UNIT 3

LOGISTICS IN SUPPLY CHAIN

3.1 THE ROLE OF TRANSPORTATION IN SUPPLY CHAIN

Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer. Transportation is an important supply chain driver because products are rarely produced and consumed in the same location. Transportation is a significant component of the costs incurred by most supply chains. According to the Bureau of Transportation Statistics (BTS), ―over 19 billion tons of freight, valued at $13 trillion, was carried over 4.4 trillion ton-miles in the United States in 2002. Only three sectors— housing, health care, and food—contributed a larger share to the gross domestic product (GDP) than transportation. Transportation-related jobs employed nearly 20 million people in 2002, accounting for 16 percent of U.S. total occupational employment.

Transportation is ―Moving of Goods from the point of origin to the point of destination across the supply chain through its members. The role of transportation in logistics has changed with transport alternatives and value added services to support the supply chain. Private transport companies have become part of the supply chain. Third party logistics companies offer a wide variety of services like to improve the efficiency of the supply chain:

- Product sorting
- Sequencing
- Customized freight delivery

Advancement in technology has improved the services of the logistics with real time visibility of tracking the vehicles using GPRS systems and the integration of delivery systems.

Development of an integrated transport management system has

- Improved the product delivery.
- Reduced the inventory and material handling resulting in reduced transportation cost.
- Improved value of transportation for the supply chain

Transportation is the back bone of an economy.

Improved transportation infrastructure helps the economy to grow. Transportation is an important element of logistics.

- It helps the supply chain in Movement of products
- Storage of products

Movement of product from the suppliers to the customers across the supply chain has become the primary value preposition of transportation in a supply chain. Its performance is based on

- Time
- Cost
- Impact on the environment

Information technology has improved the access to data on the movement of the transport and the time of delivery. It helps the supply chain to plan the exact time of delivery to the customers. On an average transportation cost is about 30% of the total logistics cost. Transportation is a non-value adding activity. The focus of the supply chain is to reduce the cost of transportation to decrease the total supply chain cost. Transportation industry is the largest consumer of fuel and oil across the globe. Efforts have been on to bring in fuel efficient vehicles which are environment friendly as they affect the environment through air pollution and noise pollution.

The role of transportation is even more significant in global supply chains. According to the BTS, the U.S. freight transportation network carried export and import merchandise worth more than $2.2 trillion in 2004, an increase of 168 percent from $822 billion in 1990. During the same period, the ratio of exports from and imports into the United States to the GDP increased from 12 percent to 21 percent. Transportation-related jobs employed nearly 20 million people. The role of transportation is even more significant in global supply chains. According to the BTS, the U.S. freight transportation network carried export and import merchandise.

Any supply chain‘s success is closely linked to the appropriate use of transportation. IKEA, the Scandinavian home furnishings retailer, has built a global network with about 270 stores in 26 countries primarily on the basis of effective transportation. IKEA‘s sales for the year ending August 2009 reached 21.5 billion euros. Its strategy is built around providing good-quality products at low prices. Its goal is to cut prices by 2 to 3 percent each year. As a result, IKEA works hard to find the most inexpensive global source for each of its products. Modular design of its furniture allows IKEA to transport its goods worldwide much more cost effectively than a traditional furniture manufacturer

The large size of IKEA stores and shipments allows inexpensive transportation of home furnishings all the way to the retail store. Effective sourcing and inexpensive transportation allow IKEA to provide high-quality home furnishings at low prices globally.

Seven-Eleven Japan is another firm that has used transportation to achieve its strategic goals. The company has a goal of carrying products in its stores to match the needs of customers as they vary by geographic location or time of day. To help achieve this goal, Seven-Eleven Japan uses a responsive transportation system that replenishes its stores several times a day so that the products available match customer’s needs. Products from different suppliers are aggregated on trucks according to the required temperature to help achieve frequent deliveries at a reasonable cost. Seven-Eleven Japan uses a responsive transportation system along with aggregation to decrease its transportation and receiving costs while ensuring that product availability closely matches customer demand.

Supply chains also use responsive transportation to centralize inventories and operate with fewer facilities. For example, Amazon relies on package carriers and the postal system to deliver customer orders from centralized warehouses. Transportation has allowed Netflix to operate a movie rental business without any stores. The company uses responsive transportation provided by the postal system along with suitably located warehouses to allow its customers to receive and return movies they want to watch.

The shipper is the party that requires the movement of the product between two points in the supply chain. The carrier is the party that moves or transports the product. For example, when Netflix uses USPS to ship its DVDs from the warehouse to the customer, Netflix is the shipper and USPS is the carrier. Besides the shipper and the carrier, two other parties have a significant impact on transportation: (1) the owners and operators of transportation infrastructure such as roads, ports, canals, and airports and (2) the bodies that set transportation policy worldwide. Actions by all four parties influence the effectiveness of transportation.

To understand transportation in a supply chain, it is important to consider the perspectives of all four parties. A carrier makes investment decisions regarding the transportation equipment (locomotives, trucks, airplanes, etc.) and in some cases infrastructure (rail) and then makes operating decisions to try to maximize the return from these assets. A shipper, in contrast, uses transportation to minimize the total cost (transportation, inventory, information, sourcing, and facility) while providing an appropriate level of responsiveness to the customer. The effectiveness of carriers is influenced by infrastructure such as ports, roads, waterways, and airports. Most transportation infrastructure throughout the world is owned and managed as a public good. It is important that infrastructure be managed in such a way that monies are available for maintenance and investment in further capacity as needed. Transportation policy sets direction for the amount of national resources that go into improving transportation infrastructure. Transportation policy also aims to prevent abuse of monopoly power; promote fair competition; and balance environmental, energy, and social concerns in transportation.

Transportation is a key supply chain process that must be included in supply chain strategy development, network design and total cost management. Transportation provides the critical links between supply chain partners, permitting goods to flow between their facilities. Transportation service availability is critical to demand fulfilment in the supply chain. Transportation efficiency promotes the competitiveness of a supply chain.

Transportation involves the movement of product, service/transit time, and cost traditional key issues of effective supply chains. It also impacts with the other issues of movement of information and integration within and among suppliers, customers and carriers. A transportation strategy, to be effective in supply chain management, is fitting the movement of goods to the corporate supply chain. It is not playing one carrier off against another. Rather it is a way to respond to the dynamics of the business, its customers, suppliers' and operation.

Actions by all the below parties influence the effectiveness of transportation.

- The shipper is the party that requires the movement of the product between two points in the supply chain. Shipper is the person or company who is usually the supplier or owner of commodities shipped. Also called Consignor.
- The carrier is the party that moves or transports the product. Carrier is a person or company that transports goods or people for any person or company and that is responsible for any possible loss of the goods during transport.
- The owners and operators of transportation infrastructure such as roads, ports, canals, and airports
- The bodies that set transportation policy worldwide.
- Consignee (party that receives the shipment)

May have certain responsiveness needs.

The transportation strategy should recognize:

- Segment: Each shipment does not have the same priority. Products, suppliers, customers, time of the year, and other factors can affect the importance and urgency of transport movements. The strategy cannot be one-dimensional. It should be segmented to reflect urgencies.
- Customer requirements: The supply chain involves continuous and efficient movement of product from vendor to manufacturer to customer. Therefore, the transportation program must reflect and meet customer needs. The time and service aspects of transportation are vital.
- Shipments must move timely: Customers demand their shipments be delivered as they require – on the date needed, by the carrier preferred, in the proper shipping packaging method and complete, both shipped complete and delivered complete and in good order. Being able to have a transportation program which can do this provides customer satisfaction and can give your company a competitive advantage.
- Mode selection: How will products move, by air versus surface? What modes will be used? What roles do transit time play in your supply chain? How will the inventory and service impacts be measured as compared to the freight charges?
- Carrier relationships: Volume creates carrier/forwarder attention. Even if there is no strategy, the number of carriers trying to get business will make firms develop one. Infrequent shipping dictates another approach.
- Carrier mergers and alliances and closings: This is an important and difficult issue. Firms should understand what is happening within each mode and align the strategy with carriers who will still be viable in the future—often five years since strategic plans may extend that far. A great strategy with a carrier who is taken over or goes out of business is suddenly not a good strategy.
- Flexibility/Adaptability: Change is happening. It is not a question of whether or not it happens. The only question is how quickly it occurs. The strategy should be able to change. New customers. New products. New businesses. New suppliers. New corporate emphasis. Each of these can dramatically impact the strategy. The times they are a changing--and so will the strategy.
- Measuring/Metrics. It is important to know how well the strategy and carriers are performing. This takes two approaches. One is measuring. Measuring means comparing performance versus agreed standards. What is the actual delivery to customer performance, on a macro basis, carrier and customer by customer basis? A macro measure can hide a problem even if the overall measure is good. And, with supply chain management, this means realizing primary customers and delivery locations. A test of measuring costs is how well the transport spend is being managed. Transport performance metrics can provide a way to view the value of the spend.
- Transportation is a key logistics function and is critical to supply chain performance. To meet the vigorous requirements of the supply chain, the strategy should be dynamic. It must be responsive, both as to service and cost demands.

