ESSEC

BAR-ILAN UNIVERSITY

Department of Operations Management

Topics in Supply Chain Management

Session 4

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TRANSPORTATION ISSUES IN THE SUPPLY CHAIN

AGENDA

- DESIGN OPTIONS FOR A TRANSPORTATION NETWORK
- TRADE-OFFS IN TRANSPORTATION DESIGN
- CHOICE OF TRANSPORTATION MODE
- INVENTORY AGGREGATION
- TRANSPORTATION COST AND CUSTOMER RESPONSIVENESS TRADE-OFF
- TAILORED TRANSPORTATION
- ROUTING AND SCHEDULING IN TRANSPORTATION

DESIGN OPTIONS FOR A TRANSPORTATION NETWORK

The design transportation network impacts the supply chain performance by establishing the infrastructure within which operational transportation decisions regarding scheduling and routing are made.

Assuming a retail chain with multiple stores and many suppliers, the following design options for transportation networks can be considered:

- Direct shipping network

- Direct shipping with milk runs

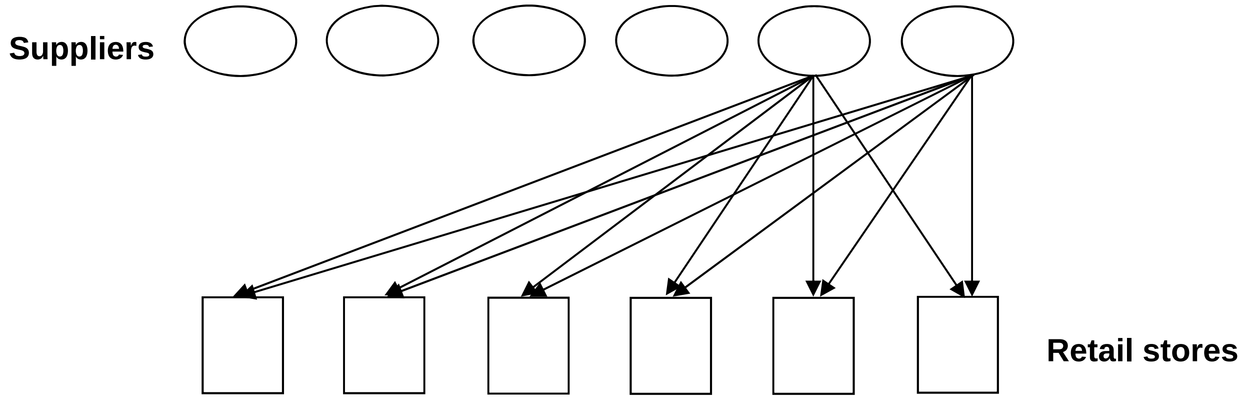
- All shipments via central distribution center

- Shipping via DC using milk runs

- Tailored network

DIRECT SHIPMENT NETWORK

With this option, all shipments come directly from suppliers to retail stores. The routing of each shipment is specified and the supply chain manager only needs to know on the quantity to ship and the mode of transportation to use. This decision involves a trade-off between transportation and inventory costs.



Characteristics:
- Elimination of intermediate warehouses
- Simplicity of operation and coordination
- Local shipment decision and no interdependencies between shipment decisions
- Short transportation time from supplier to retail store because of direct shipment.

Requirement: Retail stores should be large enough such that optimal replenishment lot sizes are close to a TL from each supplier to each retailer.

TL = truckload (single shipper's dedicated freight); LTL = Less than truckload (several shippers' consolidated freight).

With small retail stores, however, this option would be costly. That is,

* If a TL carrier is used, the high fixed cost of each truck results in large lots moving from suppliers to each retail store, resulting in high supply chain inventories.

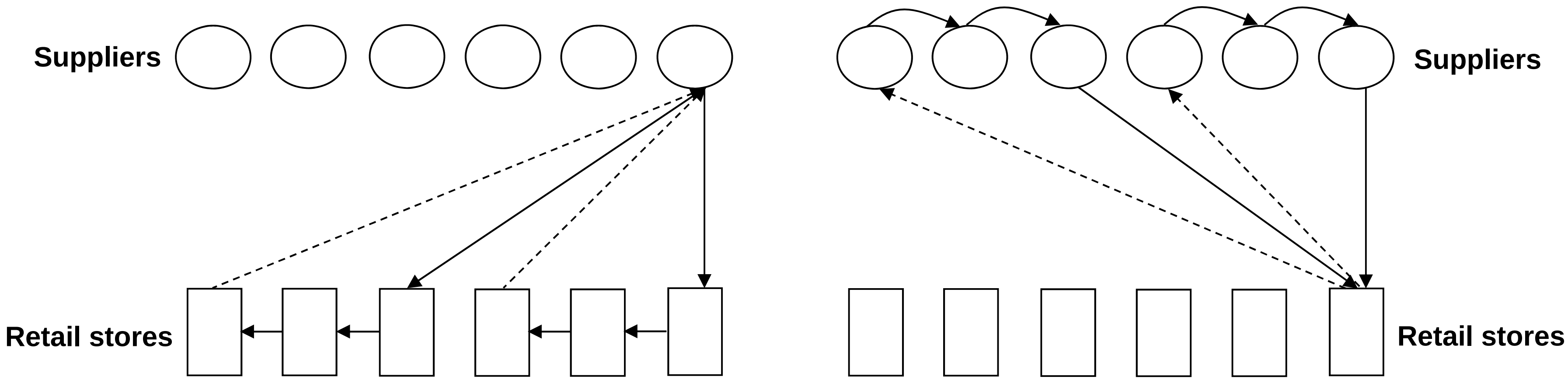
* If an LTL carrier is used, the transportation cost and delivery time increase despite lower inventories.

* If package carriers are used, transportation costs will be very high.

* With direct deliveries, receiving costs will be high because each supplier must make a separate delivery.

DIRECT SHIPMENT NETWORK WITH MILK RUNS

A milk run is a route in which a truck either delivers product from a single supplier to multiple retailers or goes from multiple suppliers to a single retailer. In direct shipping with milk runs, a supplier delivers directly to multiple retail stores on a truck, or a truck picks up deliveries from many suppliers destined for the same retail store. Here, a supply chain manager has to decide on the routing of each milk run.

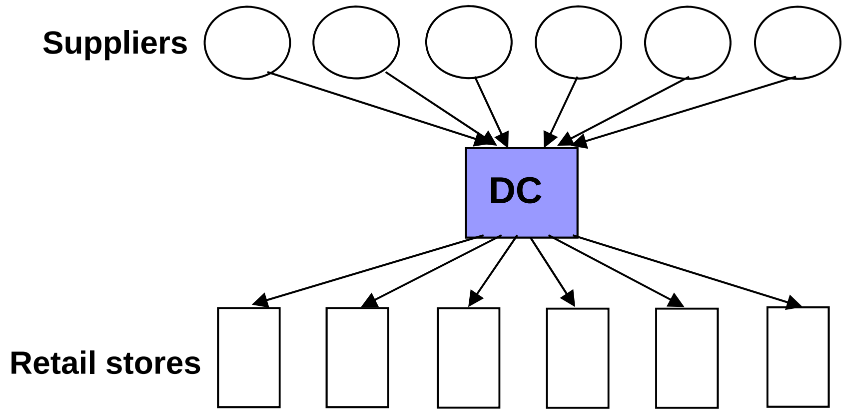


Compared with direct shipping, this option lowers transportation cost by consolidating shipments to multiple store on a single truck, which results in a better utilization of the truck in the case of small replenishment lot size for each retail store.

