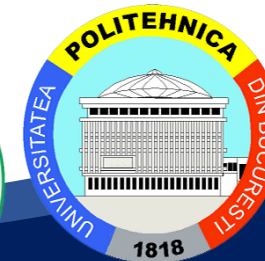




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Sustainable Supply Chain Management



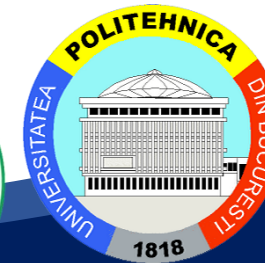
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Bullwhip Effect



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Bullwhip Effect

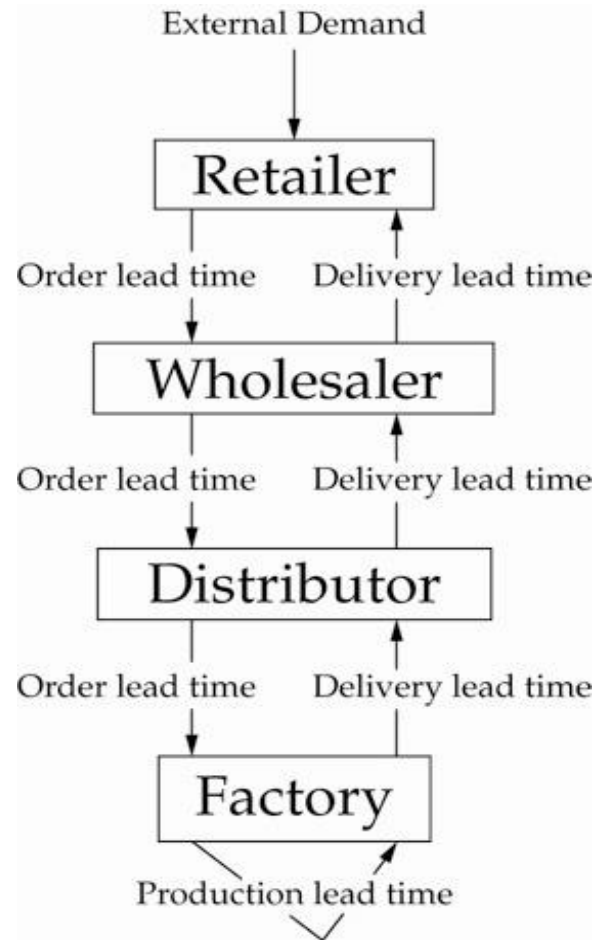
- While customer demand for specific products does not vary much
- Inventory and back-order levels fluctuate considerably across the supply chain

BULLWHIP EFFECT:

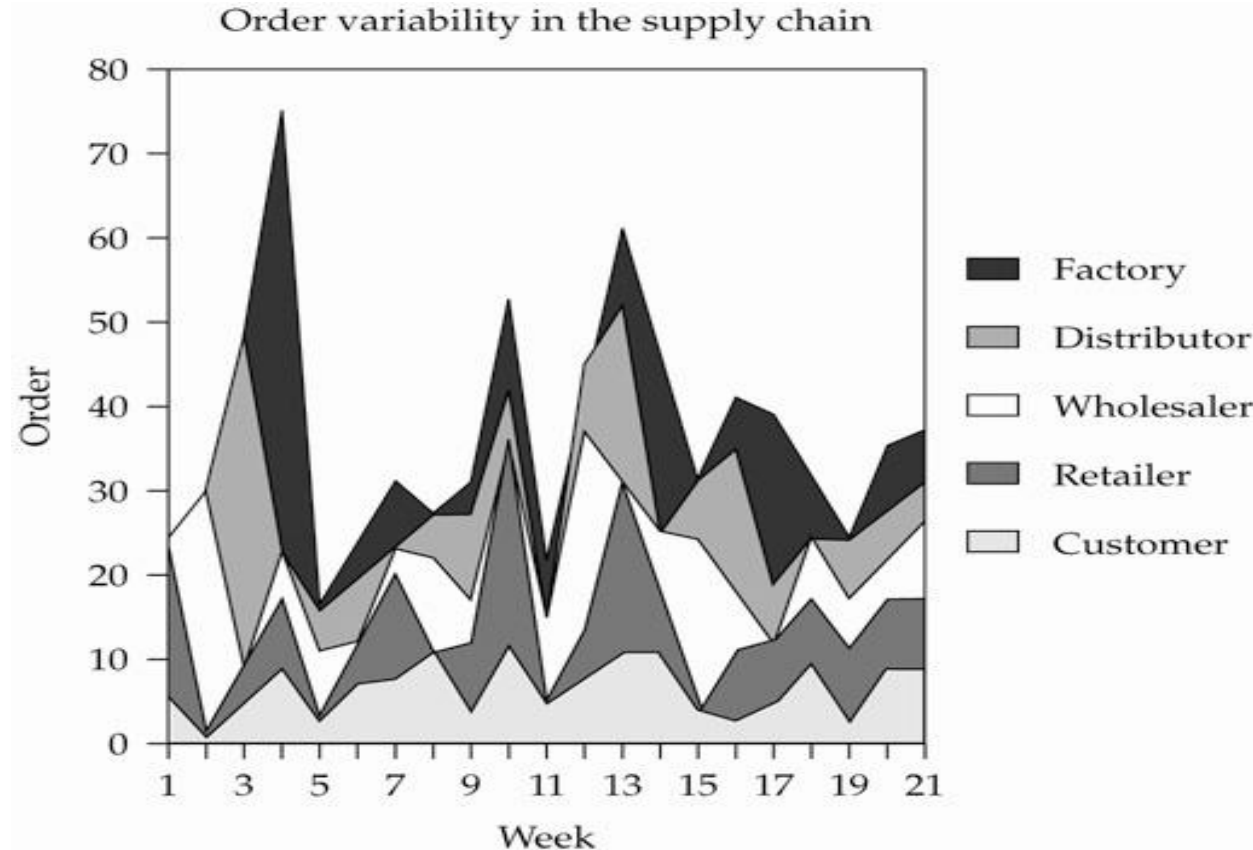
The phenomenon in which variance of demand is amplified when moving upstream



