14

Transportation in a Supply Chain

PowerPoint presentation to accompany Chopra and Meindl Supply Chain Management, 5e

Learning Objectives

1. Understand the role of transportation in a supply chain
2. Evaluate the strengths and weaknesses of different modes of transportation
3. Discuss the role of infrastructure and policies in transportation
4. Identify the relative strengths and weaknesses of various transportation network design options
5. Identify trade-offs that shippers need to consider when designing a transportation network

The Role of Transportation in a Supply Chain

- Movement of product from one location to another
- Products rarely produced and consumed in the same location
- Significant cost component
- Shipper requires the movement of the product
- Carrier moves or transports the product

Modes of Transportation and their Performance Characteristics

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

Modes of Transportation and their Performance Characteristics

Mode	Freight Value ($ billions) in 2002	Freight Tons (billions) in 2002	Freight Ton-Miles (millions) in 2002	Value Added to GNP (billion $) in 2009
Air (includes truck and air)	563	6	13	61.9
Truck	9,075	11,712	1,515	113.1
Rail	392	1,979	1,372	30.8
Water	673	1,668	485	14.3
Pipeline	896	3,529	688	12.0
Multimodal	1,121	229	233	

Table 14-1

Air

- Cost components
  - Fixed infrastructure and equipment
  - Labor and fuel
  - Variable – passenger/cargo
- Key issues
  - Location/number of hubs
  - Fleet assignment
  - Maintenance schedules
  - Crew scheduling
  - Prices and availability

Package Carriers

- Small packages up to about 150 pounds
- Expensive
- Rapid and reliable delivery
- Small and time-sensitive shipments
- Provide other value-added services
- Consolidation of shipments a key factor

Truck

- Significant fraction of the goods moved
- Truckload (TL)
  - Low fixed cost
  - Imbalance between flows
- Less than truckload (LTL)
  - Small lots
  - Hub and spoke system
  - May take longer than TL

Rail

- 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

Water

- Limited to certain geographic areas
- Ocean, inland waterway system, coastal waters
- Very large loads at very low cost
- Slowest
- Dominant in global trade
- Containers

Pipeline

- High fixed cost
- Primarily for crude petroleum, refined petroleum products, natural gas
- Best for large and stable flows
- Pricing structure encourages use for predicable component of demand

Intermodal

- Use of more than one mode of transportation to move a shipment
- Grown considerably with increased use of containers
- May be the only option for global trade
- More convenient for shippers – one entity
- Key issue – exchange of information to facilitate transfer between different modes

Transportation Infrastructure and Policies

- Governments generally take full responsibility or played a significant role in building and managing infrastructure elements
- Without a monopoly, deregulation and market forces help create an effective industry structure
- Pricing should reflect the marginal impact on the cost to society

