Transportation in the Supply Chain

8-1

Outline

- The role of transportation in the supply chain
- Factors affecting transportation decisions
- Modes of transportation and their performance characteristics
- Transportation infrastructure and policies
- Design options for a transportation network
- Trade-offs in transportation design
- Tailored transportation
- Routing and scheduling in transportation
- Making transportation decisions in practice

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Role of Transportation in Supply Chain

- Transportation refers to movement of product from the beginning of supply chain to the customer
- Transportation adds to a significant amount of cost to most supply chain
- Transportation activity represent more than 10% of GDP
- Transportation accounts for about 20 million jobs (16%)
- The role of transportation is even more significant in global supply chains
- Success of a supply chain is closely linked to proper use of transportation

Factors Affecting Transportation Decisions

- Shipper (party that requires the movement of the product between two points in the supply chain)
  - Transportation cost
  - Inventory cost
  - Facility cost
- Carrier (party that moves or transports the product)
  - Vehicle-related cost
  - Fixed operating cost
  - Trip-related cost

Transportation Modes

- Trucks
  - TL (Truck load)
  - LTL (Less than truck load)
- Rail
- Air
- Package Carriers
- Water
- Pipeline
- Intermodal

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Truckload (TL)

- Average revenue per ton mile (1996) = 9.13 cents
- Average haul = 274 miles
- Average Capacity = 42,000 - 50,000 lb.
- Low fixed and variable costs
- Major Issues
  - Utilization
  - Consistent service
  - Backhauls

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Less Than Truckload (LTL)

- Average revenue per ton-mile (1996) = 25.08 cents
- Average haul = 646 miles
- Higher fixed costs (terminals) and low variable costs
- Major issues:
  - Location of consolidation facilities
  - Utilization
  - Vehicle routing
  - Customer service

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Rail

- High fixed cost
- Average revenue / ton-mile (1996) = 2.5 cents
- Average haul = 720 miles
- Average load = 80 tons
- Key issues:
  - Scheduling to minimize delays / improve service
  - Off-track delays (at pickup and delivery end)
  - Yard operations
  - Variability of delivery times

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Air

- Key issues:
  - Location/number of hubs
  - Location of fleet bases/crew bases
  - Schedule optimization
  - Fleet assignment
  - Crew scheduling
  - Yield management

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Package Carriers

- Companies like FedEx, UPS, USPS, that carry small packages ranging from letters to shipments of about 150 pounds
- Expensive for large shipments
- Rapid and reliable delivery
- Small and time-sensitive shipments
- Preferred mode for e-businesses (e.g., Amazon, Dell, McMaster-Carr)
- Consolidation of shipments (especially important for package carriers that use air as a primary method of transport)

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Water

- Limited to certain geographic areas
- Ocean, inland waterway system, coastal waters
- Very large loads at very low cost
- Slowest
- Dominant in global trade (autos, grain, apparel, etc.)

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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 (why?)

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Intermodal

- Use of more than one mode of transportation to move a shipment to its destination
- Most common example: rail/truck
- Also 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 provides the complete service)
- Key issue involves the exchange of information to facilitate transfer between different transport modes

Transportation Infrastructure and Policies

- Transportation infrastructure often require government ownership or regulation because of its inherently monopolistic nature
- In the absence of a monopoly, deregulation and market forces are an effective mechanism
- When infrastructure is publicly owned, it is important to price usage to reflect the marginal impact on the cost to society. If it is not done, overuse and congestions result because the cost borne by a user is less than his or her marginal impact on total cost.