3.2 Factors Affecting Transportations Decision

From earlier, we know that there may be three separate parties involved. All of them have factors to consider:

1. Carrier (party that moves or transports the product) – Vehicle-related costs, Fixed operating costs, Trip-related costs – Often incurs huge investments (new fleets, etc…)

2. Shipper (party that requires the movement of the product between two points in the supply chain) – May need to balance Transportation costs with Inventory and Facility costs

3. Consignee (party that receives the shipment) – May have certain responsiveness needs We should also consider:υ

4. The owners of the infrastructure (Ports, highways, railroads)

5. Government and/or bodies that set worldwide transportation policy

The selection of a mode of transportation or service offering within a mode of transportation depends on a variety of service characteristics

Freight rates (cost of service)

- Reliability
- Transit time
- Loss, damage, claims processing tracing
- Shipper market considerations
- Carrier considerations.

Other factors

- Capability
- Availability & adequacy of equipment
- Availability of service
- Frequency of service
- Security
- Claims handling
- Shipment tracing
- Problem-solving assistance

Speed & dependability affect both the seller‘s & buyer‘s inventory level, as well as the inventory that is in transit. Slower, less reliable modes require more inventory in the distribution channel. When alternative modes are available, the one chosen should be the one that offers the lowest total cost consistent with customer service goals.

Transportation influences or is influenced by many logistics activities to include:

- Transportation costs which are directly affected by the location of the firm‘s manufacturing facilities, warehouses, suppliers, retailers and customers.
- The transportation mode selected has an impact on the packing required, and carrier classification rules determine package choice.

- Inventory requirements which are influenced by the mode of transport selected for use. When high speed, high priced transportation systems are used, the inventories required to be maintained in the logistics system would be smaller as compared to that when slow, less expensive transportation systems are used.
- Customer service goals which influence the type and quality of carrier source selected by the firm.
- The firm‘s materials handling equipment’s are determined by the type of carrier used for transportation, for example, the handling equipment’s for loading and unloading the carrier and the design of the receiving and shipping docks depend on the type of carriers used.
- An order management methodology which encourages maximum consolidation of shipments between common point’s facilities larger shipments and advantages of volume discounts.

Location decisions are a basic determinant of profitability in logistics. Decisions on where to manufacture, to assemble, to store, to tranship and to consolidate can make the difference between profit and loss. Because of differences in basic factor costs and because of exchange rate movements, location decisions are very important. Location decisions can have a continuing impact over time on the company‘s financial and competitive position.

Facility Location Models

- Break Even Analysis
- Transportation Models

Factors Affecting Transportation Decisions:

- Modes of transportation
- Size and weight
- Destination
- Routes
- Carrier
- Shipper

MODES OF TRANSPORTATION

Supply chains use a combination of the following modes of transportation:

- Air
- Package carriers
- Truck
- Rail
- Water
- Pipeline
- Intermodal

AIRLINES

They have three cost components:

- a fixed cost of infrastructure and equipment
- cost of labour and fuel that is independent of the passengers or cargo on a flight but is fixed for a flight
- a variable cost that depends on the passengers or cargo carried.

Air carriers offer a fast and fairly expensive mode of transportation for cargo. Small, high-value items or time- sensitive emergency shipments that have to travel a long distance are best suited for air transport.

Key issues that air carriers face include identifying the location and number of hubs, assigning planes to routes, setting up maintenance schedules for planes, scheduling crews, and managing prices and availability at different prices.

Advantages

- Fastest mode of transport
- Transporting goods to area which is not easily accessible by other means
- Reduces lead time
- Improved service levels

Disadvantages

- Expensive
- Not suitable for transporting heavy and bulky goods Not suitable for short distance travel

PACKAGE CARRIERS

Package carriers are transportation companies such as FedEx, UPS, and the U.S. Postal Service. They use air, truck, and rail to transport time-critical smaller packages. They also provide other value-added services such as package tracking and in some cases processing and assembly of products. They are the preferred mode of transport for online businesses

Advantages

- Shippers are rapid and reliable delivery.
- E-Business
- Consolidation of shipments

Disadvantages

- Expensive
- Small and time-sensitive shipments

TRUCK

Trucks have complete freedom to use roads. It supports flexibility of changes in location, direction, speed and timing of travel. Significant fraction of the goods are moved by

Truckload (TL)

- Low fixed cost
- Imbalance between flows

Less than truckload (LTL)

- Small lots
- Hub and spoke system
- May take longer than TL

Advantages

- Cheaper
- Flexible
- Any place can be reachable

Disadvantages

- Not economical for long distance
- High cost for bulk and heavy loads

RAIL

- Uses freight rails
- Bulk shipment of products from production plant to warehouses
- Move commodities over large distances
- High fixed costs in equipment and facilities
- Scheduled to maximize utilization
- Transportation time can be long – Trains _built' not scheduled

Advantages

Faster

Suitable for carrying heavy goods

Cost effective

Disadvantages

- Expensive for carrying goods in short distance
- Not available for remote areas
- Fixed time schedule and not flexible for loading and unloading of goods at any place.

WATER

- Limited to certain geographic areas
- Ocean, inland waterway system, coastal waters certain geographic areas.
- Very large loads at very low cost – Lowest energy/emission intensity per tonnekm, though some concern about port pollution
- Slowest – Also subject to bottlenecks at Ports
- Dominant in overseas trade (autos, grain, apparel, etc.)
- Containers

- Example of successful usage: IKEA - IKEA makes very strong use of water and other low cost transport

PIPELINE

- High fixed cost
- Primarily for crude petroleum, refined petroleum products, natural gas
- Best for large and predictable demand
- Would be used for getting crude oil to a port or refinery, but not for getting refined gasoline to a gasoline station
- Pricing structure encourages use for predicable component of demand

INTERMODAL

- Use of more than one mode of transportation to move a shipment to its destination – rail/truck, water/rail/truck or water/truck
- Grown considerably with increased use of containers
- Increased global trade has also increased use of intermodal transportation
- More convenient for shippers (one entity can provide the complete service)
- Key issue involves the exchange of information to facilitate transfer between different transport modes

DIFFERENCE BETWEEN CARRIER AND SHIPPER

Carrier

A carrier makes investment decisions regarding the transportation. Equipment and in some cases infrastructure and then makes operating decisions to try to maximize the return from these assets.

- Vehicle related cost
- Fixed operating cost
- Trip related cost

Shipper

A shipper uses transportation to minimize the total cost (transportation, inventory, information, sourcing, and facility) while providing an appropriate level of responsiveness to the customer. Most transportation infrastructure throughout the world is owned and managed as a public good.

3.3 Design option for a Transportation Network

The design of a transportation network affects the performance of a supply chain by establishing the infrastructure within which operational transportation decisions regarding scheduling and routing are made. A well-designed transportation network allows a supply chain to achieve the desired degree of responsiveness at a low cost. Three basic questions need to be considered when designing a transportation network between two stages of a supply chain:

1. Should transportation be direct or through an intermediate site?
2. Should the intermediate site stock product or only serve as a cross-docking location?
3. Should each delivery route supply a single destination or multiple destinations (milk run, discussed later)?

Based on the answers to these questions, the supply chain ends up with a variety of transportation networks. We discuss these options and their strengths and weaknesses in the context of a buyer with multiple locations sourcing from several suppliers.

1. Direct Shipment Network to Single Destination
With the direct shipment network to a single destination option, the buyer structures the transportation network so that all shipments come directly from each supplier to each buyer location. With a direct shipment network, the routing of each shipment is specified, and the supply chain manager needs to decide only the quantity to ship and the mode of transportation to use. This decision involves a trade-off between transportation and inventory costs, as discussed later in the chapter.