4-Stage Supply Chain



Effect of Order Variability



The increase in variability in the supply chain





Factors that Contribute to the Variability - *Demand Forecasting*

- *Periodic review policy*
- Characterized by a single parameter, the **base-stock level**.
- Base-stock level =
Average demand during lead time and review period +
a multiple of the standard deviation of demand during lead time and review period
(*safety stock*)
- Estimation of average demand and demand variability done using *standard forecast smoothing techniques*.
- **Estimates get modified as more data becomes available**
- Safety stock and base-stock level depends on these estimates
- Order quantities are changed accordingly increasing variability





Factors that Contribute to the Variability – *Lead Time*

- Increase in variability magnified with increasing lead time.
- Safety stock and base-stock levels have a lead time component in their estimations.
- With longer lead times:
 - a small change in the estimate of demand variability implies
 - a significant change in safety stock and base-stock level, which implies
 - significant changes in order quantities
 - leads to an increase in variability





Factors that Contribute to the Variability – *Batch Ordering*

- Retailer uses batch ordering, as with a (Q,R) or a min-max (i.e., (s,S)) policy
- Wholesaler observes a large order, followed by several periods of no orders, followed by another large order, and so on.
- Wholesaler sees a distorted and highly variable pattern of orders.
- Such pattern is also a result of:
 - Transportation discounts with large orders
 - Periodic sales quotas/incentives





Factors that Contribute to the Variability – *Price Fluctuations*

- Retailers often attempt to *stock up* when prices are lower.
 - Accentuated by promotions and discounts at certain times or for certain quantities.
 - Such **Forward Buying** results in:
 - Large order during the discounts
 - Relatively small orders at other time periods





Factors that Contribute to the Variability – *Inflated Orders*

- Inflated orders during shortage periods
- Common when retailers and distributors suspect that a product will be in short supply and therefore anticipate receiving supply proportional to the amount ordered.
- After period of shortage, retailer goes back to its standard orders
 - leads to all kinds of distortions and variations in demand estimates



Quantifying the Bullwhip

- Consider a two-stage supply chain:
 - Retailer who observes customer demand
 - Retailer places an order to a manufacturer.
- Retailer faces a fixed lead time
 - Order placed at the end of period t
 - Order received at the start of period $t+L$.
- Retailer follows a simple periodic review policy
 - retailer reviews inventory every period
 - places an order to bring its inventory level up to a target level.
 - the review period is one



Quantifying the Bullwhip

$$\text{Base-Stock Level} = L \times AVG + z \times STD \times \sqrt{L}$$

$$\text{Order up-to point} = \hat{\mu}_t \times L + z \times S_t \times \sqrt{L}$$

$\hat{\mu}_t, S_t$: Average & Standard deviation of daily demand at time t

If the retailer uses a moving average technique,

$$\hat{\mu}_t = \frac{\sum_{i=t-p}^{t-1} D_i}{p} \quad S_t^2 = \frac{\sum_{i=t-p}^{t-1} (D_i - \hat{\mu}_t)^2}{p-1}$$