Design Options for a Transportation Network

- A well-designed transportation network allows a supply chain to achieve the desired degree of responsiveness at low cost
- What are the transportation options? Which one to select? On what basis?
  - Direct shipment network
  - Direct shipping with milk runs
  - All shipments via central DC
  - Shipping via DC using milk runs
  - Tailored network

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Design Options for a Transportation Network

- **Direct shipping network**
  - Here, the buyer structures his transportation network so that all shipments come directly from each supplier to each buyer location
  - Decision involves a trade-off between transportation and inventory costs
  - The major advantage here is the elimination of intermediate warehouses resulting in simplicity of operation and coordination, independence in decision making, and short transportation time
  - May be justified if the demand is high and lot sizes are close to TL. However, inventory cost may be high
  - Low demand results in LTL leading to high transportation costs. However, inventory cost is low

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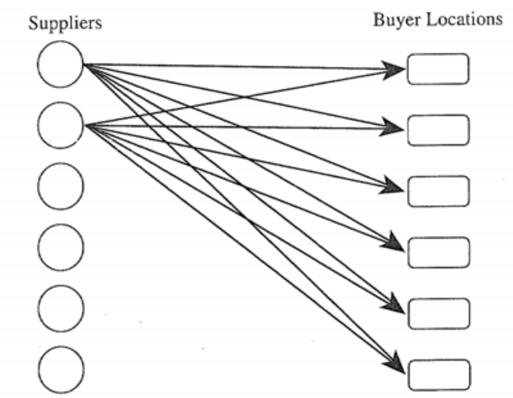
Design Options for a Transportation Network

- **Direct shipping network**



8-17

Design Options for a Transportation Network

- **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
  - Involves deciding on the routing of each milk run
  - While, as before, direct shipping provides the benefit of eliminating intermediate warehouses, milk runs lower the transportation cost by consolidating shipments to multiple locations on a single truck

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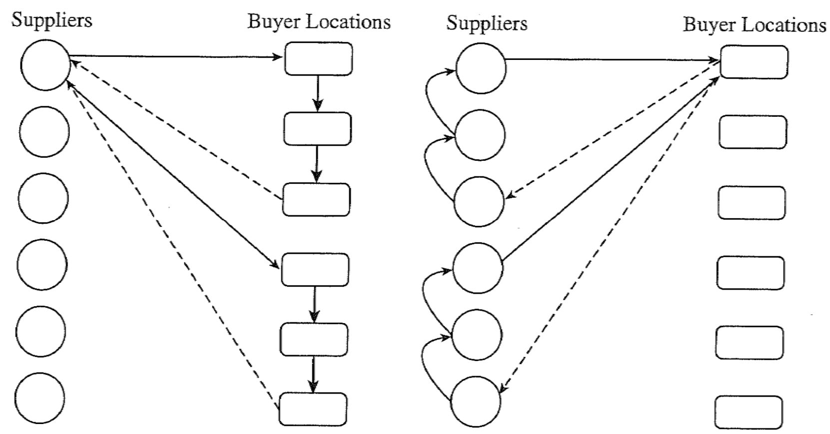
Design Options for a Transportation Network

◆ **Direct shipping with milk runs**



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Design Options for a Transportation Network

◆ **All shipments via central DC**

- Here, suppliers send their shipments to a DC and the DC then forwards appropriate shipments to each buyer location
- DC store inventory and serve as a transfer location
- DC help reduce supply chain costs when suppliers are located far from the buyer locations and transportation costs are high. Thus DC allows a supply chain to achieve economies of scale for inbound transportation to a point close to the final destination.
- DC can also be used for **cross-docking**. Here, each inbound truck contains product from a supplier for several buyer locations and each outbound truck contains products for a buyer location from several suppliers

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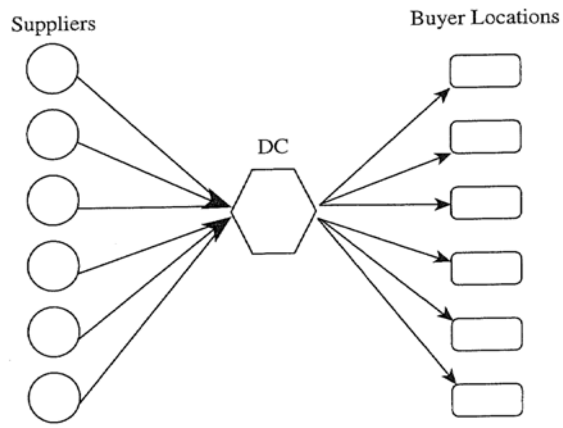
Design Options for a Transportation Network

