for illustrative purposes. More sophisticated models are needed in practice (Source: Wisner, Leong and Tan, 2005).

Consider a hypothetical situation in which a company has the option to make or buy a component part. Its annual requirement is 15,000 units. A supplier is able to supply it at $7 per unit. The firm estimates that it costs $500 to prepare the contract with the supplier.

To make the part in house, the firm must invest $25,000 in equipment and it estimates a unit cost of $5 to manufacture.

Costs	make option	buy option
Fixed cost	$25000	$500
Variable cost (per unit)	5	7

Annual requirement = 15,000 units.

Solution

The break-even quantity, Q*, is found by setting the two options equal to each other and solving for Q* (see in figure below). If the quantity Q>Q*, the make option is more desirable. Otherwise, the buy option gives a lower cost.
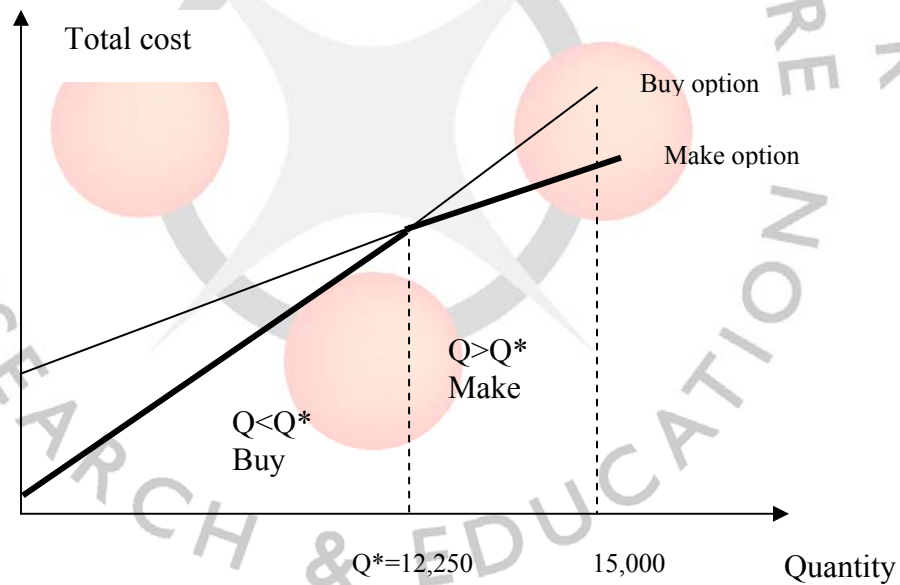

Figure 2.11 Cost curve of a product component

Total cost to make = total cost to buy
$25000+$5Q*   = $500+$7Q*   → Break-even quantity Q* = 12,250 units

Total cost at break even point TC_{BE}=$25000+$5x12250=$86,250

As to the actual demand quantity, we compare the two options below.
Total cost for make option TC_M = $25000+$5x15000=$87250
Total cost for buy option TC_B = $500+$7x15000=$105,500

National Center for Freight and Infrastructure Research and Education (CFIRE)
University of Wisconsin – Madison. Instructor: Bruce X. Wang and Ernie Wittwer.

The conclusion is to make the part in-house.

This example is a highly simplified case. In reality, a firm needs to consider whether the in-house production option is within the firm's core competency. To maintain its market competitiveness, the firm would prefer to develop in areas within its own core competency and to outsource functions in other areas.

Remarks

Procurement and outsourcing are expedited with the development of regionalization and globalization. For example, the North American Trade Agreement significantly enhances the business relationship between Canada, US and Mexico. Many manufacturing functions are outsourced or shifted to border areas with Mexico. Significant cross-border traffic is seen at crossings with Canada that go to the greater Detroit and New York areas. Procurement and outsourcing is largely driven by the complementarities of businesses, resources and technology.

It would not be surprising to see increasing traffic between regions and countries in the years to come. Great pressure will continue to build on the major freight terminals, harbors and ports. Therefore, it is safe to say that procurement is one of the drivers of logistic activities that impact the transportation system. For example, Wal-Mart heavily relies on its global purchasing. A large volume of low cost products are purchased from developing countries, and shipped to its distribution centers through the major West Coast ports and on the major freight (rail and highway) corridors within the continent US.

Literature

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Information Technology in Logistics

Information is valuable in logistics and supply chain management. It enables the supply chain processes to execute transactions and managers to make decisions. Without information, managers would not know what customers want, how much inventory is in stock, and when additional products should be produced and shipped. In short, without information, managers would have to make decisions blindly.

Using IT systems to capture and analyze information can have a significant impact on a firm's performance. For example, a major manufacturer of computer work-stations and servers found that much of the information on customer demand was not being used to set production schedules and inventory levels. The manufacturing group lacked this demand information, which forced them to make inventory and manufacturing decisions blindly. By installing a supply chain software system, the company was able to gather and analyze data to produce recommended stocking levels. Using the IT system enabled the company to cut its inventory in half because managers could now make decisions based on information rather than educated guesses. Large impacts like this underscore the importance of IT as a driver for better supply chain performance.

Information must be *accurate, accessible in a timely manner, and of the right kind* in order to be useful. Accurate information often exists. But by the time it becomes available, it is either inaccessible or out of date. Particularly useful information contains resource availability (e.g. inventory, equipments, space) and system performance data, such as shipping time and reliability.

