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Distribution Network Design and Customer Service

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Abstract

In distribution network design, it is implicit that transportation costs, travel distances, and transit times are tightly correlated. Therefore, one can argue that models directing at minimizing travel distances not only minimizes transportation costs, but also minimizes transit times. The *center of gravity*, and its various extensions, is an example of such a model. Quantitative analyses such as mathematical programming and stochastic models, the transportation costs are often the only factors of interest.

A universal metric for customer service is the customer's lead time – the time it takes to get the right quantity of the right product to the right place. If the right quantity of the right product is available, then the lead-time is the time it takes to take the goods to the right place. For example, when inventory is available, the time to get the product from the warehouse to the customer consists of the time to process the order plus the time it takes to transport it to the customer. These times do not vary much. Moreover, customers generally are aware of and accustomed to them.

If the required quantity of a product is not available, the lead-time is based on two components - inventory availability and product acquisition time. Product acquisition time is the time to get the product back in stock. This is the time to process and ship the product from some other location such as another warehouse, a manufacturing plant or a supplier.

In this paper, we examine the impact of distribution network design on customer's lead time. We conclude that the number of shipping locations may have some effect on customer's lead time. However, the effect of outbound transportation on lead-time can be small relative to product acquisition time. Acquisition time is the time to get the product back in stock. Production-inventory management determines this component of the lead-time, not distribution management.

1. Introduction

It is said that about every five years, large business organizations undertake a distribution network design project to determine if their facilities are properly positioned and located. Changes to the distribution system, e.g., opening/closing warehouses/plants involve major capital expenditure. Invariably, the analyses center on the cost of doing business, rather than how distribution network design affects customer service.

1.1 Decision Variables

Distribution system design is a complex combinatorial problem. The complexity arises from the fact that there are so many interdependent decision variables.

Oftentimes, one or more decision variables set the constraints for other decision variable. For example, plant production capacities warehouse capacities are constraints that must be satisfied in deciding on which shipping location should service which customers, or how each plant's output should be allocated among distribution points for each product. The decision variables include:

1.11 Distribution facility planning.

Distribution facilities include depots, warehouses, consolidation centers, logistic platforms, and distribution centers. Design issues include location (distance between a distribution center and a market area served by it), handling capacities (throughput at each distribution center), storage capacities, processing and storage costs, and utilization costs.

1.12 Production facility planning.

Production facilities are the plants for fabrication, transformation, and assembly. Deciding what and how much to produce at each plant depends on location, production and storage capacities, costs (production and storage costs), and utilization level.

1.13 Sourcing strategy.

In distribution system design, selecting the supplier(s) for each purchased item usually depends on location, price, quality, and availability.

1.14 Distribution channels design –

Which shipping location should service which customers? How should each plant's output be allocated among distribution points for each product?

1.15 Selection of Transportation modes, routes and rates.

For long-haul movements, business organizations usually outsource the transportation of goods to a third party logistics provider. However, many businesses opt to maintain its own fleet for local pickup and delivery. Decisions on mode of transportation (by air, land, or sea), capacity (e.g., how many trucks in the fleet), route, shipment quantities and frequencies (e.g., to split or not to split shipments), schedule, etc., have impact on cost, availability, service quality and reliability (delivery time, variability/punctuality, reputation, etc.).

1.16 Production-Inventory decisions

Major decisions in distribution system design include what and how much to produce at each plant; which inventory control system to implement, etc.

The complexity increases with the number of decision variables.

1.2 Objectives

The goal of supply chain management is to fulfill customers' need for the 4 R's – to get the right quality of product in the right quantity at the right time to the right place. In distribution system design, deciding how best to fulfill the customers' need for the 4 R's depend on location, forecasted demand of each customer for each product, delivery time windows and frequencies, etc.

What is the '*best'* way to fulfill the customers' need for the 4 R's? To know what is '*best,'* one must first understand the objectives of distribution network design, from the vantage point of the business organization making the decision.

