Important Quantitative Supply Chain Decisions

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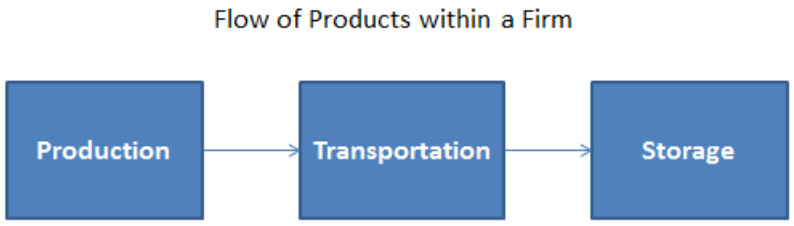
Important Logistics Decisions

Supply chain management involves the flow of products, information and money from suppliers (and their suppliers) through a company to its customers (and their customers) with the purpose of serving customers and maximizing profit. Logistics is the subset of supply chain management concerned with the production, transportation and storage of products. I titled this article "Important Quantitative Supply Chain Decisions" because logistics decisions are often the quantitative decisions a firm must make about their supply chain. Qualitative decisions fill in the remainder of the definition of supply chain management and will be covered in another white-paper.

If we consider the supply chain of a single firm, the logistics decisions become clearer. Logisticians make decisions that relate to production, transportation and storage of inventory. These decisions consider, and balance, cost, risk and customer service. We will evaluate these decisions and provide guidelines for ensuring your decisions lead to the optimal balance of profit and customer service.



Production Logistics Decisions

- Location and number of facilities
  - Cost versus Customer Service
  - Economies of scale
- Product design

Location and number of facilities

One of the decisions a firm has to make when producing is where to locate the manufacturing facility and how many sites will be producing these goods. These decisions will take into account:

- Distance from suppliers
- Distance to customers
- Labor costs and quality of the workforce
- Utility costs
- Infrastructure

- Risks
- Economies of scale

Distance to suppliers

If your raw materials are very inexpensive to produce, bulky and expensive to ship, and your product is higher value and less expensive to ship it may be optimal to locate your production facility near the location of the raw materials. An example of this is helium production. Helium deposits occur naturally, like minerals. The "mining" produces impure product. Helium producers have their purification plants near the mining operations. The output of these production facilities is pure, condensed (via high pressure or liquefaction) helium which has a high value-to-volume ratio.

On the other extreme are supply chains with raw materials that are inexpensive to ship and/or readily available. Anheuser-Busch realized this in the mid-20th century and placed breweries close to regional population centers. Water is readily available, and beer (which is mostly water) is expensive to ship in bottles or even kegs. Therefore why not place breweries close to your customers.

Distance to customers

Placing your production facility near customers may be required because of expected fast turnaround on orders. Suppliers to just-in-time automotive plants meet this definition. Alternatively, the value of your product may be very low relative to the shipping costs. Producers of, for example, foam or plastic bottles can fill up tractor-trailers with very lightweight products, creating a high cost per pound shipping scenario.

Labor costs and quality of the workforce

Inexpensive labor and highly educated workforces are often opposite choices when firms consider their labor force. Usually high labor content products benefit more from low labor costs. On the other hand, highly automated production processes require highly educated employees to operate, maintain and troubleshoot equipment. As automation has become more accessible, production facilities are being located where there is access to highly educated (and expensive) labor.

Utility costs

Utility costs, such as electricity, access to natural gas and even waste processing may be more important than labor or raw materials. Certain production processes, such as aluminum production, have a high power requirement. Data farms would also fall into this category. The main raw material for plastic is natural gas. However, it is not just these companies that would consider utility costs. Highly automated facilities will always have higher electricity usage than high labor-content production processes. Therefore, you will often see highly automated facilities locate in countries with low

utility costs and educated workforces. The renaissance of American manufacturing is a combination of these two factors.

Infrastructure

Related to utility costs is infrastructure. Infrastructure includes access to reliable electricity, ports, roads or rail and telecommunications. Depending on the other costs discussed above, it may be advantageous to place your facility in a higher cost region because it has reliable infrastructure. Currently India is at a significant disadvantage to China because of infrastructure.

