Contemporary Logistics

Managing Inventory Flows in the Supply Chain

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Outline

- A. Inventory Concepts
- B. Models and Methods
- C. Modern Inventory Management Practices
- D. ABC Analysis and Multiple-Item Inventory Management Systems

A. Inventory Concepts

- **Inventory mainly due to "Mismatch" between demand and supply (** for reasons of: timing, quantity, location, form, etc.)
- **Demand Side – Common Factors**
  - Variety (kinds)→ Product line proliferation → large SKUs (e.g., tea, m. phones)
  - Variability (amounts)→ Safety stock (e.g. heating oil)
  - Urgency (time)→ Quick Response to customer service opportunity (e.g., C.Y. Screws Co., disaster relief)
  - Channel delay (distance, form) → pipeline / buffer stock (e.g. food prep., transport delay, etc.)

- **Demand Side – Seasonality**
  - Seasonality can occur on the inbound and/or outbound side of the firm's production/logistics systems. (e.g., Halloween candies, turkey); Perishable supply in agricultural/ fishery products (e.g., king crab, Shijia fruit).
  - Event-related transportation needs (e.g., May 1 holiday traffic rush, Olympics).
  - Seasonal demand pattern causes inventory needs and compresses logistics activities.
  - Seasonality demands may be relieved by better technology (cold storage/processing) or by planned dispersion

- **Demand Side** – Event-related Factors
- Anticipation of some external event will negatively impact the demand. (e.g., airlines labor strikes, shortage of supplies due to weather or political event; reported quality problems)
- Significant price increases of material / process, regulations may prompt the firm to build inventory levels higher than normal (e.g., recent global rice price hike; price of rice wine ~ yr. 2000 in Taiwan).
- Risk assessment (under- over-stock) is important in these cases.

Supply Side: ***Batching Economies***

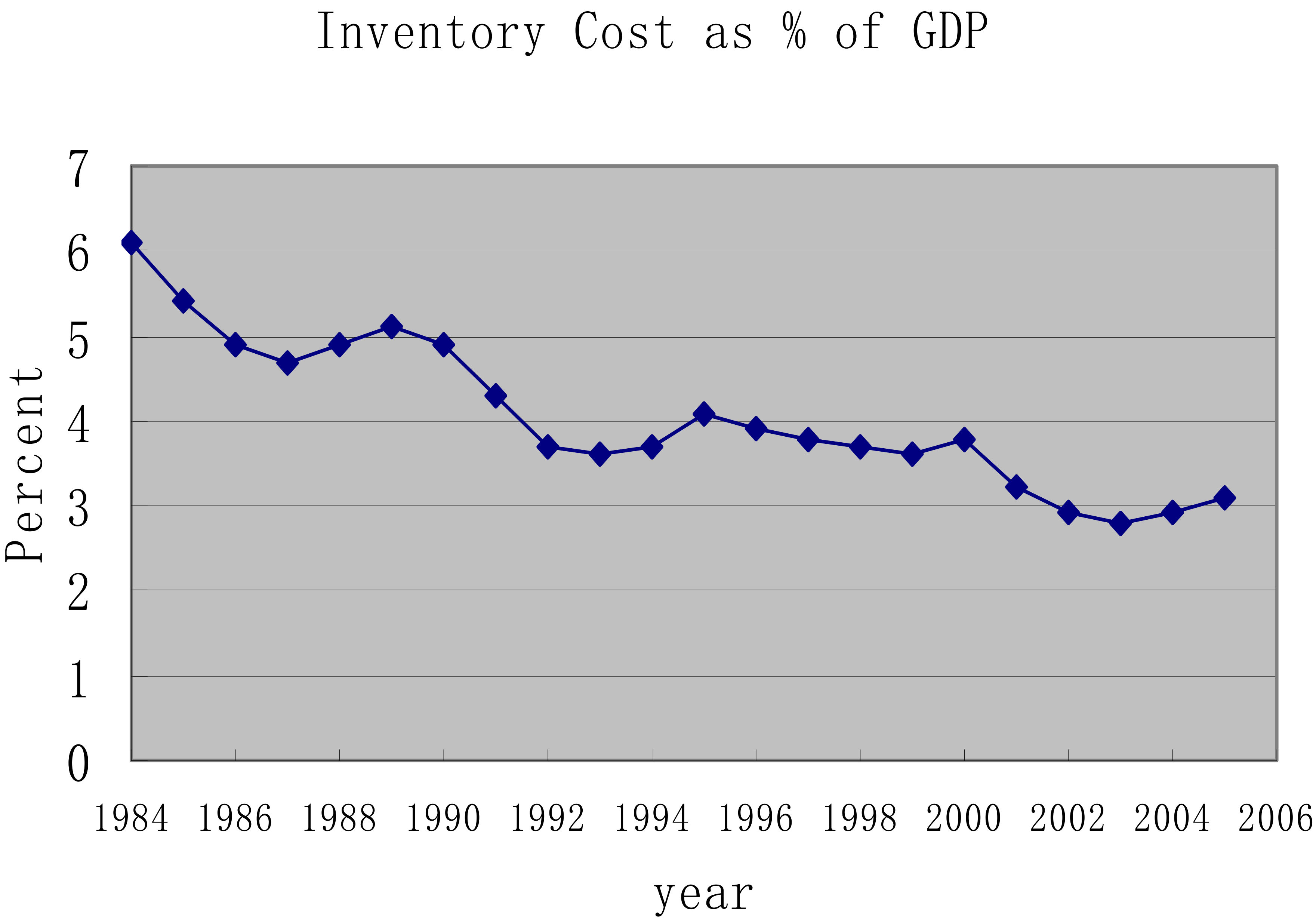
- Production economy: High setup cost, time, or complexity of adjustments favor long production runs.
- Marketing economy: Price discounts result in trade-offs between large purchases qualifying for quantity discounts and costs of storing inventory.
- Logistics Economy: Transportation rate discounts giving to large quantities shipments (carload/ truckload/ train load), lower freight rates.

Inventory: Necessary? or Evil?

- Inventory is not evil. But mismanagement of inventory is costly (tangible and intangible), so firms should try to “cut the fat out. ”
- Better demand data analysis and forecasting can provide more accuracy in inventory needs.
- Information technology such as: Bar coding, EDI, the Internet have enabled companies to reduce uncertainty (and inventory holding)
- Collaborative planning and forecasting requirements (CPFR) is helpful along the supply chain. (e.g., TAL & J.C. Penney)

Inventory in the U. S. Economy

- Inventory in the Economy has decreased.
- From 1984 to 2005, GDP has increased 3 times, but inventory value has increased only 2 times.
- As a percentage of the GDP, from 1984 to 2005, inventory levels have decreased from 6.1% to about 3.1%; a decrease of 50%.
- % of inventory, based on 1985 as 100, has decreased to ~50 in 2005.
- This Means that businesses have made significant progress in reducing the inventory burden.


Inventory Cost as % of GDP
Percent
7
6
5
4
3
2
1
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
year

- **U.S. Inventory Cost as % of Logistics Costs – 2005**
- **Inventory coats is 33.2% of Logistics costs – 2005**
- Total all business inventory value = 1763 $ Trillion

	$ B	%
Carrying costs --	$ B	%
Interest	58	
Taxes, obsolescence, depreciation, insurance	245	
Warehousing	90	
Subtotal	393	33.2
Transportation Costs –		
Truck – Interstate	394	
Truck – Local	189	
Other carriers	153	
Subtotal	736	66.2
Services & Administrative Costs	54	4.6
Total Costs	1183	

Major Types of Inventory Costs

- **1. *Inventory Carrying Cost***
  - **Capital Cost**
    - Opportunity cost associated with investing in inventory, capital tied up in inventory.
    - Assets needed to handle inventory; minimum ROA expected.
  - **Warehousing Cost**
    - Fixed facility cost and variable handling costs, rents, utilities.
  - **Inventory Service Cost**
    - Insurance and taxes on stored goods; varies according to the value of the goods.
  - **Inventory Risk Cost**
    - Due to obsolescence, damage, theft, employee pilferage.

- **2. *Order/Setup Costs***
- Order costs
  - MIS costs for inventory stock level tracking.
  - Preparing and processing purchase orders and receiving reports.
  - Inspecting and preparing inventory for sale.
- Setup Costs
  - Incurred when production changes over from one product to another.
- *Carrying Cost versus Order Cost*
- Order costs and carrying costs respond in opposite ways to increases in volume.