Quantifying the Increase in Variability

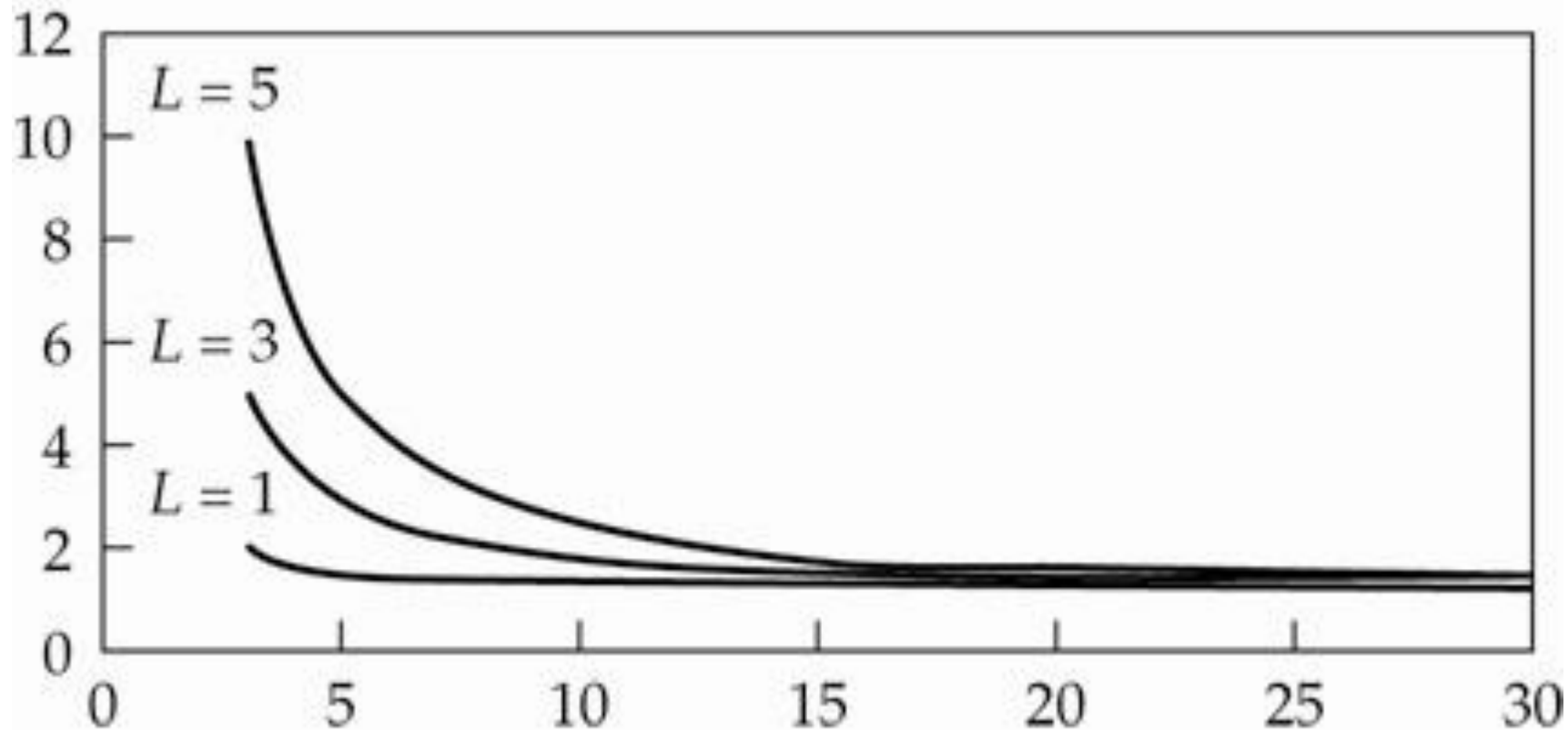
- $Var(D)$, variance of the customer demand seen by the retailer
- $Var(Q)$, variance of the orders placed by that retailer to the manufacturer

$$\frac{Var(Q)}{Var(D)} \geq 1 + \frac{2L}{p} + \frac{2L^2}{p^2}$$

- When p is large and L is small, the bullwhip effect is negligible.
- Effect is magnified as we increase the lead time and decrease p .



Lower Bound on the Increase in Variability Given as a Function of p



A lower bound on the increase in variability
given as a function of p

Impact of Variability Example

- Assume $p = 5$, $L=1$

$$\frac{\text{Var}(Q)}{\text{Var}(D)} \geq 1.4$$

- Assume $p = 10$, $L=1$

$$\frac{\text{Var}(Q)}{\text{Var}(D)} \geq 1.2$$

- Increasing the number of observations used in the moving average forecast reduces the variability of the retailer order to the manufacturer





Impact of Centralized Information on Bullwhip Effect

- Centralize demand information within a supply chain
 - Provide each stage of supply chain with complete information on the actual customer demand
 - Creates more accurate forecasts rather than orders received from the previous stage





Variability with Centralized Information

- $Var(D)$, variance of the customer demand seen by the retailer
- $Var(Q^k)$, variance of the orders placed by the k^{th} stage of the supply chain
- L_i , lead time between stage i and stage $i + 1$

$$\frac{Var(Q^k)}{Var(D)} \geq 1 + \frac{2\sum_{i=1}^k L_i}{p} + \frac{2(\sum_{i=1}^k L_i)^2}{p^2}$$

- *Variance of the orders placed by a given stage of a supply chain is an increasing function of the total lead time between that stage and the retailer*





Variability with Decentralized Information

- Retailer does not make its forecast information available to the remainder of the supply chain
- Other stages have to use the order information