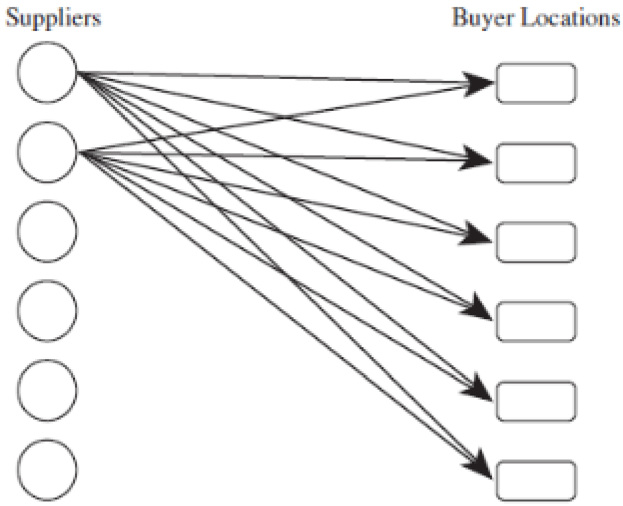

Figure 4.6 Direct Shipment Network

The major advantage of a direct shipment transportation network is the elimination of intermediate warehouses and its simplicity of operation and coordination. The shipment decision is completely local, and the decision made for one shipment does not influence others. The transportation time from supplier to buyer location is short because each shipment goes direct.
A direct shipment network to a single destination is justified only if demand at buyer locations is large enough that optimal replenishment lot sizes are close to a truckload from each supplier to each location. Home Depot started with a direct shipment network, given that most of the stores it opened until about 2002 were large stores. The stores ordered in quantities that were large enough that ordering was managed locally within the store and delivery to the store arrived directly from the supplier. The direct shipment network to a single destination, however, proved to be problematic as Home Depot started to open smaller stores that did not have large enough orders to justify a direct shipment.

2. Direct Shipping with Milk Runs

A milk run is a route on which a truck either delivers product from a single supplier to multiple retailers or goes from multiple suppliers to a single buyer location. In direct shipping with milk runs, a supplier delivers directly to multiple buyer locations on a truck or a truck picks up deliveries destined for the same buyer location from many suppliers. When using this option, a supply chain manager has to decide on the routing of each milk run.

Direct shipping provides the benefit of eliminating intermediate warehouses, whereas milk runs lower transportation cost by consolidating shipments to multiple locations on a single truck. Milk runs make sense when the quantity destined for each location is too small to fill a truck but multiple locations are close enough to each other such that their combined quantity fills the truck. Companies such as Frito-Lay that make direct store deliveries use milk runs to lower their transportation cost. If frequent small deliveries are needed on a regular basis and either a set of suppliers or a set of retailers is in geographic proximity, the use of milk runs can significantly reduce transportation costs.

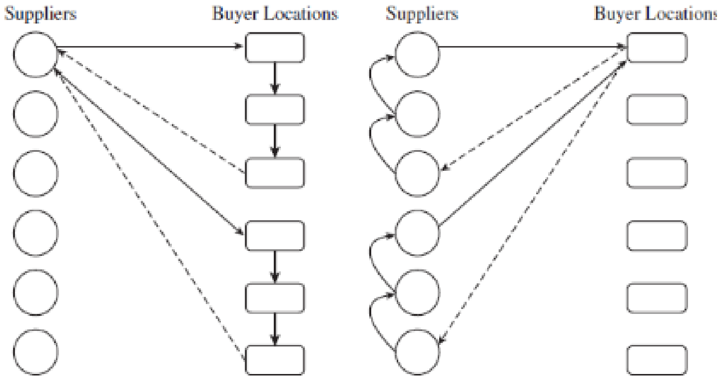

Figure 4.7 Milk Runs from Multiple Suppliers or to Multiple Buyer Locations

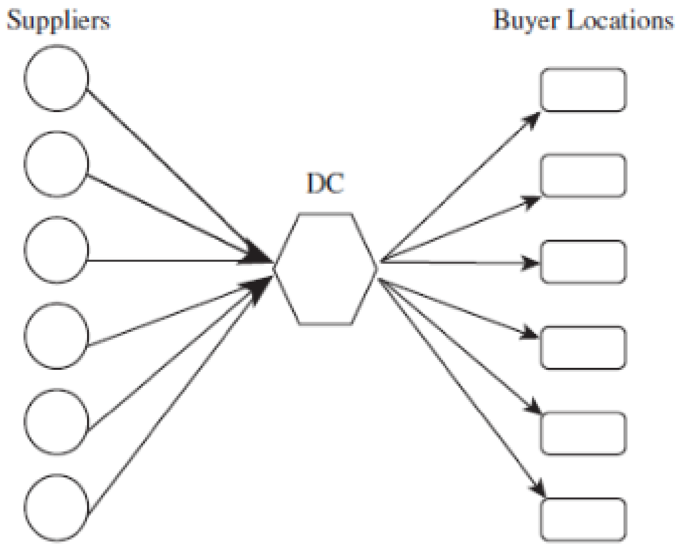

Figure 4.8 All Shipments via DC

For example, Toyota uses milk runs from suppliers to support its just-in-time (JIT) manufacturing system in both Japan and the United States. In Japan, Toyota has many assembly plants located close together and thus uses milk runs from a single supplier to many plants. In the United States, however, Toyota uses milk runs from many suppliers to each assembly plant, given the large distance between assembly plants.

3. All Shipments via intermediate Distribution Center with Storage

Under this option, product is shipped from suppliers to a central distribution center, where it is stored until needed by buyers when it is shipped to each buyer location. Storing product at

an intermediate location is justified if transportation economies require large shipments on the inbound side or shipments on the outbound side cannot be coordinated. In such a situation, product comes in large quantities into a DC, where it is held in inventory and sent to buyer locations in smaller replenishment lots when needed.
The presence of a DC allows a supply chain to achieve economies of scale for inbound transportation to a point close to the final destination, because each supplier sends a large shipment to the DC that contains product for all locations the DC serves. Because DCs serve locations nearby, the outbound transportation cost is not very large. For example, W.W. Grainger has its suppliers ship products to one of nine DCs (typically in large quantities), with each DC, in turn, replenishing stores in its vicinity with the smaller quantities they need. It would be expensive for suppliers to try to serve each store directly. Similarly, when Home Depot sources from an overseas supplier, the product is held in inventory at the DC because the lot size on the inbound side is much larger than the sum of the lot sizes for the stores served by the DC.

4. All Shipments via intermediate Transit Point with Cross-Docking
Under this option, suppliers send their shipments to an intermediate transit point (which could be a DC), where they are cross-docked and sent to buyer locations without storing them. The product flow is similar to that shown in Figure 14-4 except that there is no storage at the intermediate facility. When a DC cross-docks product, each inbound truck contains product from suppliers for several buyer locations, whereas each outbound truck contains product for one buyer location from several suppliers. Major benefits of cross-docking are that little inventory needs to be held and product flows faster in the supply chain. Cross-docking also saves on handling cost because the product does not have to be moved into and out of storage. Cross-docking is appropriate when economies of scale in transportation can be achieved on both the inbound and outbound sides and both inbound and outbound shipments can be coordinated.

Walmart has used cross-docking successfully to decrease inventories in the supply chain without incurring excessive transportation costs. Walmart builds many large stores in a geographic area supported by a DC. As a result, the total lot size to all stores from each supplier fills trucks on the inbound side to achieve economies of scale. On the outbound side, the sum of the lot sizes from all suppliers to each retail store fills up the truck to achieve economies of scale.

Another good example of the use of a transit point with cross-docking comes from Pea- pod in the Chicago area. Peapod has a DC in Lake Zurich from which it delivers to its customers using milk runs. This approach proved effective for customers in the northern and western suburbs of Chicago. Peapod, however, wanted to increase its reach to the city of Chicago and the city of Milwaukee. Both are far enough from the Lake Zurich DC that a milk run wastes about two hours in transit, making no productive deliveries. These markets were also small enough that they did not justify a local DC. Peapod’s response has been to set up a cross docking facility (which tends to be cheaper than a DC because no storage is involved) at each location. Peapod then sends out all deliveries to the local cross-docking facility in a larger truck and uses smaller trucks for local deliveries. The use of cross-docking at a transit point has allowed Peapod to increase the reach of the Lake Zurich DC without significantly increasing transportation expense.

5. Shipping via DC Using Milk Runs

As shown in Figure milk runs can be used from a DC if lot sizes to be delivered to each buyer location are small. Milk runs reduce outbound transportation costs by consolidating small shipments. For example, Seven-Eleven Japan cross-docks deliveries from its fresh-food suppliers at its DCs and sends out milk runs to the retail outlets because the total shipment to a store from all suppliers does not fill a truck. The use of cross-docking and milk runs allows Seven- Eleven Japan to lower its transportation cost while sending small replenishment lots to each store. The use of cross-docking with milk runs requires a significant degree of coordination and suitable routing and scheduling.