Example of Inventory Carrying and Order Costs

Summary of Inventory and Cost Information

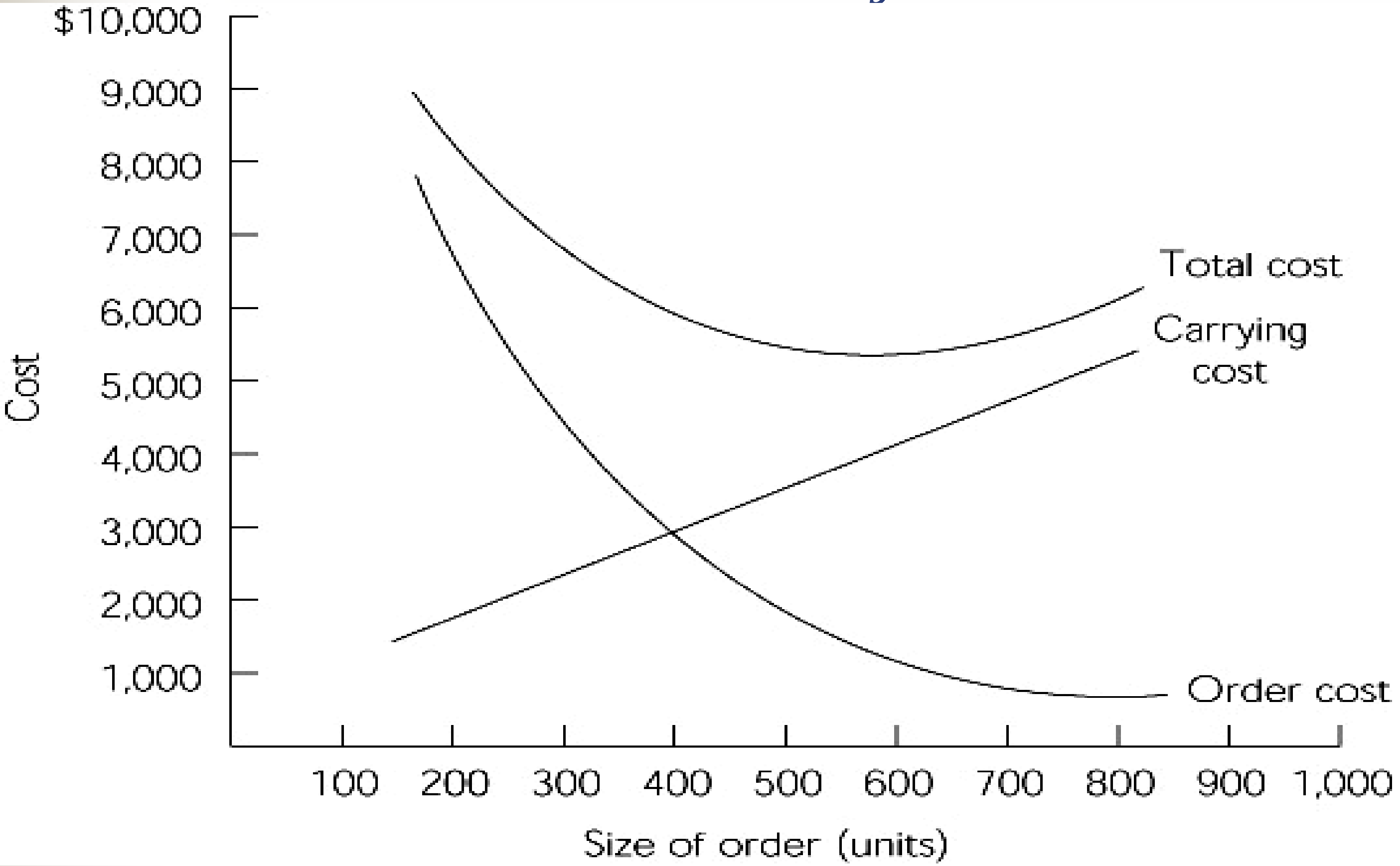
Order Period	Number of Orders per Year	Average Inventory* (Units)	Total Annual Order Cost†	Change in Total Order Cost	Total Annual Inventory Carrying Cost‡	Change in Total Carrying Cost	Total Cost
1 week	52	50	$10,400		$ 1,250		$11,650
				–5,200		+1,250	
2 weeks	26	100	5,200		2,500		7,700
				–2,600		+2,500	
4 weeks	13	200	2,600		5,000		7,600
				–1,800		+11,250	
13 weeks	4	650	800		16,250		17,050
				–400		+16,250	
26 weeks	2	1,300	400		32,500		32,900
				–200		+32,500	
52 weeks	1	2,600	200		65,000		65,200

*Assume sales or usage at 100 units per week.

†Order cost is $200.

‡Value is $100 per unit and carrying cost is 25%.

General *Inventory Cost Curves*



3. *Expected Stockout Cost*

- When inventory on hand is met with demand, it's possible that the firm may not have product available when a customer wants it. This is a stockout situation.
- Stockout cost includes lost sale, backorder costs (special order), good will loss or lost customer.
- In a manufacturing firm, a stockout may result in lost hours of production until the item is restocked.
- Stockout costs are hard to assess, but critical to an efficient inventory management system.

- Q: Should stockout be permitted? Even accepted? When should it be considered? (Ration?, Priority?)

Inventory Visibility (e.g., Saturn Parts)

- Visibility: the ability of the firm to “see” inventory on a real-time basis throughout the supply chain system. This requires:
  - Tracking and tracing inventory SKUs for all inbound and outbound orders.
  - Providing summary and detailed reports of shipments, orders, products, transportation equipment, location, and trade lane activity.
  - Notification of failures in inventory flow.

Evaluating the Effectiveness

- **How frequently does backordering and/or expediting occur?**
  - The answer to this question (never ~ frequent) can point out the need for a modification or adoption of new inventory strategies. (e.g., Hunt-Wesson Foods)
- **What is the Inventory Turnover ratio for each product SKU?**
  - This ratio can provide good information on whether the inventory is being effectively and efficiently managed.

Inventory Turns (Turnover)

- Inventory turns is a measure of how long inventory stays before being sold.
- Increasing emphasis on fully integrated supply chain means inventories barely spend any time sitting idle.
- Ideally, zero inventory will maximize cash flow.
- In reality, inventory turnover depends on product, lag time, demand pattern, etc.; potential is 30 to 40 times/year for excellent firms. (e.g., Toyota vs. 7-11, Dell, Zara, Haier)

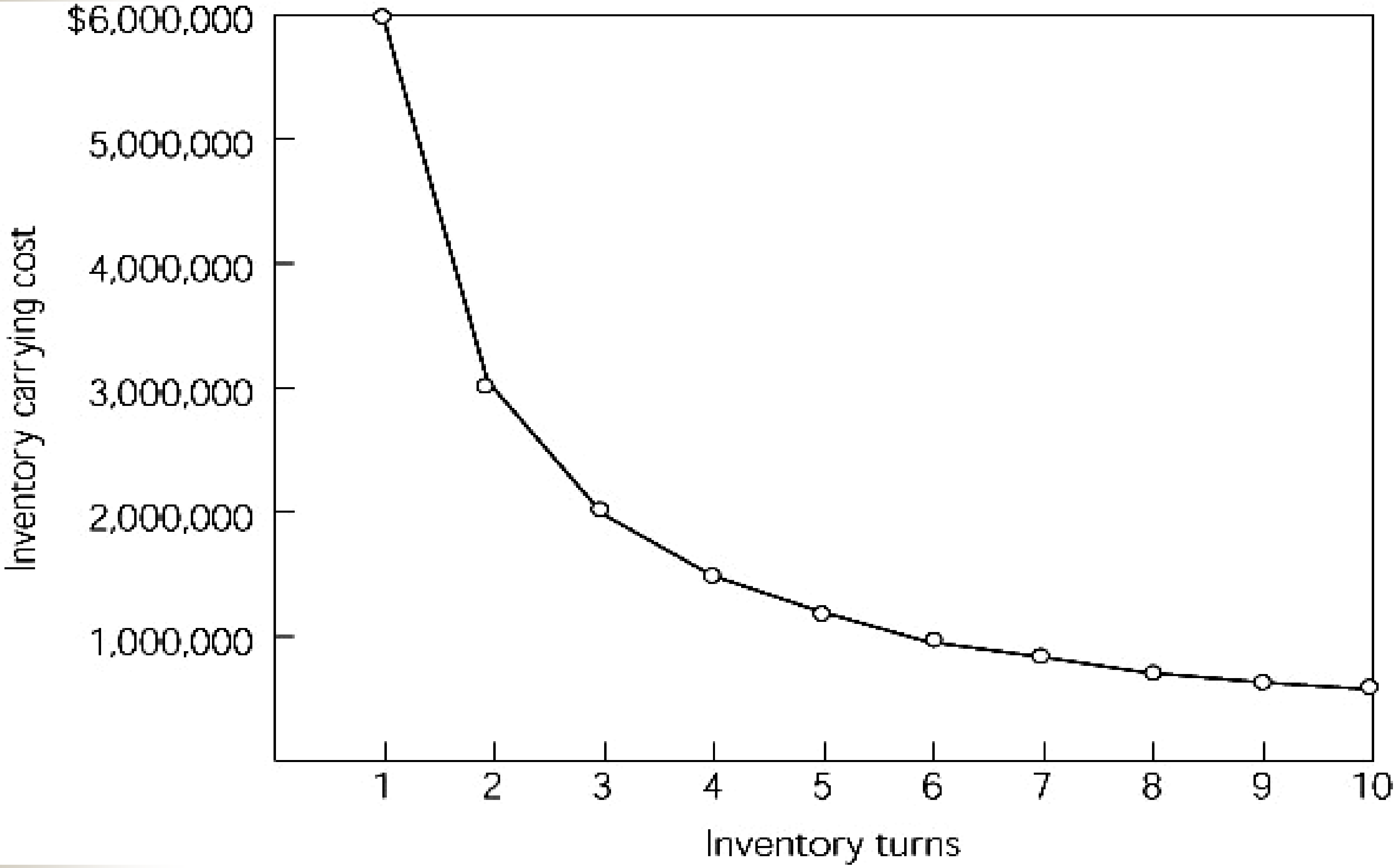
The Relationship among Inventory Turnover, Average Inventory, and Inventory Carrying Costs