For example, Toyota uses milk runs from suppliers to support its JIT manufacturing system in both Japan and the United States. In Japan, Toyota has many assembly plants located closed to each other and thus uses milk runs from a single supplier to multiple plants. Conversely, in the United States, Toyota uses milk runs from many suppliers to its assembly plant.

ALL SHIPMENTS VIA CENTRAL DC

With this option, suppliers do not send shipments directly to retail stores. The retail chain divides stores by geographical region and a DC is built for each region. Suppliers send their shipments to the DC and the DC then forwards appropriate shipments to each retail store. Compared with the direct shipping option, which involves 6 x 6 = 36 shipments at a time, this option has only 6 + 6 = 12 shipments.



The DC can serve to store inventory and/or as a transfer location. In both cases, it can help reduce supply chain costs when suppliers are located far from the retail stores and transportation costs are high. 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 enough shipment to the DC for all stores to be served. As DCs serve stores located nearby, the outbound transportation cost is not very large.

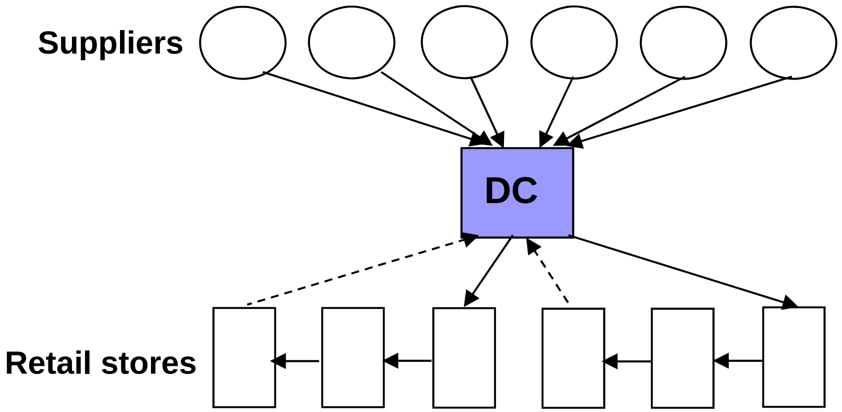
If transportation cost imposes very large inbound shipments, the DC holds inventory and send to retail stores smaller replenishment lots. When a firm sources from an overseas supplier, the product is held in inventory at the DC because the inbound lot size is much larger than the sum of the outbound lot sizes.

If outbound replenishment lots are large enough, the DC can simply cross-dock inbound shipments. Cross-docking saves on inventory cost and handling costs but requires strong coordination and synchronization between the inflows and outflows. It is appropriate for products with large, predictable demands.

For example, Wal-Mart has successfully used cross-docking to decrease inventories without incurring excessive transportation costs.

SHIPPING VIA DC USING MILK RUNS

Milk runs can be used from a DC if lot sizes to be delivered to each retail store are small. .



Milk runs reduce outbound transportation costs by consolidating all shipments. The use of cross-docking with milk runs requires strong coordination and suitable routing and scheduling of milk runs.

For example, 7- 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 7-Eleven to lower its transportation cost while sending small replenishment lots to each store.

TAILORED NETWORK

This option combines some of the previous options in order to reduce the cost and improves the responsiveness of the supply chain.

The transportation network may combine cross-docking, milk runs, and T and LTL carriers, along with package carriers, eventually.

High demand shipments to high demand retail outlets can be shipped directly while low shipments to low demand retail outlets are consolidated to and from the DC.

Operating in a tailored network requires significant investment in formation structure to facilitate the coordination.

PROS AND CONS OF VARIOUS TRANSPORTATION NETWORKS

Network structure	Pros	Cons
Direct shipping	No intermediate warehouse Simple to coordinate	High inventories Significant receiving costs
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-docking	Very 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

TRADE-OFFS IN TRANSPORTATION DESIGN

All transportation decisions in a supply chain network must take into account their impact on inventory costs, facility and processing costs, the cost of coordinating operations, as well as the level of responsiveness provided to customers.

For instance, Dell’s use of package carriers for delivering PCs to customers increases transportation cost but allows Dell to centralize its facilities and reduce inventory costs. To reduce its transportation costs, Dell should either sacrifice responsiveness to customers or increase the number of facilities and resulting inventories to move closer to customers.

The cost of coordinating operations is not easy to quantify. To make the appropriate transportation decision, companies should evaluate different transportation options in terms of costs and revenues and then rank them according to coordination complexity.

In this respect, the following trade-offs must be considered:

- Transportation and inventory cost trade-off,
- Transportation cost and customers responsiveness trade-off.

TRANSPORTATION AND INVENTORY COST TRADE-OFF

The trade-off between transportation and inventory costs is significant when designing a supply chain network. Two fundamental supply chain decisions involving this trade-off are:

- Choice of transportation mode

- Inventory aggregation.

CHOICE OF TRANSPORTATION MODE

Selecting a transportation mode is both a planning and an operational decision in a supply chain. That is, the decision regarding carriers with which a company contracts is a planning decision, while the choice of transportation mode for a particular shipment is an operational decision.

For both decisions, a shipper must balance transportation and inventory costs.

➔ The cheaper mode of transportation does not necessarily result in lower total costs for a supply chain, because cheaper modes of transport usually involve longer lead times and larger minimum shipment quantities, both of which result in larger inventory in the supply chain.

➔ Modes of transport that allow for shipping in small quantities lower inventory levels but tend to be more expensive. In general, the use of faster mode of transportation is most indicated for shipping valuable components which allow to carry low levels of inventory.

IMPACT OF TRANSPORTATION MODES ON SUPPLY CHAIN PERFORMANCE

The impact of using different modes of transportation on inventories, response time, and costs in the supply chain is reported below, each transportation mode is ranked along various dimensions with 1 being the lowest and 6 being the highest.

	Rail	**Truck (LTL)**	**Truck (TL)**	**Package**	**Air**	**Water**
Lot size	5	3	4	1	2	6
Safety inventory	5	3	4	1	2	6
In-transit inventory	5	3	4	1	2	6
Transportation cost	2	4	3	6	5	1
Transportation time	5	4	3	1	2	6

LTL = Less than truckload (several shippers' consolidated freight)

TL = truckload (single shipper's dedicated freight)

TRANSPORTATION AND INVENTORY COST TRADE-OFF

Unit inventory holding cost	Low (slow)	High (fast)
High	***Inefficient***	⇒ ***Short inventory cycle*** ⇒ ***Fast transportation modes***
Low	⇒ ***Long inventory cycle*** ⇒ ***Slow transportation modes***	***Inefficient***

Transportation cost (speed)

⇒ Faster modes of transportation are preferred for products with a high value to weight ratio where reducing inventories is important.

⇒ Conversely, slower modes are preferred for products with a small value to weight ratio where reducing transportation costs is important.

EXAMPLE: CENTRAL ELECTRIC COMPANY

To illustrate the importance of evaluating the trade-off between transportation and inventory costs, consider the example of Central Electric (CE), a major appliance manufacturer with a large plant in the Chicago area.

CE purchases all the motors for its appliances from SouthviewMotors located near Dallas. CE purchases from Southview 120 000 motors/year for $120/motor in lots of 3 000 motors.

Demand has been relatively constant for several years and is expected to remain that way.

Each motor averages 10 pounds in weight.

Southview ships each CE order ***within a day of receiving it***.

At its assembly plant, CE carries a safety stock equal to 50% of the average demand for motors during the delivery lead time.

The plant manager at CE has received several proposals for transportation and must decide on the one to accept.