The online grocer Peapod uses milk runs from DCs when making customer deliveries to help reduce transportation costs for small shipments to be delivered to homes. OshKosh B'Gosh, a manufacturer of children's wear, has used this idea to virtually eliminate LTL shipments from its DC in Tennessee to retail stores.

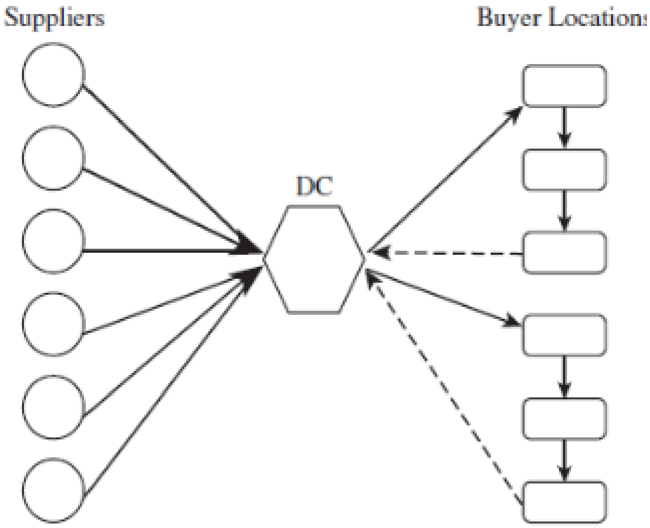

Figure 4.9 Milk Runs from DC

Network Structure	Pros	Cons
Direct shipping	No intermediate warehouse Simple to coordinate	High inventories (due to large lot size)
Direct shipping with milk runs	Lower transportation costs for small lots Lower inventories	Increased coordination complexity
All shipments via central DC with inventory storage	Lower inbound transportation cost through consolidation	Increased inventory cost Increased handling at DC
All shipments via central DC with cross-dock	Low inventory requirement Lower transportation cost through consolidation	Increased coordination complexity
Shipping via DC using milk runs	Lower outbound transportation cost for small lots	Further increase in coordination complexity
Tailored network	Transportation choice best matches needs of individual product and store	Highest coordination complexity

Figure 4.10 Pros and Cons of Different Transportation Networks

6. Tailored Network

The tailored network option is a suitable combination of previous options that reduces the cost and improves the responsiveness of the supply chain. Here, transportation uses a combination of cross-docking, milk runs, and TL and LTL carriers, along with package carriers in some cases. The goal is to use the appropriate option in each situation. High-demand products may be shipped directly to high-demand retail outlets, whereas low-demand products or shipments to low- demand retail outlets are consolidated to and from the DC. The complexity of managing this transportation network is high because different shipping procedures are used for each product and retail outlet. Operating a tailored network requires significant investment in information infrastructure to facilitate the coordination. Such a network, however, allows for the selective use of a shipment method to minimize the transportation as well as inventory costs.

3.4 Tailored Transportation

Tailored transportation is the use of different transportation networks and modes based on customer and product characteristics. Most firms sell a variety of products and serve many different customer segments. Products vary in size and value, and customers vary in the quantity purchased, responsiveness required, uncertainty of the orders, and distance. Given these differences, a firm should not design a common transportation network to meet all needs.

A firm can meet customer needs at a lower cost by using tailored transportation to provide the appropriate transportation choice based on customer and product characteristics.

The various forms of tailored transportation in supply chains are

- Tailored Transportation by Customer Density and Distance
- Tailored Transportation by Size of Customer
- Tailored Transportation by Product Demand and Value

Tailored Transportation by Customer Density and Distance

Firms must consider customer density and distance from warehouse when designing transportation networks. The ideal transportation options based on density and distance are shown in Table 3.4.1

Table 3.4.1 Transportation Options Based on Customer Density and Distance

	Short Distance	Medium Distance	Long Distance
High density	Private fleet with milk runs	Cross-dock with milk runs	Cross-dock with milk runs
Medium density	Third-party milk runs	LTL carrier	LTL or package carrier
Low density	Third-party milk runs or LTL carrier	LTL or package carrier	Package carrier

When a firm serves a high density of customers close to the DC, it is often best for the firm to own a fleet of trucks that are used with milk runs originating at the DC to supply customers, it allows good use of the vehicles and provides customer contact.

If customer density is high but distance from the warehouse is large, it is better to use a public carrier with large trucks to haul the shipments to a cross-dock center close to the customer area, where the shipments are loaded onto smaller trucks that deliver product to customers using milk runs. In this situation, it may not be ideal for a firm to own its own fleet to avoid empty trucks on return trip.

As customer density decreases, use of an LTL carrier or a third party doing milk runs is more economical because the third-party carrier can aggregate shipments across many firms.

If a firm wants to serve an area with a low density of customers far from the warehouse, even LTL carriers may not be feasible and the use of package carriers may be the best option as long as loads are small. Firms should serve areas with high customer density more frequently because these areas are likely to provide sufficient economies of scale in transportation, making temporal aggregation less valuable. To lower transportation costs, firms should use a higher degree of temporal aggregation and aim for somewhat lower responsiveness when serving areas with a low customer density.

Tailored Transportation by Size of Customer

Firms must consider customer size and location when designing transportation networks. Large customers can be supplied using a TL carrier, whereas smaller customers will require an LTL carrier or milk runs.

When using milk runs, a shipper incurs two types of costs:

- Transportation cost based on total route distance
- Delivery cost based on number of deliveries

The transportation cost is the same whether going to a large or small customer. If a delivery is to be made to a large customer, including other small customers on the same truck can save on transportation cost. For each small customer, however, the delivery cost per unit is higher than for large customers. Thus, it is not optimal to deliver to small and large customers with the same frequency at the same price. So firms either have to charge a higher delivery cost for smaller customers or to tailor milk runs so that they visit larger customers with a higher frequency than smaller customers.

Firms can partition customers into large (L), medium (M), and small (S) based on the demand at each. The optimal frequency of visits can be evaluated based on the transportation and delivery costs.

If large customers are to be visited every milk run, medium customers every other milk run, and low-demand customers every third milk run, suitable milk runs can be designed by combining large, medium, and small customers on each run.

Medium customers would be partitioned into two subsets (M1, M2), and small customers would be partitioned into three subsets (S1, S2, S3).

The firm can sequence the following six milk runs to ensure that each customer is visited with the appropriate frequency:

(L, M1, S1), (L, M2, S2), (L, M1, S3), (L, M2, S1), (L, M1, S2), (L, M2, S3).

Advantages:

- each truck carries about the same load
- larger customers are provided more frequent delivery than smaller customers
- Consistent with their relative costs of delivery.

Tailored Transportation by Product Demand and Value

The degree of inventory aggregation and the modes of transportation used in a supply chain network should vary with the demand and value of a product, as shown in the following Table 3.4.2.

Table 3.4.2 Transportation by Product Demand and Value

Product Type	High Value	Low Value
High demand	Disaggregate cycle inventory. Aggregate safety inventory. Inexpensive mode of transportation for replenishing cycle inventory and fast mode when using safety inventory.	Disaggregate all inventories and use inexpensive mode of transportation for replenishment.
Low Demand	Aggregate all inventories. If needed, use fast mode of transportation for filling customer orders	Aggregate only safety inventory. Use inexpensive mode of transportation for replenishing cycle inventory

For high-value products with high demand the inventory is disaggregated to save on transportation costs because this allows replenishment orders to be transported less expensively. For high-demand products with low value, all inventories should be disaggregated and held close to the customer to reduce transportation costs. For low-demand, high-value products, all inventories should be aggregated to save on inventory costs. For low-demand, low-value products, cycle inventories can be held close to the customer and safety inventories aggregated to reduce transportation costs.

3.5 Routing and Scheduling In Transportation

The most important operational decision related to transportation in a supply chain is the routing and scheduling of deliveries. Selecting the best paths for the transport mode to follow to minimize travel time or distance reduces transportation costs and improves customer service.

Managers must decide on the customers to be visited by a particular vehicle and the sequence in which they will be visited. For example, an online grocer such as Peapod is built on delivering customer orders to their homes. The success of its operations hinges on its ability to decrease transportation and delivery costs while providing the promised level of responsiveness to the customer.