The Relationship among Inventory Turnover, Average Inventory, and Inventory Carrying Costs

Inventory Turnover	Average Inventory	Inventory Carrying Cost*	Incremental Savings in Carrying Cost	Cumulative Savings in Carrying Cost
1.................	$20,000,000	$6,000,000	–	–
2.................	10,000,000	3,000,000	$3,000,000	$3,000,000
3.................	6,666,667	2,000,000	1,000,000	4,000,000
4.................	5,000,000	1,500,000	500,000	4,500,000
5.................	4,000,000	1,200,000	300,000	4,800,000
6.................	3,333,333	1,000,000	200,000	5,000,000
7.................	2,857,143	857,143	142,857	5,142,857
8.................	2,500,000	750,000	107,143	5,250,000
9.................	2,222,222	666,667	83,333	5,333,333
10.................	2,000,000	600,000	66,667	5,400,000

*Assume that inventory carrying cost equals 30%.

Saving Inventory Dollars by Inventory Turns



B. Models and Methods

- Basic inventory policy is twofold: how much to order (Q) and when to order (T).
- **Dependent versus Independent Demand**
- Independent demand is unrelated to the demand for another product. For many end-use items, demand is independent. (e.g., Mengniu, d. rings)
- Dependent demand is directly related to the demand for another product. For many manufacturing processes, demand is dependent.
- (e.g., Refrig. Parts; cell phone display, etc.)
- Some products are both Independent and Dependent
- (e.g., IKEA furniture, auto tires, battery)

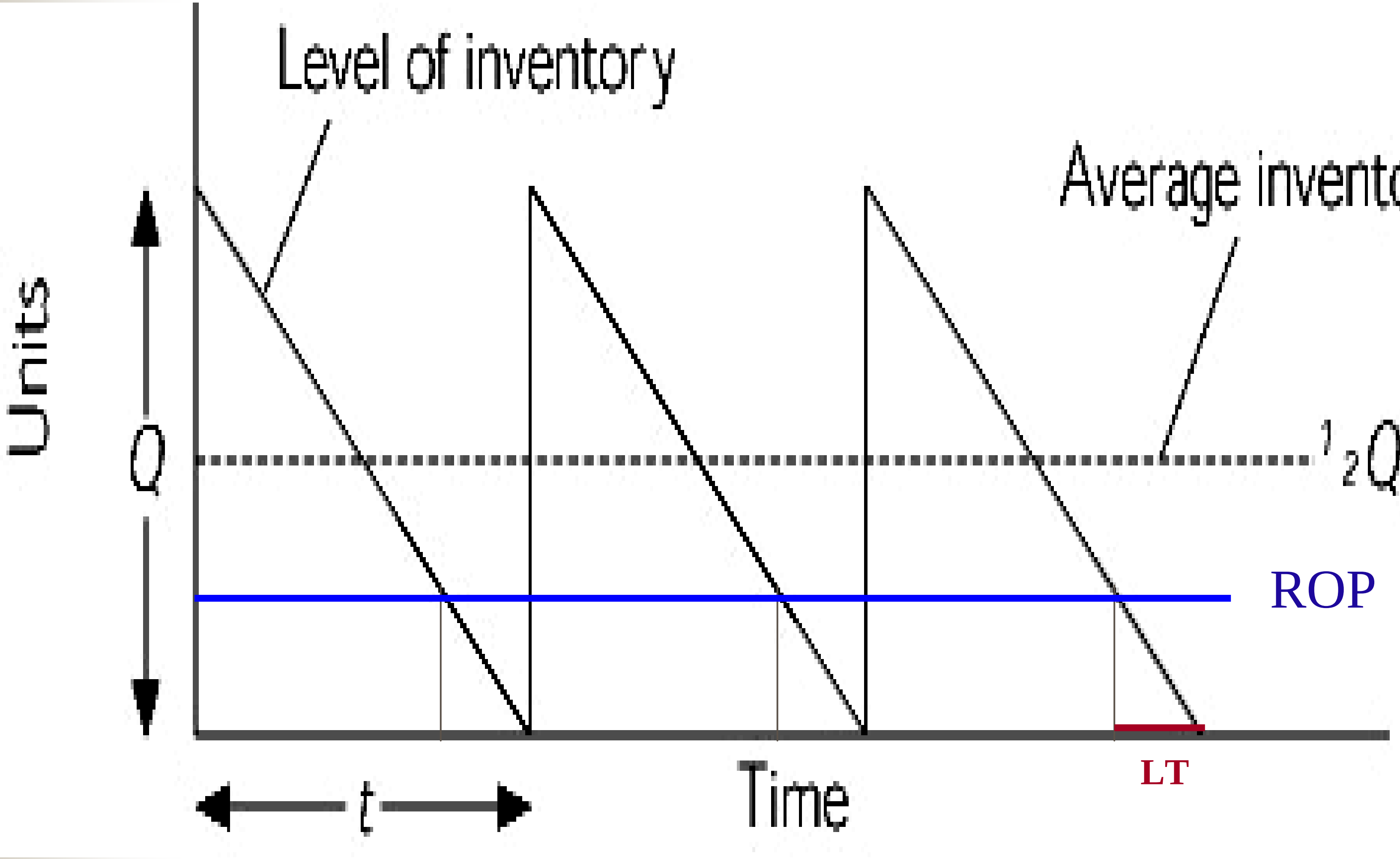
B. Models and Methods

- Inventory models based on variations of the
  Economic Order Quantity (EOQ) Model:
- Four basic inventory models for a single item:
  - Fixed quantity/fixed order interval
  - Fixed quantity/variable order interval
  - Variable quantity/fixed order interval
  - Variable quantity/variable order interval

1. Fixed Order Quantity: B*asic EOQ Model*

- Assumptions
  - Continuous, constant, known rate of demand on one independent item
  - A constant and known replenishment time (LT= constant)
  - Satisfaction of all demand (no shortage allowed).
  - Constant cost, independent of order quantity or time (no Quantity discount).

Saw tooth chart of the EOQ Model



Basic EOQ Model -- Notations

- R = annual rate of demand
- Q = quantity ordered (lot size in units)
- A = order or setup cost = $/ per order
- V = value (or cost) of each unit of item in $
- W = carrying cost (= % of V)
- S = VW = annual carrying cost in $/unit, per year
- t = time in days
- TAC = total annual costs in $ / year

EOQ Model – Cost equation

$$TAC = (Q/2) * S + (R/Q) * A$$

First term is the average carrying cost

Second term is order or setup costs per year

TAC is a quadratic curve.