First, we must assume that we know what the 4 R's are, i.e., we know what quantities of which product our customers need, and we know when and where our customers want them. (Of course, we can not simply assume that we know what the 4 R's are. But this is beyond the scope of this paper.) Then, design objectives can be summed up by two words: *service* and *cost*.

What is customer service? A universal metric for customer service is the customer's lead time – the time it takes to get the right quantity of the right product to the right place. A way to operationalize this conceptual measure of customer service is to look at what constitutes customer's lead time.

2. The Cost Objective

Decisions on distribution system design are customarily based on forecasted demand (for each product at each customer zone), dimensions and weights of the goods flowing through the network, handling requirements (Fragile and/or perishable versus durable and/or robust), packaging, and costs (production, inventory, etc.).

In modeling, it is implicit that transportation costs, travel distances, and transit times are tightly correlated. Therefore, one can argue that models directing at minimizing travel distances not only minimizes transportation costs, but also minimizes transit times. The *center of gravity*, and its various extensions, is an example of such a model. Quantitative analyses such as mathematical programming and stochastic models, the transportation costs are often the only location factor of interest.

Network design affects the cost of doing business, and the flow of goods and services. The faster the flow of goods and service in one direction, the lower the inventory, and the quicker funds ($$$) flow back in the reverse direction.

Decisions are either demand-pulled, supply-pushed, or more frequently, both demand-pulled and supply pushed. By demand-pulled, we mean market-related factors such as the profile of customers, the profile of the competition, the need for room for expansion, etc.

Supply-pushed location factors are based on the cost of doing business. The cost of doing business includes the cost of acquiring and operating plants, distribution centers, warehouses, transportation facilities, communications equipment, data processing means, etc. Inbound and outbound transportation costs depend on the number, and the location of various components of the distribution network.

Figure 1, based on an illustration in [3] shows the relationship between various cost categories and the number of shipping location.

Inbound transportation cost increases with the number of shipping locations because there are more locations to receive shipments from the suppliers.

Outbound transportation cost, however, decreases with the number of shipping locations because with more shipping locations to serve the customers, each shipping location serves its nearest customers.

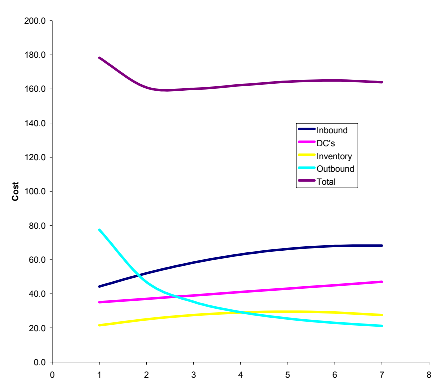

Figure 1. Cost vs. Number of Shipping Locations

More shipping locations means more inventory because each location has to maintain an adequate level of inventory. The operating cost (labeled DC's) also increases with the number of shipping locations.

Let:
N = number of shipping locations.
$C_{Inbound}$ = Inbound transportation cost
$= a_1 + b_{11} N + b_{12} N^2$
C_{DC} = Distribution-center operating cost
$= a_2 + b_{21} N + b_{22} N^2$
$C_{Inventory}$ = Inventory-holding cost
$= a_3 + b_{31} N + b_{32} N^2$
$C_{Outbound}$ = Outbound transportation cost
$= a_4 + b_{41} /N + b_{42} /N^2$

Let $\alpha = a_1 + a_2 + a_3 + a_4$, $\beta_1 = b_{11} + b_{21} + b_{31}$, $\beta_2 = b_{12} + b_{22} + b_{32}$, $\beta_3 = b_{41}$, $\beta_4 = b_{42}$, then the total cost =

$$C = \alpha + \beta_1 N + \beta_2 N^2 + \beta_3 /N + \beta_4 /N^2 \quad (1)$$

For example,

$a_1 = 35.00$	$a_2 = 33.00$	$a_3 = 17.00$	$a_4 = 10.00$
$b_{11} = 10.00$	$b_{21} = 2.00$	$b_{31} = 5.00$	$B_{41} = 80.00$
$b_{12} =-0.75$	$B_{22} =0.00$	$B_{32} =-0.50$	$B_{42} =-12.50$

Then
$\alpha = 95.00$

$\beta_1 = 17.00$	$\beta_3 = 80.00$
$\beta_2 = -1.25$	$\beta_4 = -12.50$

Solving the unconstrained integer programming problem in (1) yields the optimal solution of N = 3.