TRANSPORTATION PROPOSALS FOR CENTRAL ELECTRIC

Carrier	Range of quantity shipped (cwt.)	Shipping cost ($/cwt.)
AMC Rail	200+	6.50
NE Trucks	100+	7.50
Green Freight	50-150	8.00
Green Freight	150-250	6.00
Green Freight	250-400	4.00

1 cwt. = 100 pounds.

Green's pricing represents a *marginal unit quantity discount*.

Green's representative has proposed lowering the marginal rate for the quantity over 250 cwt. in a shipment from $4/cwt. to $3/cwt.

⇒ Green's new proposal will result in very low transportation costs for CE if the plant manager order in lots of 4 000 motors.

CE's annual cost of holding inventory is 25%, which implies an annual holding cost of

$$H = \$120 \times 0.25 = \$30/\text{motor}$$

Shipments par rail require a 5-day transit time, whereas shipments by truck have a transit time of 3 days.

The transportation decision affects the cycle inventory, safety inventory, and in-transit inventory for CE. Therefore, the plant manager decides to evaluate the total transportation and inventory cost for each transportation option.

TRANSPORTATION AND INVENTORY COST AT CE WITH AMC RAIL

The AMC Rail requires a minimum shipment of 20 000 lbs. or 2 000 motors. The replenishment lead time in this case is ***L = 5 + 1 = 6 days***. For a lot size of *Q* = 2 000 motors, the plant manager obtains the following:

Cycle inventory = *Q*/2 = 2 000/2 = 1 000 motors

Safety inventory = *L* /2 days of demand = (6/2)(120 000/365) = 986 motors

In-transit inventory = 120 000(5/365) = 1 644 motors

Total average inventory = 1 000 + 986 + 1 644 = 3 630 motors

Annual holding cost using AMC Rail = 3 630 x $30 = $108 900

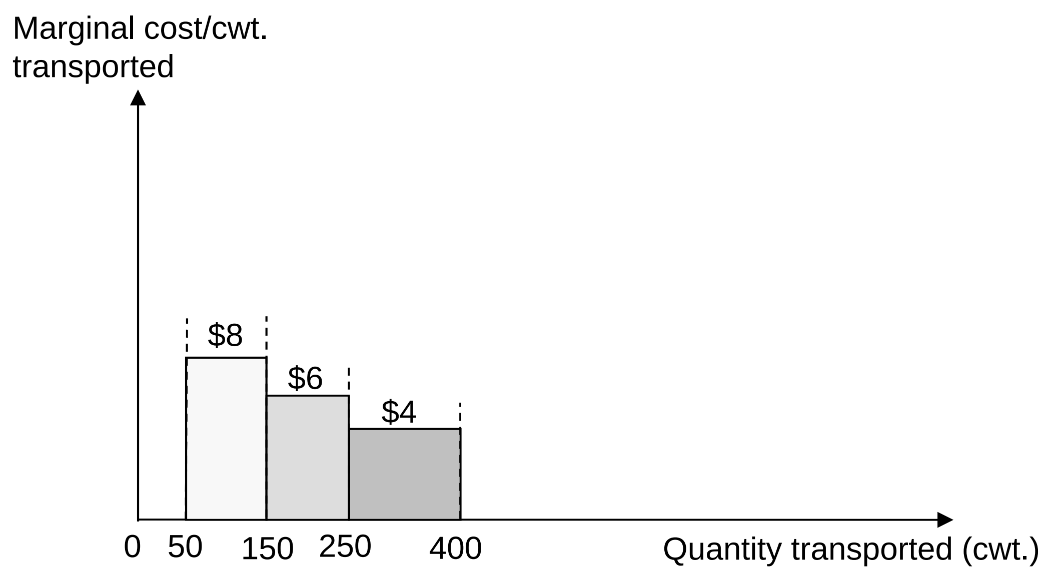
AMC Rail charges $6.50/cwt., that is, $0.65/motor. Thus,

Annual transportation cost using AMC Rail = 120 000 x $0.65 = $78 000

The total annual cost for inventory and transportation using AMC Rail is thus $186 900.

TRANSPORTATION AND INVENTORY COST AT CE WITH GREEN FREIGHT

Green's proposal relies on marginal unit quantity discounts (or multi-block tariffs).



If all the orders placed are within the size range 500-1500, the annual transportation cost with Green is:

$$120\,000 \times \$0.80 = \$96\,000$$

If an order of size $Q \in\ ]1500, 2500]$ is placed, the first 1500 units are priced at \$0.8, and the remaining Q – 1500 units are priced at \$0.6, and so on.

Therefore, the annual transportation cost is:

$$(120\,000/Q)[0.8 \times 1500 + 0.6 \times (Q - 1500)]$$

For Q = 2 500, we get: (120 000/2 500)[0.8 x 1500 + 0.6 x (2 500 – 1500)] = 48[1 200 + 600] = \$86 400

For Q = 3 000, we get: (120 000/3 000)[0.8 x 1500 + 0.6 x (2 500 – 1500) + 0.3 x (3 000 – 2 500)] = \$78 000

TRANSPORTATION AND INVENTORY COST AT CE

The plant manager then evaluates the cost associated with each transportation option.

Alternatives	Lot size (motors)	Transportation cost	Cycle inventory	Safety inventory	In-transit inventory	Inventory cost	Total cost
AMC Rail	2 000	$78 000	1 000	986	1 644	$108 900	$186 900
NE Trucks	1 000	$90 000	500	658	986	$64 320	$154 320
Green	500	**$96 000**	250	658	986	$56 820	**$152 820**
Green	1 500	$96 000	750	658	986	$71 820	$167 820
Green	2 500	$86 400	1 250	658	986	$86 820	$173 220
Green	3 000	$78 000	1 500	658	986	$94 320	$172 320
Green (old proposal)	4 000	$72 000	2 000	658	986	$109 320	$181 320
Green (new proposal)	4 000	**$67 500**	2 000	658	986	$109 320	**$176 820**

Based on the analysis above, the plant manager decides to sign a contract with Green and order motors in lots of 500. This option has the highest transportation cost but the lowest overall cost.

If the selection of the transportation option was made using only the transportation cost incurred, Green's new proposal lowering the price for large shipments would look attractive. Actually, CE pays a high overall cost for this proposal. Thus, considering the trade-off between inventory and transportation costs allows the plant manager to make a transportation decision that minimizes CE's total cost.

INVENTORY AGGREGATION

Firms can significantly reduce the safety stock they require by physically aggregating inventories in one location. Most e-businesses have used this technique to gain advantage over firms with facilities in many locations.

For instance, Amazon.com has focused on decreasing its facility and inventory costs by holding inventory in a few warehouses, whereas booksellers like Barnes have to hold inventory in many retail stores.

Transportation cost, however, increases when inventory is aggregated.

Consider a bookstore chain such as Barnes. The inbound transportation cost to Barnes is due to the replenishment of bookstores with new books. There is no outbound cost because customers transport their own books home.

If Barnes decides to close all its bookstores and only sell online, it will have to incur both inbound and outbound costs. The inbound transportation cost to warehouses will be lower than to all bookstores. On the outbound side, however, transportation cost will increase significantly because the outbound shipment to each customer will be small and will require an expensive mode such as package carrier. The total transportation cost will increase on aggregation because each book will travel the same distance as when it was sold through a bookstore, except that a large fraction of the distance will be on the outbound side using an expensive mode of transportation.

INVENTORY AGGREGATION AND TRANSPORTATION COSTS

As the degree of inventory aggregation increases, total transportation cost goes up.

$\Rightarrow$ All firms planning inventory aggregation must consider the trade-off between transportation, inventory, and facility costs when making this decision.

Inventory aggregation is relevant If:

- Inventory and facility costs form a large fraction of a supply chain's total costs. It is useful for products with a large value to weight ratio and for products with high demand uncertainty (e.g. PCs industry).