◆ **All shipments via central DC**



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Design Options for a Transportation Network

◆ **Shipping via DC using milk runs**

– Milk runs can be used from a DC if lot sizes to be delivered to buyer location are small. Milk runs reduce outbound transportation costs by consolidating small shipments

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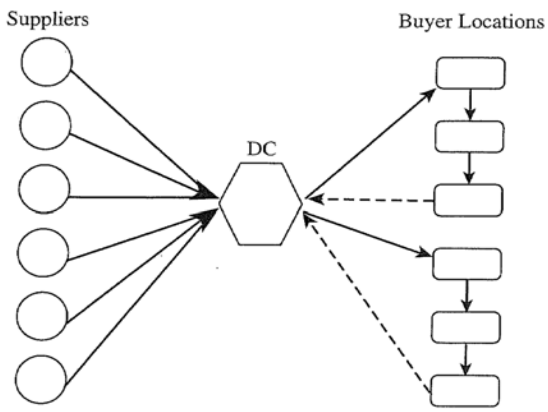
Design Options for a Transportation Network

- **Shipping via DC using milk runs**



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Design Options for a Transportation Network

- **Tailored network**
  - The tailored network option is a suitable combination of previous options that reduces the cost and improves responsiveness of the supply chain

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Design Options for a Transportation 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 cost for small lots • Lower inventories	• Increased coordination complexity
All shipping via central DC with inventory storage	• Lower inbound transportation cost through consolidation	• Increased inventory cost • Increased handling at DC
All shipping 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 that best matches the needs of individual product and buyer	• Highest coordination complexity

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Selecting a Transportation Network

- **Example**
  - A retail chain has eight stores in a region with four supply sources for four different products. Trucks have a capacity of 40,000 units and cost $1,000 per load plus $100 per delivery. Thus, a truck making two deliveries charges $1,200. The cost of holding one unit of a product in inventory at a retail store for a year is $0.20. The manager of supply chain is considering whether to use direct shipping from suppliers to retail stores or setting up milk runs from suppliers to retail stores. (a) What network would you recommend if annual sales for each product at each retail store are 960,000 units? (b) What network would you recommend if sales for each product at each retail store are 120,000 units? (Assume that all trucks are full when they leave from the supplier.)

8-26

Selecting a Transportation Network

- **Solution**
  - (a) Demand = 960,000 units/store
  - Analysis of direct shipping network
    - » Batch size shipped from each supplier to each store=40,000 units
    - » No. of shipments/year per supplier to each store=960,000/40,000=24
    - » Annual trucking cost for direct network=24*1,100*4*8=$844,800
    - » Average inventory at each store for each product=40,000/2=20,000 units
    - » Annual inventory cost=20,000*0.20*4*8=$128,000
    - » Total cost of direct network =$844,800+$128,000=**$972,800**

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Selecting a Transportation Network

- Analysis of direct shipping with milk runs (assume supplier is running milk runs to two stores on each truck.)
  - » Batch size shipped fr. each supplier to each store=40,000/2=20,000 units
  - » No. of shipments/year per supplier to each store=960,000/20,000=48
  - » Trucking cost/shipment per store=$1,000/2 + $100=$600
  - » Annual trucking cost for milk run network=48*600*4*8=$921,600
  - » Average inventory at each store for each product=20,000/2=10,000 units
  - » Annual inventory cost=10,000*0.20*4*8=$64,000
  - » Total cost of direct network =$921,600+$64,000=**$985,600**

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Selecting a Transportation Network