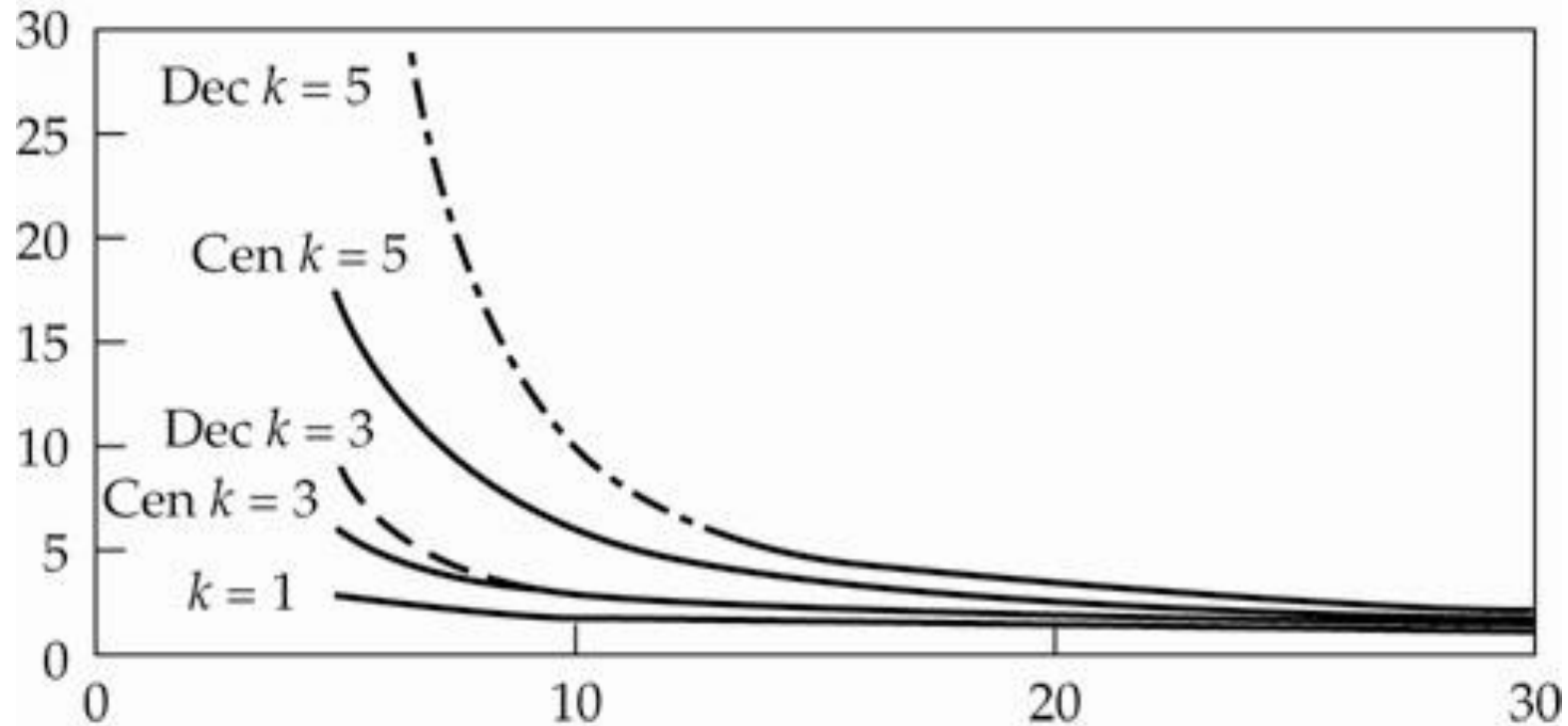
$$\frac{\text{Var}(Q^k)}{\text{Var}(D)} \geq \prod_{i=1}^k \left(1 + \frac{2L_i}{p} + \frac{2L_i^2}{p^2}\right)$$

- Variance of the orders:
 - becomes larger up the supply chain
 - increases multiplicatively at each stage of the supply chain.



- Variance increases up the supply chain in both centralized and decentralized cases
- Variance increases:
 - Additively with centralized case
 - Multiplicatively with decentralized case
- *Centralizing demand information can significantly reduce the bullwhip effect*
 - Although not eliminate it completely!!

Increase in Variability for Centralized and Decentralized Systems



Increase in variability for centralized and decentralized systems



Methods for Coping with the Bullwhip

- *Reducing uncertainty* by Centralizing demand information
- *Reducing variability.*
 - Reducing variability inherent in the customer demand process.
 - “Everyday low pricing” (EDLP) strategy.





Methods for Coping with the Bullwhip

- *Lead-time reduction*
 - Lead times magnify the increase in variability due to demand forecasting.
 - Two components of lead times:
 - order lead times [can be reduced through the use of cross-docking]
 - Information lead times [can be reduced through the use of electronic data interchange (EDI).]
- *Strategic partnerships*
 - Changing the way information is shared and inventory is managed
 - Vendor managed inventory (VMI)
 - Manufacturer manages the inventory of its product at the retailer outlet
 - VMI the manufacturer does not rely on the orders placed by a retailer, thus avoiding the bullwhip effect entirely.