- Customer orders are large enough to ensure sufficient economies of scale on outbound transportation.

When products have a low value to weight ratio and customer orders are small, however, inventory aggregation may hurt a supply chain's performance because of high transportation costs. Compared to PCs, the value of inventory aggregation is smaller for best-selling books that have a lower value to weigh ratio and more predictable demand.

EXAMPLE: HAMPTON INC.

To illustrate the tradeoff involved in making aggregation decisions, consider the example of Hampton Inc., a manufacturer of medical equipment used in heart procedures.

Hampton is located in Wisconsin and cardiologists all over North America use its equipment. The medical equipment is directly sold to doctors.

Hampton has currently divided the United States into 24 territories, each with its own sales force.

All product inventories are maintained locally and replenished from Madison every four weeks using UPS.

The average replenishment lead time using UPS is one week. UPS charges at a rate of \$0.66 + 0.26x, where x is the quantity shipped in pounds.

The products sold fall into two categories – Moreval and Lessval. Moreval products weigh 0.1 lbs. and cost \$200 each. Lessval products weigh 0.04 lbs. and cost \$30 each.

Weakly demand for Moreval products in each territory is normally distributed with a mean of μ_M = 2 and a standard deviation of σ_M = 5. Weakly demand for Lessval products in each territory is normally distributed with a mean of μ_L = 20 and a standard deviation of σ_L = 5.

Hampton maintains sufficient safety inventories in each territory to provide customer service level of 0.997 for each product. Holding cost at Hampton is 25%.

HAMPTON INC. (continued)

The management team of Hampton wants to evaluate the operating cost of the current operating procedure and compare it with two other options they have been considering.

1. ***Option A*****:** Keep the current structure but start replenishment inventory once a week rather once every four weeks.
2. ***Option B:*** Eliminate inventories in the territories, aggregate all inventories in a finished goods warehouse at Madison, and replenish the warehouse once a week.

If inventories are aggregated at Madison, orders will be shipped using Fedex, which charges \$5.53 + 0.53*x* per shipment where *x* is the quantity shipped in pounds.

The factory requires a one-week lead time to replenish finished goods inventories at the Madison warehouse.

An average customer order is for 1 unit of Moreval and 10 units of Lessval.

Hampton can reduce transportation cost by aggregating the quantity shipped at a time because prices for both UPS and Fedex display economies of scale.

When comparing Option A with the current system, the management team must trade off the savings in transportation cost through less frequent replenishment with the savings in inventory cost with more frequent replenishment.

When considering Option B, the management team must trade off the increase in transportation cost upon aggregation of inventories and the use of faster but more expensive carrier (Fedex) with the decrease in inventory cost.

HAMPTON INC. (continued)

The management team first analyzes the current situation. For each territory, we have:

Replenishment lead time	L = 1 week
Reorder interval	T = 4 weeks
	CSL = 0.997

1. Hampton inventory costs (current scenario):

For Moreval in each territory, the management team obtains the following:

Average lot size Q_M = Expected demand during T weeks = $T\mu_M$ = 4 x 2 = 8 units

Safety inventory $ss_M = F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sigma_M (T+L)^{0.5} = NORMINV(0.997) \times 5(4+1)^{0.5}$ = 30.7 units

Total Moreval inventory = $Q_H/2 + ss_M$ = (8/2) + 30.7 = 34.7 units

Across all 24 territories, Hampton thus carries Moreval inventory of 24 x 34.7 = 832.8 units.

For Lessval in each territory, the management team obtains the following:

Average lot size Q_L = Expected demand during T weeks = $T\mu_L$ = 4 x 20 = 80 units

Safety inventory $ss_L = F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sigma_L (T+L)^{0.5} = NORMINV(0.997) \times 5(4+1)^{0.5}$ = 30.7 units

Total Lessval inventory = $Q_L/2 + ss_L$ = (80/2) + 30.7 = 70.7 units

Across all 24 territories, Hampton thus carries Lessval inventory of 24 x 70.7 = 1696.8 units.

Annual inventory holding for Hampton = (average Moreval inventory x \$200 + average Lessval inventory x \$30) x 0.25 = (832.8 x \$200 + 1696.8 x \$ 30) x 0.25 = \$54 366.

HAMPTON INC. (continued)

2. Hampton transportation cost (current scenario): the average replenishment order from each territory consists of Q_M units of Moreval and Q_L units of Lessval. Thus:

Average weight of each replenishment order = $0.1Q_M + 0.04Q_L$ = 0.1 x 8 + 0.04 x 80 = 4 lbs.

Shipping cost per replenishment order = $0.66 + 0.26 x 4 = $1.7

Each territory has 13 replenishment orders per year (i.e., 1 every 4 weeks), and there are 24 territories, which gives:

Annual transportation cost = $1.7 x 13 x 24 = $530

3. Hampton total cost (current scenario): Annual inventory and transportation cost at Hampton = $54 366 + $530.4 = $54 896.4

The Hampton management team evaluates the cost for Option A and Option B similarly (cf. following table).

HAMPTON COSTS UNDER DIFFERENT NETWORK OPTIONS

	Current scenario	Option A	Option B
Number of stock locations	24	24	1
Reorder interval	4 weeks	1 week	1 week
Moreval cycle inventory	96 units	24 units	24 units
Moreval safety inventory	736.8 units	466 units	95.2 units
Moreval inventory	832.8 units	490 units	119.2 units
Lessval cycle inventory	960 units	240 units	240 units
Lessval safety inventory	736.8 units	466 units	95.2 units
Lessval inventory	1 696.8 units	706 units	335.2 units
Annual inventory cost	$54 366	$29 795	$8 474
Shipment type	Replenishment	Replenishment	Customer order
Shipment size	8 Moreval + 80 Lessval	2 Moreval + 20 Lessval	1 Moreval + 10 Lessval
Shipment weight	4 lbs.	1 lb.	0.5 lbs.
Annual transport cost	$530	$1 148	$14 464
Total annual cost	$54 896	$30 943	**$22 938**

HAMPTON FINAL CHOICE

• Increasing the replenishment frequency under Option A decreases total cost at Hampton. The increase in transportation costs is much smaller than the decrease in inventory costs resulting from smaller lots. Hampton can reduce the total cost the most by aggregating all inventories and using Fedex for transportation because the decrease in inventories on aggregation is larger than the increase in transportation costs.

• If customer order sizes are small, the increase in transportation cost on aggregation can be significant and inventory aggregation may increase total costs. Assume now that each customer order averages 0.5 Moreval and 5 Lessval (half the size considered earlier).

⇒ The cost for the current option as well as Option A remain unchanged because Hampton does not pay for outbound transportation and only incurs the cost of transporting replenishment orders under both options.

⇒ Option B, however, becomes more expensive because outbound transportation costs increase with a decrease in customer order size. The costs under Option B are as follows:

Average weight of each customer order = 0.1 x 0.5 + 0.04 x 5 = 0.25 lbs.
Shipping cost per customer order = $5.53 + 0.53 x 0.25 = $5.66
Number of customer orders per territory per week = 4
Total customer orders per year = 4 x 24 x 52 = 4 992
Annual transportation cost = 4 992 x 5.66 = $28 255
Total annual cost = inventory cost + transportation cost = $8 474 + $28 255 = $36 729

Thus, with small customer orders, inventory aggregation is no longer the lowest cost option for Hampton because of the large increase in transportation costs. The company is better off maintaining inventory in each territory and using Option A, which gives a lower total cost.

TRANSPORTATION COST AND CUSTOMER RESPONSIVENESS TRADE-OFF

The transportation cost a supply chain incurs is closely related to the degree of responsiveness the supply chain aims to provide.