Given a set of customer orders, the goal is to route and schedule delivery vehicles such that the costs incurred to meet delivery promises are as low as possible. Typical objectives when routing and scheduling vehicles include a combination of minimizing cost by

- decreasing the number of vehicles needed
- the total distance travelled by vehicles
- the total travel time of vehicles

- eliminating service failures such as a delays in shipments

In this note, routing and scheduling problems are discussed from the point of view of the manager of a Peapod distribution center (DC). After customers place orders for groceries online, staff at the DC has to pick the items needed and load them on trucks for delivery. The manager must decide which trucks will deliver to which customers and the route that each truck will take when making deliveries. The manager must also ensure that no truck is overloaded and that promised delivery times are met.

For example, the DC manager at Peapod has delivery orders from thirteen different customers. The DC‘s location, each customer on the grid, and the order size from each customer are shown in Table 3.5.1. The manager has four trucks, each capable of carrying up to 200 units. The manager believes that the delivery costs are strongly linked to the total distance the trucks travel, and that the distance between two points on the grid is correlated with the actual distance a vehicle will travel between those two points. The manager thus decides to assign customers to trucks and identify a route for each truck, with a goal of minimizing the total distance traveled.

Table 3.5.1: Customer Location and Demand for Peapod

	X-Coordinate	Y-Coordinate	Order Size ai
Warehouse	0	0	
Customer 1	0	12	48
Customer 2	6	5	36
Customer 3	7	15	43
Customer 4	9	12	92
Customer 5	15	3	57
Customer 6	20	0	16
Customer 7	17	-2	56
Customer 8	7	-4	30
Customer 9	1	-6	57
Customer 10	15	-6	47
Customer 11	20	-7	91
Customer 12	7	-9	55
Customer 13	2	-15	38

The DC manager must first assign customers to be served by each vehicle and then decide on each vehicle‘s route. After the initial assignment, route sequencing and route improvement procedures are used to decide on the route for each vehicle.

The DC manager decides to use the following computational procedures to support

The Savings Matrix method

The Generalized Assignment method

Savings Matrix method

This method is simple to implement and can be used to assign customers to vehicles even when delivery time windows or other constraints exist. The major steps in the savings matrix method are:

- identify the distance matrix ,
- identify the savings matrix ,
- assign customers to vehicles or routes ,
- sequence customers within routes

The first three steps result in customers being assigned to vehicles and the fourth step is used to route each vehicle to minimize the distance traveled.

Identify the Distance Matrix

The distance matrix identifies the distance between every pair of locations to be visited. The distance is used as a surrogate for the cost of travelling between the pair of locations. If the transportation costs between every pair of locations are known, the costs can be used in place of distances. The distance Dist(A,B) on a grid between a point A with coordinates (XA,YA) and a point B with coordinates (XB,YB)is evaluated as:

$$\text{Dist(A,B)}= \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2} \quad (1)$$

The distance between every pair of locations for Peapod is shown in Table 3.5.2. The distances between every pair of locations are next used to evaluate the savings matrix. Table

3.5.2: Distance Matrix for Peapod Deliveries

	DC	Cust 1	Cust 2	Cust 3	Cust 4	Cust 5	Cust 6	Cust 7	Cust 8	Cust 9	Cust 10	Cust 11	Cust 12	Cust 13
DC	0													
Cust 1	12	0												
Cust 2	8	9	0											
Cust 3	17	8	10	0										
Cust 4	15	9	8	4	0									
Cust 5	15	17	9	14	11	0								
Cust 6	20	23	15	20	16	6	0							
Cust 7	17	22	13	20	16	5	4	0						
Cust 8	8	17	9	19	16	11	14	10	0					
Cust 9	6	18	12	22	20	17	20	16	6	0				
Cust 10	16	23	14	22	19	9	8	4	8	14	0			
Cust 11	21	28	18	26	22	11	7	6	13	19	5	0		
Cust 12	11	22	14	24	21	14	16	12	5	7	9	13	0	
Cust 13	15	27	20	30	28	22	23	20	12	9	16	20	8	0

Identify the Savings Matrix

The savings matrix represents the savings that accrue on consolidating two customers on a single truck. Savings may be evaluated in terms of distance, time, or money. The manager at the Peapod DC constructs the savings matrix in terms of distance. A trip is identified as the sequence of locations a vehicle visits. The trip DC -> Cust x -> DC starts at the DC, visits customer x, and returns to the DC. The savings S(x,y) is the distance saved if the trips DC -> Cust x -> DC and DC -> Cust y -> DC are combined to a single trip, DC -> Cust x -> Cust y -> DC. These savings can be calculated by the following formula:

$S(x,y) = Dist(DC, x) + Dist(DC, y) – Dist(x, y)$ (2)

For example, using Table 3.5.2 the manager evaluates S(1,2) = 12 + 8 – 9 = 11.

The savings matrix for the Peapod deliveries is shown in Table 3.5.3. The savings matrix is then used to assign customers to vehicles or routes. Table 3.5.3: Savings Matrix for Peapod Deliveries

	Cust 1	Cust 2	Cust 3	Cust 4	Cust 5	Cust 6	Cust 7	Cust 8	Cust 9	Cust 10	Cust 11	Cust 12	Cust 13
Cust 1	0												
Cust 2	11	0											
Cust 3	21	15	0										
Cust 4	18	15	28	0									
Cust 5	10	14	18	19	0								
Cust 6	9	13	17	19	29	0							
Cust 7	7	12	14	16	27	33	0						
Cust 8	3	7	6	7	12	14	15	0					
Cust 9	0	2	1	1	4	6	7	8	0				
Cust 10	5	10	11	12	22	28	29	16	8	0			
Cust 11	5	11	12	14	25	34	32	16	8	32	0		
Cust 12	1	5	4	5	12	15	16	14	10	18	19	0	
Cust 13	0	3	2	2	8	12	12	11	12	15	16	18	0

Assign Customers to Vehicles or Routes

When assigning customers to vehicles, the manager attempts to maximize savings. An iterative procedure is used to make this assignment. Initially each customer is assigned to a separate route. Two routes can be combined into a feasible route if the total deliveries across both routes do not exceed the vehicle‘s capacity. At each iterative step, the Peapod manager attempts to combine routes with the highest savings into a new feasible route. The procedure is continued until no more combinations are feasible. At the first step, the highest savings of 34 results on combining truck Routes 6 and 11. The combined route is feasible because the total load is 16 + 91 = 107, which is less than 200. The two customers are thus combined on a single route, as shown in Figure 3.5.1, and the saving of 34 is eliminated from further consideration

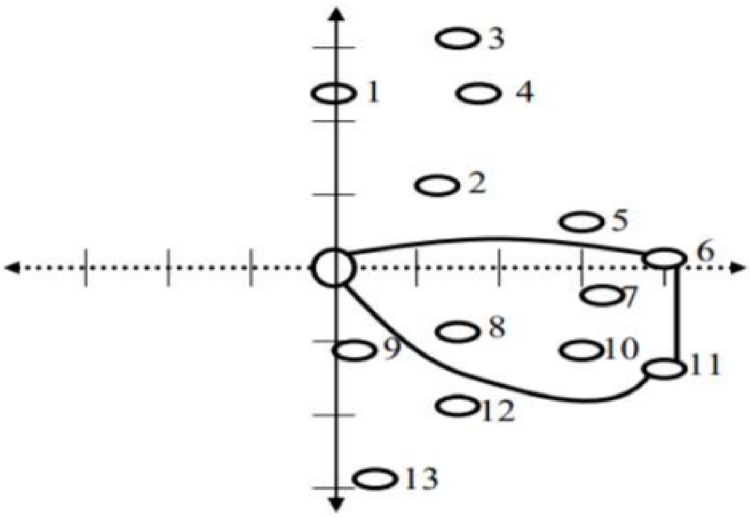

Figure 3.5.1: Delivery Route by Assigning 6 and 11 to a Common Route

The next highest saving is 33, which results from adding Customer 7 to the route for Customer 6. This is feasible because the resulting load is 107 + 56 = 163, which is less than 200. Thus, Customer 7 is also added to Route 6, as shown in Figure 3.5.2.

