MATERIALS MANAGEMENT

Module 9

July 22, 2014

Inventories and their Management

“Inventories”= ?

New Car Inventory Sitting in Parking Lots

Types of Inventory

1. Materials

- A. Raw material

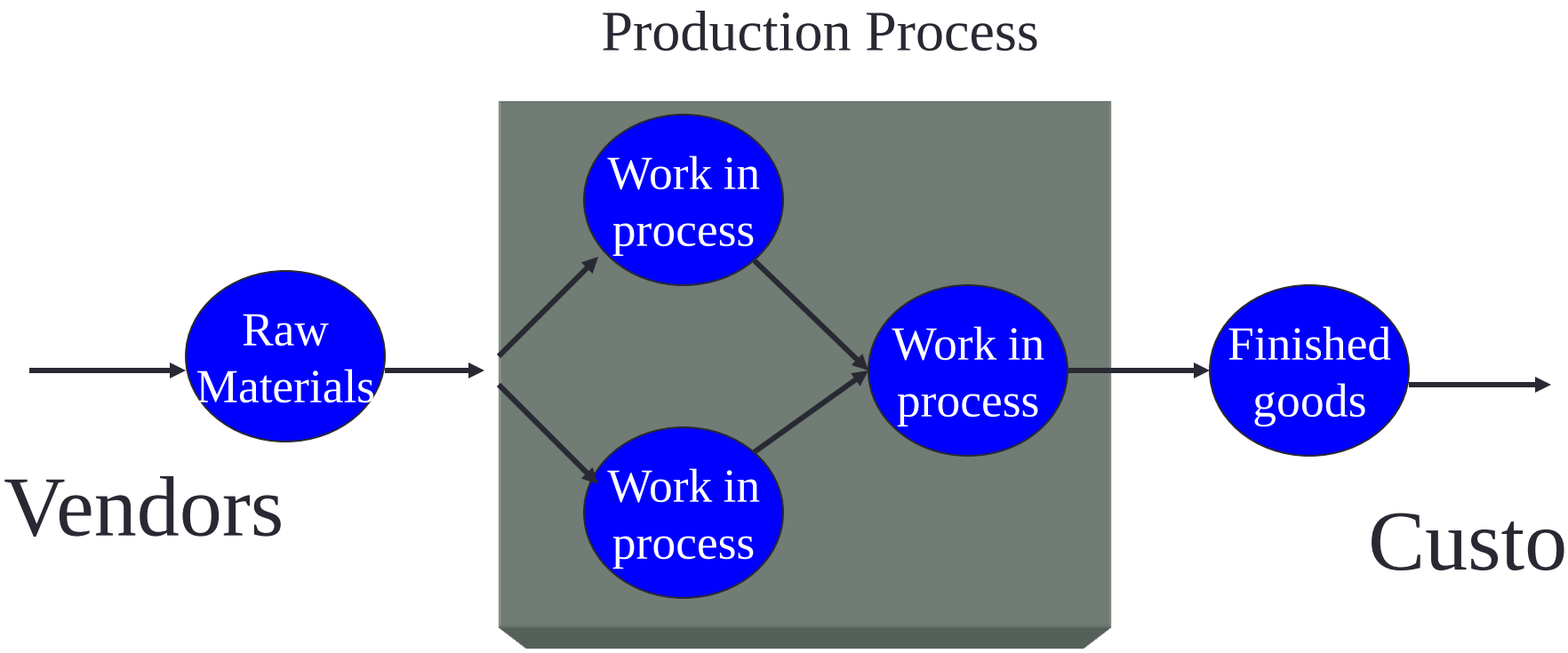
- B. WIP

- C. Finished Goods

Types of Inventory

1. Components
   - A. Subassemblies
   - B. Purchased parts that “go into”
2. Distribution inventories
   - A. Sometimes called “pipeline” inventories
   - B. In a warehouse or in transit
3. “MRO”
   - A. Maintenance items
   - B. Repair parts
   - C. Operating supplies

A Material-Flow Process



What is inventory and Inventory management?