• If a firm has high responsiveness and ships all orders within a day of their receipt from the customer, it will have small outbound shipments resulting in a high transportation cost.

• If it decreases its responsiveness and aggregates orders over a longer time horizon before shipping them out, it will be able to exploit economies of scale and incur a lower transportation cost because of larger shipments.

⇒ Therefore, a firm must consider the trade-off between responsiveness and transportation cost when designing its transportation network.

EXAMPLE: ALDI STEEL

To illustrate the tradeoff between transportation cost and customer responsiveness, consider the example of Aldi Steel, a steel service center in the Cleveland area.

Aldi ships orders to customers using truck that charges \$100 + 0.01*x*, where *x* is the number of pound of steel shipped on the truck. The carrier also charges \$10 for each customer delivery.

Currently, Aldi Steel ships orders on the day they are received. Allowing for two days in transit, this policy allows Aldi to achieve a response time of two days.

Daily demand at Aldi Steel over a two-week period is reported below.

Week 1	19 970	17 470	11 316	26 192	20 263	8 381	25 377
Week 2	39 171	2 158	20 633	23 370	24 100	19 603	18 442

The general manager at Aldi Steel feels that customers do not really value the 2-day response time and be satisfied with a four-day response.

As the response time increases, Aldi Steel has the opportunity to aggregate demand over multiple days before shipping (e.g., for a response time of four days, demand can be aggregated over three days before shipping).

ALDI STEEL (continued)

The manager evaluates the quantity shipped and transportation costs for different response times over the two-week period as follows.

		2-Day response		3-Day response		4-Day response	
Day	**Demand**	**Quantity shipped**	**Cost**	**Quantity shipped**	**Cost**	**Quantity shipped**	**Cost**
1	19 970	19 970	$299.7	0	$-	0	$-
2	17 470	17 470	$274.7	37 440	$474.40	0	$-
3	11 316	11 316	$213.16	0	$-	48 756	$587.56
4	26 192	26 192	$361.92	37 508	$475.08	0	$-
5	20 263	20 263	$302.63	0	$-	0	$-
6	8 381	8 381	$183.81	28 644	$386.44	54 836	$648.36
7	25 377	25 377	$353.77	0	$-	0	$-
8	39 171	39 171	$491.71	64 548	$745.48	0	$-
9	2 158	2 158	$121.58	0	$-	66 706	$767.06
10	20 633	20 633	$306.33	22 791	$327.91	0	$-
11	23 370	23 370	$333.70	0	$-	0	$-
12	24 100	24 100	$341.00	47 470	$574.70	68 103	$781.03
13	19 603	19 603	$296.03	0	$-	0	$-
14	18 442	18 442	$284.42	38 045	$480.45	38045	$480.45
			$4 164.46		**$3 464.46**		**$3 264.46**

ALDI STEEL (end)

The transportation cost for Aldi Steel decreases as the response time increases. The benefit of temporal consolidation, however, declines rapidly on increasing the response time since an increase in the response time from two to three days over the two-week window decreases the transportation cost of $700, while an increase in the response time from three to four days reduces the transportation cost by $200 only (i.e., decreasing marginal benefit).

Therefore, a limited amount of temporal aggregation can be very effective at reducing transportation cost in a supply chain. Firms must however trade-off the decrease in transportation cost of temporal aggregation with the loss of revenue because of poorer responsiveness when choosing the appropriate response time.

Temporal aggregation also smoothes transportation operations as it results in more stable shipments. When Aldi Steel sends daily shipments, the coefficient of variation (σ / μ) is 0.44, whereas a four-day response time has a coefficient of variation of only 0.16. More stable shipments allow both Aldi Steel and the carrier to better plan operations and improve utilization of their assets.

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. Given these differences, such firms 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.

Various forms of tailored transportation can be considered in supply chains, that is:

-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.

	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 distribution center (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 because this scenario makes appropriate use of the vehicles.

• If the density is high but distance from the warehouse is large, it is not appropriate to send milk runs from the warehouse because trucks will travel a long distance empty on the return trip. In this situation, it is preferable 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. It may not be ideal for a firm to own its own fleet.

• 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 very low density of customers far from the warehouse even LTL carriers may not be feasible and the use of package carriers may be most appropriate.

Customers density and distance should also be considered when firms decide on the degree of temporal aggregation to use when supplying customers. Firms should serve areas with high customers 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 when serving areas with low customer density.

TAILORED TRANSPORTATION BY SIZE OF CUSTOMER

Firms must consider customer size and location when designing transportation networks. Very large customers can be supplied using a TL carrier, whereas smaller customers will require LTL carriers 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. One option firms have is to charge a higher delivery cost for smaller customers. Another option is to tailor milk runs so that they visit larger customers with a higher frequency than smaller customers. Firms can split customers into large (L), medium (M) small (S) based on the demand of each (e.g., ABC analysis). 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 three milk runs, suitable milk runs can be designed by combining large, medium, and small customers on each run. Medium customers would be partitioned into two subsets (M_1, M_2), and small customers would be partitioned into three subsets (S_1, S_2, S_3). The firm can sequence the following six milk runs to ensure that each customer is visited with the appropriate frequency:

$$(L, M_1, S_1), (L, M_2, S_2), (L, M_1, S_3), (L, M_2, S_1), (L, M_1, S_2), (L, M_2, S_3)$$

This tailored sequence has the advantage that each truck carries about the same load and 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 below.

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 lot 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

The cycle inventory for high value products with high demand is disaggregated to save on transportation costs because this allows replenishment orders to be transported less expensively. Safety inventory for these products can be aggregated to reduce inventories and a fast mode of transportation can be used if the safety inventory is required to meet customer demand.

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 products, high-value products, all inventories should be aggregated to save on inventory costs.

For low-demand products, low-value products, cycle inventories can be held close to the customer and safety inventories aggregated to reduce transportation costs while taking some advantage of aggregation. Cycle inventories are replenished using an inexpensive transportation mode to save costs.

ROUTING AND SCHEDULING IN TRANSPORTATION

The most important operational decision related to transportation in a supply chain is the routing and scheduling of deliveries.

Managers must decide on the customers to be visited by a particular vehicle and the sequence in which they will be visited. The success of these operations relies on their 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 are a combination of minimizing cost by decreasing the number of vehicles needed, the total distance traveled by vehicles, and the total travel time of vehicles, as well as minimizing delay in shipments.

THE SIMPLEST PROBLEM

Consider N customers that are to be delivered by vehicles from a DC denoted by 0.

