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Sustainable Supply Chain Management

Universidade do Minho

Curriculum Development
of Master's Degree Program in
Industrial Engineering for Thailand Sustainable Smart Industry

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

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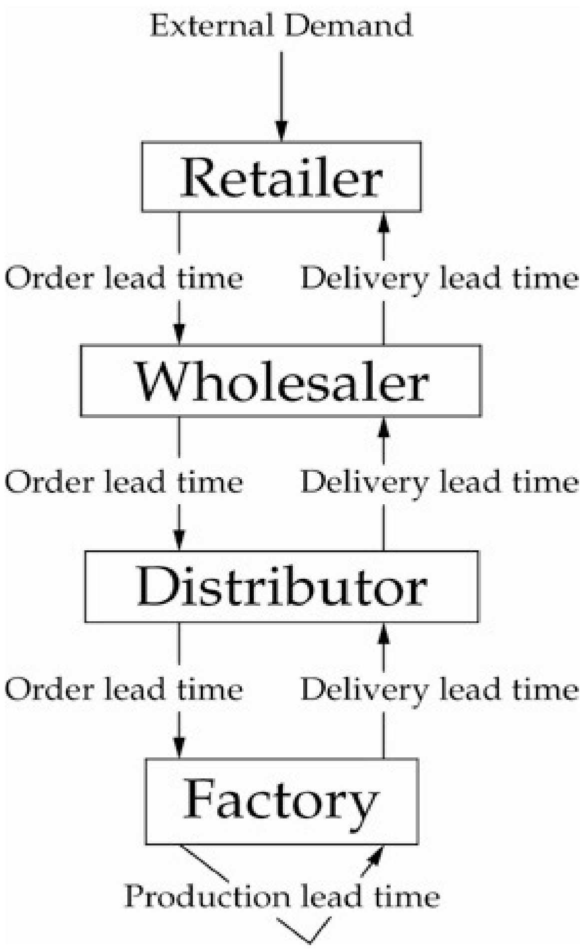
4-Stage Supply Chain



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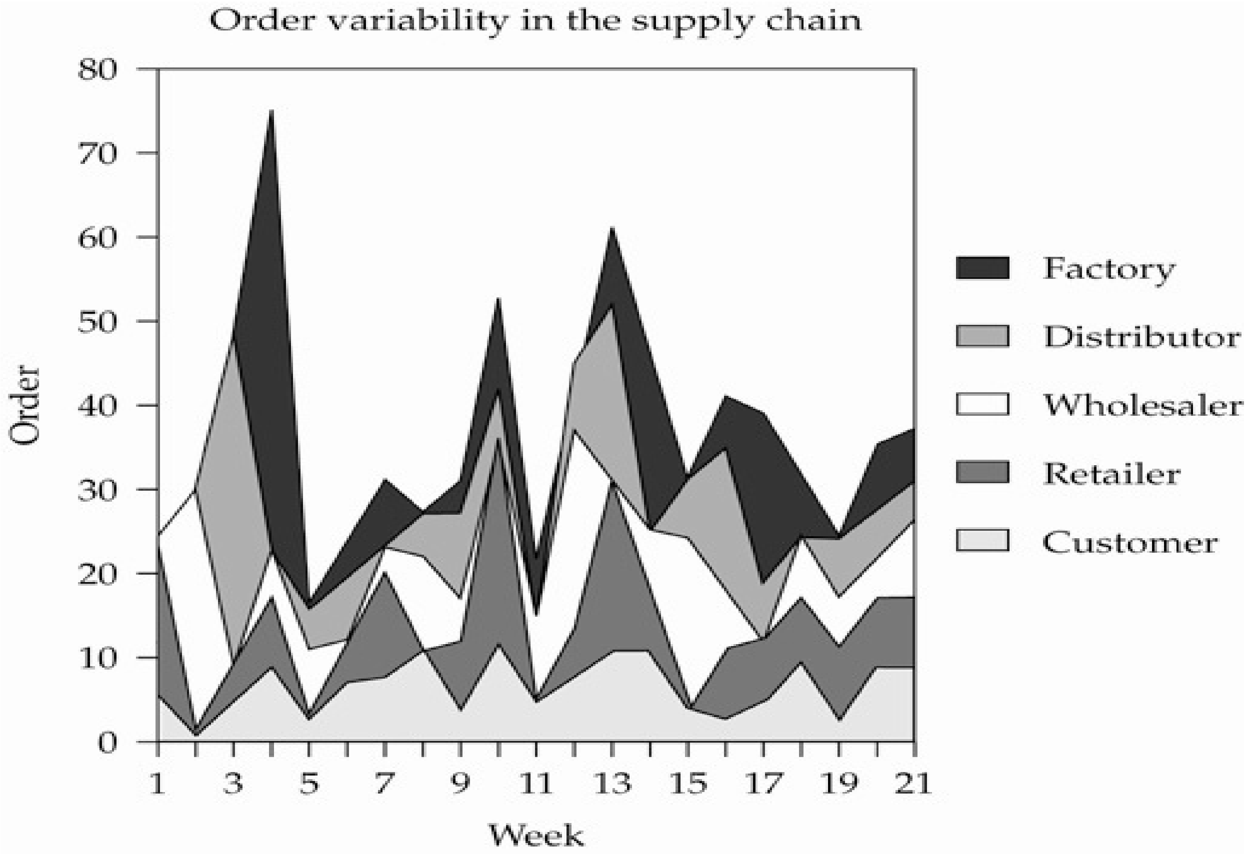
Effect of Order Variability