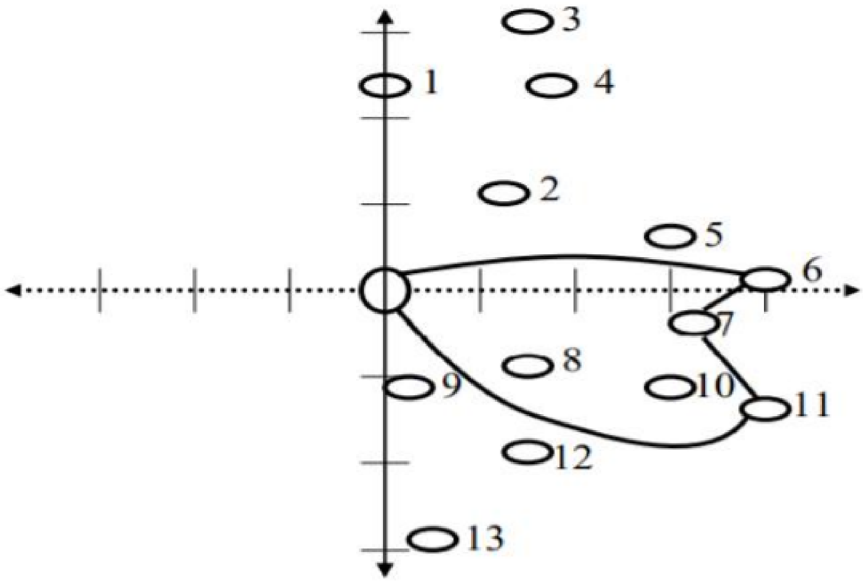

Figure 3.5.2: Delivery Route by Assigning 6, 7, and 11 to a Common Route

The next highest saving now is 32, which results from adding Customer 10 to Route 6 (we need not consider the saving of 32 on combining Customer 7 with Customer 11 because both are already in Route 6). This, however, is not feasible, as Customer 10 has a delivery totaling 47 units and adding this amount to the deliveries already on Route 6 would exceed the vehicle capacity of 200. The next highest saving is 29, which results from adding either Customer 5 or 10 to Route 6. Each of these is also infeasible because of the capacity constraint. The next highest saving is 28, which results from combining Routes 3 and 4, which is feasible. The two routes are combined into a single route, as shown in Figure 3.5.3

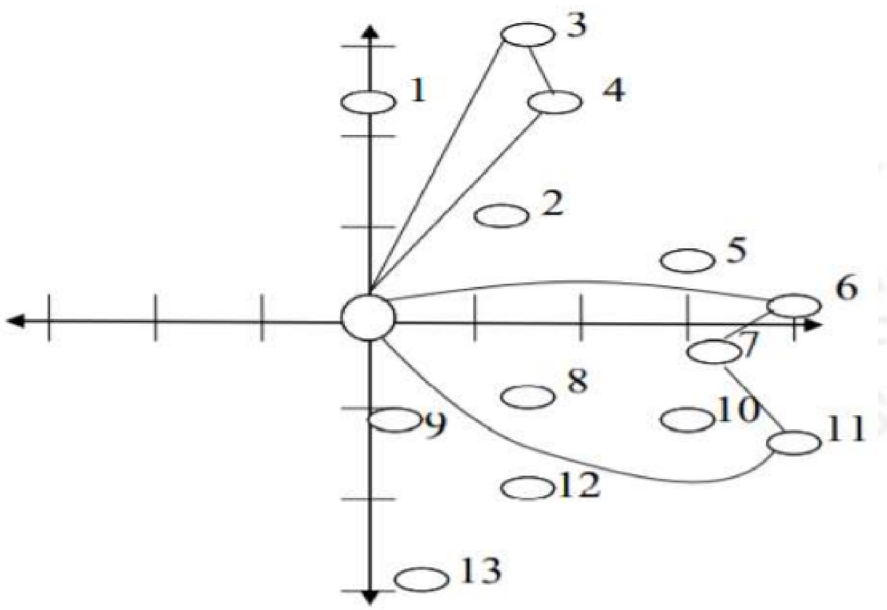

Figure 3.5.3: Delivery Route by Assigning 3 and 4 to a Common Route

Continuing the iterative procedure, the manager partitions customers into four groups {1, 3, 4}, {2, 9}, {6, 7, 8, 11}, {5, 10, 12, 13}, with each group assigned to a single vehicle. The next step is to identify the sequence in which each vehicle will visit customers.

Sequence Customers within Routes

At this stage the manager‘s goal is to sequence customer visits so as to minimize the distance each vehicle must travel. Changing the sequence in which deliveries are made can have a significant impact on the distance traveled by the vehicles. Consider the truck that has been assigned deliveries to Customers 5, 10, 12, and 13. If the deliveries are in the sequence 5, 10, 12, 13, the total distance traveled by the truck is 15 + 9 + 9 + 8 + 15 = 56 (distances are obtained from Table 3.5.2). In contrast, if deliveries are in the sequence 12, 5, 13, 10, the truck covers a larger distance of 11 + 14 + 22 + 16 + 16 = 79. Delivery sequences are determined by obtaining an initial route sequence and then using route improvement procedures to obtain delivery sequences with a lower transportation distance or cost.

ROUTE SEQUENCING PROCEDURES

The Peapod manager can use route sequencing procedures to obtain an initial trip for each vehicle. The initial trip is then improved using the route improvement procedure discussed later in this note. All route sequencing procedures are illustrated for the vehicle assigned to Customers 5, 10, 12, and 13.

Farthest Insert

Given a vehicle trip (including a trip consisting of only the DC) for each remaining customer, find the minimum increase in length for this customer to be inserted from all the potential points in the trip that they could be inserted. Then choose to actually insert the customer with the largest minimum increase to obtain a new trip. This step is referred to as a farthest insert because the customer farthest from the current trip is inserted. The process is continued until all remaining customers to be visited by the vehicle are included in a trip.

For the Peapod example, the manager is seeking a trip starting at the DC and visiting Customers 5, 10, 12, 13. The initial trip consists of just the DC with a length of 0. Including Customer 5 in the trip adds 30 to its length, including Customer 10 adds 32, including Customer 12 adds 22, and including Customer 13 adds 30 (see Table 3.5.2). Using the farthest insert, the manager adds Customer 10 to obtain a new trip (DC, 10, DC) of length 32.

At the next step, inserting Customer 5 in the trip raises the length of the trip to a minimum of 40, inserting Customer 12 raises it to 36, and inserting Customer 13 raises it to 47. The manager thus inserts the farthest Customer 13 to obtain the new trip (DC, 10, 13, DC) of length 47. This still leaves Customers 5 and 12 to be inserted. The minimum cost insertion for Customer 5 is (DC, 5, 10, 13, DC) for a length of 55, and the minimum cost insertion for Customer 12 is (DC, 10, 12, 13, DC) for a length of 48. The manager thus inserts Customer 5 to obtain a trip (DC, 5, 10, 13, DC) of length 55. Customer 12 is then inserted between Customers 10 and 13 to obtain a trip (DC, 5, 10, 12 13, DC) of length 56.

Nearest Insert

Given a vehicle trip (including a trip consisting of only the DC) for each remaining customer, find the minimum increase in length for this customer to be inserted from all the potential points in the trip that they could be inserted. Insert the customer with the smallest minimum increase to obtain a new trip. This step is referred to as a nearest insert because the customer closest to the current trip is inserted. The process is continued until all remaining customers the vehicle will visit are included in a trip.

For the Peapod example, the manager applies the nearest insert to the vehicle serving Customers 5, 10, 12, and 13. Starting at the DC, the nearest customer is 12.

Inserting Customer 12 results in the trip (DC, 12, DC) of length 22. At the next step, inserting Customer 5 results in a trip of length 40, inserting Customer 10 results in a trip of length 36, and inserting Customer 13 results in a trip of length 34. Customer 13 results in the smallest increase and is inserted to obtain a trip (DC, 12, 13, DC) of length 34. The next nearest insertion is Customer 10 resulting in a trip (DC, 10, 12, 13, DC) of length 48, and the final insertion of Customer 5 results in a trip (DC, 5, 10, 12, 13, DC) of length 56.

Nearest Neighbour

Starting at the DC, this procedure adds the closest customer to extend the trip. At each step, the trip is built by adding the customer closest to the point last visited by the vehicle until all customers have been visited.

For the Peapod example, the customer closest to the DC is 12 (see Table 3.5.2). This results in the path (DC, 12). The customer closest to Customer 12 is 13, extending the path to (DC, 12, 13). The nearest neighbour of Customer 13 is 10 and the nearest neighbour of Customer 10 is 5. The Peapod manager thus obtains a trip (DC, 12, 13, 10, 5, DC) of length 59.

Sweep

In the sweep procedure, any point on the grid is selected (generally the DC itself) and a line is swept either clockwise or counter clockwise from that point. The trip is constructed by sequencing customers in the order they are encountered during the sweep.

The Peapod manager uses the sweep procedure with the line centred at the DC. Customers are encountered in the sequence 5, 10, 12, 13 to obtain the trip (DC, 5, 10, 12 13, DC) for a length of 56.