Using differential calculus, solving for the minimum cost point Q*

Setting first order derivative = $S/2 - RA/Q^2 = 0$,

$Q^2 = 2RA/ S$, so

$$Q^* = \sqrt{\frac{2RA}{S}}$$

EOQ Example – annual model

R = 3600 units; A = $200 /order

V = $100; W = 25%; S (or VW)= $25/yr;

$$Q^* = \sqrt{\frac{2RA}{S}}$$

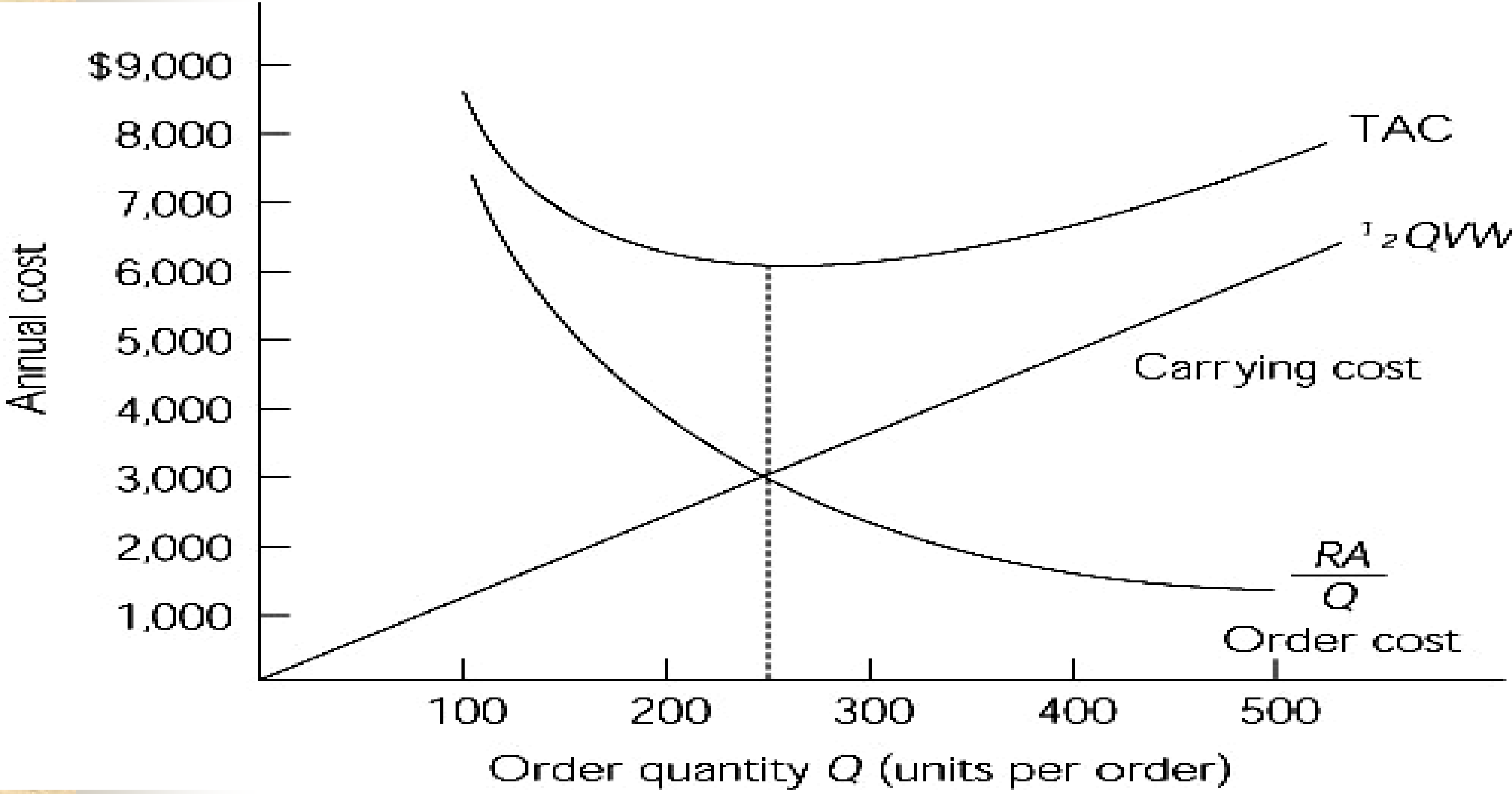
$$= \sqrt{\frac{2*3600*\$200}{\$25}}$$

Q* = 240 units

Total Costs for Various EOQ Amounts

Q	Order Costs *AR/Q*	Carrying Cost ½ *QVW*	Total Cost
100	$7,200	$1,250	$8,450
140	5,143	1,750	6,893
180	4,000	2,250	6,250
220	3,273	2,750	6,023
Q* = 240	3,000	3,000	6,000
260	2,769	3,250	6,019
300	2,400	3,750	6,150
340	2,118	4,250	6,368
400	1,800	5,000	6,800
500	1,440	6,250	7,690

Cost Graph for the EOQ Example

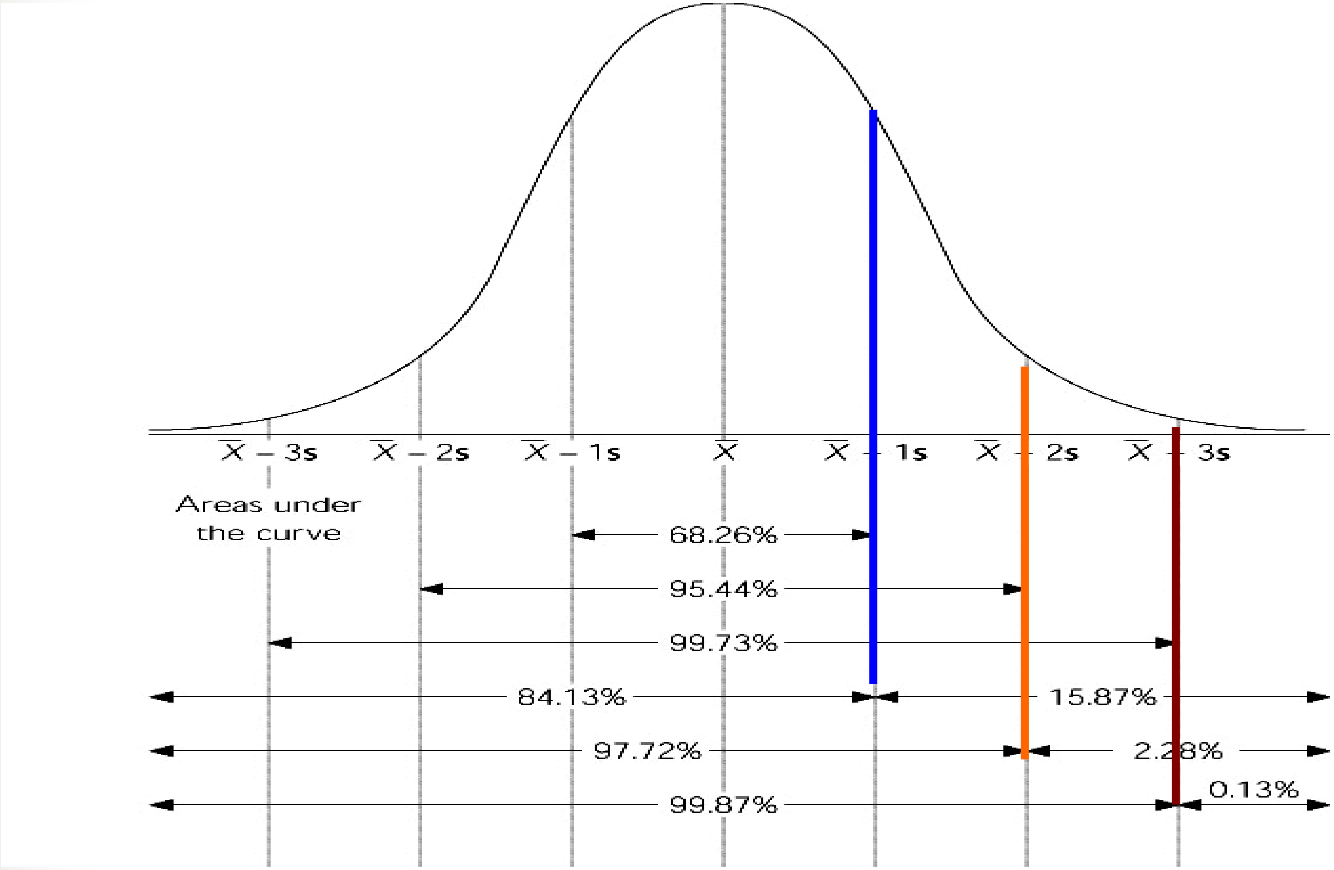


2. Fixed Order Quantity: with Uncertainty

- Demand Uncertainty is often affected by exogenous factors---weather, special occasions, etc.
- Lead time uncertainty
- Note the variability in lead times and demand on the next graph.
  - The reorder point becomes the average daily demand during lead time plus the safety stock.