The following graph shows flows of information and goods in the supply chain.
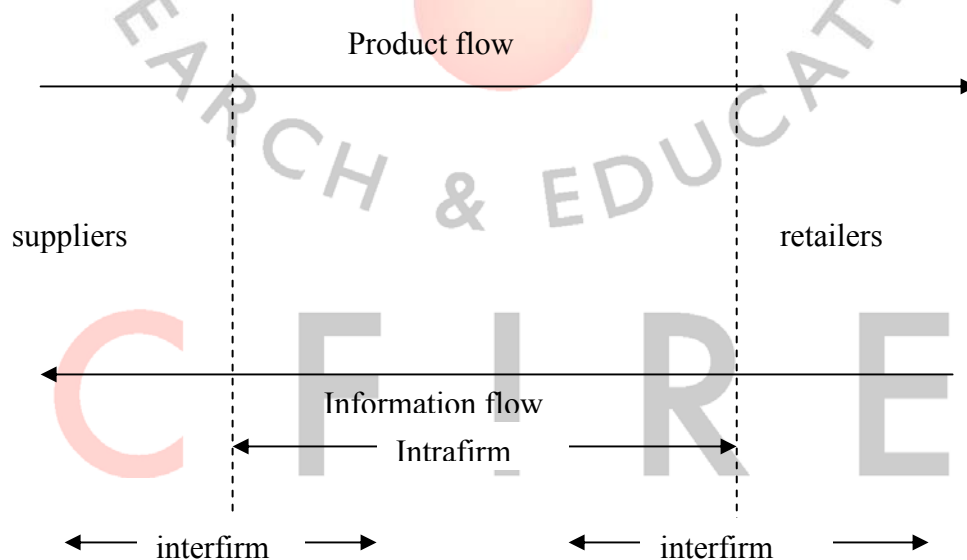

Figure 2.12. Flow of information and goods in the supply chain[3]

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[3] *Source: Simchi-levi et al. 2003.*

Figure 2.12 shows two types of flows along the supply chain: commodity and information. The flow of information is critical to the timing of the commodity flow. The retail information is eventually the deciding factor in making manufacturing, distribution, and marketing decisions. Smooth flow of this retail information all the way to the supplier is critical. Along with demand information, information about system performance such as transit time duration and reliability is also important. Transportation system performance evidently affects the distribution decisions, at both the strategic and tactical levels.

Simchi-levi *et al.* (2003) present an illustrative graph of the relationship between the goals and means of supply chain management.
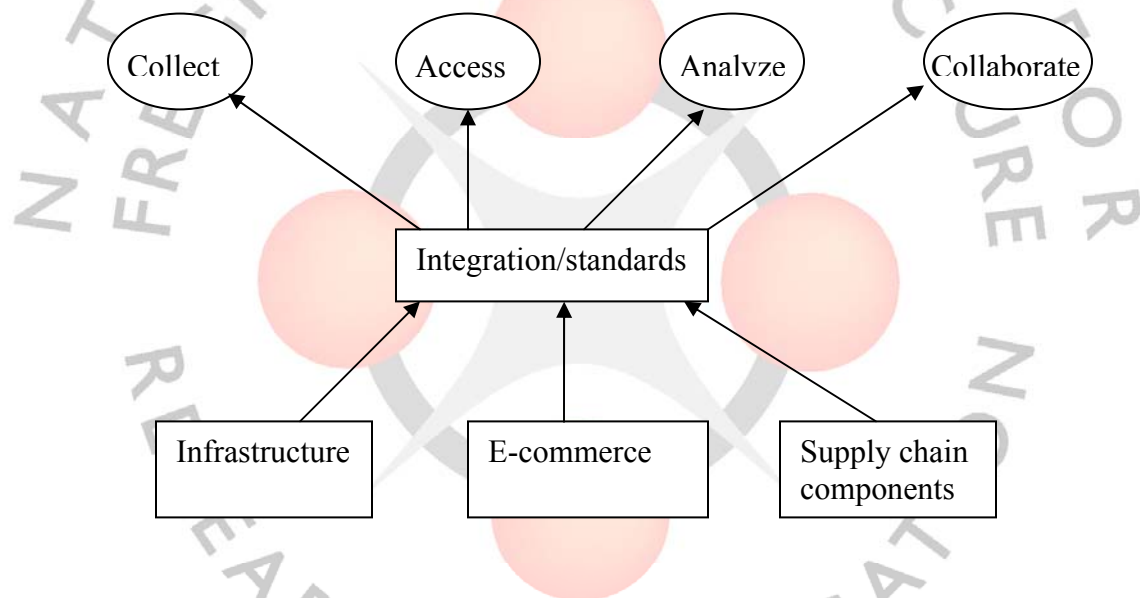

Figure2.13. Goals and means of supply chain management
(*Source: Simchi-Levi, et al. 2003*)

The major means to make an efficient IT system are explained below.
- *Standardization* is critical to cost and feasibility of implementation. There are many issues to be considered in this process such as market forces, interconnectivity, new software models and economies of scale.
- *Information technology infrastructure* is critical in the success or failure of any system implementation. It includes interface devices such as PCs, voice mail, terminals, internet devices, barcode scanners, RFID, etc.; communications (e.g. EDI, LAN, mainframe, intranet, etc.); databases (legacy databases, relational databases, object databases, data warehouses, groupware databases, etc.); systems; architecture; (e.g. client/server computing system) and electronic commerce.