Transportation Infrastructure and Policies

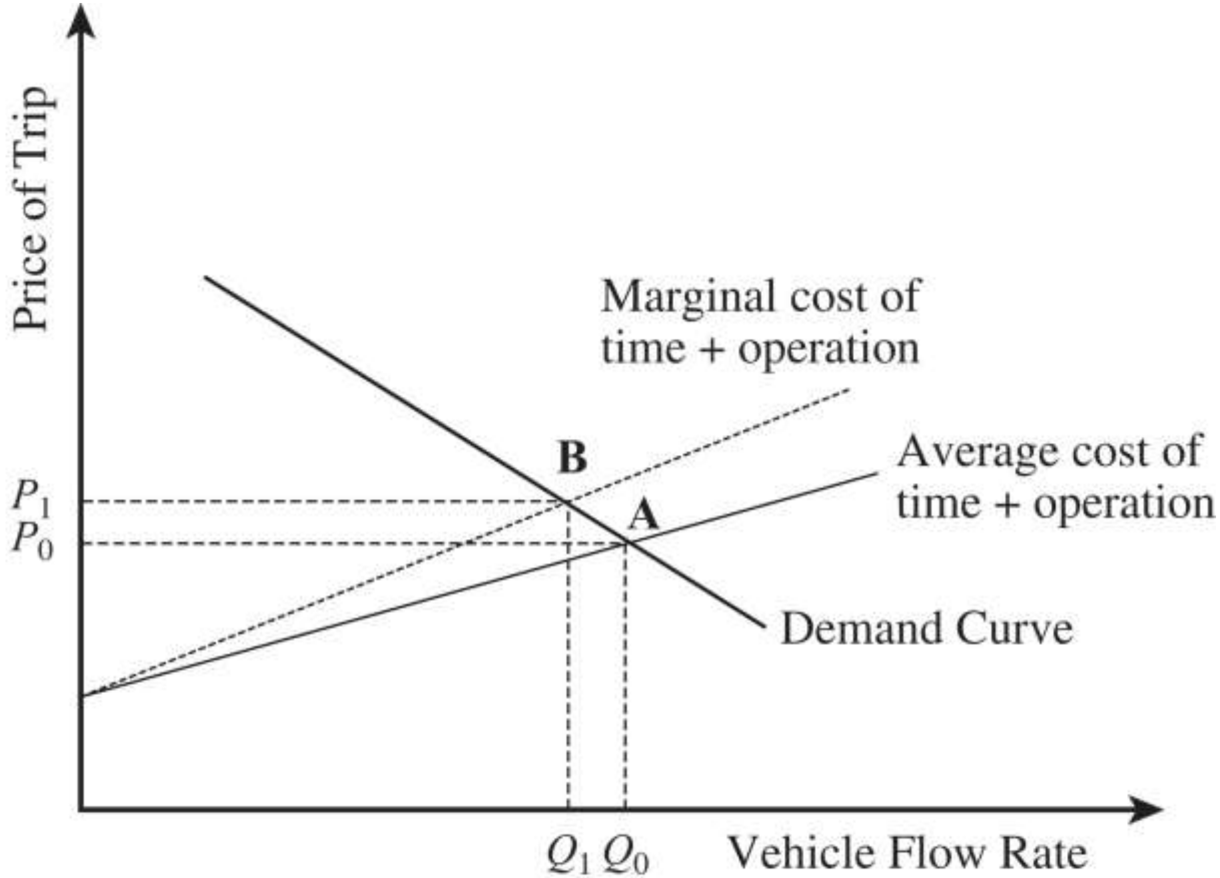

Figure 14-1

Design Options for a Transportation Network

- When designing a transportation network
  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)?