(Lead-time demand Distribution X-bar = mean)

Area under the Normal Curve

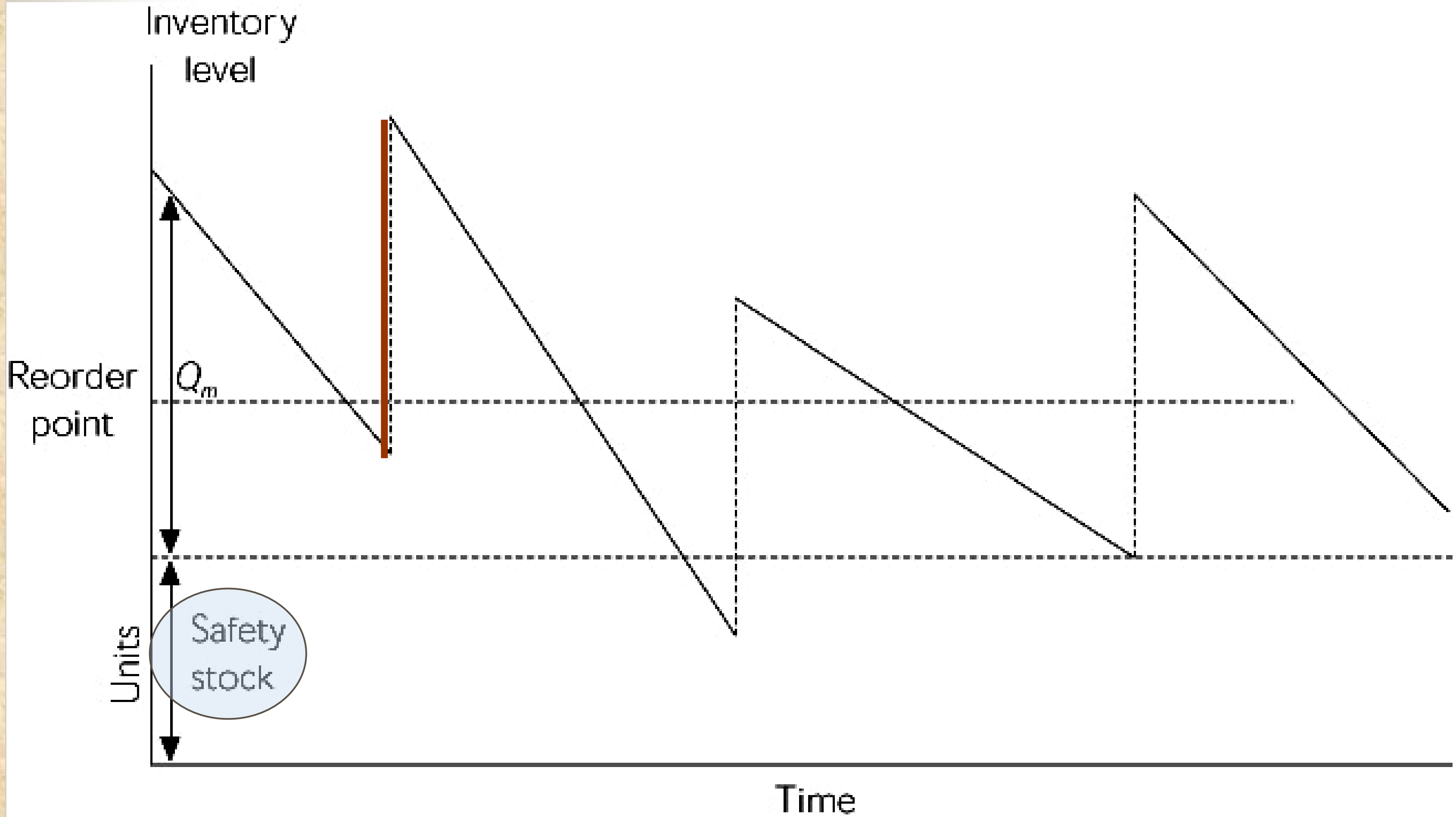


Example of *Reorder Point Alternatives and Stock out Possibilities* ***Assume: x-bar= 160, stdev = 42***

[redacted] Reorder Point Alternatives and Stockout Possibilities

Reorder Point	Probability of No Stockout Occurring	Probability of a Stockout Situation
$\bar{X} + 1s = 202$	84.13%	15.87%
$\bar{X} + 2s = 244$	97.72%	2.28%
$\bar{X} + 3s = 286$	99.87%	0.13%

Fixed Order Quantity Model under Conditions of Uncertainty



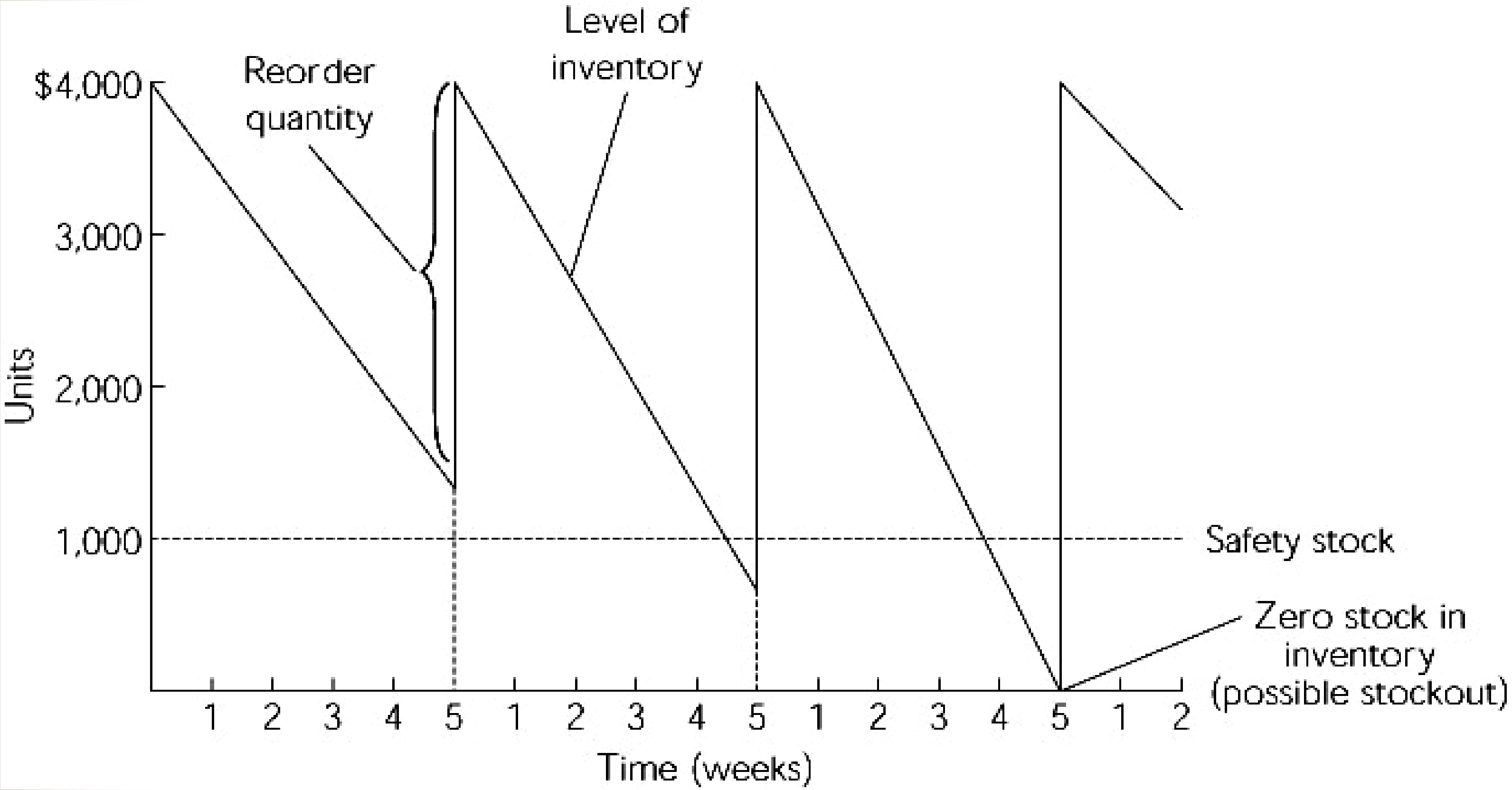
Other Inventory Models

- 3. Fixed Order Interval – various Q
  - Involves ordering at fixed intervals and varying Q depending upon the remaining stock at the time the order is placed.
  - Less monitoring than the basic model
  - Amount ordered over each five weeks in the example varies each week. (see next graph)
- 4. Fixed Review Interval – various Q
  - Review at fixed time. Order only if INV is below ROP, order various amount (see next graph)
- Continuous Review – order when INV < ROP,

  order various Q (see next graph)

Fixed Order Interval- various Q Model

(with Safety Stock)



C. Other Inventory Management Practices

- Three new approaches to inventory management that have special relevance to supply chain management:
  - **JIT (Just in Time)**
  - **MRP (Materials Requirements Planning)**
  - **DRP (Distribution Resource Planning)**

Just-In-Time (JIT)

- JIT is a widely used and effective strategy for managing the movement of parts, materials, semi-finished products from points of supply to production facilities, in small quantity and high frequency; to eliminate waste.
- parts should arrive just in time, with no tolerance for early or late deliveries.
- Goal is zero inventory, *and with tight quality requirement, zero defects*.