- Inventory: a stock of materials used to facilitate production or to satisfy customer demand
  - Managing the flow of goods into, through, and out of an organization

Inventory

- One of the most expensive assets of many companies representing as much as 50% of total invested capital
- Operations managers must balance inventory investment and customer service

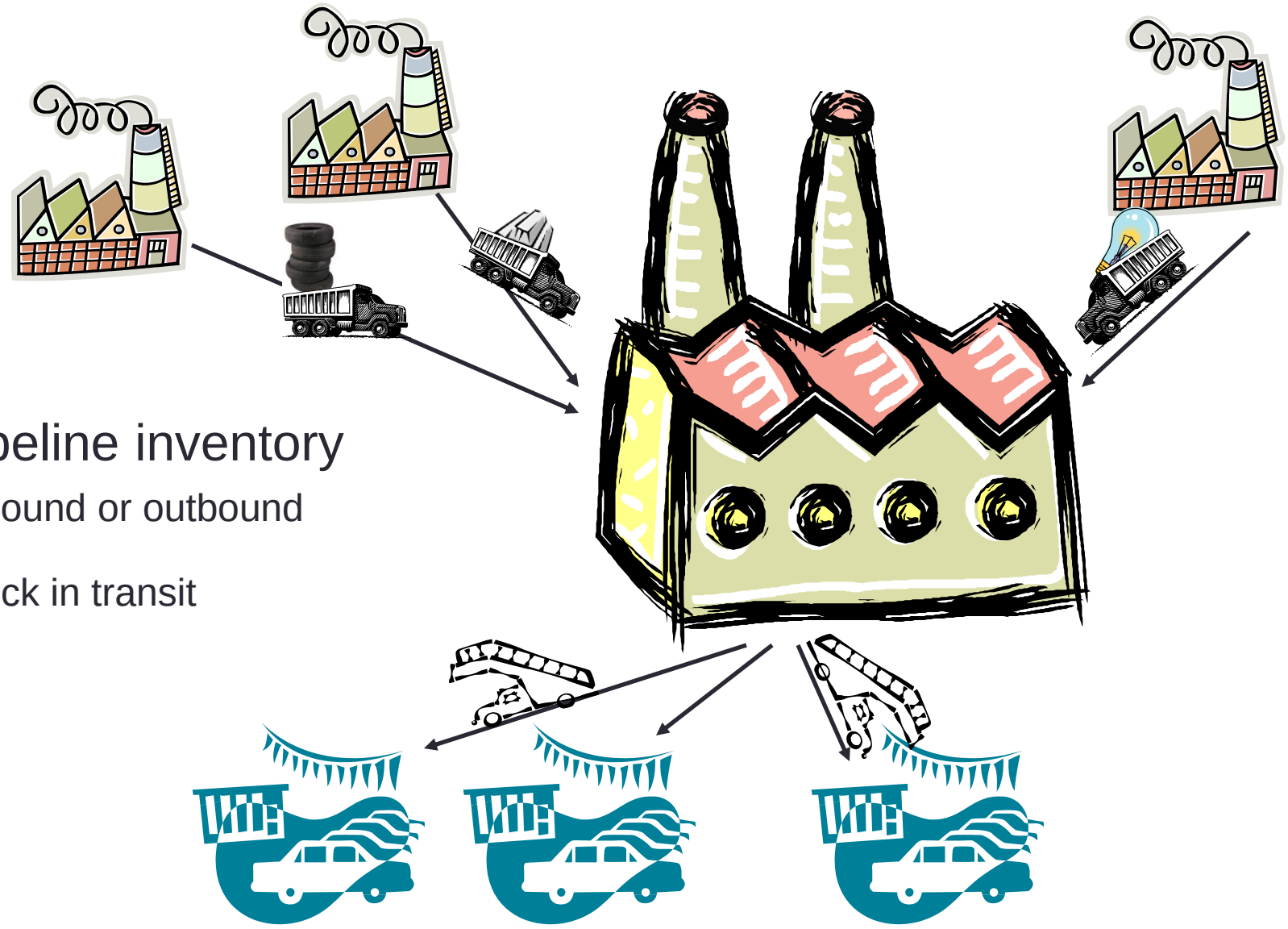
Purpose of Inventories

- To protect against *uncertainties*
  - in demand
  - supply
  - lead times
  - schedule changes
  - Reduction: shorten throughput times