Assumptions:

- There are as many vehicles as customers
- The traveling cost, the traveling distance or the traveling penalties between the locations are symmetric:

$$\text{Total cost: } 2C_{01} + 2C_{02} + \ldots + 2C_{0N}$$

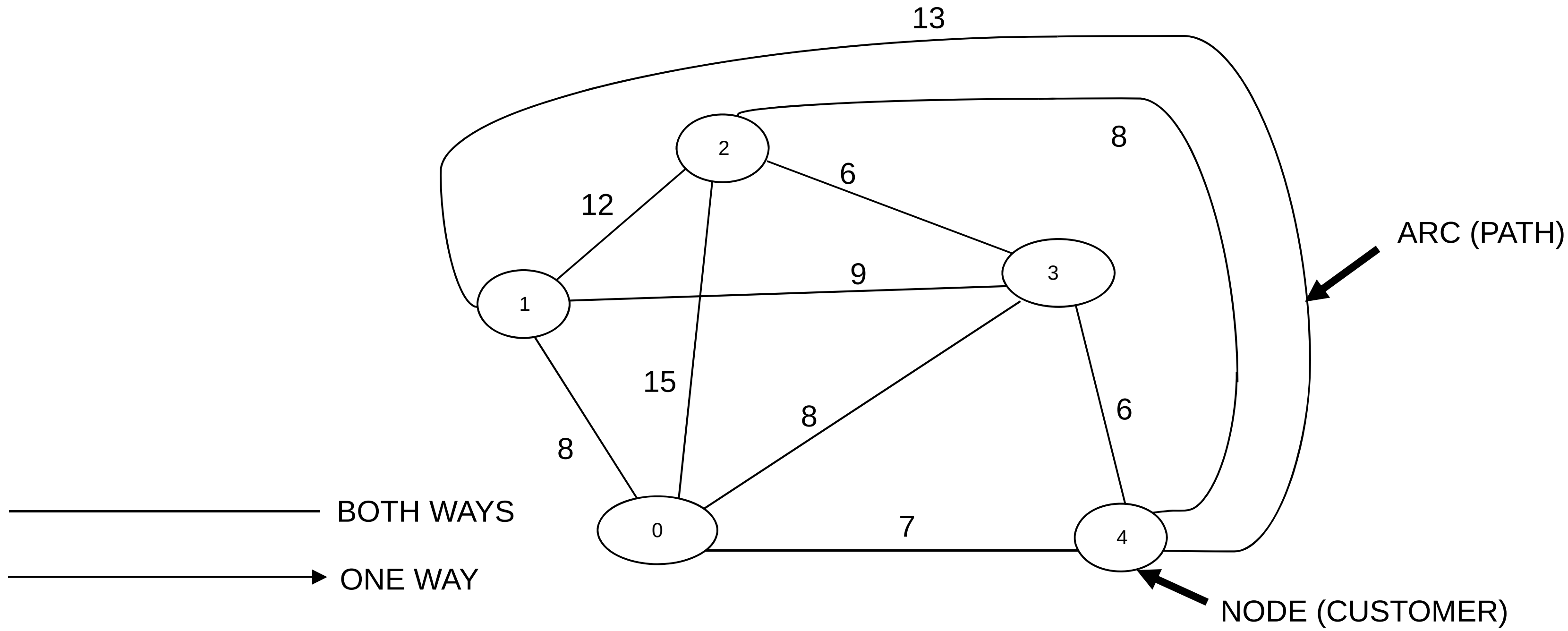
➔ The net savings obtained by connecting locations i et j on the same route are :

$$S_{ij} = C_{0i} + C_{0j} – C_{ij}$$

The route is designed sequentially by connecting the locations that allow for the largest net savings.

THE SIMPLEST EXAMPLE

Assume that 4 customers are to be delivered from a DC denoted by 0. The distance (in miles) between each pair of locations is perfectly known. Note that if the transportation costs between every pair of locations are known, the cost can be used in place of distances.



		1	2	3	4
DC	0	8	15	8	7
	1		12	9	13
CUSTOMERS	2			6	8
	3				6

CLARK-WRIGHT ALGORITHM

1 – Make an initial assignment with one vehicle for one customer

➔ Initial solution

Total distance round-way for four vehicles (one vehicle/customer) = 76 miles (2 x 38)

2 – Determine the net savings S_{ij} for each pair of customers

➔ Savings matrix

Potential savings

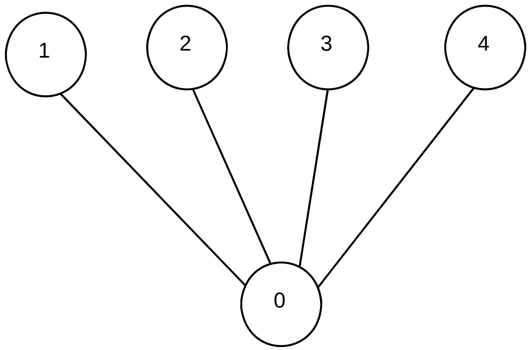
			1	2	3	4
DC	0		-	-	-	-
			1	11	7	2
		CUSTOMERS		2	17	14
					3	9

CLARK-WRIGHT ALGORITHM (Continued)

3 – Write the appropriate value of the binary variable T_{ij} in the first row of the saving matrix and circle them.

$T_{ij} = 0$	No vehicle travels between locations i and j
$T_{ij} = 1$	One vehicle travels from location i to location j (one-way trip)
$T_{ij} + T_{jj} = 2$	One vehicle travels from location i to location j and back (round-way trip)

		1	2	3	4
DC	0	②	②	②	②
		1	11	7	2
	CUSTOMERS		2	17	14
				3	9



Graph

Routes

(i) 0 – 1 – 0
(ii) 0 – 2 – 0
(iii) 0 – 3 – 0
(iiii) 0 – 4 – 0

CLARK-WRIGHT ALGORITHM (end)

4 – Identify the maximum potential saving. If the maximum potential saving is between i and j, the locations i et j can be connected if the following conditions are fulfilled:

a. T_{0i} and T_{0j} are both larger than zero,

b. Locations i and j are not on the same route, yet.

c. Connecting i and j does not violate any constraint.

5 – If all conditions in step 4 – are fulfilled, write $T_{ij} = 1$.
Locations i and j are now on the same route.

6 – Make the needed adjustments for T_{0i} and T_{0j} by subtracting the value 1.

7 – Return to step 4 –.

8 – When all the locations are on the same route, the problem is solved.

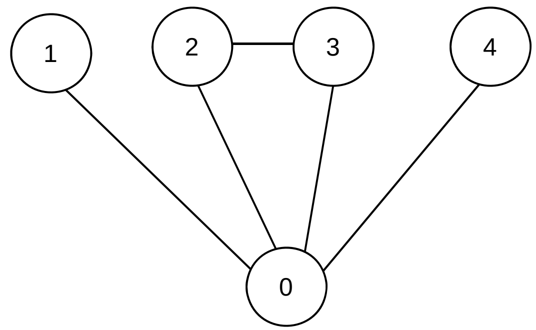
RESOLUTION

First iteration:

	1	2	3	4
0	②	①	①	②
1		11	7	2
2			① 17	14
3				9

Circuits

(i) 0 – 1 – 0
(ii) 0 – 2 – 3 – 0
(iii) 0 – 4 – 0

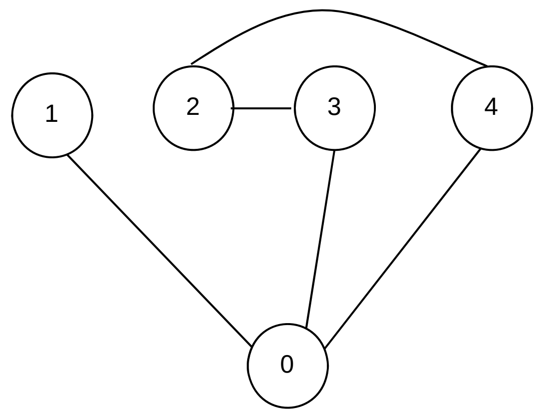


Second iteration:

	1	2	3	4
0	②	. . .	①	①
1		11	7	2
2			① 17	① 14
3				9

Circuits

(i) 0 – 1 – 0
(ii) 0 – 3 – 2 – 4 – 0

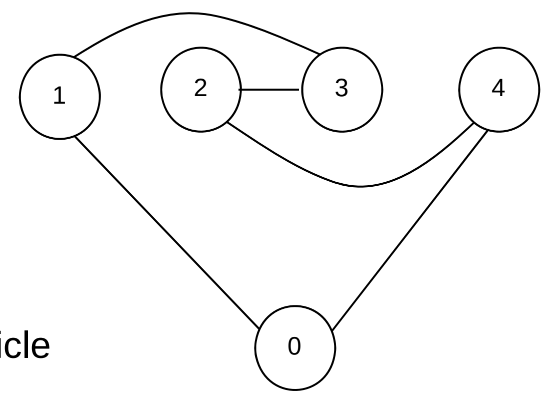


Third iteration:

	1	2	3	4
0	①	. . .	. . .	①
1		11	① 7	2
2			① 17	① 14
3				9

Circuit

0 – 1 – 3 – 2 – 4 – 0



➔ Total distance: 38 miles with 1 vehicle

ROUTING UNDER LOAD CAPACITY CONSTRAINT: THE CHILDGUM CASE

To illustrate the problem of routing and scheduling under load capacity constraint, consider the example of Childgum, an online grocer that delivers customer orders to their homes.