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It might be of interest to provide a more detailed introduction to electronic commerce (e-commerce). E-commerce refers to the replacement of physical processes with electronic ones and the creation of new models for collaboration with customers and suppliers. It facilitates transactions between businesses, and also between businesses and consumers. Worth mentioning for the use of internet is the portal, a role based entry into a company's systems. A portal aggregates all the applications and sources of information employees need in order to perform their jobs into a single desktop environment, typically through the web browser. Portals typically require integration technology such as databases, java classes, web services and XML. E-commerce, according to Simchi-Levi *et al.* (2003) typically has four levels: one way communication, database access, data exchange and process sharing.

IT technology has a profound impact on the logistics and supply chain management. Its capabilities can be classified into four layers.
- Strategic network design
  This layer decides the optimal number of facilities (manufacturing plants, warehouses, distribution centers, etc.), their locations, outsourcing strategies and best distribution channels, etc. These decisions lay the ground for the general cost structure.
- Supply chain master planning
  This layer of decision-making is made on a weekly to monthly schedule in order to coordinate production, distribution strategies, and storage requirements by efficiently allocating supply chain resources to maximize profit or minimize system cost.
- Operational planning
  These systems enable efficiencies in production, distribution, inventory and transportation for short term planning. The planning horizon is typically from daily to weekly. This layer includes typically four factors: demand planning, production scheduling, inventory management, and transportation planning.
- Operational execution
  This system generally provides the data, transaction processing, user access, and infrastructure for running a company. It includes five factors: enterprise resource planning (ERP), customer relationship management, supplier relationship management, supply chain management and transportation management.

The upper layers are mainly about strategic decision making through decision support systems while the lower ones are more about information system management. Most of the information management systems in the layer of *Operational Execution* are the ones most often heard and seen. An ERP system is an example of an IT system that transverses the several layers. The ERP system spans manufacturing, human resources, and financials, and is now the backbone of most companies' IT infrastructure. It includes the most up-to-date information about resources available, demand updates, and short term planning. These systems are expanding to include new functionalities.

The decision support system deserves special attention. Taking advantage of the increasingly powerful computer technology, more and more decisions regarding the complicated system are made with computers using large scale optimization technologies in such areas as the distribution network design, production scheduling, real time demand forecast, warehousing and inventory management, etc. It generally uses operations research techniques, simulation and artificial intelligence methodologies. The decision support system needs basic data input such as shipping time and reliability, freight rate, market demand, fleet capacity, and so on.

Wide application of IT technologies in industry results in a close relationship between manufacturers and vendors. The suppliers and vendors become more responsive to demand changes as information is becoming more transparent across the supply chain. Inventory management becomes more efficient and redundant inventory is eliminated. All of these mean a shorter response time from the manufacturers to market and freight infrastructure changes. The reason is that it is easier to accommodate the changes in its decision processes and to take advantages of these changes with the IT system. To put it differently, the suppliers are held closer to the market in terms of responsive distribution and production.

In the following, we introduce a few IT technologies that have had wide applications in practices.

- **RFID**

Radio Frequency Identification (RFID) is a rapidly emerging identification and logging technology.
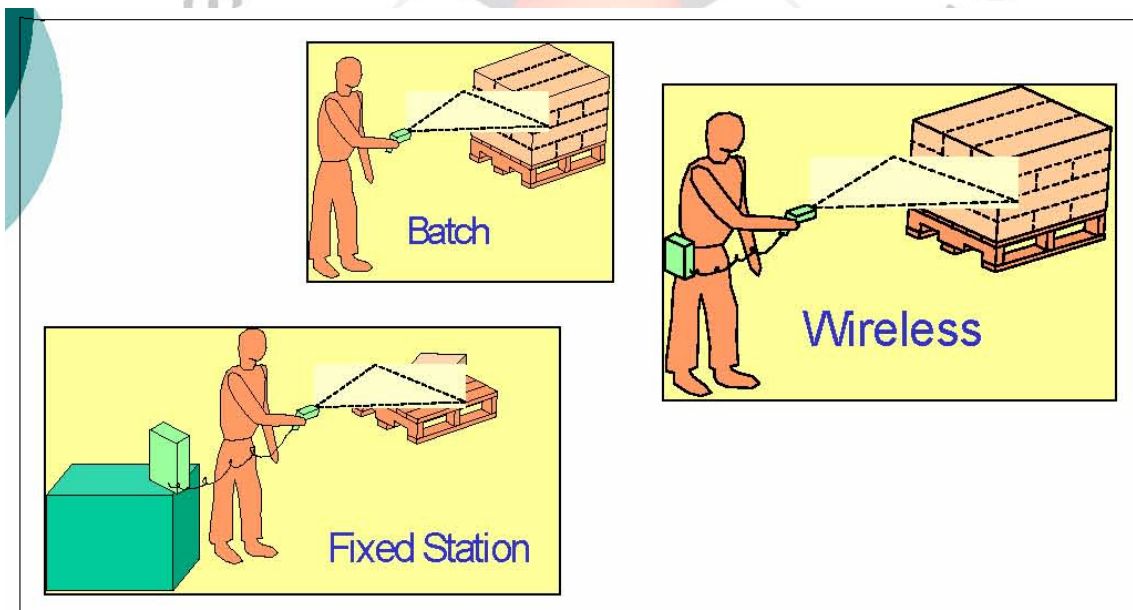