Types of Inventory

- External
- Internal

Types of Inventory (external)



Pipeline inventory

inbound or outbound

stock in transit

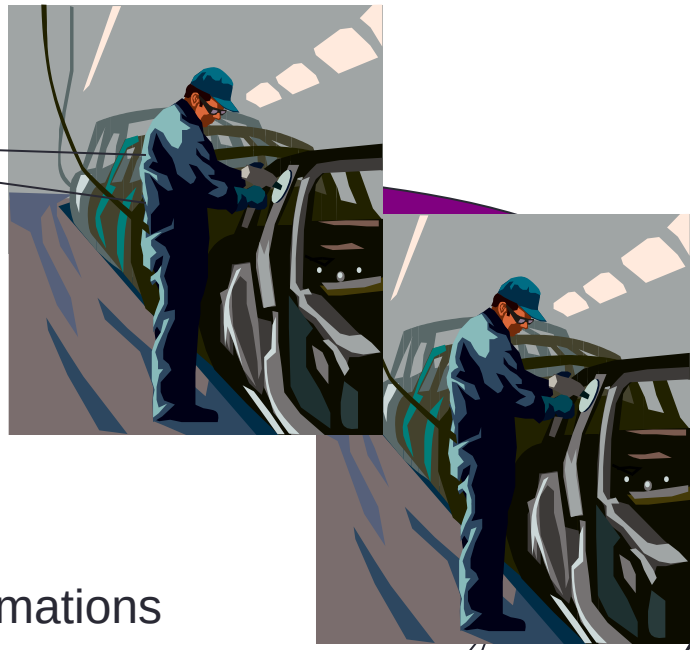
Types of Inventory (internal)

Raw Material

product which has not yet undergone any transformation

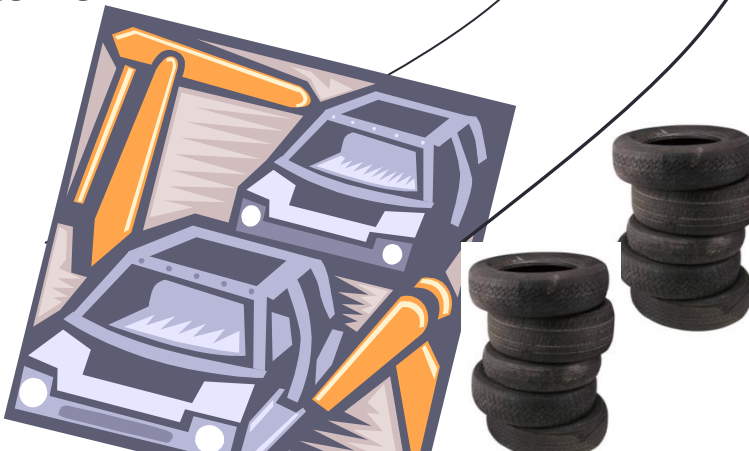
Work-in-process (WIP)

inventory which has already undergone some transformation but not yet completed



Finished Goods

inventory which has undergone all transformations and is ready to be passed on to the customer



Negative Aspects of Inventory

- Financial cost of carrying too much inventory
- Risk of obsolescence or damage
- Large inventories hide operational problems

Holding (or Carrying) Cost

- 1. Cost to carry one unit of stock for one unit of time, e.g., $2 / unit / year
  - A. Varies with the inventory level
- 2. Notation: H
- 3. Components:
  - A. Capital costs or Opportunity costs
  - B. Storage cost
  - C. Insurance & Taxes
  - D. Risk costs
    - a. Pilferage & Obsolescence
- 4. Sometimes derived from:
  - A. holding cost "rate", e.g., 25% per year
  - B. Multiplied by the unit value

Inventory Cost Structures

How the 35 percent carrying cost is distributed

- Cost of Capital—9-20 percent
- Obsolescence—2-5 percent
- Storage—2-5 percent
- Material Handling—1-3 percent
- Shrinkage—1-3 percent
- Taxes & Insurance—1-3 percent

Source: Mark Williams, APICS Instructor Listserv, 22 January 2001

Inventory Cost Structures

- Shrinkage
  - "…'shrinkage'…cost U.S. retailers about $41.6 billion last year." This is more than the combined total from other crimes such as robberies, auto theft and larceny.