The initial trips resulting from each route sequencing procedure and their lengths are summarized in Table 3.5.4.

Table 3.5.4: Initial Trips Using Different Route Sequencing Procedures at Peapod

Route Sequencing Procedure	Resulting Trip	Trip Length
Farthest insert	DC, 5, 10, 12, 13, DC	56
Nearest insert	DC, 5, 10, 12, 13, DC	56
Nearest neighbor	DC, 12, 10, 5, 13, DC	59
Sweep	DC, 5, 10, 12, 13, DC	56

ROUTE IMPROVEMENT PROCEDURES

Route improvements procedures start with a trip obtained using a route sequencing procedure and improve the trip to shorten its length. The Peapod manager next applies route improvement procedures to alter the sequence of customers visited by a vehicle and to shorten the distance a vehicle must travel. The two route improvement procedures discussed are illustrated on the trip obtained as a result of the nearest neighbor procedure.

2-OPT

The 2-OPT procedure starts with a trip and breaks it at two places. This results in the trip breaking into two paths, which can be reconnected in two possible ways. The length for each reconnection is evaluated, and the smaller of the two is used to define a new trip. The procedure is continued on the new trip until no further improvement results.

For example, the trip (DC, 12, 10, 5, 13, DC) resulting from the nearest neighbor procedure can be broken into two paths (13, DC) and (12, 10, 5) and reconnected into the trip (DC, 5, 10, 12, 13, DC), as shown in Figure 3.5.4. The new trip has length 56, which is an improvement over the existing trip.

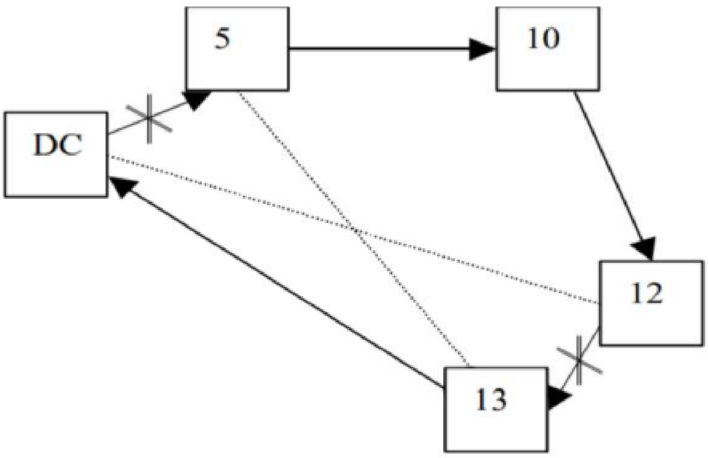

Figure 3.5.4: Improving Route Sequencing Using 2-OPT

3-OPT

The 3-OPT procedure breaks a trip at three points to obtain three paths that can be reconnected to form up to eight different trips. The length of each of the eight possible trips is evaluated and the shortest trip is retained. The procedure is continued on the new trip until no further improvement results.

The trip (DC, 5, 10, 12, 13, DC) resulting from the 2-OPT procedure is broken up into three paths (DC), (5, 10), and (12, 13). The various resulting trips on reconnecting the three paths are (DC, 12, 13, 5, 10, DC) of length 65, (DC, 12, 13, 10, 5, DC) of length 81, and (DC, 13, 12, 5, 10, DC) of length 61. All other trips correspond to one of these four trips reversed. This application of the 3- OPT procedure does not improve the trip because the current trip is the shortest. At this stage the Peapod manager can form three new paths from the trip and repeat the procedure.

The Peapod manager uses route sequencing and improvement procedures to obtain delivery trips for each of the four trucks, as shown in Table 3.5.5 and Figure 3.5.5. The total travel distance for the delivery schedule is 185.

Table 3.5.5: Peapod Delivery Schedule Using Saving Matrix Method

Truck	Trip	Length of Trip	Load on Truck
1	**DC, 2, 9, DC**	**32**	**93**
2	DC, 1, 3, 4, DC	39	183
3	DC, 8, 11, 6, 7, DC	58	193
4	DC, 5, 10, 12, 13, DC	56	197

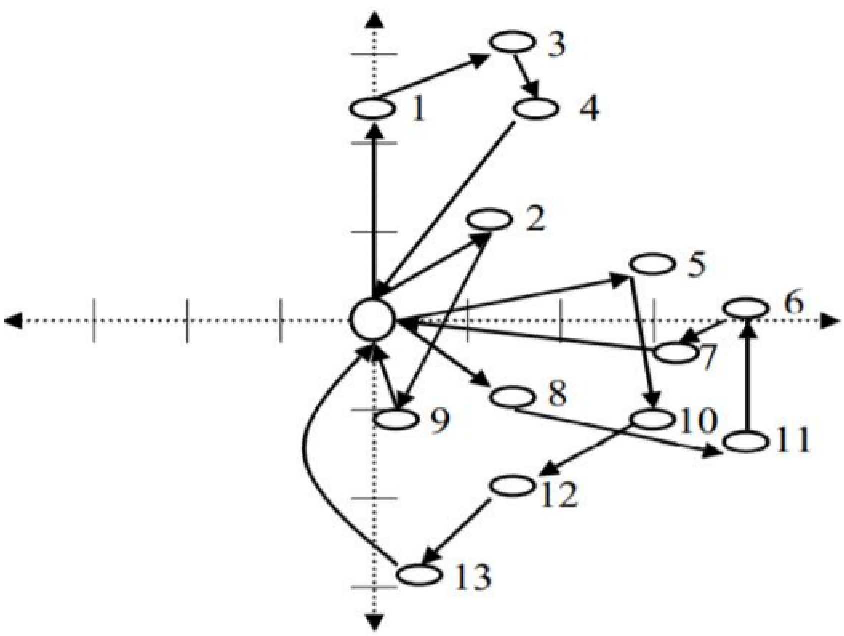

Figure 3.5.5: Delivery Routes at Peapod Using Savings Matrix Method

GENERALIZED ASSIGNMENT METHOD

The generalized assignment method is more sophisticated than the savings matrix method and usually results in better solutions when there are few delivery constraints to be satisfied. The procedure for routing and sequencing of vehicles consists of the following steps:

1. Assign seed points for each route.

2. Evaluate insertion cost for each customer.

3. Assign customers to routes.

4. Sequence customers within routes.

The first three steps result in customers being assigned to a vehicle, and the fourth step identifies a route for each vehicle to minimize the distance traveled. We discuss each step in greater detail in the context of the delivery decision at Peapod.

Assign Seed Points for Each Route

The goal of this step is to determine a seed point corresponding to the center of the trip taken by each vehicle using the following procedure:

1. Divide the total load to be shipped to all customers by the number of trucks to obtain Lseed, the average load allocated to each seed point.

2. Starting at any customer, use a ray starting at the DC to sweep clockwise to obtain cones assigned to each seed point. Each cone is assigned a load of Lseed.

3. Within each cone, the seed point is located in the middle (in terms of angle) at a distance equal to that of the customer (with a partial or complete load allocated to the cone) farthest from the DC.

The manager at Peapod uses the procedure described earlier to obtain seed points for the deliveries described in Table 1. Given four vehicles and a total delivery load across all customers of 666 units, the manager obtains an average load per vehicle of
$L_{seed} = 666 / 4 = 166.5$ units.

The next step is to sweep clockwise with a ray emanating from the DC to obtain four cones, one for each vehicle, including all customers. The first step in defining the cones is to obtain the angular position of each customer. The angular position (teta *i*) of customer *I* with coordinates (*xi* , *yi*)is the angle made relative to the *x* axis by the line joining the customer *I* to the origin (DC), as shown in **Figure 6**

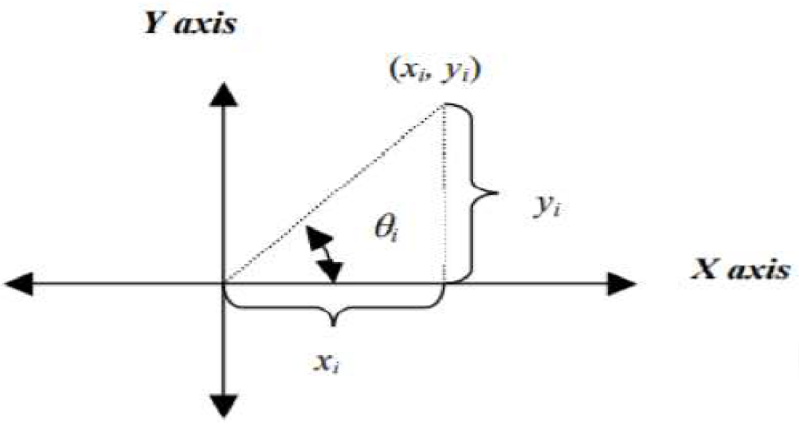

Figure 3.5.6 Angular Position of Customer i

The angular position of each customer is obtained as the inverse tangent of the ratio of its Y coordinate to the x coordinate.

$$\theta_i = \tan^{-1}(y_i/x_i)$$

The inverse tangent can be evaluated using the Excel function *ATAN()* as

$$\theta_i = \mathrm{ATAN}(y_i/x_i)$$

The angular position of each customer is obtained using Equation 4, as shown in **Table 6**

.