        Figure 2.14. RFID used in warehouse management
(Source: http://events.fcw.com/events/2006/wireless/downloads/WRFID06_T-3_Wyld.pdf.   Accessed on may 20, 2007)
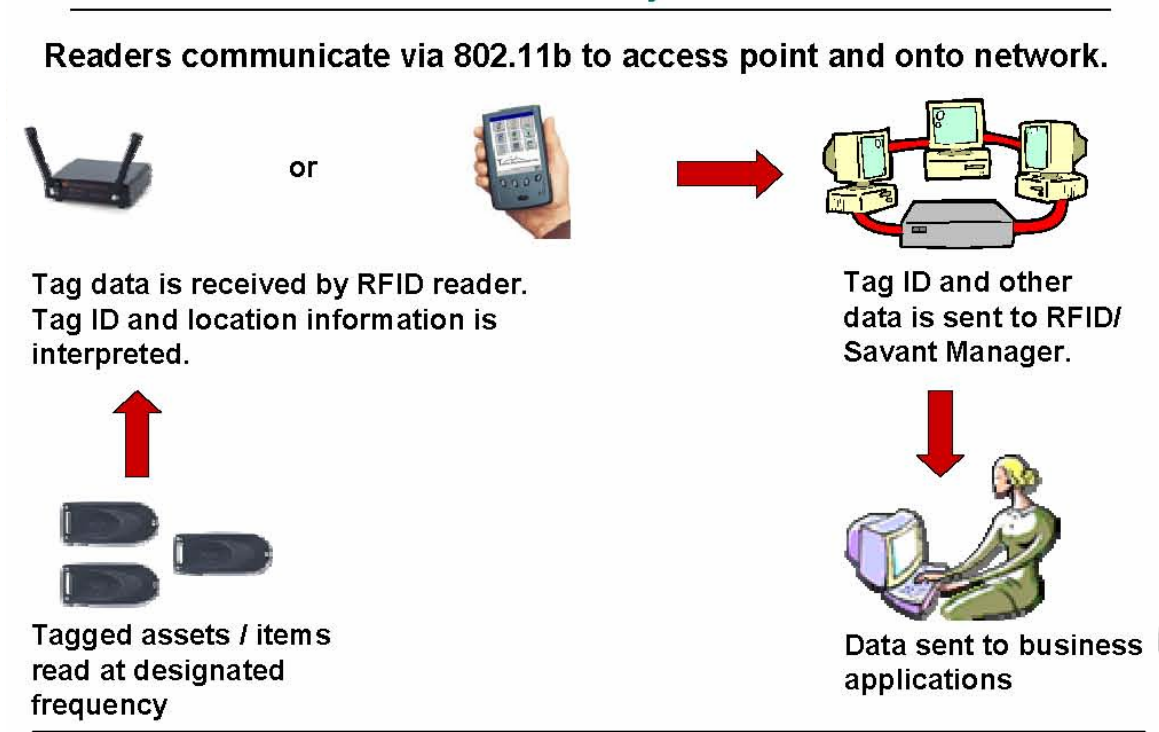
Figure 2.15. Illustrative graph of how RFID is integrated into the system

An RFID tag is used to store the information. RFID tags consist of an integrated circuit (IC) attached to an antenna—typically a small coil of wires—plus some protective packaging (like a plastic card) as determined by the application requirements. These tags are also sometimes are called "transponders". RFID tags can come in many forms and sizes. Some can be as small as a grain of rice. Data is stored in the IC and transmitted through the antenna to a reader. An RFID chip can typically store 2000 bytes of information.

The RFID device serves the same purpose as a bar code or a magnetic strip on the back of a credit card or ATM card; it provides a unique identifier for that object. And, just as a bar code or magnetic strip must be scanned to get the information, the RFID device must be read to retrieve the identifying information. A significant advantage of RFID devices over the others just mentioned is that the RFID device does not need to be positioned precisely relative to the scanner.

RFID has a couple of basic types of tags. Passive tags have no power source of their own, while active tags are self powered, usually by some type of battery. Passive tags generally operate at a maximum distance of 3 meters or less, and have power only when in communication with an RFID reader.

In an RFID system, RFID tags are "interrogated" by an RFID reader. The tag reader generates a radio frequency "interrogation" signal that communicates with the tags. The reader also has a receiver that captures a reply signal from the tags, and decodes that signal. The reply signal from the tags reflects the tag's data content.

RFID provides an excellent means to synchronize freight flow or physical movements of goods with information flow. With RFID applications, planners and managers are able to better visualize the flow of materials and products along the supply chain. The first two most pronounced examples of RFID applications are at Wal-Mart and the US Department of Defense.

- **GPS**

The global positioning system (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. Largely for its affordability and availability, this system has been used in transportation, mainly for tracking movement of commercial vehicles in the private sector for efficient dispatching operations. In the recent years, it's seen in some applications in vehicle telematics in the area of intelligent transportation systems (ITS).