Source: Wall Street *Journal*, 11 July 2007, p. B4.

Inventory Cost Structures

- Stock out cost (back order or lost sales)
  - record maintenance
  - lost income
  - customer dissatisfaction
  - Typically expressed as a fixed cost per backorder or as a function of aging of backorders.

Hidden Costs of Inventory

- Longer lead times
- Reduced responsiveness
- Underlying problems are hidden rather than being exposed and solved
- Quality problems are not identified immediately
- No incentive for improvement of the process

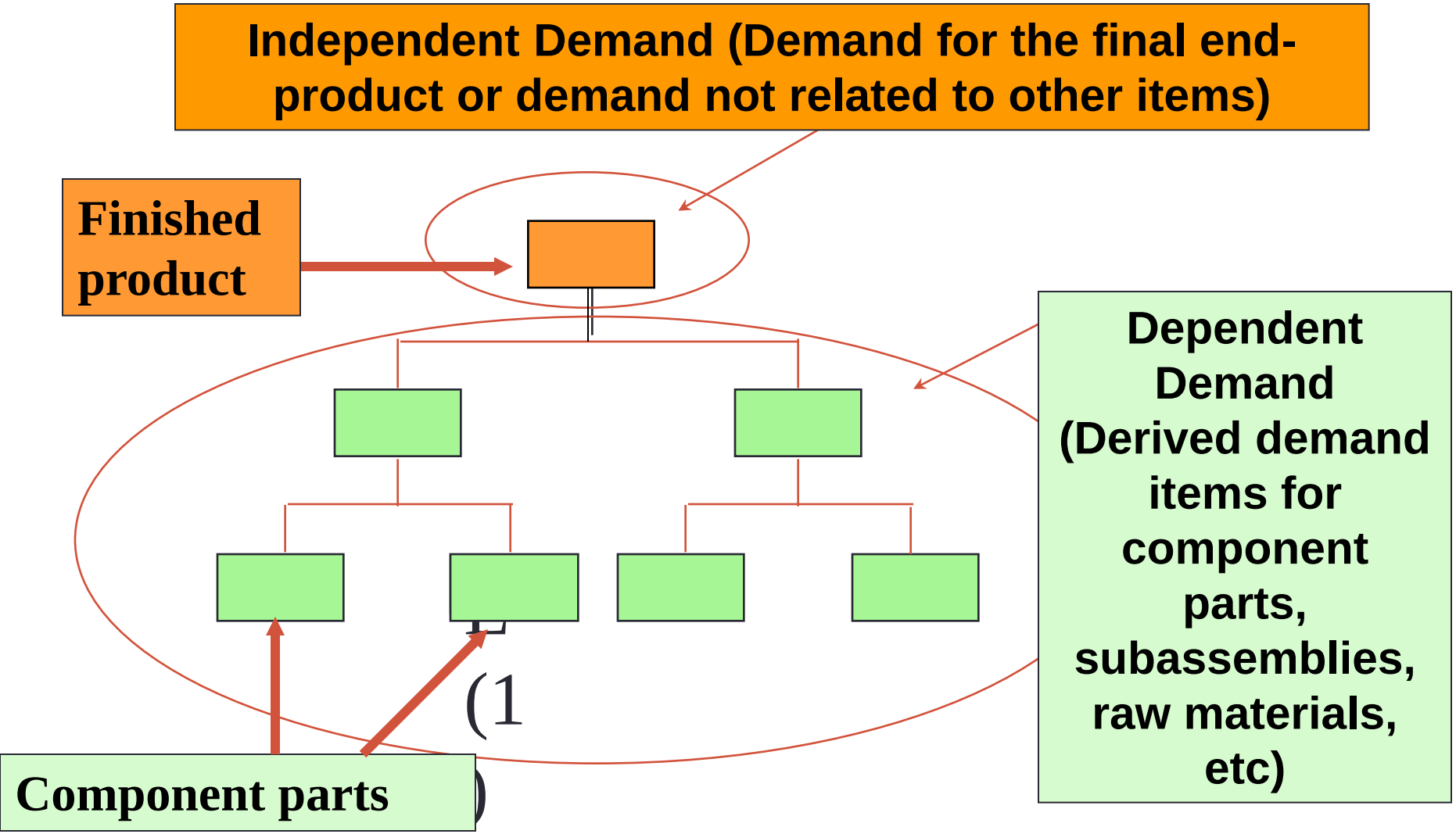
Two Forms of Demand

- Independent demand (this chapter)
  - finished goods, spare parts,
  - based on market demand
  - requires forecasting
  - managed using ‘replenishment philosophy’, i.e. reorder when reach a pre-specified level.

Two Forms of Demand

- Dependent demand (next chapter)
  - parts that go into the finished products
  - dependent demand is a known function of independent demand
  - calculate instead of forecast
  - Managed using a ‘requirements philosophy’, *i.e*. only ordered as needed for higher level components or products.

Independent vs. Dependent Demand



Basic Inventory Management Issues And Decisions

1. For which items should inventory be carried?
2. Where should inventory be stored?
3. What is the right inventory level for each product?
4. How can we control inventories?
5. How can we evaluate inventory performance?

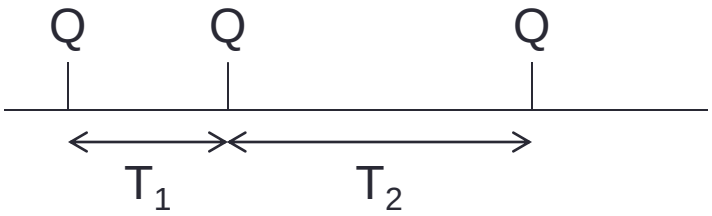
Inventory Decisions Involve Trade-Offs!

Inventory Systems

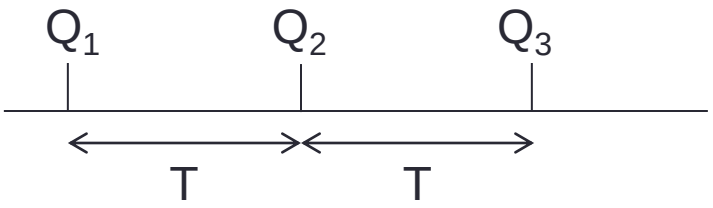