Direct Shipment Network to Single Destination

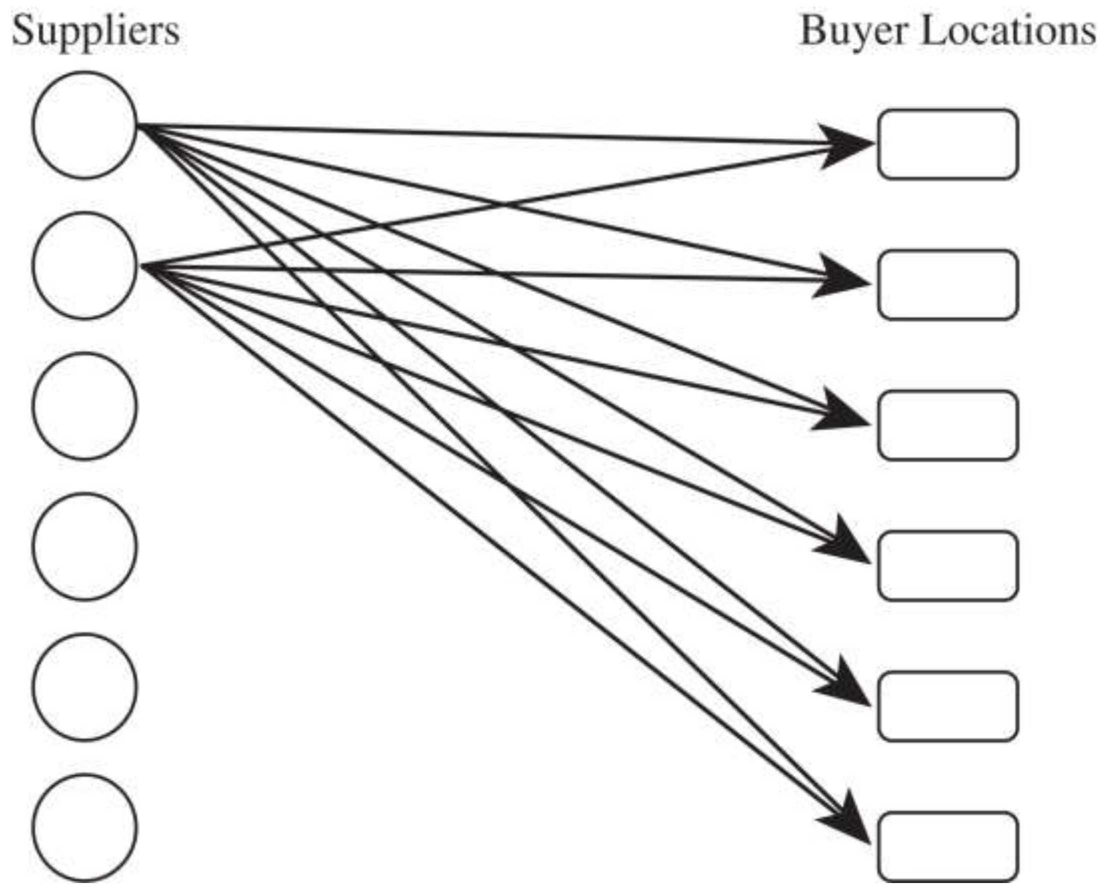

Figure 14-2

Direct Shipping with Milk Runs

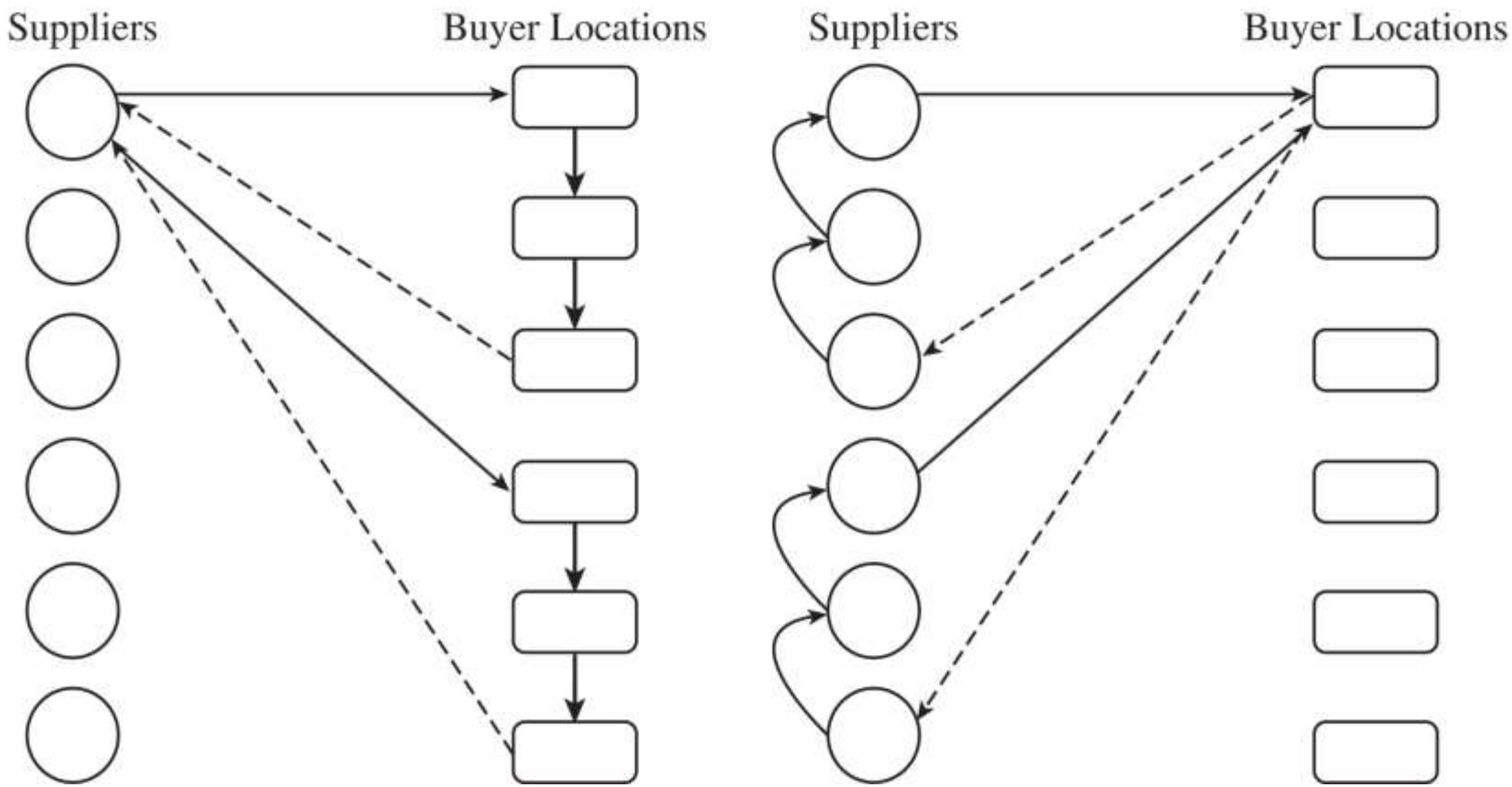

Figure 14-3

All Shipments via Intermediate Distribution Center with Storage