Information Sharing And Incentives

- Centralizing information will reduce variability
- Upstream stages would benefit more
- Unfortunately, information sharing is a problem in many industries
- Inflated forecasts are a reality
- Forecast information is inaccurate and distorted
 - Forecasts inflated such that suppliers build capacity
 - Suppliers may ignore the forecasts totally





Contractual Incentives to Get True Forecasts from Buyers

- Capacity Reservation Contract
 - Buyer pays to reserve a certain level of capacity at the supplier
 - A menu of prices for different capacity reservations provided by supplier
 - Buyer signals true forecast by reserving a specific capacity level
- Advance Purchase Contract
 - Supplier charges special price before building capacity
 - When demand is realized, price charged is different
 - Buyer's commitment to paying the special price reveals the buyer's true forecast





Locating Desired Products

- Meet customer demand from available retailer inventory
- What if the item is not in stock at the retailer?
 - Being able to locate and deliver goods is sometimes as effective as having them in stock
 - If the item is available at the competitor, then this is a problem



Lead-Time Reduction

- Numerous benefits:
 - The ability to quickly fill customer orders that can't be filled from stock.
 - Reduction in the bullwhip effect.
 - More accurate forecasts due to a decreased forecast horizon.
 - Reduction in finished goods inventory levels
- Many firms actively look for suppliers with shorter lead times
- Many potential customers consider lead time a very important criterion for vendor selection.
- Much of the manufacturing revolution of the past 20 years led to reduced lead times

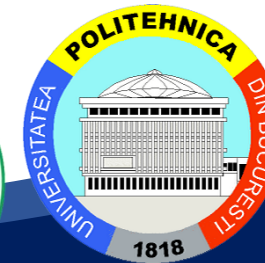




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Distribution Strategies



Curriculum Development
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Introduction

- Two fundamental distribution strategies
 - Items can be **directly shipped** from the supplier or manufacturer to the retail stores or end customer
 - Use **intermediate inventory storage points** (typically warehouses and/or distribution centers).
- Issues with warehouses
 - Manufacturing strategy (make-to-stock vs. make-to-order)
 - Number of warehouses
 - Inventory policy
 - Inventory turn over ratio
 - Internal warehouses vs. outside distributor
 - Owned by a single firm or by a variety of firms





Direct Shipment Distribution Strategies

- Advantages:
 - The retailer avoids the expenses of operating a distribution center
 - Lead times are reduced.
- Disadvantages:
 - Risk-pooling effects are negated due to no central warehouse
 - Manufacturer and distributor transportation costs increase
- Commonly used scenarios:
 - Retail store requires fully loaded trucks
 - Often mandated by powerful retailers
 - Lead time is critical.
 - Manufacturer may be reluctant but may have no choice
 - Prevalent in the grocery industry
 - **Lead times are critical because of perishable goods.**





Intermediate Inventory Storage Point Strategies

- A variety of characteristics distinguish different strategies. One of the most fundamental involves
 - Length of time that inventory is stored at warehouses and distribution centers.
- Strategies:
 - Traditional warehousing strategy
 - distribution centers and warehouses hold stock inventory
 - provide their downstream customers with inventory as needed.
 - Cross-docking strategy
 - warehouses and distribution centers serve as transfer points for inventory
 - no inventory is held at these transfer points.
 - Centralized pooling and transshipment strategies
 - may be useful when there is a large variety of different products → difficult to predict demand for a specific product





Traditional Warehousing

- Session 2.1: Inventory management and risk pooling key factors
- Other factors also play a significant role
 - Centralized vs Decentralized Management
 - Central vs Local Production & Warehousing Facilities





Centralized vs Decentralized Management

- Decentralized system
 - Each facility identifies its most effective strategy without considering the impact on the other facilities in the supply chain.
 - Leads to local optimization.
- Centralized system
 - Decisions are made at a central location for the entire supply network.
 - Typical objective: minimize the total cost of the system subject to satisfying some service-level requirements.
 - Centralized control leads to global optimization.
 - At least as effective as the decentralized system.
 - Allow use of coordinated strategies
- If system cannot be centralized
 - Often helpful to form partnerships to approach the advantages of a centralized system.



Central vs. Local Facilities

- Centralized facilities
 - Employ both fewer warehouses and distribution centers
 - Facilities are located further from customers.
- Other factors:
 - **Safety stock.** Lower safety stock levels with centralized facilities
 - **Overhead.** Lower total overhead cost with centralized facilities
 - **Economies of scale.** Greater economies of scale with centralized facilities
 - **Lead time.** Lead time to market reduced with local facilities
 - **Service.**
 - Utilization of risk pooling better with centralized
 - Shipping times better with local
 - **Transportation costs.**
 - Costs between production facilities and warehouses higher with local
 - Costs from warehouses to retailers lesser with local



A Hybrid Decision

- Some products use centralized strategy while others use local strategy
- Not necessarily an either-or decision
- Varying degrees of centralization and localization due to the varying levels of advantages and disadvantages



Cross-Docking

- Popularized by Wal-Mart
- Warehouses function as inventory coordination points rather than as inventory storage points.
- Goods arriving at warehouses from the manufacturer:
 - are transferred to vehicles serving the retailers
 - are delivered to the retailers as rapidly as possible.
- Goods spend very little time in storage at the warehouse
 - Often less than 12 hours
 - Limits inventory costs and decreases lead times