- 1. An inventory system provides the structure and operating policies for maintaining and controlling goods to be stocked in inventory.
- 2. The system is responsible for ordering, tracking, and receiving goods.
- 3. There are two essential questions to answer that define a policy:
  - 1. How much or *what quantity* of an item to order
  - *2. When* should an order for that item be placed?

Two Types of Systems

- **1. Continuous review system**: an inventory system that always orders the same quantity of items but has differing periods of time between orders



- **2. Periodic review system**: an inventory system that has a fixed time between orders but has different order quantities from order to order



Order or Setup Cost

- 1. Cost to place an order or to initiate a production run, e.g., $10 / order
  - A. A fixed cost
- 2. Notation: S
- 3. Components:
  - Order Cost -> Time of personnel, receiving, inspection, etc.
  - Setup Cost -> Opportunity cost, waste, etc.

Shortage Cost

- 1. Also known as ***stockout*** cost
  - A. Occurs when inventory not sufficient to meet demand
- 2. Could result in:
  - A. Back order
  - B. Lost sale
- 3. Direct, and indirect, dollar consequences:
  - A. Downtime of operations
  - B. Premiums for expediting
  - C. Extra transportation and handling
  - D. Lost of customer goodwill

EOQ

- 1. You want to review your inventory *continually*
- 2. You want to replenish your inventory when the level falls below a minimum amount, and order the same Q each time
- 3. Typical of a retail item, or a raw material item in a manufacturer