Figure 2.16. GPS technology

The most essential function of a GPS receiver is to pick up the transmissions of at least four satellites and combine the information from those transmissions with information in an electronic almanac, all in order to figure out the receiver's position on Earth.
Once the receiver makes this calculation, it can tell you the latitude, longitude and altitude (or some similar measurement) of its current position. To make the navigation more user-friendly, most receivers plug this raw data into map files stored in memory.

The GPS device not only makes drivers (freight and passengers alike) conscious of where they are, but also is capable of integrating into a GIS system that relates their routing decisions to road conditions (speed limit, distance, congestion, meal/lodge available, gas stations, etc). It also leads to better informed decisions with changing road traffic conditions.

- **EDI**

Electronic Data Interchange (EDI) is a set of standards for structuring information to be electronically exchanged between and within businesses, organizations, government entities and other groups. The standards describe structures that emulate documents, for example purchase orders to automate purchasing. The term EDI is also used to refer to the implementation and operation of systems and processes for creating, transmitting, and receiving EDI documents.

EDI documents generally contain the same information that would normally be found in a paper document used for the same organizational function. For example an EDI 940 ship-from-warehouse order is used by a manufacturer to tell a warehouse to ship product to a retailer. It typically has a ship-to address, bill-to address, a list of product numbers (usually a UPC code) and quantities. It may have other information that the parties agree to include. However, EDI is not confined to just business data related to trade but encompasses all fields such as medicine (e.g., patient records and laboratory results), transport (e.g., container and modal information), engineering, and construction, etc. In some cases, EDI will be used to create a new business information flow (that was not a paper flow before).

EDI enables integration of information systems across the supply chain. It basically helps business partners 'talk' with each other based on a common IT language. There are different standards developed and recommended by different organizations.

EDI is used very intensively in transportation. Some additional information is available at http://www.mima.gov.my/mima/htmls/papers/pdf/apandi/edi-transport.pdf.

Other information management systems for logistics management exist such as the Enterprise Resource Planning (ERP) system, which are skipped here.

Remarks

All these types of devices and systems lay a general information platform on which private firms operate. It is worth mentioning that information technology in general, and decision support systems in particular, have become more and more important in both daily operations and long term planning. Those decision support systems are built upon the rich data available. Nuances in freight shipping cost, traffic congestion, parking availability, regulatory restrictions and other factors can be more and more easily taken into consideration by these intelligent decision support systems with data from RFID, GPS, and other sources. One may conclude that the private sectors are using better and better information about our freight infrastructure and road network to make their business decisions, often in real time.

Network performance and traffic information sharing between the public and private sector will be a niche area where public and private sectors work in a partnership. A potential benefit to the public sector is its increased capability of responding to the changes in the private sector operations in terms of early symptoms of system disruption and shift of freight demand.

Literature

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2. http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=2 (online materials introducing how RFID works. Accessed May 25, 2007)
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Comparison of Private and Public Sector Planning & Implementation

It is important for transportation planners to understand the logistics system planning and operation in the private sector. It is desirable for freight planners to incorporate the potential logistical benefits in their planning projects and operational controls. However, freight planners should be conscientious about the differences between the private and public planning.

Public sector planning provides the infrastructure, laying ground for private sector planning. The infrastructure, once constructed, cannot be removed and usually lasts for a very long time. In turn, the private sector relies on the infrastructure to establish its production and distribution network. After its facilities have been established, they are intended to be used for at least 10 years. After the market has changed, these facilities may have to be converted, sold, or abandoned.

The fundamental differences between public and private sector planning exist in a number of domains. In the private sector, all the cost has to be covered by revenue in order to sustain the production and operation. Timeframe is a critical issue in the private sector. A private firm cannot sustain a lack of profit. Private sector planning is profit driven. Its goal is to make a profit through optimizing the use of its resources and location decisions. Its decisions have to be quick and its operational system has to be responsive to market changes.

In contrast, the public sector planning is for the general public good. For example, corridor congestion relief through the use of ITS and an addition of new capacity or bypasses only takes the government budget, and seldom returns revenue to the government unless it is a toll road.

Contributing to the differences between public sector planning and private sector planning might also be the performance measure. The measure in private sector is straight forward. If an investment decision does not bring in profit, it is considered a failure. In contrast, the public sector evaluates a project impact based on many factors that are usually 'vague' and hard to quantify such as environmental protection, economic growth or traffic improvement. It is almost impossible to find a benchmark to convincingly evaluate a public project.

The following are some materials from the Federal Highway Administration (FHWA) (http://www.fhwa.dot.gov, accessed May 15, 2007) detailing the differences between public and private sectors.

Timeframes

Public project planning and implementation, even for relatively small projects, will take a minimum of 5 to 10 years, depending on the complexity of the project. As a result, the private sector often loses interest in projects that seemingly take "forever" to be built. As one private sector representative commented, *"We know that we have to get engaged with*

the MPOs to get our projects. When I come to the meetings and ask when we can get some help, they tell me to come back in 7 years. That's not good enough. We can't wait that long. That's why we have a hard time getting engaged with government agencies...we have a different time horizon and they have a hard time dealing with that."