- Analysis of direct shipping with milk runs (assume supplier is running milk runs to four stores on each truck.)
  - » Batch size shipped fr. each supplier to each store=40,000/4=10,000 units
  - » No. of shipments/year per supplier to each store=960,000/10,000=96
  - » Trucking cost/shipment per store=$1,000/4 + $100=$350
  - » Annual trucking cost for milk run network=96*350*4*8=$1,075,200
  - » Average inventory at each store for each product=10,000/2=5,000 units
  - » Annual inventory cost=5,000*0.20*4*8=$32,000
  - » Total cost of direct network =$1,075,200+$32,000=**$1,107,200**

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Selecting a Transportation Network

- (b) Demand = 120,000 units/store
- Analysis of direct shipping network
  - » Batch size shipped from each supplier to each store=40,000 units
  - » No. of shipments/year per supplier to each store=120,000/40,000=3
  - » Annual trucking cost for direct network=3*1,100*4*8=$105,600
  - » Average inventory at each store for each product=40,000/2=20,000 units
  - » Annual inventory cost=20,000*0.20*4*8=$128,000
  - » Total cost of direct network =$105,600+$128,000=**$233,600**

8-30

Selecting a Transportation Network

- Analysis of direct shipping with milk runs (assume supplier is running milk runs to two stores on each truck.)
  - » Batch size shipped fr. each supplier to each store=40,000/2=20,000 units
  - » No. of shipments/year per supplier to each store=120,000/20,000=6
  - » Trucking cost/shipment per store=$1,000/2 + $100=$600
  - » Annual trucking cost for milk run network=6*600*4*8=$115,200
  - » Average inventory at each store for each product=20,000/2=10,000 units
  - » Annual inventory cost=10,000*0.20*4*8=$64,000
  - » Total cost of direct network =$115,200+$64,000=**$179,200**

8-31

Selecting a Transportation Network

- Analysis of direct shipping with milk runs (assume supplier is running milk runs to four stores on each truck.)
  - » Batch size shipped fr. each supplier to each store=40,000/4=10,000 units
  - » No. of shipments/year per supplier to each store=120,000/10,000=12
  - » Trucking cost/shipment per store=$1,000/4 + $100=$350
  - » Annual trucking cost for milk run network=12*350*4*8=$134,400
  - » Average inventory at each store for each product=10,000/2=5,000 units
  - » Annual inventory cost=5,000*0.20*4*8=$32,000
  - » Total cost of direct network =$134,400+$32,000=**$166,400**

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Trade-offs in Transportation Design

- Transportation decisions must take into account
  - The impact on inventory costs, facility and processing costs and the cost of coordinating operations (hard to quantify)
  - The level of responsiveness provided to customers
- Following trade-offs must be considered
  - Transportation and inventory cost trade-off
  - Transportation cost and responsiveness trade-off

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Transportation and Inventory Cost Trade-off

- Two fundamental supply chain decisions involving this trade-off are
  - Choice of transportation mode
  - Inventory aggregation

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Some Inventory Concepts

- **Cycle inventory** is the average inventory that builds up in the supply chain because a supply chain stage either produces or purchases in lots that are larger than those demanded by the customer
- **Cycle service level (CSL)** is the fraction of replenishment cycle that meets all customer demand
- **Safety inventory** is the inventory carried for the purpose of satisfying demand that exceeds the amount forecasted in a given period
- **Average inventory** is therefore cycle inventory plus safety inventory

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Choice of Transportation Mode

- A manager must account for inventory costs when selecting a mode of transportation
- A mode with higher transportation costs can be justified if it results in significantly lower inventories

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Choice of Transportation Mode

- **Example**
  - Eastern Electric (EE) is a major appliance manufacturer with a large plant in the Chicago area. EE purchases all the motors for its applications from Westview Motors, located near Dallas. EE currently purchases 120,000 motors each year from Westview at a price of $120 per motor. Demand has been relatively constant for several years and is expected to stay that way. Each motor averages about 10 pounds in weight, and EE has traditionally purchased lots of 3,000 motors. Westview ships each EE order within a day of receiving it. At its assembly plant, EE carries a safety inventory equal to 50 percent of the average demand for motors during the delivery lead time.