How to Determine Q

- Use the "**EOQ**" formula

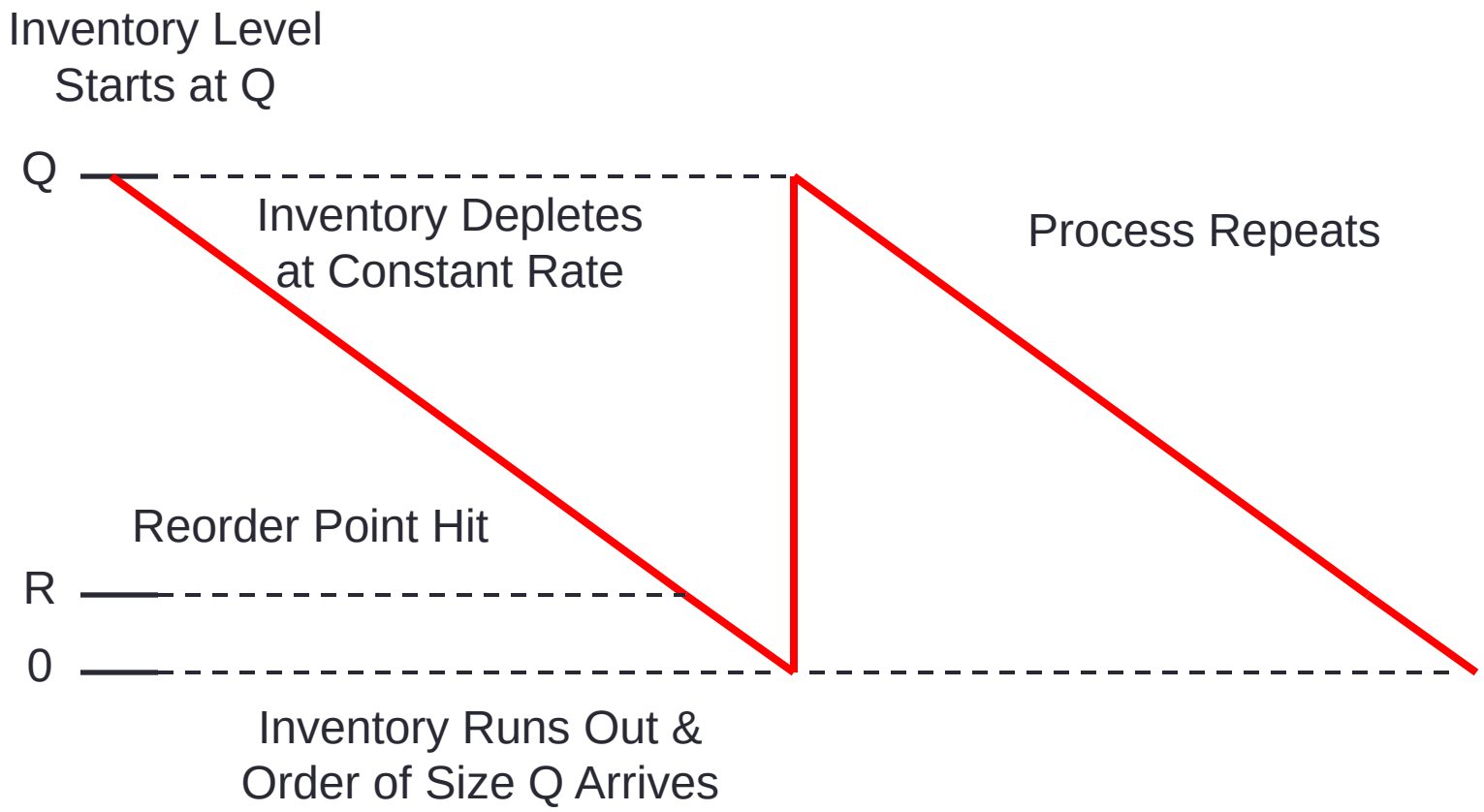
$$Q = \sqrt{\frac{2DS}{H}}$$

- D = Demand
- S = Order or Setup Cost
- H = Holding Cost

EOQ Assumptions

- 1. For the Square Root Formula to Work Well:
  - A. Continuous review of the inventory position
  - B. Demand is known & constant …
    no safety stock is required
  - C. Lead time is known & constant
  - D. No quantity discounts are available
  - E. Ordering (or setup) costs are constant
  - F. All demand is satisfied (no shortages)
  - G. The order quantity arrives in a single shipment