Risks

One of the most important topics in supply chain management is risk. All of the other costs and benefits discussed above can be nullified by potential risk. This risk is usually political in nature. It may be that the best host country is a dictatorship that does not have reliable rule-of-law. There may be political unrest, such as is occurring in Egypt and other middle-eastern countries. Firms can use probabilities, and replacement or customer service costs, to quantify risk.

Another consideration is the potential for natural disaster. Coastal regions, with easy access to sea transport, are also prone to weather events that seem to be increasing in frequency and severity.

Economies of scale

Economies-of-scale is often a tradeoff with customer service. Larger production facilities will (almost) always enjoy a cost advantage over smaller facilities. There are economies of scale in construction and management. The costs of building and managing facilities are not proportional to output. Certain construction, utility and management costs are somewhat fixed, or do not increase linearly with output. Therefore there is a reason to build single, larger production facilities, versus smaller facilities located closer to customers.

Product design

In addition to location, an important logistical decision is production strategy. The way a company decides how to manufacture their products has important implications for location, transportation and inventory storage. The production strategy is largely realized at the product design and development stage. Possible strategies include:

- Highly standardized products
- Mass customization
- Postponement
- Push/pull

- Mix model production
- Job shop

Highly standardized products

One option for production is to manufacture high volumes of very few designs. Henry Ford popularized this idea with the Model T, but it has recently been copied by Apple. Only in 2013 did Apple give consumers the choice of colors for their IPhone. In a move that harkens back to Henry Ford, you could have an Iphone in any color, as long as that color was black!

Highly standardized products simplify inventory decisions in the supply chain and create economies of scale in purchasing and production.

Mass customization

Mass customization was popularized in the 1990's when information technology tools allowed companies to configure their products into numerous choices, but base these customized products on standardized modules. This method allows what many would consider the "best of both worlds" by taking advantage of standardization, but giving customers want they want.

Postponement

The strategy of postponement is related to mass customization but is simpler, and is often implemented in distribution centers. HP first made postponement popular by standardizing much of their printer. These standardized printers were shipped to distribution centers around the world, but not in consumer packaging. The distribution center added power supplies, and then final-packaged the product, based on the destination country. This final customization is done as late as possible… in other words, it is postponed. It is easy to see that this strategy reduced inventory by reducing stock-keeping-units (SKUs) and reduced shipping costs by eliminating bulky consumer-packaging.

Push/pull

Another inventory strategy, similar to mass customization and postponement is managing the push/pull boundary. Push items are inventory materials and components with long lead times and large minimum order quantities. These items would have to be purchased using some type of forecasting process. This is best done using material requirements planning (MRP) software systems. The manufacturer would use these components and materials to build sub-assemblies that could be assembled-to-order. The sub-assemblies would reside in a kanban system, which would be replenished based on actual demand (the pull system). This push/pull strategy allows companies to buy materials at the best cost, minimize work-in-process (WIP) and finished goods inventory, while having quick-turnaround times for customers.

Mixed-model

Mixed model production allows a company to make a variety of different products on one production line. This method was first popularized by Toyota. As the legend goes, Taiichi Ohno, VP of production for Toyota, saw the assembly line used by Ford but didn't have enough demand of any individual vehicle to dedicate one assembly line to one model. His assembly lines produced every type of Toyota vehicle. This method takes advantage of assembly line efficiency, but more importantly it creates a flexible production process that can react to changing customer tastes.

Job Shop

Job shops are often associated with smaller manufacturers who need the ultimate flexibility to manufacture many different products for many different customers. These facilities are often close to customers and inventory is purchased only when orders are received. Lead-times and labor productivity suffer to accommodate flexibility of the product line offering and minimizing inventory investment.

Transportation Logistics Decisions

- Routing vehicles
- Transportation mode
    - Economies-of-scale versus Speed and Flexibility

Transportation costs are the majority of all supply chain costs. This is why facility location is such an important factor. However, once a facility location decision is made, logisticians still seek to minimize costs by minimizing distance travelled and time on the road.

Routing Vehicles

Vehicle routing can often be simplified by considering two problems. The first minimizes the distance, time or cost to serve a single customer when there are multiple possible routes. The second, and much more difficult problem, is how to route a delivery truck that will have multiple stops. This problem has been called the "travelling sales rep" or TSR problem. (Note, its' original name was the travelling salesman problem, or TSM, but I think it is time to modernize this acronym.)