Choice of Transportation Mode

- The plant manager at EE has received several proposals for transportation and must decide on one to accept. The details of various proposals are provided in the table below:
  (cwt = centum weight or hundredweight = 100 pounds)

Carrier	*Qty Range (cwt)*	*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

(Note that marginal unit quantity discounts mentioned above for Golden Freightways are also referred to as ***multiblock tariffs****. In this case, the pricing schedule contains specified break points. It is not the average cost of a unit but the marginal cost of a unit that decreases at a breakpoint).*

Choice of Transportation Mode

- Golden's pricing represents a marginal unit quantity discount. Golden's representative has proposed lowering the marginal rate for the quantity over 250 cwt in a shipment from \$4/cwt to \$3/cwt and suggested that EE increase its batch size to 4,000 motors to take advantage of the lower transportation cost. Shipments by rail require a five-day transit time, whereas shipments by truck have a transit time of three days. If EE's annual cost of holding inventory is 25 percent, what should the plant manager do?

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Choice of Transportation Mode

- **Solution**
  - Annual cost of holding inventory is 25%
  - Therefore, holding cost, H = \$120 × 0.25 = \$30 per motor/year
  - Transit time by rail = 5 days
  - **<u>AM Rail Proposal</u>**
  -
  - Minimum shipment is 20,000lbs or 2,000 motors
  - Replenishment lead time, L = 5+1 = 6 days
  - For Q = 2,000 motors,

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Choice of Transportation Mode

- Cycle inventory = Q/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 = 3,630 × \$30 = \$108,900
- Annual transportation cost =120,000 × 0.65 = \$78,000

Total annual cost = \$108,900 + \$78,000 = **\$186,900**

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Inventory Aggregation

- As a result of physical aggregation
  - Inventory costs decrease
  - Inbound transportation cost decreases
  - Outbound transportation cost increases
- Inventory aggregation decreases supply chain costs if the product has a high value to weight ratio, high demand uncertainty, or customer orders are large
- Inventory aggregation may increase supply chain costs if the product has a low value to weight ratio, low demand uncertainty, or customer orders are small

8-42

Managing Uncertainty

- On aggregation, safety inventory for a given CSL is given by

$$F_S^{-1}(CSL)\sqrt{L}\,\sigma_D$$

where F_S^{-1} is the inverse of standard normal distribution
CSL is the cycle service level
L is the lead time
D is the average demand/ period
σ_D is the standard deviation of the demand/ period

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Inventory Aggregation

- **Example**
  - HighMed, a manufacturer of medical equipment used in heart procedures, is located in Madison, Wisconsin, and its products are used by cardiologists all over North America. The medical equipment is not sold through purchasing agents but directly to doctors. HighMed currently divides 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+0.26*x*, where *x* is the quantity shipped in pounds. The products sold fall into two categories - Highval and Lowval. Highval products weigh 0.1 pounds and cost \$200 each. Lowval products weigh 0.04 pounds and cost \$30 each.

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Inventory Aggregation

- Weekly demand for Highval products in each territory is normally distributed, with a mean of μ_H=2 with a standard deviation of σ_H=5. Weekly demand for Lowval products in each territory is normally distributed, with a mean of μ_L=20 with a standard deviation of σ_L=5. HighMed maintains sufficient safety inventories in each territory to provide a cycle service level (CSL) of 0.997 for each product. Holding cost at HighMed is 25 percent.
- In addition to the current approach, the management team at HighMed is considering two other options:

Inventory Aggregation

- ***Option A***. Keep the current structure but replenish once a week rather that 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.
- If inventories are aggregated at Madison, orders will be shipped using FedEx, which charges \$5.53+0.53x 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 one unit of Highval and 10 units of Lowval.
- What should HighMed do?