EOQ Inventory Behavior



Where the EOQ formula comes from:

- Find the Q that minimizes
  the total annual inventory related costs:
  - Annual number of orders: N = D / Q
    1. Annual Ordering Cost: $S \times (D / Q)$
  - Average Inventory: Q / 2
    2. Annual Carrying Cost: $H \times Q / 2$

How the costs behave:

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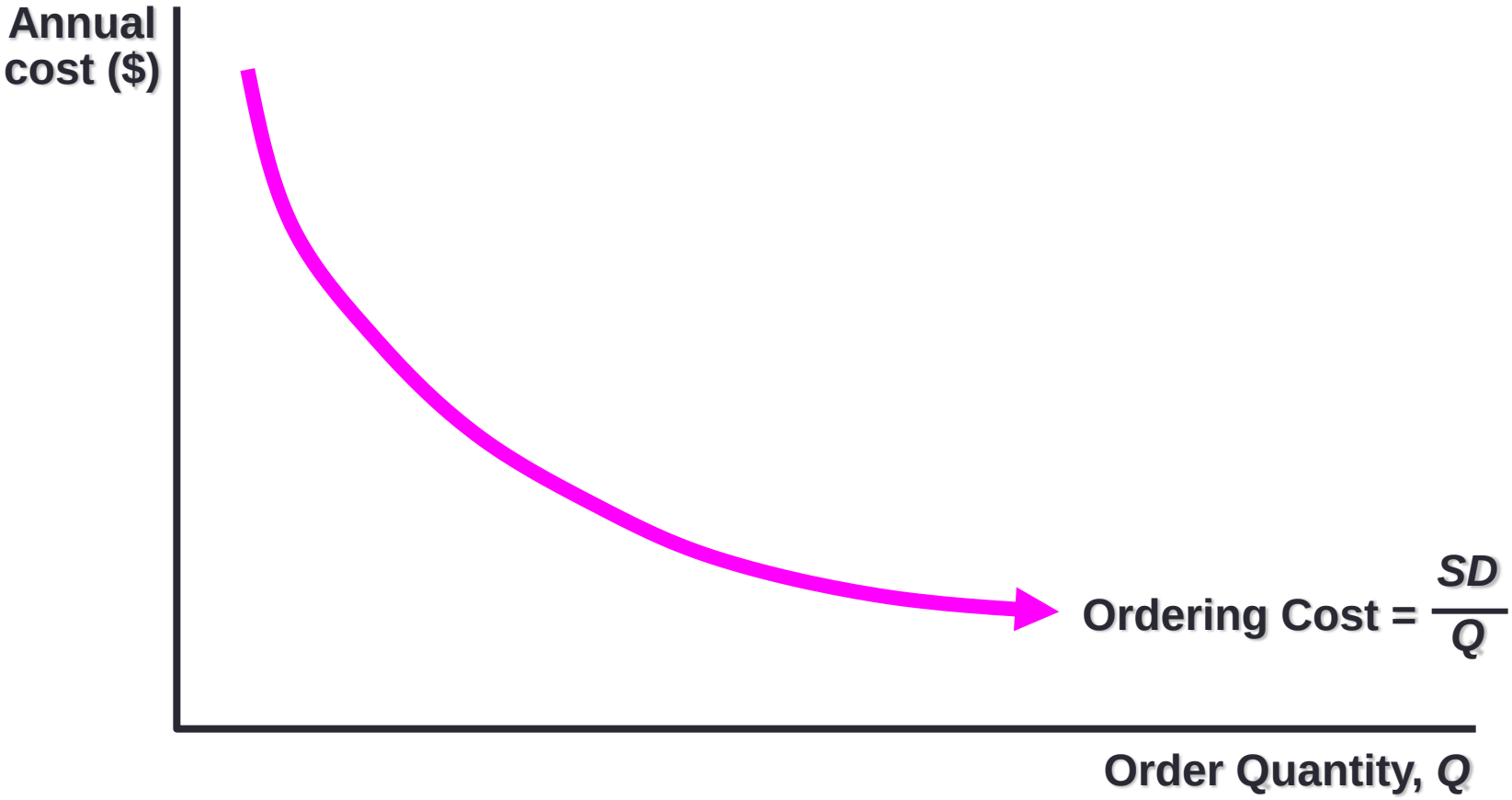