The increase in variability in the supply chain

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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

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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

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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

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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

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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

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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

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Quantifying the Bullwhip

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

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,

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

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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*.

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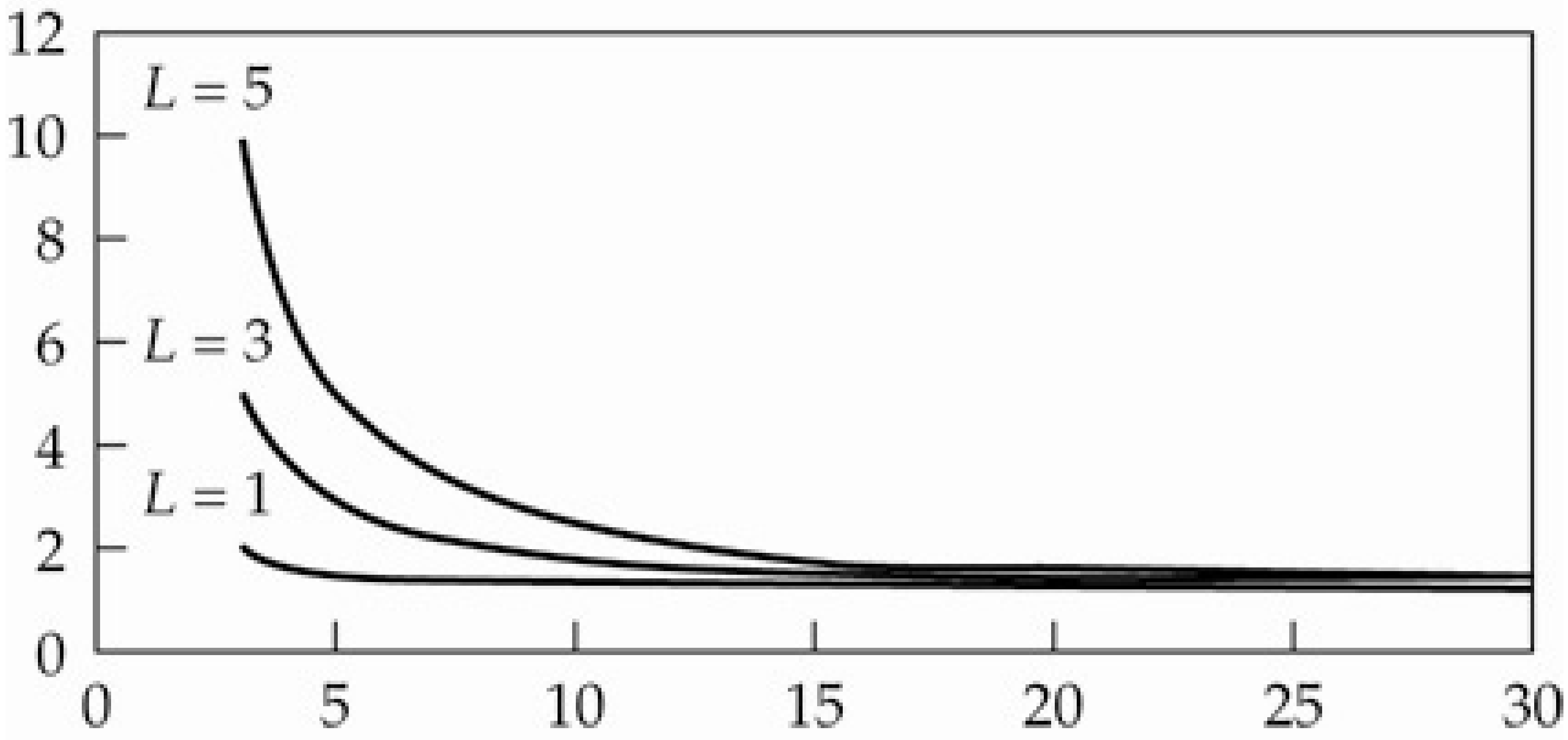
Lower Bound on the Increase in Variability Given as a Function of *p*



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

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Impact of Variability Example

- Assume p = 5, L=1

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

- Assume p = 10, L=1

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

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

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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

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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*

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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

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

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

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Managerial Insights

- 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!!