- JIT relies on high-quality incoming products and on exceptionally high-quality inbound logistics operations.
- JIT requires a strong, mutual commitment between buyer and seller, emphasizing quality and win-win outcomes for both partners.
- Toyota, Kawasaki, etc.

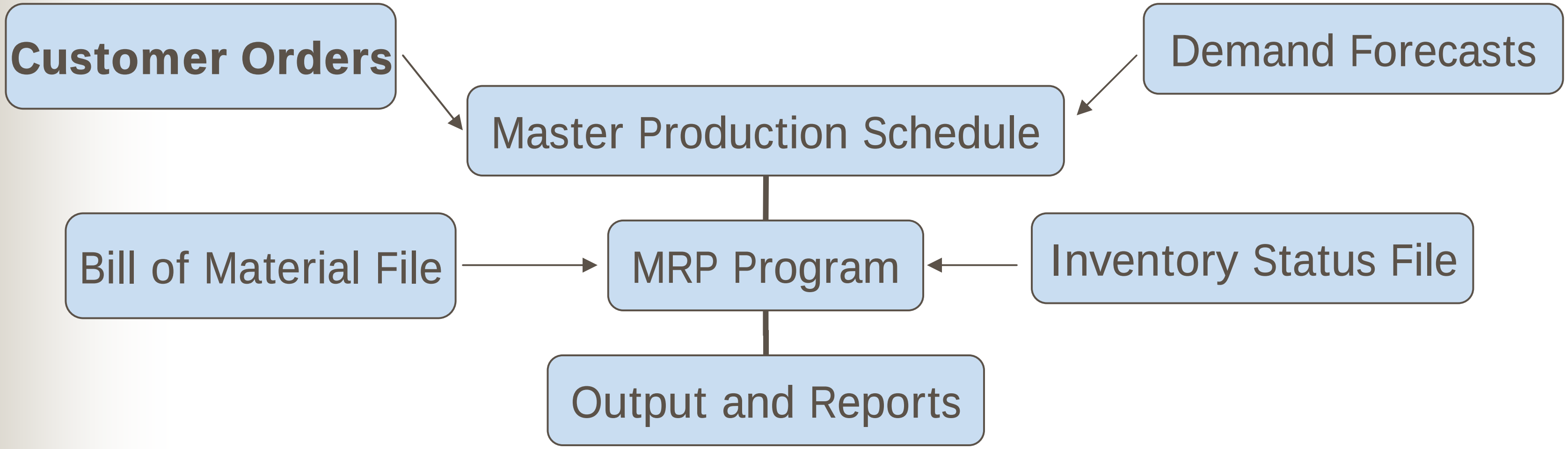
Material Requirement Planning (MRP)

- MRP system translates a master production schedule into time-phased net inventory requirements for each component item needed to implement this schedule.
- Ensure the availability of materials, components, and products for planned production.
- Maintain lowest possible inventory level.
- MRP system re-plans net requirements based on changes in schedule, demand, etc.
- Most suitable for batch or intermittent production schedules.

MRP

- **Key elements of an MRP:**
  - **Master production schedule**
  - **Bill of materials file**
  - **Inventory status file**
  - **MRP program**
  - **Outputs and reports**

An MRP System



Case: Running Inventory ***Like a Deere (1)***

- **John Deere** is a global renowned heavy equipment manufacturer (Illinois, USA)
- In 2001, the C&CE division (revenue = $4B), with finished goods inventory (FGI) = $1.4B → $2B (70% in 2500 dealers, 30% in CW). Wanted to reduce FGI to $1B in five years.
- Dealers were concerned that this would affect their product availability (due to: seasonal demands; March to June=65% of demands; needs stock on hand, long LT, slow replenishment, etc.).

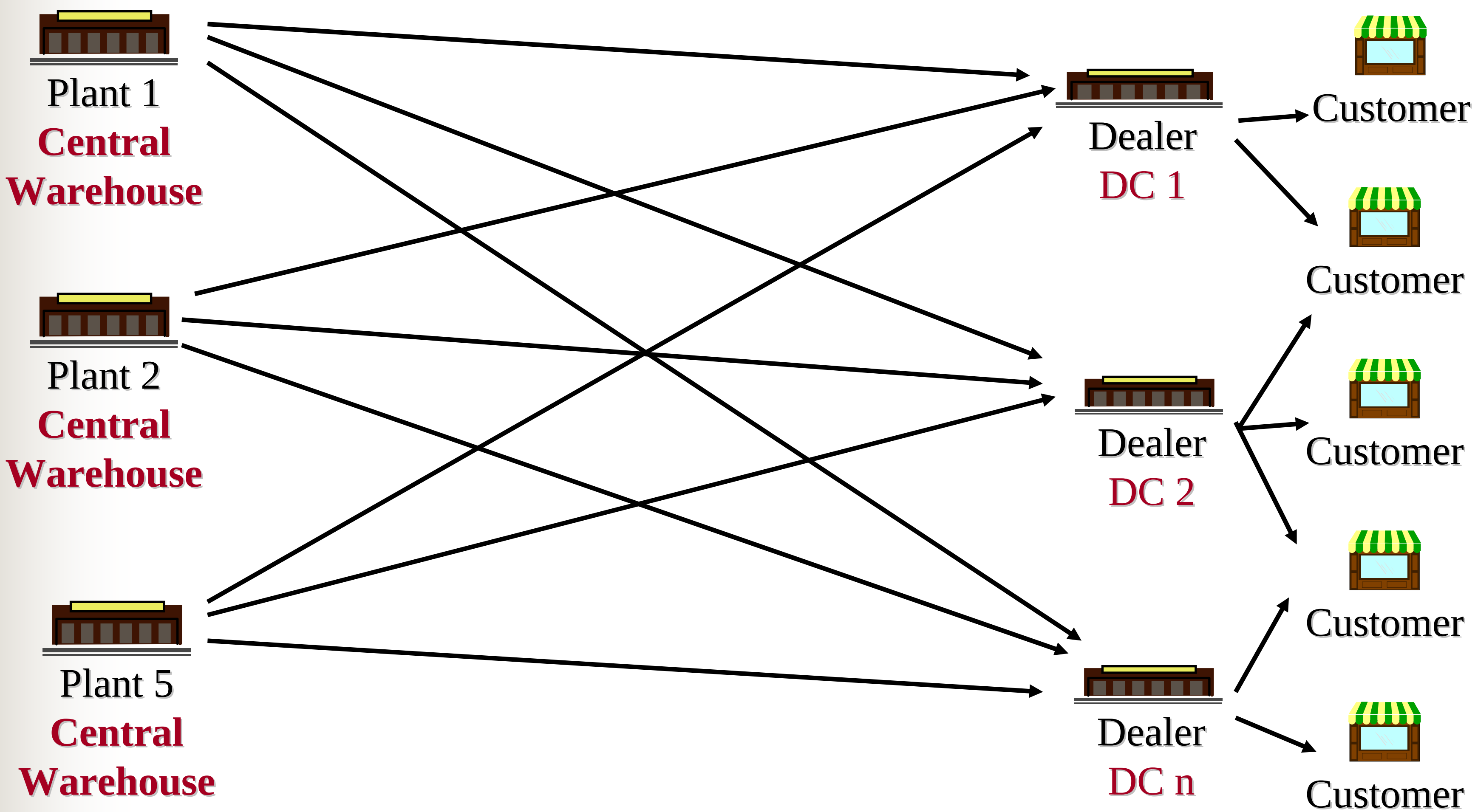
Case: Running Inventory ***Like a Deere (2)***

- Assisted by Carnegie Mellon Prof. (SmartOpt) to reduce (better match) inventory to market needs.
- **Target**: feasibility study of network optimization showed that it could reduce FGI by $250M/each year for 4 years.
- Needs to change SC operations for speed, volume, cost.
- **Production**: flexible scheduling to meet seasonal target; monthly re-planning; weekly monitoring; small lot size; mixed production; volume range = 3~4 time for high demand season.