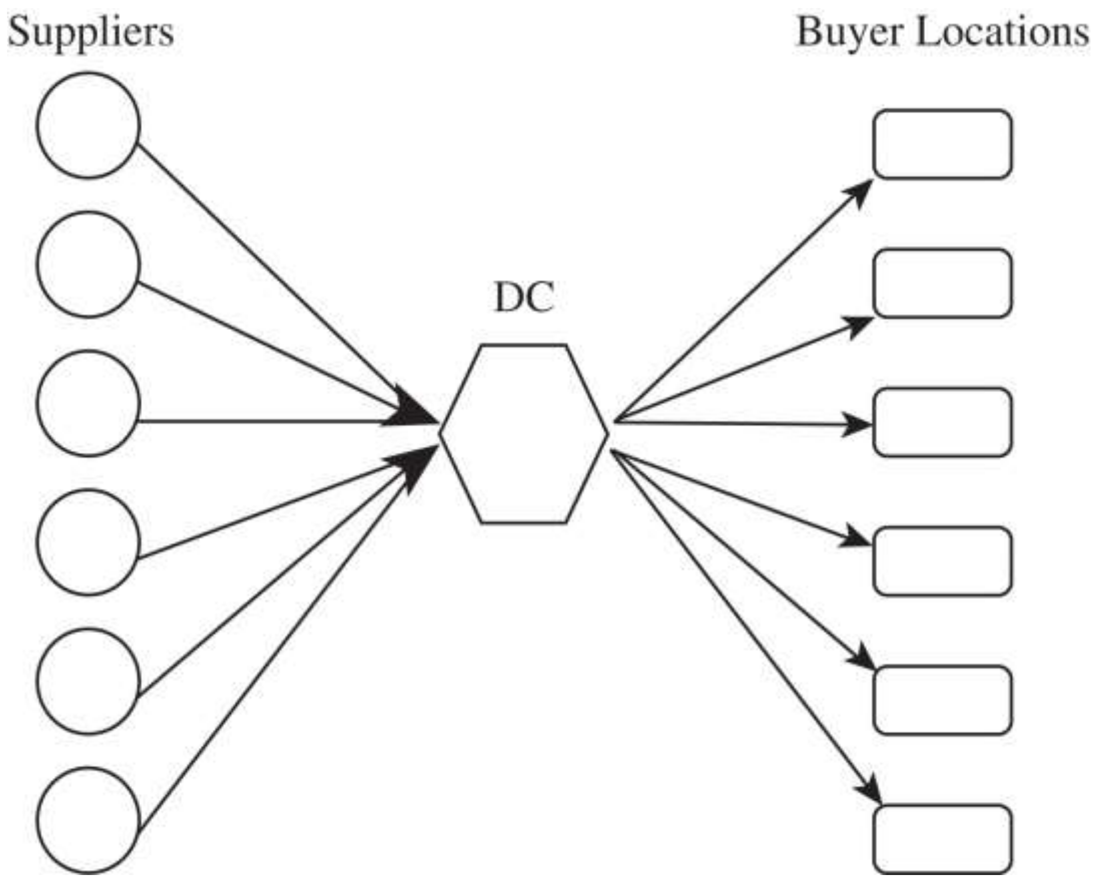

Figure 14-4

All Shipments via Intermediate Transit Point with Cross-Docking

- Suppliers send their shipments to an intermediate transit point
- They are cross-docked and sent to buyer locations without storing them