Inventory Aggregation

- **Solution**
  - **<u>Current Scenario</u>**
  - Replenishment lead time, L = 1 wk
  - Reorder interval, T = 4 wks
  - CSL = 0.997
  - F^{-1}(CLS) = F^{-1}(0.997) = z = 2.75

  - **1. HighMed Inventory Cost**
  - For Highval
  - Average lot size, Q_H =expected demand during T wks= $T^*\mu_H$ = 4*2 = 8 units
  - Safety inventory, $SS_H = F^{-1}(CSL)\sigma_{T+L} = F^{-1}(CSL)\sqrt{T+L}\,\sigma_H = F^{-1}(0.997)\sqrt{4+1} * 5 =$ 30.7 units
  - Total Highval inventory = $Q_H/2 + SS_H$ = (8/2) + 30.7 = 34.7 units
  - Total across all 24 territories = 24*34.7 = 832.8 units

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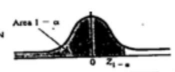
Inventory Aggregation

THE CUMULATIVE STANDARDIZED NORMAL DISTRIBUTION FUNCTION

(Note: $.9^{2}8650 = .998650$)

Entry = $P(Z < Z_{1-\alpha}) = 1 - \alpha$



$Z_{1-\alpha}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7703	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8661
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.97030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	$.9^{2}0097$	$.9^{2}0358$	$.9^{2}0613$	$.9^{2}0863$	$.9^{2}1106$	$.9^{2}1344$	$.9^{2}1576$
2.4	$.9^{2}1802$	$.9^{2}2024$	$.9^{2}2240$	$.9^{2}2451$	$.9^{2}2656$	$.9^{2}2857$	$.9^{2}3053$	$.9^{2}3244$	$.9^{2}3431$	$.9^{2}3613$
2.5	$.9^{2}3790$	$.9^{2}3963$	$.9^{2}4132$	$.9^{2}4297$	$.9^{2}4457$	$.9^{2}4614$	$.9^{2}4766$	$.9^{2}4915$	$.9^{2}5060$	$.9^{2}5201$
2.6	$.9^{2}5339$	$.9^{2}5473$	$.9^{2}5604$	$.9^{2}5731$	$.9^{2}5855$	$.9^{2}5975$	$.9^{2}6093$	$.9^{2}6207$	$.9^{2}6319$	$.9^{2}6427$
2.7	$.9^{2}6533$	$.9^{2}6636$	$.9^{2}6736$	$.9^{2}6833$	$.9^{2}6928$	$.9^{2}7020$	$.9^{2}7110$	$.9^{2}7197$	$.9^{2}7282$	$.9^{2}7365$
2.8	$.9^{2}7445$	$.9^{2}7523$	$.9^{2}7599$	$.9^{2}7673$	$.9^{2}7744$	$.9^{2}7814$	$.9^{2}7882$	$.9^{2}7948$	$.9^{2}8012$	$.9^{2}8074$
2.9	$.9^{2}8134$	$.9^{2}8193$	$.9^{2}8250$	$.9^{2}8305$	$.9^{2}8359$	$.9^{2}8411$	$.9^{2}8462$	$.9^{2}8511$	$.9^{2}8559$	$.9^{2}8605$
−3.0	$.9^{2}8650$	$.9^{2}8684$	$.9^{2}8736$	$.9^{2}8777$	$.9^{2}8817$	$.9^{2}8856$	$.9^{2}8893$	$.9^{2}8930$	$.9^{2}8965$	$.9^{2}8999$

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Inventory Aggregation

- For Lowval
- Average lot size, Q_L =expected demand during T wks= $T*\mu_L$ =4*20=80 units
- Safety inventory, $SS_H = F^{-1}(CSL)\sigma_{T+L} = F^{-1}(CSL)\sqrt{T+L}\,\sigma_L = F^{-1}(0.997)\sqrt{4+1} * 5 =$ 30.7 units
- Total Lowval inventory = $Q_L/2 + SS_L$ = (80/2) + 30.7 = 70.7 units
- Total across all 24 territories = 24*70.7 = 1696.8 units