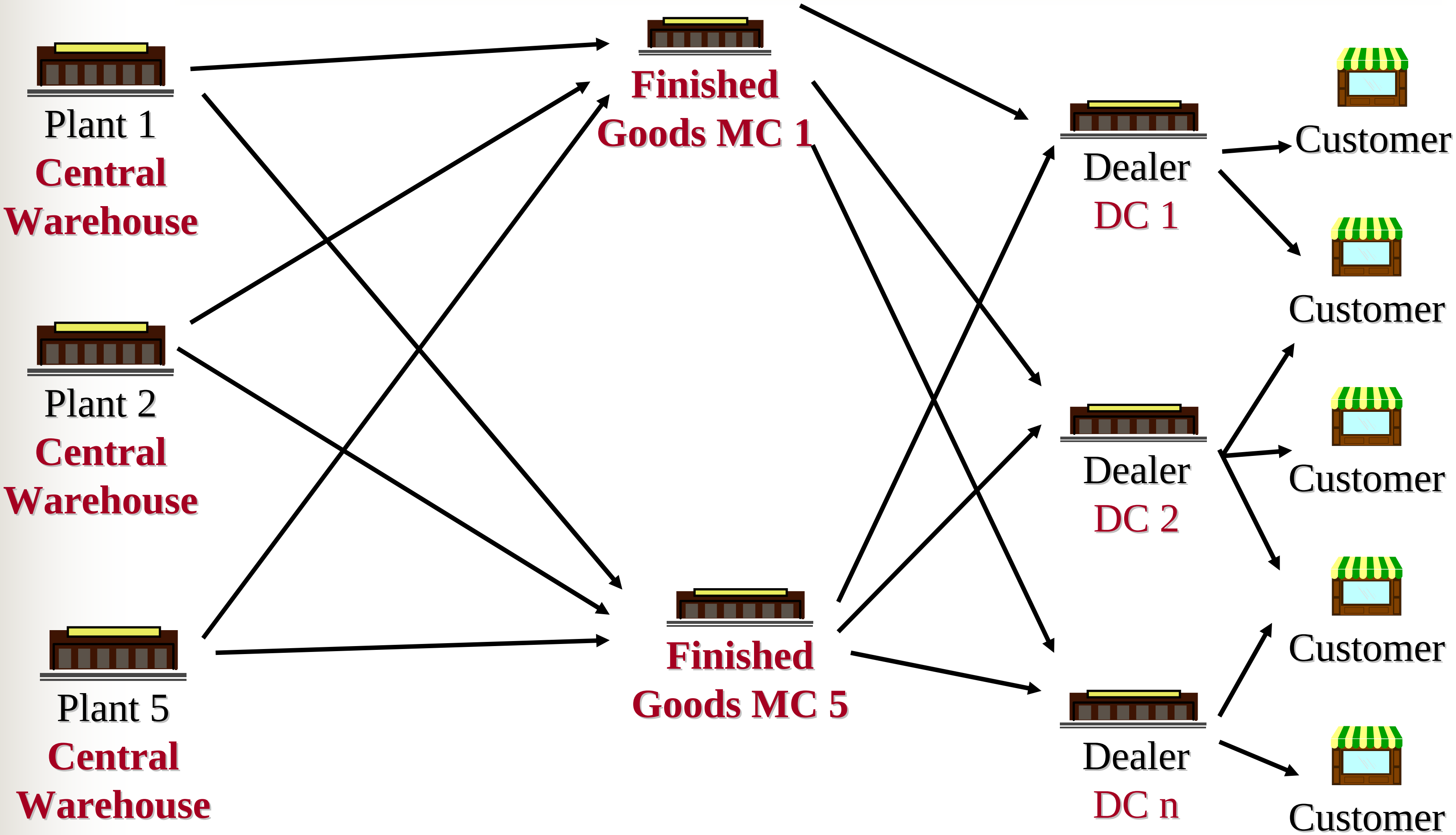
Case: Running Inventory ***Like a Deere (3)***

- **Suppliers**: required lower LT, flexible, accurate supply.
  allowing: slight buffer stock for long-LT items
- **Distribution network redesign**:
  - Old: had 5 plants + 5 DCs (close to plants) – shipped directly to dealers
  - New: Add 5 Merge Centers (MC) – closer to dealers;
  - Consolidation (mixed shipments), reduced shipments from MC to dealers.
  - Improved response time; reduced network cost ($250M/yr); offset MC asset cost
- **Dealers**: less holding, but get speedier replenishment

SC Network and Functions – Old Deere



SC Network and Functions – New Deere



Case: Running Inventory ***Like a Deere (4)***

- **Net Results**: In 2007:
- **FGI down by 1/2** from [170 days (dealers) + 70 days (CW)]
- **Order cycle**: 10days → 5 days →3 days for some items.
- Total FGI reduced to **$1B**; increased shareholder value by $200M/year
- **Better customer service** (even with lower inventory)
- **Network Optimization solution**

  + **SC redesign (production, supplier, distribution process)**

  + **diligent execution = SUCCESS!**

D. ABC Analysis & Multiple-Item Inventory Management System

- ABC is an inventory ranking system:
  - Developed in 1951 by H. Ford Dickey of General Electric.
  - Suggested that GE **classify items** according to relative sales volume, cash flows, lead time, or stock out cost.
  - Most important inventory put in **Group A**; lesser impact goods put in Groups B and C respectively.

ABC Analysis

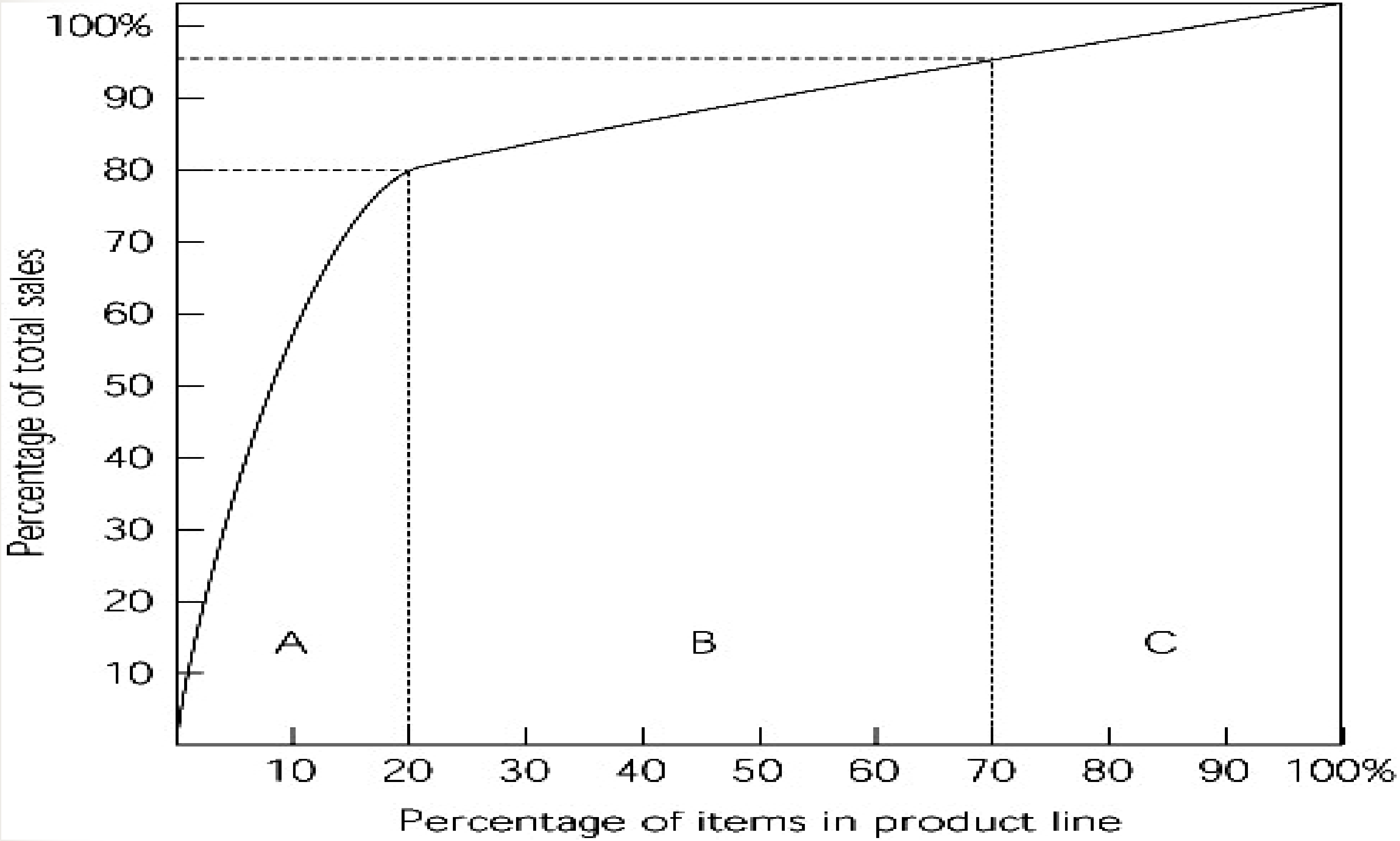
- **Pareto's Rule (80-20 Rule)**
  - Based on a nineteenth century mathematician's observation that many situations were dominated by a very few elements.
  - Separates the "trivial many" from the "vital few".
  - E.g., ~ 80% of sales will come from 20% of the inventory SKUs.
  - ~ 80% of sales will come from 20% of the customers

Example: ABC Analysis for Big Orange Products, Inc.