3. The Time Objective

The customer's lead time is a source of competitive advantage, and is a constraint that must be satisfied. This constraint may be stated in terms of "service level." In inventory theory, the "service level' is probability (likelihood) of meeting a customer's required lead time. For example, a "service level" of 99% means that 99% of the time, the right quality of product in the right quantity is delivered to the right place at the right time.

3.1 If item is available in inventory

If the right quantity of the right product is available, then the lead-time is the time it takes to take the goods to the right place. Outbound transportation lead time decreases with the number of shipping locations because with more shipping locations to serve the customers, each shipping location serves its nearest customers.

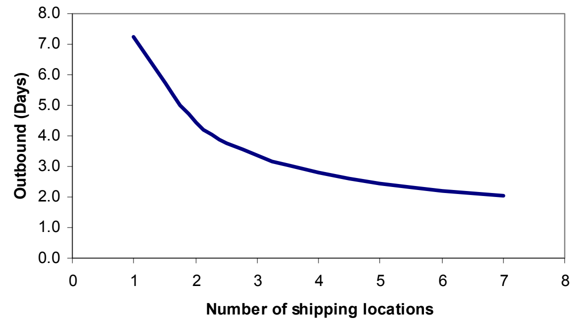

Figure 2. Outbound Lead-Time vs. No. of Shipping Locations

When inventory is available, the time to get the product from the warehouse to the customer is almost always fixed. It consists of the time to process the order plus the time it takes to transport it to the customer.

Figure 2 shows the relationship between outbound lead-time and the number of shipping location. With one shipping location, the lead-time is about 1 week. With two shipping locations, the lead-times drops to approximately 4.5 days, and with three shipping locations, the lead-times drops to about 3.5 days, etc. With 5 or more shipping locations, the lead-time is about 2 days.

Evidently, when inventory is available, lead-times normally do not vary much. More importantly, customers generally are aware of and accustomed to them.

3.2 If item is not available

Now, if the required quantity of a product is not available, then the lead-time is based on two components: inventory availability and product acquisition time. Indeed, the acquisition time is only relevant when the inventory is unavailable.

Acquisition time is the time to get the product back in stock. This is the time to process and ship the product from some other location such as another warehouse, a manufacturing plant or a supplier.

Suppose a warehouse processes all the orders for which it has inventory in t_1 days and the outbound transportation lead-time $t_2 = a + b_1/N + b_2/N^2$, where N is the number of shipping locations. If inventory is available, the customer's lead time = $t_1 + t_2$ days.

Let p = probability that the item is available. If the item is not available from inventory, the average time to acquire out-of-stock product is t_3 days.

The expected customer's lead time = $t_1 + t_2$ days + $(1-p)* t_3 = (t_1 + t_2 + t_3) - pt_3$ days. For example, suppose $t_1 =1$, $t_2 = 1.0 + 7.5/N - 1.25/N^2$, and $t_3 =10$. Figures 3a and 3b show the lead-time as a function of N and p.

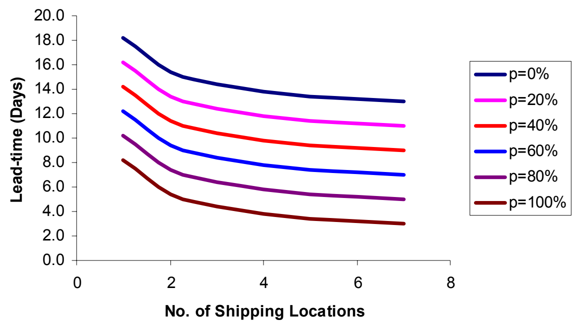

Figure 3a. Lead-time as a function of N

What determines the customer's lead-time? The customer's lead-time depends on the transit time (t_2, is about 3.5 days for N=3, the minimum cost solution found in Section 2.), the order processing time (one day), the probability that inventory is available, and the acquisition time (10 days).