- Annual inventory holding cost for HighMed = (average HighVal inventory * $200 + average LowVal inventory * $30) * 0.25
  = (832.8 * $200 + 1696.8 * $30) * 0.25
  = $54,366

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Inventory Aggregation

- **2. HighMed Transportation Cost**
- Average weight of each replenishment order = $0.1Q_H + 0.04Q_L$
  = 0.1*8 + 0.04*80 = 4 pounds
- Shipping cost per replenishment order = $0.66 + 0.26 × 4 = $1.70

- Annual transportation cost (each territory has 13 replenishment orders per year and there are 24 territories) = $1.70*13*24 = $530.40

- **3. HighMed Total Cost**
- HighMed Total Annual Cost = inventory cost + transportation cost
  = $54,366 + $530.40
  = **$54,896.40**

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Transportation Cost and Responsiveness Trade-off

- Transportation cost of a supply chain is closely linked to the degree of responsiveness the supply chain aims to provide
- High responsiveness means small outbound shipments resulting in high transportation cost
- **Temporal aggregation** is the process of combining orders across time
- Temporal aggregation reduces transportation cost because it results in larger shipments and reduces variation in shipment sizes
- However, temporal aggregation reduces customer responsiveness

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Transportation Cost and Responsiveness Trade-off

- **Example**
  - Alloy Steel is a steel service center in the Cleveland area. All orders are shipped to customers using an LTL carrier that charges \$100+0.01*x*, where *x* is the number of pounds of steel shipped on the truck. Currently, Alloy Steel ships orders on the day they are received. Allowing for two days in transit, this policy allows Alloy Steel to achieve a response time of two days. Daily demand at Alloy Steel over a two-week period is shown in the table below.

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Transportation Cost and Responsiveness Trade-off

	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

- The general manager at Alloy Steel feels that customers do not really value the two-day response time and would be satisfied with up to a four-day response. What are the cost advantages of increasing the response time?

Transportation Cost and Responsiveness Trade-off

- **Solution**

		Two-Day Response		*Three-Day Response*		*Four-Day Response*	
Day	***Demand***	***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	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	38,045	480.45
Total			4,164.46		3,464.46		**3,264.46**

Tailored Transportation

- Tailored transportation is the use of different transportation networks and modes based on customer and product characteristics
- It allows a supply chain to achieve appropriate responsiveness and low cost
- Factors affecting tailoring:
  - Customer distance and density
  - Customer size
  - Product demand and value

Tailored Transportation: Customer distance and density

	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

Tailored Transportation: Customer size

- Firms must consider customer size and location when designing transportation networks
- Very large customers can be supplied using a TL carrier and 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

Tailored Transportation: Product demand and value

Product Type	*High Value*	*Low Value*
High Demand	• Disaggregate cycle inventory • Aggregate safety inventory • Use inexpensive mode of transportation for replenishing cycle inventory and fast mode when using safety inventory	• Disaggregate all inventories • Use inexpensive mode of transportation for replenishment
Low Demand	• Aggregate all inventories • Use fast mode of transportation for filling customer demand	• Aggregate only safety inventory • Use inexpensive mode of transportation for replenishing cycle inventory

Role of IT in Transportation

- The complexity of transportation decisions demands the 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

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Risk Management in Transportation

- Three main risks to be considered when transporting a shipment between two nodes are:
  - Risk that the shipment is delayed (due to congestion or capacity limitation)
  - Risk that the shipment does not reach its destination because intermediate links are disrupted by external forces
  - 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 modes, modification of physical and chemical properties can prove to be effective

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Making Transportation Decisions in Practice

- Align transportation strategy with competitive strategy
- Consider both in-house and outsourced transportation
- Design a transportation network that can handle e-commerce
- Use technology to improve transportation performance
- Design flexibility into the transportation network

Summary of Learning Objectives

- What is the role of transportation in a supply chain?
- What are the strengths and weaknesses of different transport modes?
- What are the different network design options and what are their strengths and weaknesses?
- What are the trade-offs in transportation network design?