Issues with Cross-Docking

- Require a significant start-up investment and are very difficult to manage
- Supply chain partners must be linked with advanced information systems for coordination
- A fast and responsive transportation system is necessary
- Forecasts are critical, necessitating the sharing of information.
- Effective *only* for large distribution systems
 - Sufficient volume every day to allow shipments of fully loaded trucks from the suppliers to the warehouses.
 - Sufficient demand at retail outlets to receive full truckload quantities





Inventory Pooling – GM Example

- 1,500 Cadillacs parked at a regional distribution center in Orlando
- Await delivery to dealers statewide within 24 hours
- 10% to 11% sales loss because a car is not available...
- Test program expected to:
 - improve customer service
 - boost sales of Cadillacs by 10%





Centralized Pooled Systems Perform Better

- For the same inventory level, a centralized system provides:
 - Higher service level
 - Higher sales
- Push-pull supply chain
 - Moving from a push supply chain
 - Dealers have to order before demand is realized
 - To a push-pull supply chain
 - Dealers pull from regional distribution centers.
- Implications:
 - End consumers will see better customer service
 - More cars are available to them.



Other Factors

- Will GM sell more cars to GM dealers?
 - Inventory is pooled → Total number of cars ordered by dealers will not necessarily increase, even as customer service increases.
 - So, will this benefit GM? **YES** (see example in the next slide)
- What about the dealers?
 - Dealers have access to more inventory
 - **Potentially can sell more.**
 - Levels out the playing field between dealers.
 - **Small dealers would favor such a system but competitive advantage of large dealers wiped out**



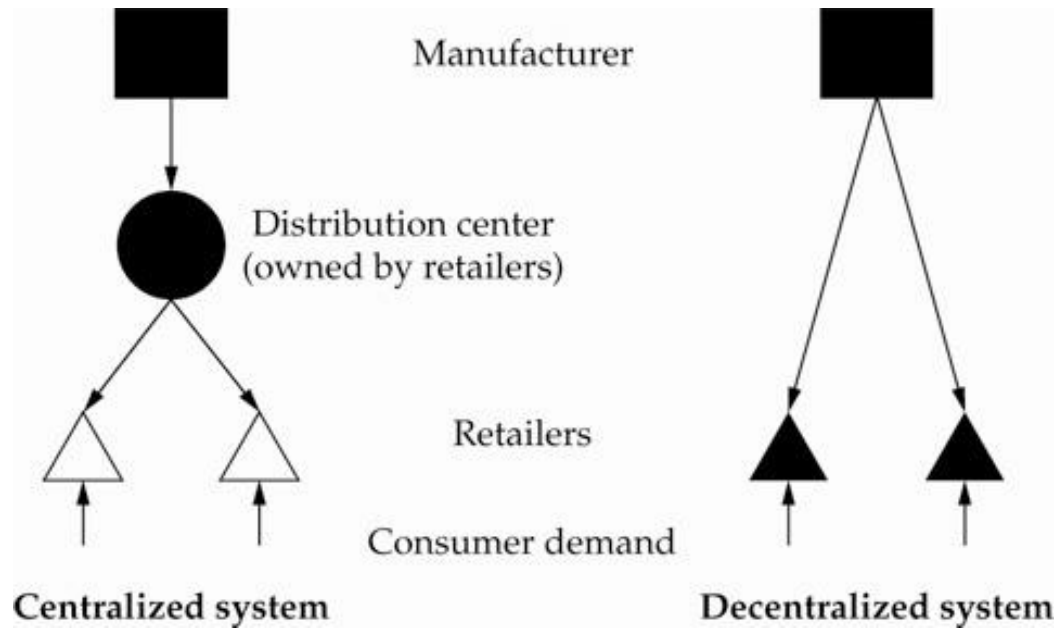


Example of Inventory Pooling

- Two retailers face random demand for a single product.
- No differences between the retailers
- Compare two systems
 - Centralized pooled system,
 - retailers together operate a joint inventory facility
 - take items out of the pooled inventory to meet demand.
 - Decentralized system
 - each retailer individually orders from the manufacturer to meet demand
- In both systems, inventory is owned by the retailers



The Two Systems



The centralized and decentralized systems



Probabilistic demand faced by each retailer

Other Data

- Wholesale price = \$80 per unit
- Selling price = \$125 per unit
- Salvage value = \$20 per unit
- Production cost = \$35 per unit





Costs and Profits in the Two Systems

- Decentralized system
 - Each dealer orders 12,000 units
 - Expected profit per dealer = \$470,000, Total = \$940,000
 - Expected sales = 11,340 units, Total = 22,680 units
 - Manufacturer profit = \$1,080,000
- Centralized system
 - Two dealers together will order 26,000 units
 - Total expected profit = \$1,009,392
 - Joint expected sales = 24,470 units
 - Manufacturer profit = \$1,170,000





Effect of Customer Search

- If the (loyal) customer arrives at a dealer and does not find the item
 - Switches to another dealer
 - Helps the manufacturer sell more products
- Which system is better under customer search?
 - No impact on the centralized system





Impact on Decentralized System

- If a dealer knows that its competitors do not keep enough inventory
 - This dealer should raise the inventory level to satisfy:
 - its own demand
 - demand of customers who initially approach other dealers with limited inventory.
- If a dealer knows that its competitors has significant inventory
 - This dealer will reduce the inventory level
 - It is not likely to see customers who switch
- Dealer's strategy depends on its competitor's strategy.