Shipping via DC Using Milk Runs

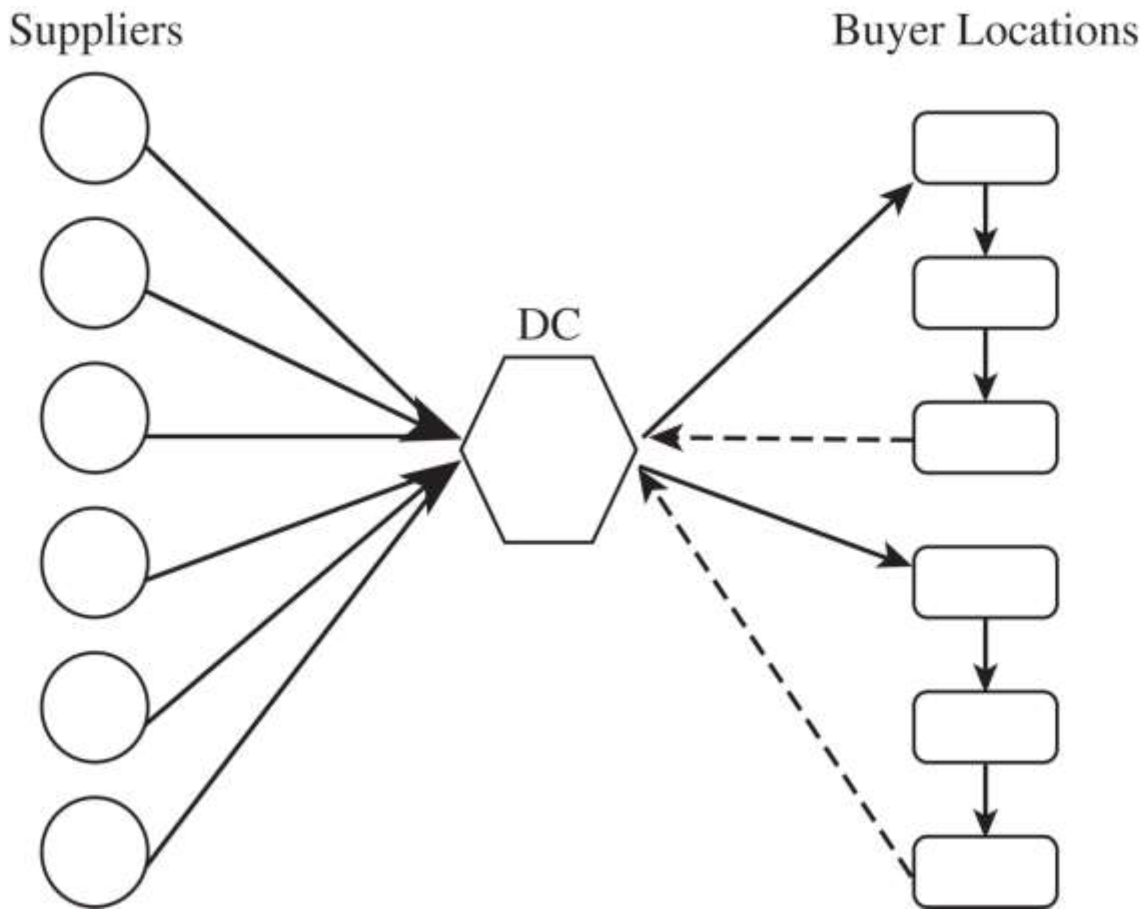

Figure 14-5

Tailored Network

Network Structure	Pros	Cons
Direct shipping	No intermediate warehouse Simple to coordinate	High inventories (due to large lot size) Significant receiving expense
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

Table 14-2

Selecting a Transportation Network

- Eight stores, four supply sources
- Truck capacity = 40,000 units
- Cost $1,000 per load, $100 per delivery
- Holding cost = $0.20/year

Selecting a Transportation Network

Annual sales = 960,000/store   Direct shipping

Batch size shipped from each
supplier to each store = 40,000 units

Number of shipments/yr from
each supplier to each store = 960,000/40,000 = 24

Annual trucking cost
for direct network = 24 x 1,100 x 4 x 8 = $844,800

Average inventory at each
store for each product = 40,000/2 = 20,000 units

Annual inventory cost
for direct network = 20,000 x 0.2 x 4 x 8 = $128,000

Total annual cost of
direct network = $844,800 + $128,000 = $972,800

Selecting a Transportation Network

Annual sales = 960,000/store   Milk runs

Batch size shipped from each supplier to each store	= 40,000/2 = 20,000 units
Number of shipments/yr from each supplier to each store	= 960,000/20,000 = 48
Transportation cost per shipment per store (two stores/truck)	= 1,000/2 + 100 = $600
Annual trucking cost for direct network	= 48 x 600 x 4 x 8 = $921,600
Average inventory at each store for each product	= 20,000/2 = 10,000 units
Annual inventory cost for direct network	= 10,000 x 0.2 x 4 x 8 = $64,000