The travelling sales rep problem seeks to minimize the time, distance or cost to visit multiple customers in a territory. Additional considerations, when delivering products (versus a sales rep) are 1) capacity of the vehicle, 2) time windows at customers and 3) whether the truck is delivering and picking up. (Delivery and pick-up is often called a "milk-run" because when many households got their milk from a delivery service, milk delivery drivers dropped off full bottles of milk and picked up empties. Milk-runs are

now commonly used by manufacturing companies that package with reusable packaging.)

Transportation mode

Often firms use certain transportation modes (ship, rail, tractor-trailer (full truck or less-than-truckload), box-truck, van, plane) without questioning if a different way of shipping would improve cost or customer service. An evaluation of transportation mode can yield, potentially, the greatest of all supply chain savings. This choice should be based on cost, flexibility and speed.

Bigger vehicles are always lower cost because of economies-of-scale. You need one driver for a tractor-trailer, box truck or van, even though the amount that can be transported is very different. This drives down the cost per unit shipped when using larger vehicles. The same is true of ships. Larger vessels don't need proportionally larger crews. Trains require a very small crew relative to the amount of freight they move.

However, larger vehicles are also the least flexible. You cannot easily change where a railcar is going, once it is underway. Speed is another consideration. Electronics ship by plane from Asia to Europe and the Americas because of the inventory value and potential for obsolescence. Companies may ship by full truck, even if they don't fill up the truck, to ensure it ships directly to the destination versus less-than-truckload (LTL) shipments that may stop off at terminals and change vehicles.

Storage Logistics Decisions

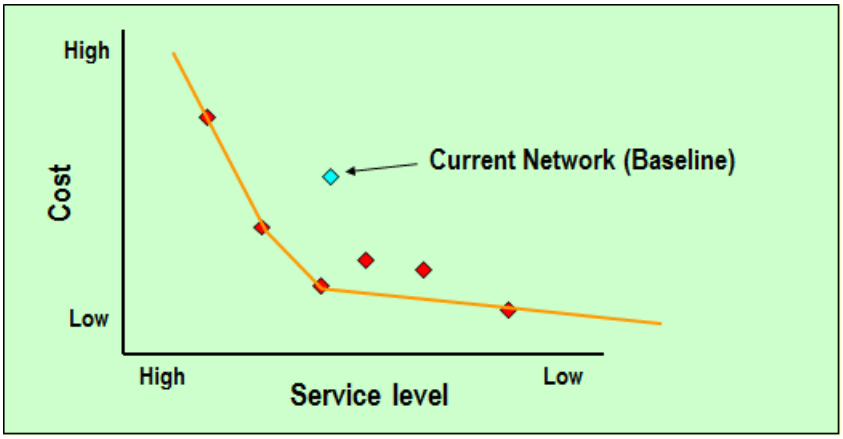
- Location and Number of facilities
  - Cost versus Service
- Type of facility
  - Direct-to-consumer warehouse, B2B warehouse, Cross-dock warehouse, Value-added provider, Retail store
- Inventory levels
  - Stockout costs versus Obsolescence
  - Safety stock and Reorder point
  - Order (Production or Purchase) Quantity
- Packaging
  - Customer perception versus Costs

Location and Number of Facilities

Storage logistical decisions are similar to those discussed above when determining the location of production facilities; however, because they are not explicitly adding value, customer service implications can be more important. Before determining the cost

versus service of a particular site, it is important to determine how to quantify service. Many firms use average distance or delivery time to customers. Some will use a percentage cut-off, such as being able to reach 80% of customers in one day.

When determining the number and location of distribution, warehousing or retail locations, a concept that is very helpful is the efficient frontier. The figure below shows seven choices of facilities (each diamond is a site). The three that are above the line are what we would call inefficient. Their combination of cost and service are such that a company would always be better off choosing one of the four sites whose cost/service combination are along the line. The location in the upper left corner has the highest cost site, but it provides the best service (fastest delivery or serves the most customers in a short delivery time). The site in the lower right corner has the worst service (slowest to deliver) but is the least expensive to operate. Any of the choices along the line may be good choices based on your priorities.