Nash Equilibrium (Game Theory)

Dealers may/may not know their competitor strategy → not clear how they decide on their inventory level; not clear about the impact of search on the manufacturer

The problem is *addressed* by the concept of Nash Equilibrium

- If two competitors are making decisions, they have reached Nash equilibrium if they have both made a decision on an amount to order such that
 - Neither can improve their expected profit by changing the order amount if the other dealer doesn't change his order amount.



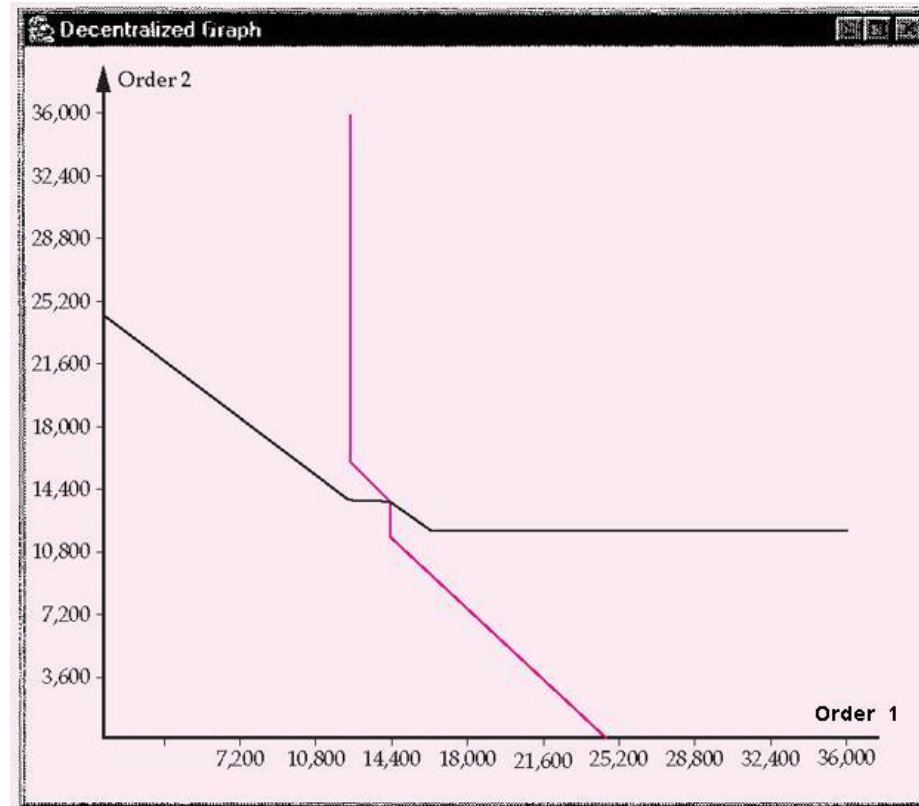


Example (see slide 16 above)

- α = percentage of customers that search the system
- Each retailer can determine what their effective demand (initial demand + search demand) will be if the other retailer orders a specific amount.
- Based on this information, they can calculate how much they should order given any order by their competitors.
 - This is known as their “Best Response”



Best Response with $\alpha=90\%$



Black: Retailer 2
Pink: Retailer 1

Retailers' best response

Nash Equilibrium of the System

- Retailer one orders about 20,000 units, retailer two will respond by ordering about 12,000 units
- If this is the case, then retailer one should modify its strategy and reduce the order quantity
- No retailer has an incentive to modify its strategy if their order amounts associated with the intersection of the two curves.
- Optimal order quantity for each retailer = 13,900 units
- Total expected profit for each retailer = \$489,460
- Total expected profit = \$978,920
- Total expected sales = 25,208
- Total amount ordered from the manufacturer = 27,800
- Manufacturer's profit = \$1,251,000.





Decentralized and Centralized Systems for Search Level of 90%

Strategy	Retailers	Manufacturer	Total
Decentralized	978,920	1,251,000	2,229,920
Centralized	1,009,392	1,170,000	2,179,392

- Centralized system does not dominate the decentralized system.
- Retailers prefer the centralized system
- Manufacturer's profit is higher in the decentralized system





As α Increases

- Each retailer's order quantity and profit increases
- Retailers' total expected profit will be higher in the centralized pooling system than in the decentralized system.
- But the situation is not clear for manufacturer