Notice that in Figure 3b, the lead-time curve is a steep linear function of p. On the other hand, beyond N=3 (in our example), the lead-time curve shown in Figure 3a is rather flat with respect to the number of shipping locations N.

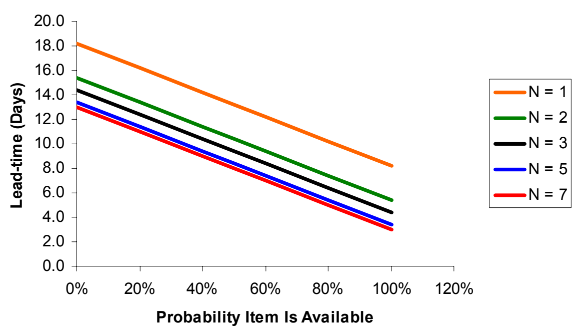

Figure 3b. Lead-time as a function of p

4. Number of shipping locations

Now, which of the components of lead-time is dependent on the number of shipping locations? Clearly, the number of shipping locations impacts only one of these elements: the outbound transit time to the customer. This transit time generally depends on the distance from the warehouse to the customer. In most supply chains the average distance decreases as shipping locations are added to the network.

Suppose the product is available 90% of the time. For N=3 (the minimum cost solution in Section 2.), t_2 is about 3.5 days. The expected customer's lead time = (1 + 3.5 + 10) -90%*10 = 5½ days. Outbound transportation impacts 3.5 days of the customer lead time. That's 65% of the total!

Think about the capability of the network to decrease transit times by adding more shipping locations. However, as seen in Figure 3a, the lead-time curve is rather flat with respect to the number of shipping locations N. In a 3-shipping location network, for example, the transit time is reduced by about half a day by adding a 4th shipping location. Adding a 5^{th} shipping location further reduces the transit time by about 1/3 of a day, etc.

Figure 3b tells us a very different story. At N=3, and p = 90%, we see that the total lead time is about 5½ days. The linear curves in Figure 3b tell us that every 10% drop in probability that the item is available, will add a day to the customers' expected lead-time. For example, if p drops to 80%, the expected lead-time is about 6½ days, if p = 70%, the expected lead-time is about 7½ days, etc.

Figures 3a and 3b assume that, when the item is not available from inventory, the average time to acquire out-of-stock product is 10 days. If the item has to be sourced from abroad, the acquisition time may take 3 weeks. This case is illustrated in Figures 4a and 4b below:

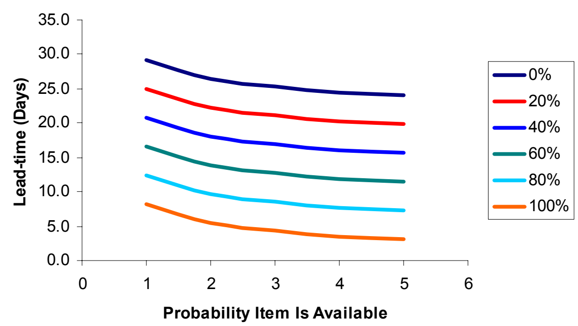

Figure 4a. Lead-time as a function of N (t_3 =21)

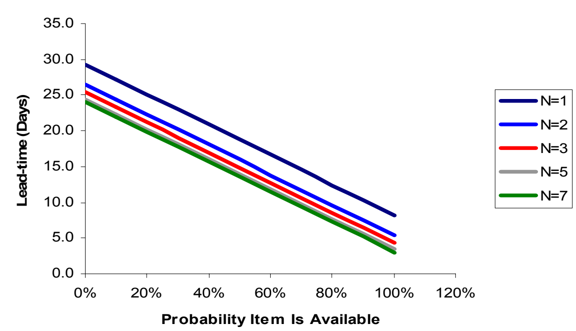

Figure 4b. Lead-time as a function of p (t_3 =21)

Figure 4a shows the lead-time to be flat, with respect to the no. of shipping locations. Facility location may have some effect on customer's lead time. However, the effect of outbound transportation on lead-time can be small relative to product acquisition time (see Figure 4a). Acquisition time is the time to get the product back in stock. Production-inventory management determines this component of the lead-time, not distribution management.