Total annual cost of direct network	= $921,600 + $64,000 = $985,600

Selecting a Transportation Network

Annual sales = 120,000/store   Direct shipping

Batch size shipped from each
supplier to each store = 40,000 units

Number of shipments/yr from
each supplier to each store = 120,000/40,000 = 3

Annual trucking cost
for direct network = 3 x 1,100 x 4 x 8 = $105,600

Average inventory at each
store for each product = 40,000/2 = 20,000 units

Annual inventory cost
for direct network = 20,000 x 0.2 x 4 x 8 = $128,000

Total annual cost of
direct network = $105,600 + $128,000 = $233,600

Selecting a Transportation Network

Annual sales = 120,000/store   Milk runs

Batch size shipped from each supplier to each store	= 40,000/4 = 10,000 units
Number of shipments/yr from each supplier to each store	= 120,000/10,000 = 12
Transportation cost per shipment per store (two stores/truck)	= 1,000/4 + 100 = $350
Annual trucking cost for direct network	= 12 x 350 x 4 x 8 = $134,400
Average inventory at each store for each product	= 10,000/2 = 5,000 units
Annual inventory cost for direct network	= 5,000 x 0.2 x 4 x 8 = $32,000
Total annual cost of direct network	= $134,400 + $32,000 = $166,400

Trade-offs in Transportation Design

- Transportation and inventory cost trade-off
  - Choice of transportation mode
  - Inventory aggregation
- Transportation cost and responsiveness trade-off

Trade-offs in Transportation Design

Mode	Cycle Inventory	Safety Inventory	In-Transit Cost	Transportation Time	Transportation Cost
Rail	5	5	5	2	5
TL	4	4	4	3	3
LTL	3	3	3	4	4
Package	1	1	1	6	1
Air	2	2	2	5	2
Water	6	6	6	1	6