For extensive projects involving multiple jurisdictions, environmental evaluations, complex financing, and State/Federal project development oversight, the time horizon may be even lengthier. In addition, States and MPOs use multiyear programming of projects as a means of relating the planning process to project development. Typically, programs will be established 3 to 5 years out, with periodic updates to reprioritize projects as needed. Private sector decision making, in contrast, is accelerated to accommodate the demands of competitive international environments for quick response to market pressures. This means that public sector time frames for freight connector improvements are increasingly lagging private sector requirements for decision-making. [http://ops.fhwa.dot.gov/freight/freight_analysis/nhs_intermod_fr_con/chap_4.htm. accessed on May 15, 2007]

Challenges Placed on Infrastructure

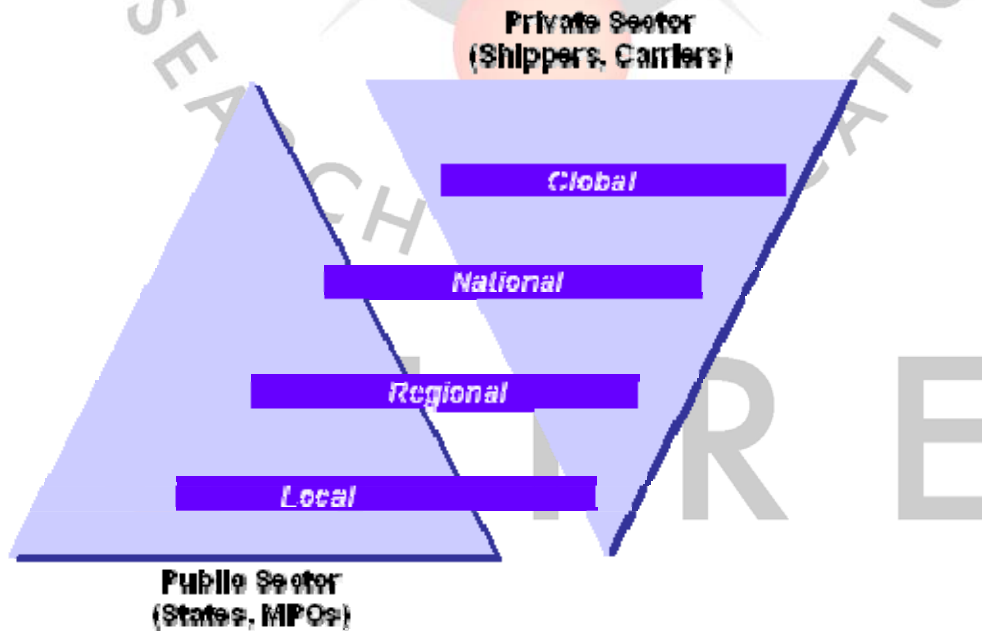(Source: http://www.fhwa.dot.gov/freightplanning/caldwell.htm)
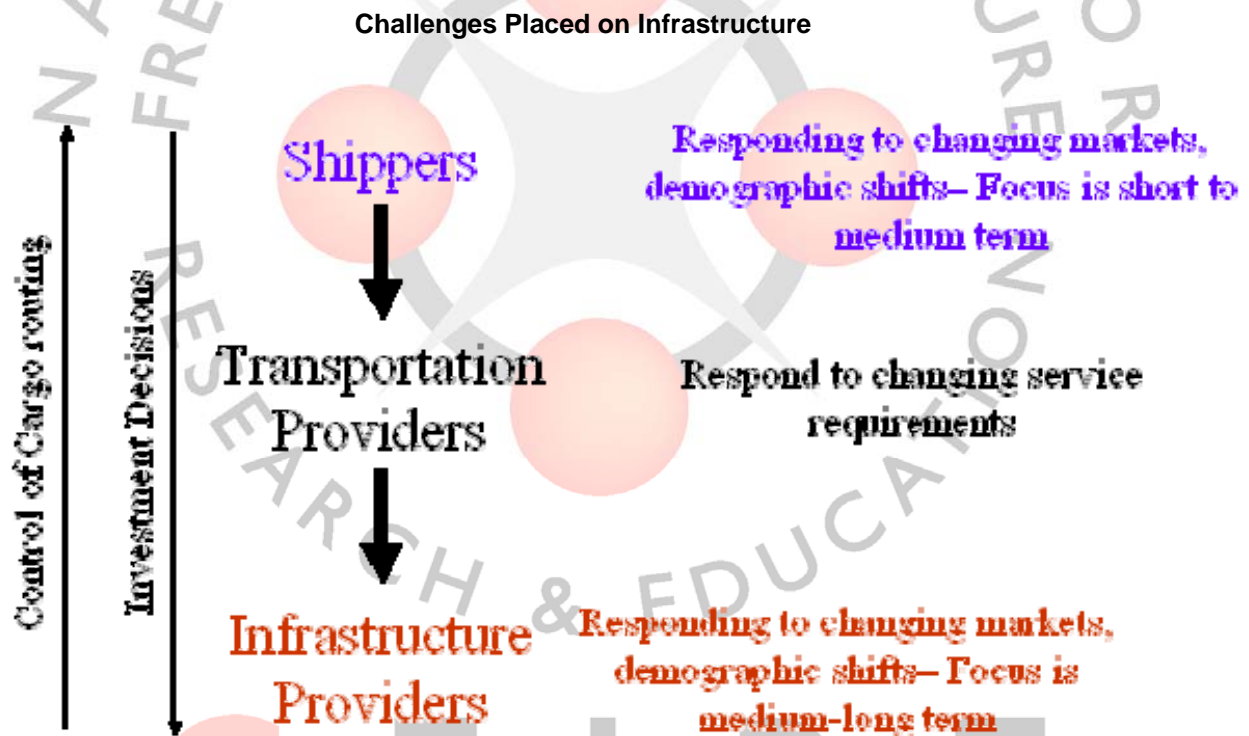
Introducing new projects, especially freight projects, into the pipeline is a political challenge when legitimate transportation needs invariably exceed anticipated revenues. Several states and MPOs are actively involved in freight planning, including the establishment of freight advisory committees, but it is difficult to maintain a high level of visibility over time. Examination of a better means of institutionalizing freight concerns and addressing the conflicts between public and private sector decision making will be