The DC manager at Childgum has orders from 13 different customers that are to be delivered. The manager has 4 trucks, each with a carrying capacity of 200 units. The manager considers that the delivery costs are correlated with the total traveling distance of the trucks and that the distance between 2 points on the grid is correlated with the actual distance that a vehicle will travel between those 2 points. The location of the DC, each customer on a grid, and the order size from each customer are reported below.

	***X*-coordinate**	***Y*-coordinate**	**Order size a_i**
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

IDENTIFY THE DISTANCE MATRIX

The distance matrix identifies the distance between every pair of locations to be visited.

We compute the (Euclidian) distance *Dist*(*A*, *B*) on a grid between a point *A* with coordinates (x_A, y_A) and a point *B* with coordinates (x_B, y_B) as:

$$Dist(A, B) = [(x_A - x_B)^2 + (y_A - y_B)^2]^{1/2}$$

	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 SAVING MATRIX

The distance matrix identifies the distance between every pair of locations to be visited.

We compute the saving *S*(*A*, *B*) between the locations *A* and point *B* as:

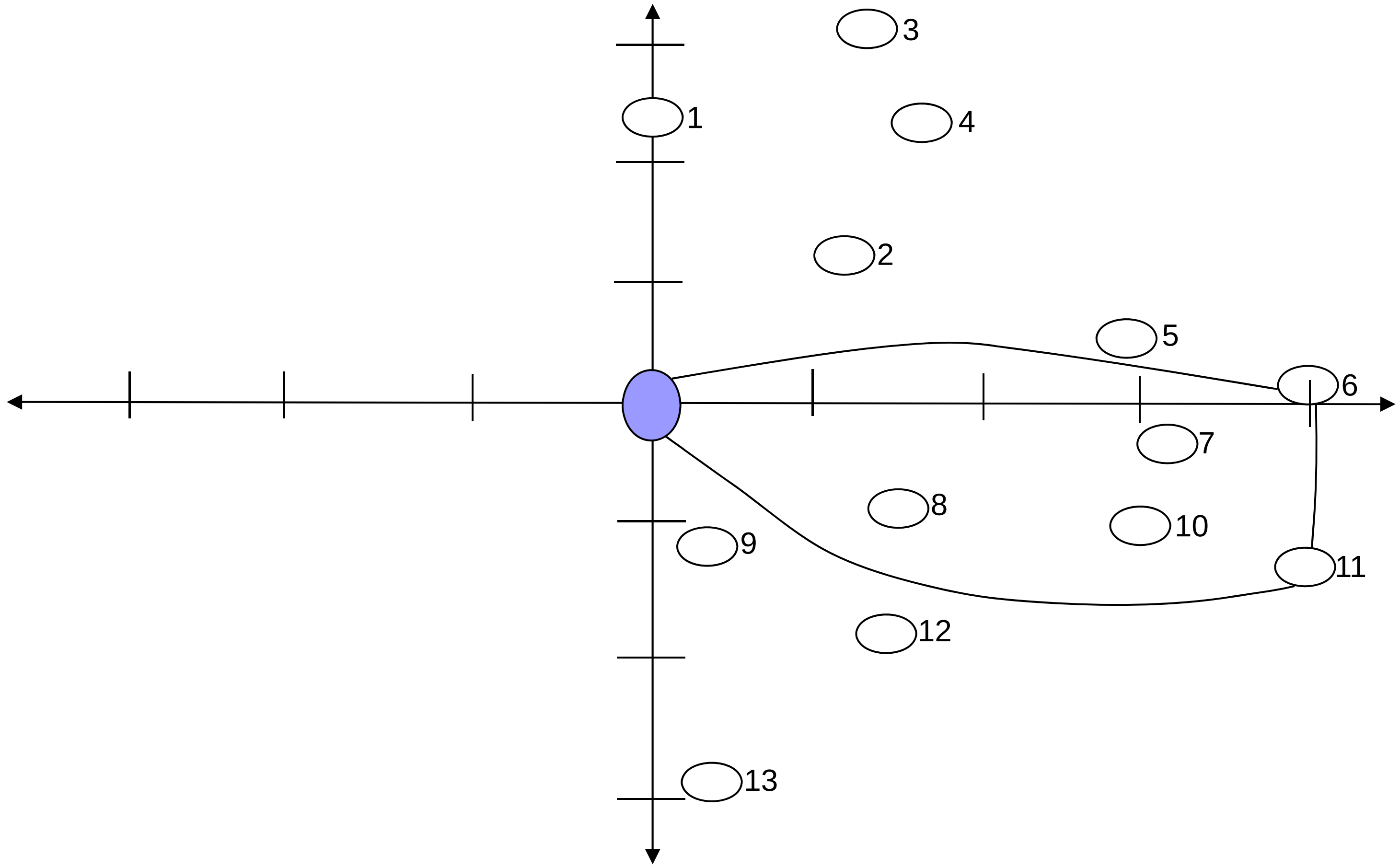
$$S(A, B) = Dist(DC, A) + Dist(DC, B) - Dist(A, B)$$

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

(*) : customers 7 and 11 are already in route 6.
(**): infeasible due to excess load