Table 3.5.6: Angular Positions of Peapod Customers

	X Coordinate	Y Coordinate	Angular Position (Radians)	Demand
DC	0	0		
Customer 1	0	12	1.57	48
Customer 2	6	5	0.69	36
Customer 3	7	15	1.13	43
Customer 4	9	12	0.93	92
Customer 5	15	3	0.20	57
Customer 6	20	0	0.00	16
Customer 7	17	-2	-0.12	56
Customer 8	7	-4	-0.52	30
Customer 9	1	-6	-1.41	57
Customer 10	15	-6	-0.38	47
Customer 11	20	-7	-0.34	91
Customer 12	7	-9	-0.91	55
Customer 13	2	-15	-1.44	38

The next step is to sweep clockwise and order the customers as encountered. For Peapod, a clockwise sweep encounters customers in the order 1, 3, 4, 2, 5, 6, 7, 11, 10, 8, 12, and 9. Starting with Customer 1, four cones, each representing a load of Lseed = 166.5 units, are formed. Customers 1 and 3 combine to load 91 units on the truck. Customer 4 is encountered next in the sweep. Adding the entire load for Customer 4 would result in a load of 183, which is larger than Lseed = 166.5. To get a load of 166.5, only 166.5 – 91 = 75.5 units of the load should be included. Thus, the first cone extends to a point that is 75.5 / 92 of the angle between Customers 3 and 4. Customer 3 has an angular position of 1.13 and Customer 4 has an angular position of 0.93, resulting in an angle between them of 1.13 – 0.93 = 0.20. The first cone thus extends to an angle (75.5 / 92) x 0.20 beyond Customer 3 with a resulting angle of 1.13 – (75.5 / 92) x 0.20 = 0.97. The first cone thus has one end at Customer 1 (angle of 1.57) and the other at an angle of 0.97, as shown in Figure 3.5.7.

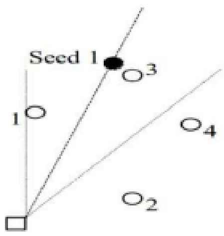

Figure 3.5.7: Sweep Method to Locate Seed 1

Seed Point	X Coordinate	Y Coordinate
S_1	5	16
S_2	20	2
S_3	19	-5
S_4	5	-5

Evaluate Insertion Cost for Each Customer

For each Seed Point Sk and Customer i, the insertion cost cik is the extra distance that would be traveled if the customer is inserted into a trip from the DC to the seed point and back and is given by:

$$c_{ik} = Dist(\mathrm{DC}, i) + Dist(i, S_k) - Dist(\mathrm{DC}, S_k),$$

where the Dist() function is evaluated as in Equation 1. For Customer 1 and Seed Point 1, the insertion cost is given by:

$$c_{11} = Dist(\mathrm{DC}, 1) + Dist(1, S_1) - Dist(\mathrm{DC}, S_1) = 12 + 10 - 17 = 5.$$

The Peapod manager evaluates all insertion costs cik, as shown in Table 3.5.9.

Table 3.5.9: Insertion Costs for Peapod Deliveries for Each Customer and Seed Point

Customer	Seed Point 1	Seed Point 2	Seed Point 3	Seed Point 4
1	2	14	18	23
2	2	2	5	11
3	2	15	21	30
4	4	10	15	25
5	15	0	4	21
6	25	2	5	29
7	22	2	1	22
8	11	2	0	3
9	12	7	4	3
10	24	5	0	19
11	32	10	4	29
12	20	8	4	8
13	30	20	15	18

Assign Customers to Routes

The manager next assigns customers to each of the four vehicles to minimize total insertion cost while respecting vehicle capacity constraints

The assignment problem is formulated as an integer program and requires the following input:

cik = insertion cost of Customer i and Seed Point k,

ai = order size from Customer i,

bk = capacity of Vehicle k.

Define the following decision variables:

yik = 1 if Customer i is assigned to Vehicle k, 0 otherwise.

The integer program for assigning customers to vehicles is given by:

$$\underset{y_{ik}}{Min} \sum_{k=1}^{K} \sum_{i=1}^{n} c_{ik}$$

subject to:

$$\sum_{k=1}^{K} y_{ik} = 1,\ i = 1,\ldots,n,$$

$$\sum_{i=1}^{n} a_i\, y_{ik} \leq b_k\ ,\ k = 1,\ldots,K,$$

$$y_{ik} = 0 \text{ or } 1, \text{ for all } i \text{ and } k.$$

For Peapod, the order size for each customer is given in Table 3.5.1, the insertion cost cik is obtained from Table 3.5.9, and the capacity of each vehicle is 200 units. The manager at Peapod solves the integer program using the Solver tool in Excel to obtain the assignment of customers to vehicles as shown in Table 3.5.10 and Figure 3.5.8. The sequencing of customers within each trip is obtained using the route sequencing and route improvement procedures discussed earlier. The total distance traveled for the delivery schedule is 159.

Table 3.5.10: Peapod Delivery Schedule Using Generalized Assignment Method

Truck	Trip	Length of Trip	Load on Truck
1	DC, 1, 3, 4, DC	39	183
2	DC, 2, 5, 6, 7, 8, DC	45	195
3	DC, 10, 11, 12, DC	45	193
4	DC, 9, 13, DC	30	95

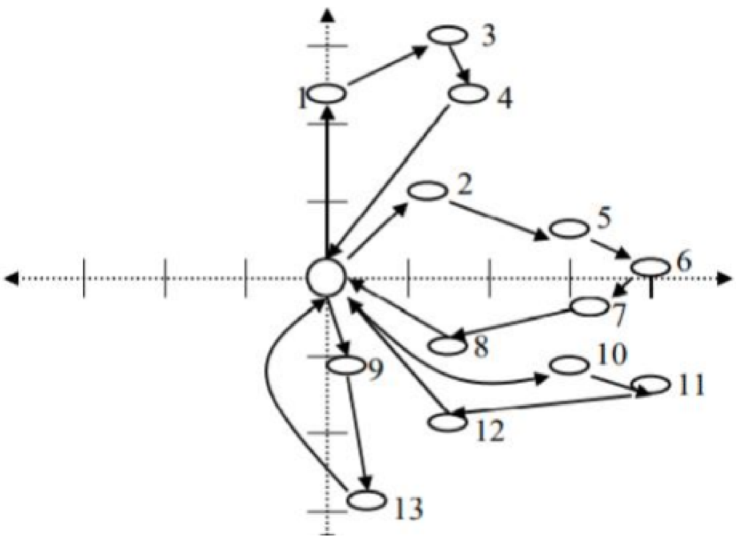

Figure 3.5.8: Delivery Routes at Peapod Using Generalized Assignment Method

Applicability of Routing and Scheduling Methods

The delivery schedule for Peapod resulting from the generalized assignment method in Table 3.5.10 is superior to the solution obtained from the savings matrix method in Table 3.5.5. The generalized assignment method is more sophisticated and generally gives a better solution than the savings matrix method when the delivery schedule has no constraints other than vehicle capacity.

The main disadvantage of the generalized assignment method is that it has difficulty generating good delivery schedules as more constraints are included. For example, if Peapod has fixed time windows within which deliveries must be made to customers, it is difficult to use the generalized assignment method to generate a delivery schedule. The generalized assignment method is recommended if the constraints are limited to vehicle capacity or total travel time.

The main strength of the savings matrix method is its simplicity and robustness. The method is simple enough to be easily modified to include delivery time windows and other constraints and robust enough to give a reasonably good solution that can be implemented in practice.

Its main weakness is the quality of the solution. It is often possible to find better delivery schedules using more sophisticated methods. The savings matrix method is recommended in case there are many constraints that need to be satisfied by the delivery schedule. Software packages for transportation planning and routing and scheduling of deliveries are available from many supply chain software companies.