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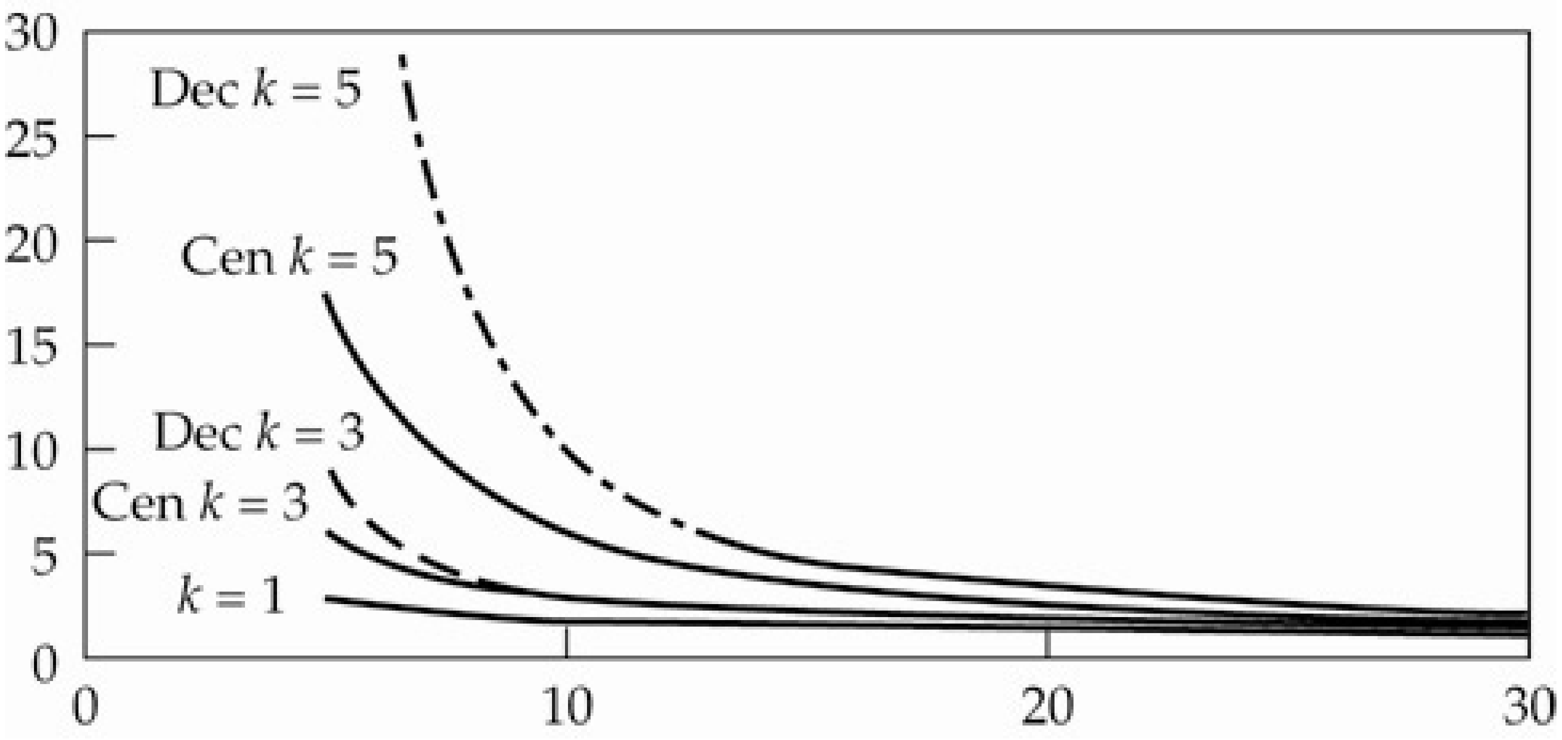
Increase in Variability for Centralized and Decentralized Systems



Increase in variability for centralized and decentralized systems

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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.

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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.

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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

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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

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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

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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

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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

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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.

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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

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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

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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.

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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

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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

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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

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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

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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%

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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.