To help make this choice there is optimization software, or methods, that will choose the best choice. These models can incorporate multiple criteria, such as cost and distance to customers, or percentage of customers within 1 day delivery time. Note, that a firm would use these models when the choices are not obvious. In the graph above, it may be relatively easy to choose from the four sites along the efficient frontier. However, when the numbers of sites, the costs included in the calculation and the customers is more than a few, the choice may not be obvious. In these cases, optimization models can assist with choosing a site.

Type of Facility
When building or buying a inventory storage site it is important to plan its purpose. These will affect the layout and racking or shelving design.

Direct-to-consumer
These sites are often now called internet order-fulfillment facilities, because most of the orders are from the internet. They are typically designed for efficient small quantity picking and packing. Larger companies can use the Kiva robot shelving retrieval system to bring the shelving unit with the purchased item directly to the order-picker and packer. The downside of the Kiva robot system is the fact that these shelves are all people-height. Therefore, your design should be low-rise building. Given that many existing warehouses are high-ceiling, this wastes much of your vertical storage space.

Other designs use 20 – 30 foot tall racking/shelving. These warehouses typically use pick-trucks which are driven over RFID or wire-in-the-floor guidance systems that allow for very narrow aisles. The advantage of these systems are the space efficiency. Companies can also use lower-tech warehouses for direct-to-consumer operations that use shopping carts to pick multiple orders on an order-picking-trip. These designs will place the faster moving items closer to the pack stations.

Both the pick-truck and manual “shopping cart” warehouses will drop off the multiple orders picked by an order-picker in plastic totes. These are then packed and shipped at packing stations. Packing stations are often laid out as perpendicular stations to a roller conveyor that sends the plastic totes with orders down the conveyor for packing. The packer/shipper will pack the items in a shipping box, create the shipping label and put the box back on the conveyor. Ideally, the packages go directly into a USPS, Fedex or UPS truck.

B2B Warehouse
B2B warehouses are often dealing with multiple pallet orders. They ship less-than-truckload (LTL) shipments and often fill up entire trailers. These warehouses are usually suppling manufacturing facilities. Pallet racking and forktrucks are used. Because most order-pickers are fulfilling a single order, it is optimal to lay out your warehouse with the fastest-moving items placed close to the dock-doors. Often orders will be staged in front of the dock door designated for that shipment. In addition, while a warehouse can have dock doors along an entire length of the building, the doors in the center are used most often. Therefore, the SKU velocity will be highest at the front and center of the warehouse and lessen as you move to the ends and back. Automation is available to replace manual forktrucks, if labor costs are high enough to justify this investment.

Crossdock Warehouse

Crossdock warehouses do not store products. They are used to breakdown pallets from suppliers into boxes for individual stores. This type of facility was made popular by Wal-mart. These facilities take advantage of economies of scale in shipping by consolidating many vendors onto pallets that fill up a truck or allow a single truck to make multiple deliveries to stores along an efficient route. Trucks from vendors arrive on one side of the warehouse and trucks delivering to stores are on the other. Pallets from suppliers will often have mutliple boxes that are labeled by store so they can be quickly broken down into store-specific pallets.

Value Added Provider

These facilities are the sites that are referenced in the postponement product stratetgy. This warehouse will also provide the final customization and/or packaging for a postponed product. They can be internet fulfillment warehouse sending a product to a consumer, or B2B warehouses sending product to a retail store or crossdock facility.

Retail Store

Retail stores have separate location and design considerations that often fall outside the scope of logistics. However, logisticians have still assisted with quantifying retail locations. Harold Hotelling published a method (in 1929) still used today, called the “ice cream vendor” location problem. In this study, he argues that the best place to put your store is right next to your competitor. We see this strategy carried out by Lowes and Home Depot all over suburbs of the United States. Harold Hotelling discovered that any profit maximizing firm will locate their store in the middle of the largest population. If you don’t locate your facility next to your competitor, and driving is a consideration for your customers, then you will always be serving a smaller base than your competitors.

Inventory Levels

Stockout Costs versus Obsolescence

Inventory levels are a competition between the cost of not having what customers want and the riks of obsolescence. In 1997 a professor from Wharton School of Business, Marshall Fisher, wrote a seminal article on designing your supply chain, and inventory system, for your business. Flexible supply chains are needed for fast changing businesses because you need to flex up or down on your inventory levels. Conversly, low cost, but inflexible supply chains are appropriate when cost is the primary concern and you have little chance of obsolescence.