required to address NHS connector and other intermodal freight transportation concerns in a more consistent manner. The designation of the connectors as NHS has increased the awareness of intermodal connectors; however, it is important to ensure that the appropriate public sector agencies and private sector freight stakeholders are involved in planning capital improvements and ensuring efficient operations. Improving awareness of freight and coordination are fundamental to the furtherance of this goal.

Freight projects usually given priority are the high-profile major port, rail terminal, or airport terminal initiatives with the vast majority of connectors unnoticed in the planning process. High profile projects have been funded through the MPOs, states, and High Priority Projects under ISTEA and TEA-21. Approximately 20 percent of all federally funded freight transportation improvements have received funding under the Demonstration or High Priority Project programs (http://ops.fhwa.dot.gov/freight /freight_analysis/nhs_intermod_fr_con/chap_4.htm#note9#note9). These high profile projects (for example: Alameda Corridor in California, Point Mack Terminal in Maine, FAST Corridor in Washington State, New Jersey Portway, Cross Harbor Freight Study in New York City, etc.) have brought to the attention of public officials the potential for economic growth in the area, state, and nation as well as community, air quality, and congestion benefits. In contrast, most NHS intermodal freight connector improvements have not necessarily been understood, well defined, or caught the imagination of the decision makers, and as a result, have not been funded. This was seen in the field review, which showed that a very large share of the reported investments were on only a handful of connector projects.

Freight Transportation Perspectives
State and MPO focus is regional and local; private sector focus is increasingly national and global

(Source: http://www.fhwa.dot.gov/freightplanning/caldwell.htm)

National Center for Freight and Infrastructure Research and Education (CFIRE)
University of Wisconsin – Madison. Instructor: Bruce X. Wang and Ernie Wittwer.

A few additional words about the global nature of private sector planning might be helpful for a better understanding. Large manufacturing firms operate their manufacturing and distributions on a global scale as well as big retail stores such as Wal-Mart. The global network builds upon regional complimentarity in terms of labor, natural resources and transportation infrastructure. In contrast, public sector freight planning often focuses on local scales.   For example, a freight intermodal terminal planning often targets congestion reduction in and around the terminal, or along an interstate corridor for a limited distance.

The differences between public and private sector planning give rise to frictions when it comes time for both to sit together jointly, planning some transportation infrastructure project. It is important that the public freight planners bear in mind the process and characteristics in which the private sector operates. With the use of information technologies and globalization, it is clear that the market follows population, that distribution centers follow market balancing transportation cost, and that if a local or regional freight system does not lead to overall logistical advantages, it be out of the private sector's consideration in designing their logistical network.

Remarks

Public and private sector planning are different, but intimately interact with each other. The public sector planning takes a much longer time than private sectors, but the infrastructure becomes fundamental to private sector planning and operations as well. Due to time horizon differences and differences in planning criteria, it does not appear completely appropriate for the public sector to cater to the private sector interest for short term concerns. Public freight planning should be for long term economic interests including long term private sector interests. However, to be able to foresee the private sector shifts in their respective distribution networks definitely will prove to be of value in public sector freight planning.

On the other hand, the public freight system has its goals to serve the economic interests of the region. With this in mind, freight system planners should be aware that the freight system becomes most efficient when it reduces the overall logistical cost of the private sector, instead of just freight cost and congestion.

Logistics Vocabulary[4]

Service level: the percentage of customers whose orders are fulfilled at the time of demand.

Freight forwarder: an enterprise that provides services to facilitate the transport of shipments. Services can include documentation preparation, space and equipment reservation, warehousing, consolidation, delivery, clearance, banking and insurance services, and agency services. The forwarder may facilitate transport by land, air, ocean, or may specialize in one mode of transport. Also referred to as forwarder.

Freight alongside ship: The point of embarkment chosen by the buyer, from where a carrier transports goods. Under this designation, a seller is obligated to pay the cost and assumes all risks for transporting goods from the place of businesses to the FAS point.

General Agreement on Tariffs and Trade: GATT for short. A multilateral trade agreement aimed at expanding international trade as a means of raising world welfare.

General-commodities carrier: A common motor carrier that has operating authority to transport general commodities, or all commodities not listed as special ones.

Lead time: the time interval from order placing to order arrival.

Load factor: a measure of operating efficiency used by air carriers to determine a plane's utilized capacity percentage or the number of passengers over the total number of seats.

Log book: a daily record of the hours an interstate driver spends driving, off duty, sleeping in the birth, or on duty but not driving.

Lot size: the quantity of goods a company purchases or produces in anticipation of future use or sale.

Line-haul shipment: a shipment that moves between cities and over distances more than 100 to 150 miles in length.