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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

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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

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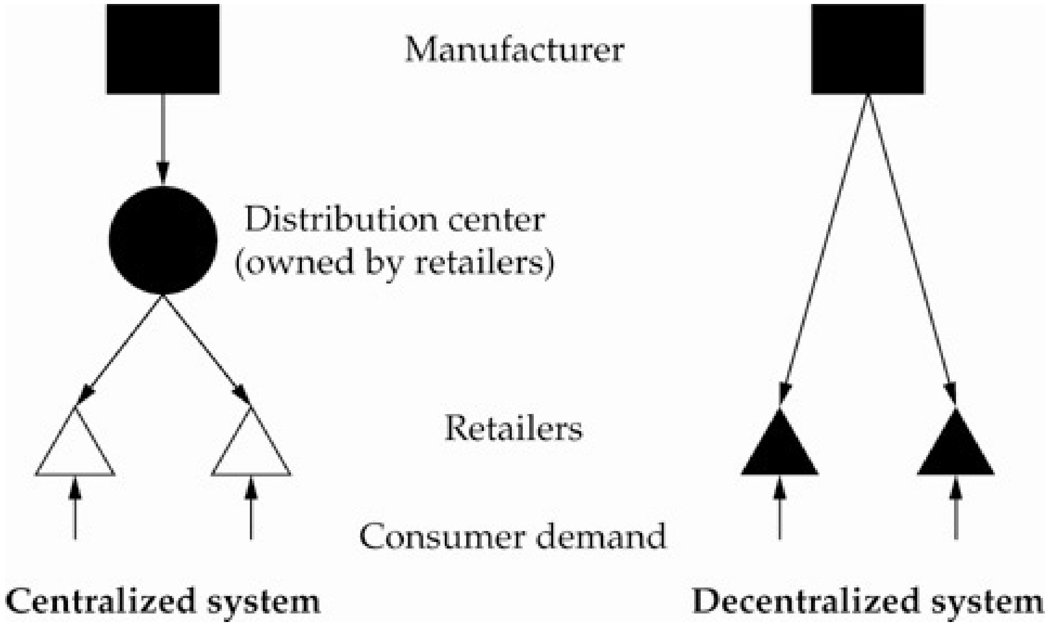
The Two Systems



The centralized and decentralized systems

Probabilistic demand faced by each retailer

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Other Data

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

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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

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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

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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.

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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.

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Example (see slide 41 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"

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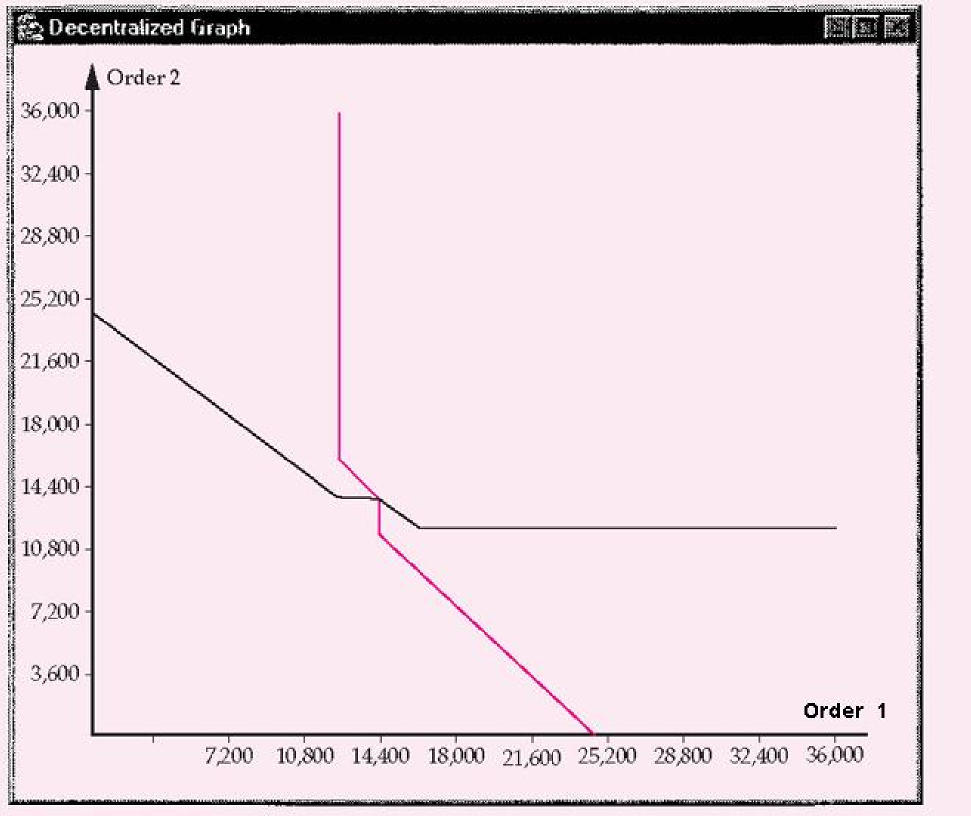
Best Response with α=90%



Retailers' best response

Black: Retailer 2
Pink: Retailer 1

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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.