Safety Stock and Reorder Point

This background leads to the sizing of your inventory levels. The basic formula for calculating your reorder point (the inventory level at which you would place an order) is:

(average demand * lead time) + (safety stock)

If you size your inventory to handle only average demand, then you will stockout 50% of the time that you are reordering. We add safety stock to average-demand-times-leadtime to handle variation, and specifically variation that is greater than the average. (You are not worried about variation that is less than the average, because you will have "too-much" inventory at these times.)

To use this formula you need to choose the service level of the inventory items. The most popular method is the ABC inventory classification. All inventory items are sorted by, either sales, profit or volume. Using the Pareto analysis formula we will categorize the A items as the top 20% of items, B as the next 30% and C as the remaining 50%. Alternatively you can categorize A items as encompassing 80% of sales/profit/volume, B as the next 15% and C as the last 5%. Once the ABC classification has been determined, you apply a service level.

Service level is the percentage of orders you want to be able to fill with on-hand inventory, during the reordering leadtime of your production process or supplier. A common design is as follows:

A items = 98%
B items = 90%
C items = 80%

It should be noted that in reality your B and C items will likely achieve a higher actual service level, because you will not constantly be reordering. These lower volume items will often have inventory levels above the reorder point, which means your service level at this time is 100%. The service level only "kicks-in" when you are at your reorder point and ordering more inventory from your supplier or production process.

A+ and F classifications can also be used. If a few items are a very high cumulative percentage of your sales/profit/volume, you can alter the classification and make the very top items A+ and make the very worst items F. A+ would be given a extremely high service level, such as 99% and F items would be not kept in stock, but rather would be ordered-on-demand or produced-to-order.

A+ items = 99%
A items = 95%
B items = 90%
C items = 80%
F items = 0%

The formula used above can be further refined by adding variation of the lead time. This is not often done in practice, so we will limit the use of this formula and assume that lead-time is fixed.

Order Quantity

The most popular lot (for production) or order (for purchasing) quantity formula is the economic-order-quantity calculation. This formula balances the cost of machine set-up or ordering (which could include shipping costs) with the cost of holding inventory. Using the EOQ formula you are assured to have the lowest cost quantity. However, many companies use it to determine how low they must drive down set-up or shipping cost.

EOQ = square-root (2 * D * S / c * i)

D = annual demand in units
S = set-up or ordering costs
c = unit cost of the product
i = inventory holding cost (usually 20 – 25%)

An important parameter in this formula is the inventory holding cost. This cost is made up of the following factors:

- Cost of money or borrowing
  - Often 5 – 10%
- Handling / warehousing cost
  - If you are paying a third-party logistics provider this cost would be the annual fee for handling and storage
- Obsolenscence / damage
  - This should be based on actual figures, but you may want to average the prior three years

If you are calculating the appropriate percentage you would divide all costs (handling / warehousing, obsolesence/damage) by the average on-hand inventory value.

Another popular, but less scientific method, is basing the production or order frequency on the item classification. This guideline could work as follows; order A items every week, B items every month and C items quarterly. Note, you could use any frequency desired.

Packaging

The final consideration when storing inventory is packaging. Packaging can dramatically reduce storage and product costs, but must be weighed against consumer perception. Examples of interesting storage involve wine and deodorant. Connoisseur of wine would never consider buying boxed wine. However, the bag and box design stores more wine in a smaller space, keeps the wine fresh because it does not let air in (which oxidizes the wine ruining the flavor), and is less expensive to ship (cardboard weighs less than glass). However, glass bottles still are preferred in most countries. Therefore, we need to balance cost with consumer perception. Even the most dedicated supply chain manager would likely not show up to a party with a box of wine!

Another famous packaging story involves one of the great supply chain companies in the world, Wal-mart. A buyer at Wal-mart realized that deodorant, which was packaged in the plastic container and then in small cardboard boxes, was unnecessarily double-packaged. She demanded that the cardboard boxes be eliminated, and all product information be printed directly on the plastic container. This buyer may be responsible for saving more trees than any human in our entire history.