Table 14-3

Trade-offs When Selecting Transportation Mode

Demand = 120,000 motors, Cost = $120/motor,

Weight = 10 lbs/motor, Lot size = 3,000,

Safety stock = 50% ddlt

Carrier	Range of Quantity Shipped (cwt)	Shipping Cost ($/cwt)
AM Railroad	200+	6.50
Northeast Trucking	100+	7.50
Golden Freightways	50–150	8.00
Golden Freightways	150–250	6.00
Golden Freightways	250+	4.00

Table 14-4

Trade-offs When Selecting Transportation Mode

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 AM Rail	= 3,630 x $30 = $108,900
Annual transportation cost using AM Rail	= 120,000 x 0.65 = $78,000
The total annual cost for inventory and transportation using AM Rail	= $186,900

Trade-offs When Selecting Transportation Mode

Alternative	Lot Size (Motors)	Transpor-tation Cost	Cycle Inventory	Safety Inventory	In-Transit Inventory	Inventory Cost	Total Cost
AM Rail	2,000	$78,000	1,000	986	1,644	$108,900	$186,900
Northeast	1,000	$90,000	500	658	986	$64,320	$154,320
Golden	500	$96,000	250	658	986	$56,820	$152,820
Golden	1,500	$96,000	750	658	986	$71,820	$167,820
Golden	2,500	$86,400	1,250	658	986	$86,820	$173,220
Golden	3,000	$80,000	1,500	658	986	$94,320	$174,320
Golden (old proposal)	4,000	$72,000	2,000	658	986	$109,320	$181,320
Golden (new proposal)	4,000	$67,000	2,000	658	986	$109,320	$176,820

Table 14-5

Tradeoffs When Aggregating Inventory

Highval – weekly demand $\mu_H = 2$, $\sigma_H = 5$, weight = 0.1 lbs, cost = $200

Lowval – weekly demand $\mu_L = 20$, $\sigma_L = 5$, weight = 0.04 lbs, cost = $30

CSL = 0.997, holding cost = 25%, L = 1 week, T = 4 weeks

UPS lead time = 1 week, $0.66 + 0.26$x$

FedEx lead time = overnight, $5.53 + 0.53$x$

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

Tradeoffs When Aggregating Inventory

1. **HighMed inventory costs (current scenario, HighVal)**

$$\text{Average lot size, } Q_H = \text{ expected demand during } T \text{ weeks}$$

$$= T\mu_H = 4 \times 2 = 8 \text{ units}$$

$$\text{Safety inventory, } ss_H = F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sqrt{T+L} \times \sigma_H$$

$$= F^{-1}(0.997) \times \sqrt{4+1} \times 5 = 30.7 \text{ units}$$

$$\text{Total HighVal inventory } = Q_H / 2 + ss_H = (8/2) + 30.7 = 34.7 \text{ units}$$

All 24 territories, HighVal inventory = 24 x 34.7 = 832.8 units

Tradeoffs When Aggregating Inventory

1. HighMed inventory costs (current scenario, LowVal)

$$\text{Average lot size, } Q_L = \text{ expected demand during } T \text{ weeks}$$

$$= T\mu_H = 4 \times 20 = 80 \text{ units}$$

$$\text{Safety inventory, } ss_L = F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sqrt{T+L} \times \sigma_L$$

$$= F^{-1}(0.997) \times \sqrt{4+1} \times 5 = 30.7 \text{ units}$$

$$\text{Total LowVal inventory } = Q_L / 2 + ss_L = (80/2) + 30.7 = 70.7 \text{ units}$$

All 24 territories, LowVal inventory = 24 x 70.7 = 1696.8 units

Tradeoffs When Aggregating Inventory

Annual inventory holding cost for HighMed = (average HighVal inventory x $200 + average LowVal inventory x $30) x 0.25

= (832.8 x $200 + 169.8 x $30) x 0.25

= $54,366 ($54,395 without rounding)