Inventory in-transit: inventory that has been ordered, but has not arrived at the warehouse yet.

Inventory position: current in-stock inventory plus inventory in-order;

(s, S) policy: an inventory management policy in which a replenishment order is placed whenever the inventory position falls below a threshold level *s* to make the inventory position back up to *S*.

Re-order point: a threshold inventory point at which a replenishment order is placed.

Marginal cost: the cost of producing one additional unit of product.

Order cycle: The time from an order is received to its actual delivery. Another definition from the order fulfiller's perspective is the time from order received to order assembled.

Order Processing: The activities associated with filling customer orders.

Order Cost: The cost of placing an inventory order with a supplier.

Outsource: Getting a third party to provide a function that was historically performed in house.

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[4] Many of the terms are based on *Speaking the Language of Freight and Logistics* by Wilbur Smith Associates published in 2007.

Pallet: A platform device used for moving and storing goods. A forklift truck is used to lift and move the loaded pallet. It is an efficient means to handle goods movement.

Safety stock: stock that is constantly carried to prevent from stockout due to unexpected spike of demand.

Economic lot size model: Also called EOQ model as introduced in the text. It decides the order quantity for inventory replenishment.

Continuous review policy: An inventory management policy which assumes a capability of continuous review of inventory position.

Peak demand: The demand during a time period in which customers demand the greatest quantity.

Periodic review policy: In contrast to the continuous review policy, this policy assumes that inventory position is reviewed periodically.

Per diem: A payment rate one railroad makes to use another's car.

Physical distribution: The movement and storage of finished goods from manufacturing plants to warehouses to customers; used synonymously with business logistics.

Picking by aisle: A method by which pickers all needed items in an aisle regardless of the items ultimate destination; the items must be sorted later.

Picking by source: A method in which pickers successively pick all items going to a particular destination regardless of the aisle in which each item is located.

Piggyback: A rail truck service. A shipper loads a highway trailer, and a carrier drives it to a rail terminal and loads it on a rail flatcar; the railroad moves the trailer-on-flatcar combination to the destination terminal, where the carrier offloads the trailer and delivers it to the consignee.

Port of entry: A port at which foreign goods are admitted into the receiving country.

Port of discharge: Port where vessel is off loaded.

For hire carrier: A carrier that provides transportation services to the public on a fee basis. It is subject to government regulation regarding service provision.

Private warehousing: The storage of goods in a warehouse owned by the company that has title to the goods.

Public warehousing: The storage of goods by a firm that offers storage service for a fee to the public.

Rail waybill: The bill of lading issued by rail carriers to their customers.

Replenishment: The process of re-stocking inventory, especially at a store level as in "rapid replenishment" programs.

Reverse logistics: The process of collecting, moving, storing used, damaged, outdated, or returned products and packaging from end users. It moves in the opposite direction to the initial distribution process.

RO/RO: Roll-on/Roll-off. A type of cargo designed to permit cargo to be driven on at origin and off at destination; used extensively for the movement of automobiles.

Route: Path of a complete movement of a shipment from its origin to its destination by a carrier.

Shipment: A shipment is a user defined unit containing goods (single or multiple units) and requires transportation from one location to another. A shipment becomes a shipment when it leaves the consignor's location, and is complete when it arrives at the consignee's destination.

Stock keeping unit: also called SKU. The unit in which a product is kept in stock.

Spur track: a railroad track that connects a company's plant or warehouse with a railroad track; the user bears the cost of the spur track and its maintenance.

Stockout: A situation in which the items that a customer orders are currently unavailable.

Tandem: A truck or trailer that has two axles.

Tare weight: The weight of a vehicle when it is completely empty.

F.O.B origin: A special terms of sales. The seller agrees to deliver the goods to the point of origin. The buyer assumes all responsibility and risk thereafter. FOB refers to free on board.

F.O.B destination: The seller agrees to deliver the goods to the destination point after which the buyer assumes all responsibility.

Total cost analysis: A decision making approach that considers total system cost minimization and recognizes the interrelationship among system variables such as transportation, warehousing, inventory, and customer service.

TEU: twenty foot equivalent unit. The basic size used to measure container traffic volume.

Traffic Management: Buying and controlling of transportation services for a shipper or consignee, or both.

Transit privilege: A carrier service that permits the shipper to stop the shipment in transit to perform a function that changes the commodity's physical characteristics, but to still pay the through rate. It was a railroad practice before, and is rarely used now.

Transportation Research Board: A division of the National Academy of Sciences which pertains to transportation research.

Transportation Research Forum: A professional association that provides forum for the discussion of transportation ideas and research techniques.

Transshipment: The shipment of merchandise to a single point of destination on more than one vessel or vehicle. The liability may be passed from one carrier to another, or it may be covered by Through Bills of Lading issued by the first carrier.

Unit train: A train that repeatedly runs between the same pair of origin and destination without car switching or locomotive changes.

Value-of-service pricing: Pricing according to the value of the product that the company is transporting; third degree price discrimination; demand oriented pricing; charging what the traffic will bear.

Variable cost: a cost that fluctuates with the volume of business.

Vendor: A firm or individual that supplies goods or services; the seller.

Wharfage: A charge assessed by a pier or dock owner against the cargo or a steamship company for use of the pier or dock for the handling of incoming or outgoing cargo.