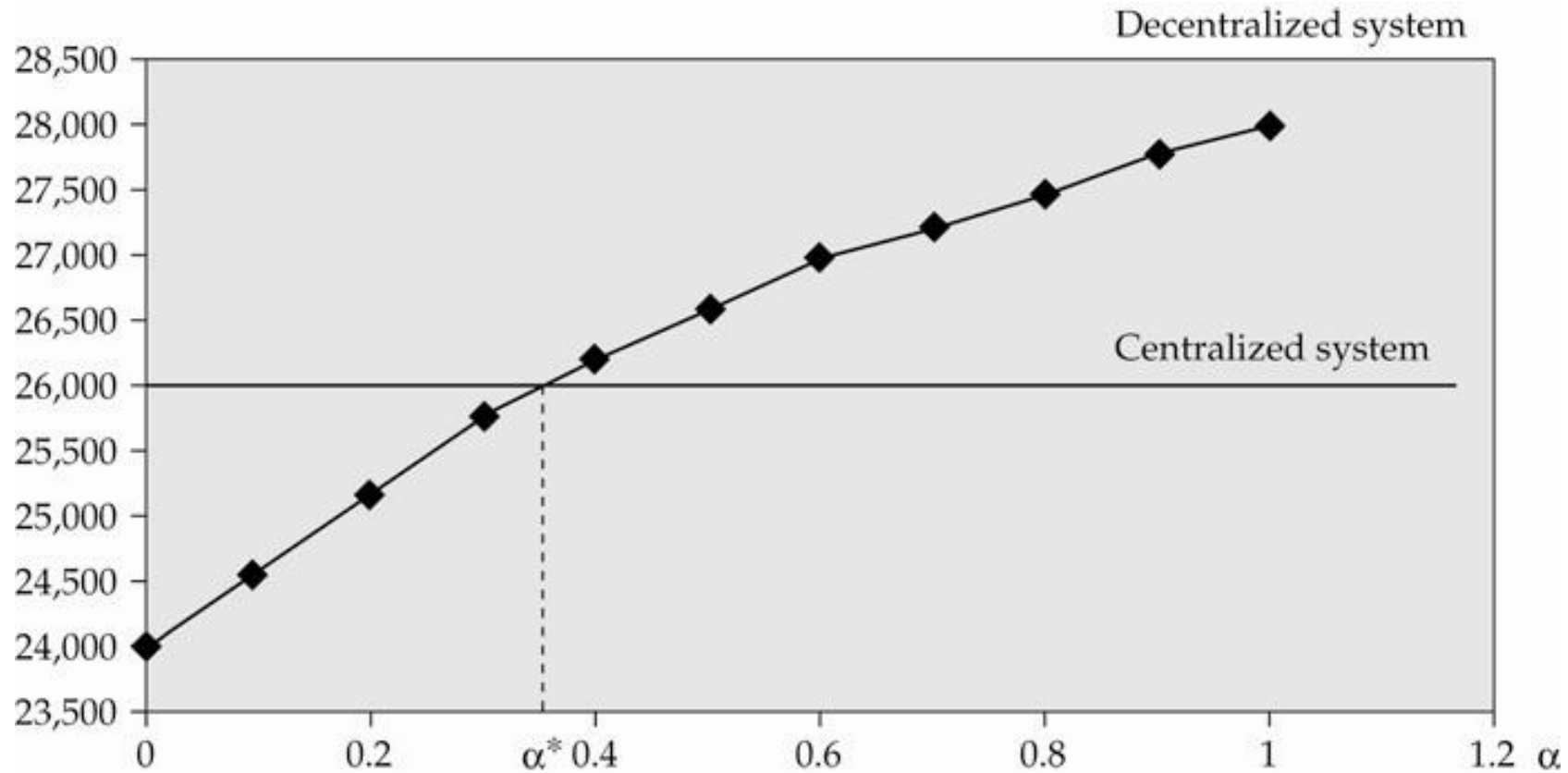


As α Increases

- With larger α
 - retailers will order more in a decentralized system
 - manufacturer will prefer a decentralized system
 - retailers will prefer a centralized system
- With smaller α
 - retailer will order less in a decentralized system
 - both the retailers and the manufacturer will prefer a centralized pooling system.



Effect of α on Amounts Ordered



Amount ordered by dealers as a function of the search level



Critical Search Level

- Presence of a critical search level
 - manufacturer prefers the centralized system below the level
 - otherwise, manufacturer prefers the decentralized system.
- Manufacturer always prefers a higher search level





How Can the Search Level Be Increased?

- Increase brand loyalty
 - customers will more likely search for a particular brand at another retailer if their first choice does not have the product in inventory.
- Information technology initiatives to increase communication between retailers
 - increases the ease with which customers can search in the system
 - higher likelihood that customers will search in the system





Transshipment

- Shipment of items between different facilities *at the same level in the supply chain* to meet some immediate need
- Occurs mostly at the retail level
- Can be achieved:
 - With advanced information systems
 - Shipping costs are reasonable
 - Retailers have same owner



Retailers with Different Owners

- May not want to do transshipments because they don't want to help their competitors
- Not clear regarding inventory levels: how much to keep? because
 - A retailer's strategy depends on competitors' strategies





Summary of the Distribution Strategies

Strategy → Attribute ↓	Direct shipment	Cross-docking	Inventory at warehouses
Risk pooling			Take advantage
Transportation costs		Reduced inbound costs	Reduced inbound costs
Holding costs	No warehouse cost	No holding costs	
Allocation		Delayed	Delayed

Allocation row: refer to the point in time at which the allocation of different products to different retail outlets should be made

For direct shipment: allocation decisions should be made earlier → longer forecast horizon