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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

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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

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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.

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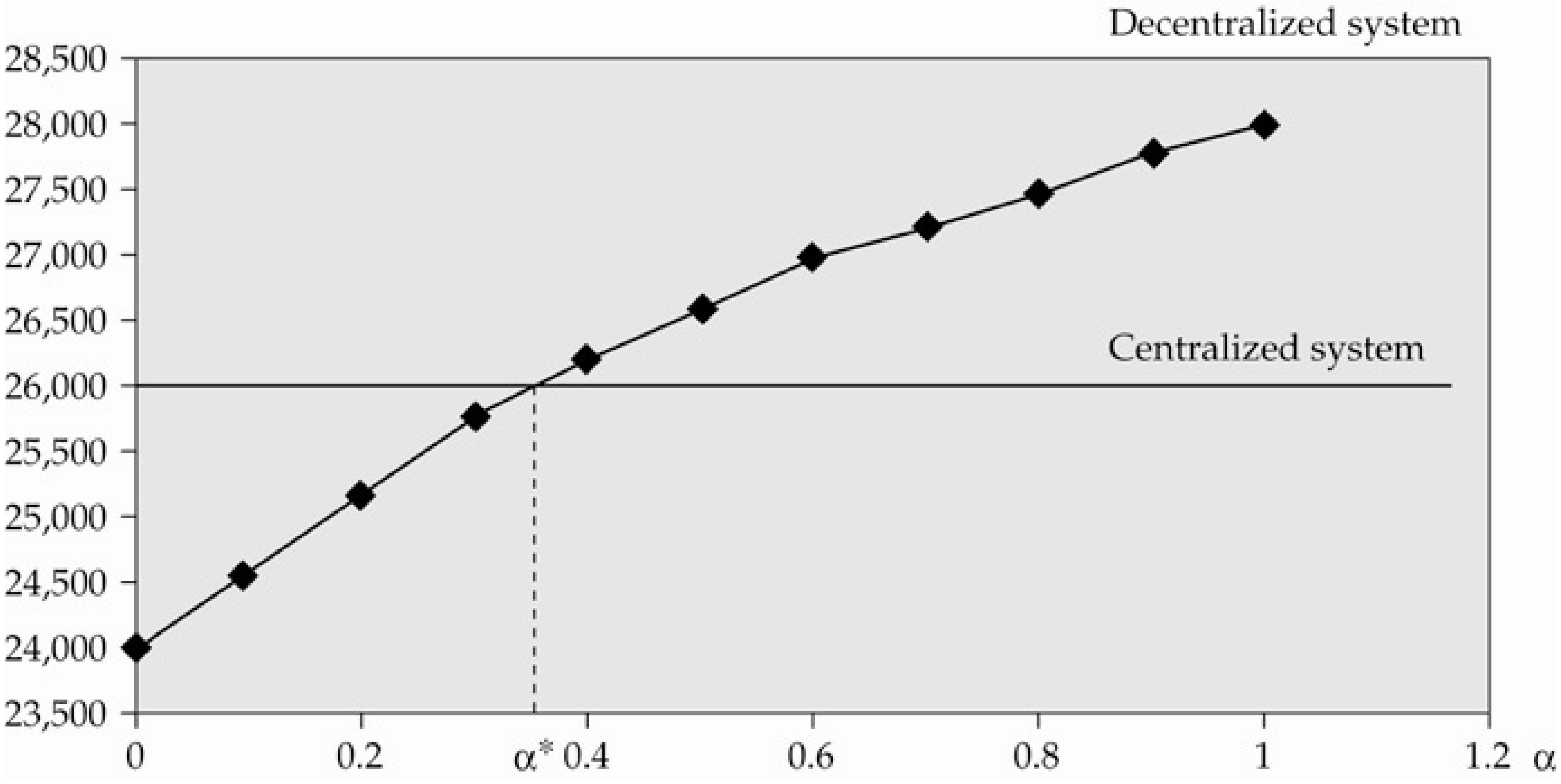
Effect of α on Amounts Ordered



Amount ordered by dealers as a function of the search level

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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

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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

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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

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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

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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

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