ABC Analysis for Big Orange Products, Inc.

Item Code	Annual Sales ($)	Percentage of Annual Sales	Cumulative Sales	Percentages Items	Classification Category
64R	$ 6,800	68.0%	68.0%	10.0%	A
89Q	1,200	12.0	80.0	20.0	A
68I	500	5.0	85.0	30.0	B
37S	400	4.0	89.0	40.0	B
12G	200	2.0	91.0	50.0	B
35B	200	2.0	93.0	60.0	B
61P	200	2.0	95.0	70.0	B
94L	200	2.0	97.0	80.0	C
11T	150	1.5	98.5	90.0	C
20G	150	1.5	100.0	100.0	C
	$10,000	100.0%			

Example Graph of ABC Inventory Analysis

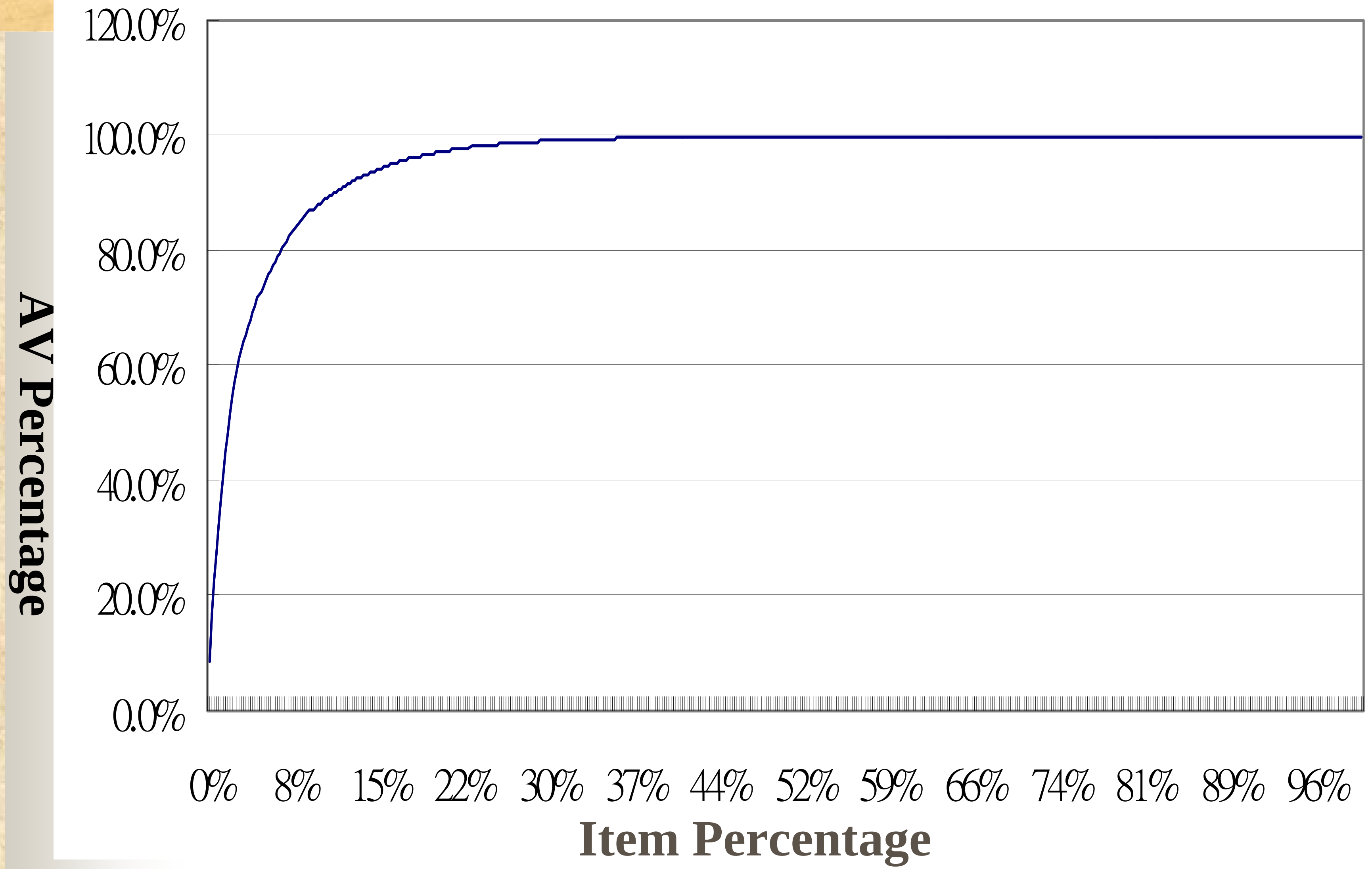


Case: A Study of Hospital Inventory Management — by **B.T. Yang et el, NDHU**

- The hospital is a regional medical center in Taiwan.
- Data source: monthly medication usage for year 2000 (489 SKUs with regular usage)
- Pricing data/unit via Taiwan's CHI pricing list
- The case study applied ABC Analysis for inventory classification and different management policies:
  - Rank SKUs (H>>L) by Annual Value (AV) = Q * P
  - Calculate cumulative % of AV , and find breaking points, for A, B, C classifications

Table for ABC classification, Item % and TV %

Category	Numbers of Items	Item Percentage	AV %
A	30	6.14%	78.96%
B	60	12.27%	17.41%
C	399	81.59%	3.63%
Total	489	100%	100%



Graph for ABC Analysis

- **Determining Ordering Model for different Categories of Medicine**
- By EOQ model – calculate best Q* for all SKUs
  - Estimating holding cost (=10% of unit price) and ordering cost (=NT$1200)
- Form Inventory policies:
  - Modify EOQ ordering policy for all SKUs to fit business practice.
  - Round ordering cycle (OC days) and consolidate orders from same supply source.
- Pattern 1： Based on the EOQ OC and round OC of all SKUs to nearest integer. Set minimum OC = 4 days, and maximum OC = 365 days.
  - Group all SKUs with same OC into one order (or also by source).

- **Varying OC for practical management control:**
- Pattern 2：group OC into 7 days, 15 days, 30 days, 90 days, 180 days, and 365 days. Round EOQ OC up to the group days, and place order according to the grouping of OC days.
- Pattern 3: Group OC by 5 day interval (e.g., 5, 10, 15, etc). Round EOQ OC up to the group days, use group median day as ordering cycle day. Consolidate orders by grouping days.
- Pattern 4: Group SKUs into ~ 30 items as one group, one consolidated order. OC is set as the maximum EOQ OC for that group.

Simulation Test of Inventory Policies

- **Simulation:** assume daily demand of each SKU are Independently, Identically Distributed Normal distribution (IID) with own μ and σ .
- Assume replenishment LT=4; calculate Safety Stock policy for 99.73% level (i.e., Z = 2.0)
- Simulated 100 top SKUs, each for 365 days, using the above 4 inventory patterns.
- Results: Pattern 1 has the min TAC, but most complex inventory ordering policy. Other patterns are as shown in the next table.

Comparison of Annual Inventory Cost for order patterns

Pattern 1 is closest to EOQ OC, so it has the lowest TAC

	Pattern 1	Pattern 2	Pattern 3	Pattern 4
TAC	25,963,100	25,971,889	25,967,765	25,963,213

Pattern 2 is most convenient- using common OC (weekly, bi-weekly, monthly and annually). Pattern 3 has a finer OC classification (5-day scale) , so its TAC is better than Pattern 2. Pattern 4 is by ranked positions, with a good TAC. But this grouping may be too arbitrary.