Tradeoffs When Aggregating Inventory

2. HighMed transportation cost (current scenario)

Average weight of each replenishment order

$= 0.1Q_H + 0.04Q_L$ = 0.1 x 8 + 0.04 x 80 = 4 pounds

Shipping cost per replenishment order

= $0.66 + 0.26 x 4 = $1.70

Annual transportation cost = $1.70 x 13 x 24 = $530

3. HighMed total cost (current scenario)

Annual inventory and transportation cost at HighMed

= inventory cost + transportation cost

= $54,366 + $530 = $54,896

Tradeoffs When Aggregating Inventory

	Current Scenario	Option A	Option B
Number of stocking locations	24	24	1.2 units
Reorder interval	4 weeks	1 week	1 week
HighVal cycle inventory	96 units	24 units	24 units
HighVal safety inventory	737.3 units	466.3 units	95.2 units
HighVal inventory	833.3 units	490.3 units	119.2 units
LowVal cycle inventory	960 units	240 units	240 units
LowVal safety inventory	737.3 units	466.3 units	95.2 units
LowVal inventory	1,697.3 units	706.3 units	335.2 units
Annual inventory cost	$54,395	$29,813	$8,473
Shipment type	Replenishment	Replenishment	Customer order
Shipment size	8 HighVal + 80 LowVal	2 HighVal + 20 LowVal	1 HighVal + 10 LowVal
Shipment weight	4 lbs.	1 lb.	0.5 lb.
Annual transport cost	$530	$1,148	$13,464
Total annual cost	$54,926	$30,961	$22,938

Table 14-6

Tradeoffs When Aggregating Inventory

Average weight of each customer order

= 0.1 x 0.5 + 0.04 x 5 = 0.25 pounds

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

Annual transportation cost = 4,992 x \$5.66 = \$28,255

Total annual cost = inventory cost + transportation cost

= \$8,474 + \$28,255 = \$36,729

Tradeoffs When Aggregating Inventory

	Aggregate	Disaggregate
Transport cost	Low	High
Demand uncertainty	High	Low
Holding cost	High	Low
Customer order size	Large	Small

Table 14-7

Trade-off Between Transportation Cost and Responsiveness

Steel shipments LTL = $100 + 0.01x$

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
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

Table 14-8

Trade-off Between Transportation Cost and Responsiveness

Table 14-9

Day	Demand	Two-Day Response		Three-Day Response		Four-Day Response	
		Quantity Shipped	Cost ($)	Quantity Shipped	Cost ($)	Quantity Shipped	Cost ($)
1	19,970	19,970	299.70	0		0	
2	17,470	17,470	274.70	37,440	474.40	0	
3	11,316	11,316	213.16	0		48,756	586.56
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	47,70	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	38,045	480.45
			$4,164.46		3,464.46		3,264.46

Tailored Transportation

- The use of different transportation networks and modes based on customer and product characteristics
- Factors affecting tailoring
  – Customer density and distance
  – Customer size
  – Product demand and value

Tailored Transportation

	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

Table 14-10

Tailored Transportation

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.

Table 14-11

Role of IT in Transportation

- The complexity of transportation decisions demands use of IT systems
- IT software can assist in:
  - Identification of optimal routes by minimizing costs subject to delivery constraints
  - Optimal fleet utilization
  - GPS applications

Risk Management in Transportation

- Three main risks to be considered in transportation are
  1. Risk that the shipment is delayed
  2. Risk of disruptions
  3. Risk of hazardous material
- Risk mitigation strategies
  - Decrease the probability of disruptions
  - Alternative routings
  - In case of hazardous materials the use of modified containers, low-risk transportation models, modification of physical and chemical properties can prove to be effective

Making Transportation Decisions in Practice

1. Align transportation strategy with competitive strategy
2. Consider both in-house and outsourced transportation
3. Use technology to improve transportation performance
4. Design flexibility into the transportation network

Summary of Learning Objectives

1. Understand the role of transportation in a supply chain
2. Evaluate the strengths and weaknesses of different modes of transportation
3. Discuss the role of infrastructure and policies in transportation
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5. Identify trade-offs that shippers need to consider when designing a transportation network