ASSIGN CUSTOMERS TO VEHICLES OR ROUTES

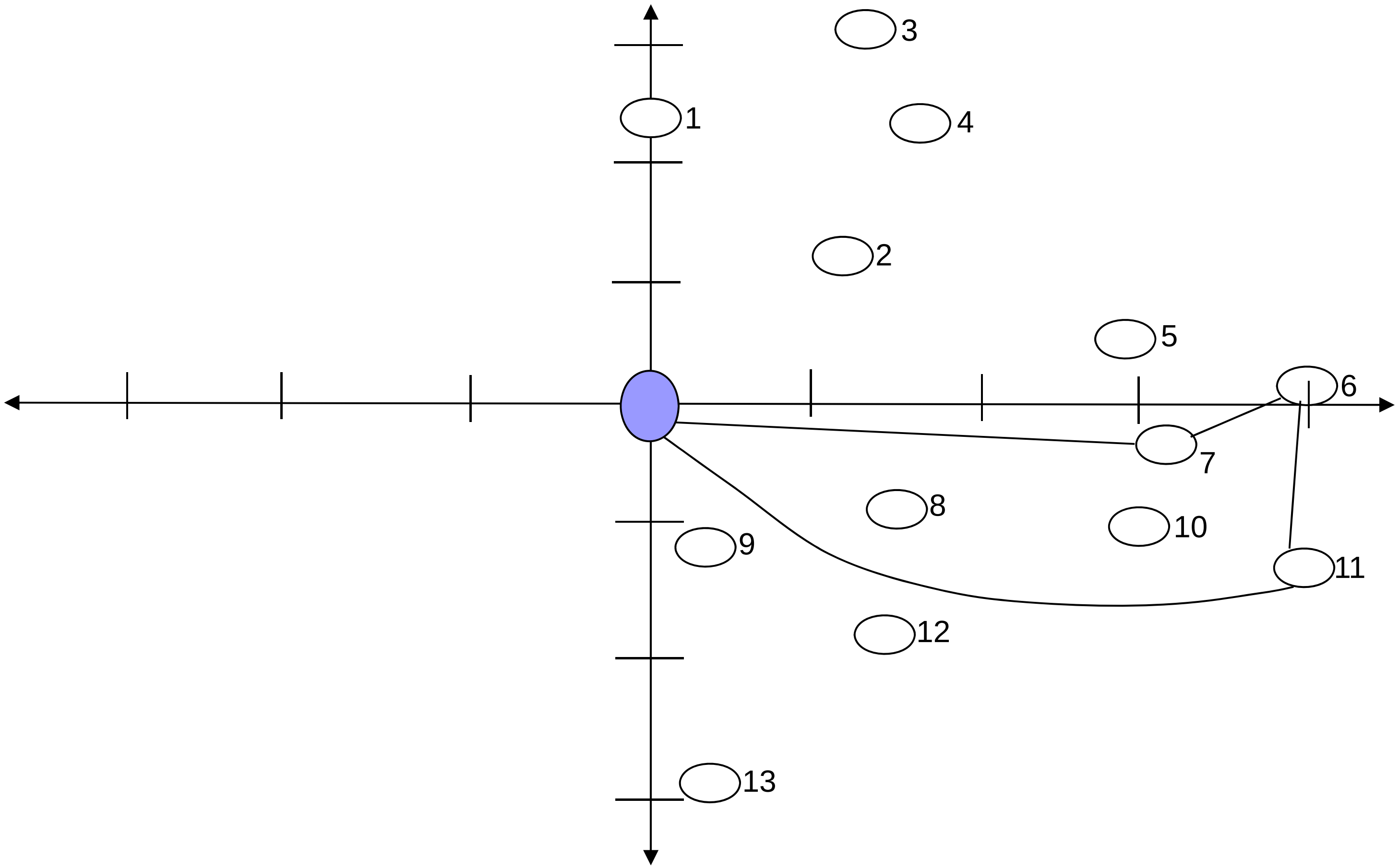
Initially, each customer is assigned to a separate route. Two routes can be combined into a feasible route if the total deliveries across both routes do not exceed the vehicle's capacity. At each iteration step, the Childgum manager attempts to combine routes with the highest savings into a new feasible route. The procedure is continued until no more combinations are feasible.



With the highest savings of 34, routes 6 and 11 are combined with a total load = 16 +91 = 107 < 200

ASSIGN CUSTOMERS TO VEHICLES OR ROUTES (Continued)

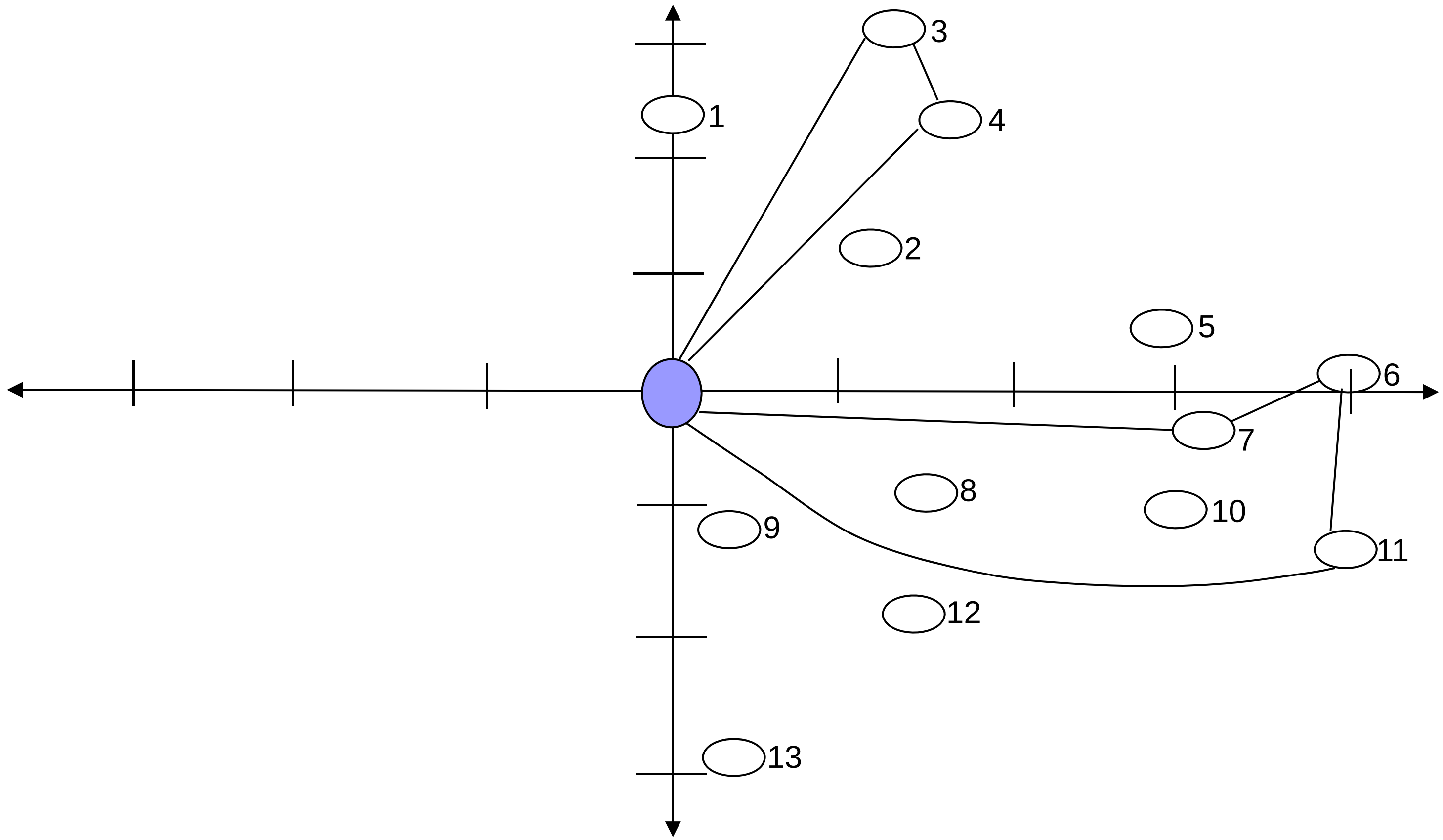
With the next highest savings of 33, customer 7 is added to the route for customer 6, with a total load = 107 + 56 = 163 < 200.



ASSIGN CUSTOMERS TO VEHICLES OR ROUTES (Continued)

The next highest saving now is 32, but it can not be added to route 6 because the total load would equal 163 + 47 = 210 > 200. The next highest saving is 29 on adding either customer 5 or 10 on route 6. Each of these is also infeasible because of the capacity constraint.

The next highest saving is 28 on combining routes 3 and 4, which is feasible since 43 + 92 = 135.



Continuing the iterative procedure, the manager partitions customers into four groups, that is:
[8, 11, 6, 7], [1,3, 4], [2, 9], and [5, 10, 12, 13].

DELIVERY ROUTES AT CHILDGUM

Truck	Trip	Length of trip	Load on truck
1	DC, 2, 9, DC	26	93
2	DC, 1, 3, 4, DC	39	183
3	DC, 8, 11, 6, 7, DC	49	193
4	DC, 5, 10, 12, 13, DC	56	197
	Total	170	666