The goal of supply chain management is to fulfill customers' need for the 4 R's – to get the right quality of product in the right quantity at the right time to the right place. The next section presents some real world examples illustrating the consequences of (a) not having the right quantity, (b) not having the right product, and (c) not knowing where the right quantities of the right products are. In each case, the failure was nothing short of spectacular.

5. Product, Quantity, Time, Place

5.1 Not having the right quantity

During the Internet boom of the late 1990's, networking gear (routers, switches) was hard to get. Desperate customers resorted to placing duplicate orders with multiple equipment vendors.

Each vendor, like Cisco, forecast robust growth and, to "lock in supplies", solicited long-term bids from multiple contract manufacturers. Each contract manufacturer wanted to lock in *its* supplies and started negotiation for long-term deliveries from chipmakers.

For the few chipmakers in the world, it all added up to an extraordinary surge in demand for their products. They promptly raised their prices or rationed their output, which frightened buyers so much they decided to hedge by placing still more orders, which re-enforced the vicious cycle.

However, customers intended to acquire only a fraction of this stupendous production – from whoever delivers first among their many orders. The whole pyramid, bloated with phantom demand, eventually imploded – the bubble burst. In 2001, Cisco was forced to write down $2.2 billion worth of obsolete inventory, victim of a pernicious pathology in its supply chain [4].

5.2 Not having the right product

Nike went live in June 2000, with its much-ballyhooed demand forecasting application, acquired from i2 for $400 million.

Nine months later, the inaccurate forecasts produced by the new systems had led Nike to write-off $90 million in inventory of unsellable shoes, on top of an estimate of $100 million in lost sales, due to shortage of sneakers in high demand [5].

5.3 Not knowing where the right quantities of the right products are

In August, 1999, Hershey announced that its IT teams had just completed its R/3 implementation — a $112 million project which includes ERP from SAP, CRM from Siebel, and supply chain software from Manugistics.

A month later, Kenneth L. Wolfe, then CEO and Chairman of Hershey Foods, told Wall Street analysts that the company was having problems with their new SAP implementation, and that the problems were going to keep Hershey from delivering $100 million worth of Kisses and Jolly Ranchers for Halloween that year [2].

That year, order management and fulfillment processes broke down, causing the company to fail to meet many retailers' orders. The immediate impact was about $150 million in lost sales for the year. Hershey's stock price fell more than 8 percent on that day.

Who is to blame for Hershey's dilemma in 1999? The new ERP system did not know where the right quantities of the right products are. According to Carr [1], Hershey had informal mechanisms for dealing with the tremendous buildup of inventory to prepare for the holiday rush. Hershey had rented warehouse space on a temporary basis, and spare rooms within factory buildings to store inventory. Unfortunately, these locations hadn't been recorded as storage points in the SAP data model!

Before SAP fulfills a customer order, it first checks its records of available inventory, and in this case a significant amount of inventory was not where the official records said it was [1].

In short, Hershey might have the right product, at the right quantity, at the right place. Unfortunately, their new ERP system did not where the inventory was, and $100 million worth of candies were not delivered to right place in time for the Halloween and Christmas holidays.

6. Summary

A universal metric for customer service is the customer's lead time – the time it takes to get the right quantity of the right product to the right place.

In this paper, we examine the impact of distribution network design on customer's lead time. We conclude that the number of shipping locations may have some effect on customer's lead time. However, the effect of outbound transportation on lead-time can be small relative to product acquisition time. Moreover, customers generally are aware of and accustomed to outbound lead-times.

Acquisition time is the time to get the product back in stock. Production-inventory management determines this component of the lead-time, not distribution management.

Thus, the objective of facility planning should be focused on minimizing cost, i.e., find a minimal-annual-cost configuration of the distribution network that satisfies product demands at specified customer service levels.

References

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