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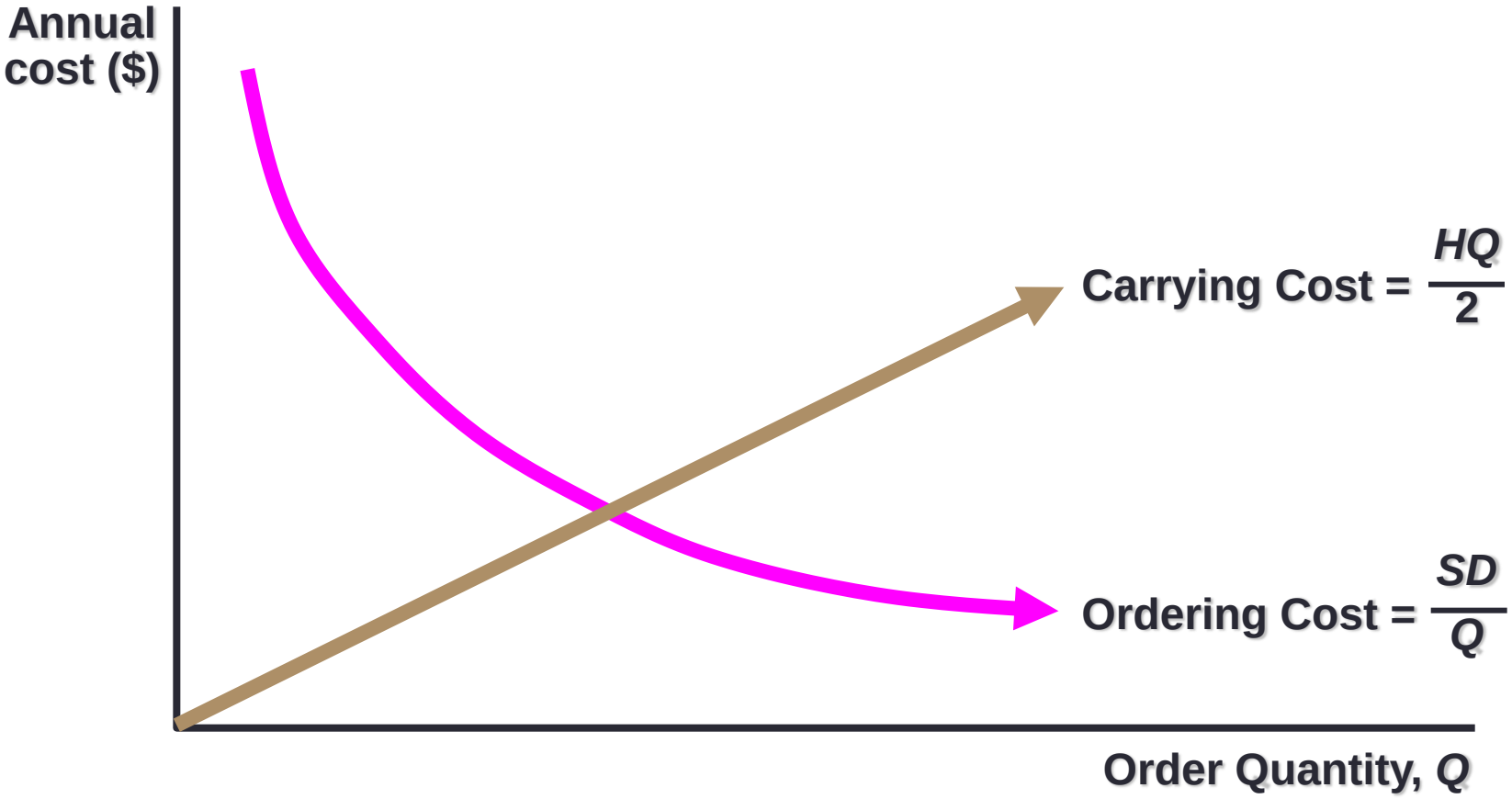

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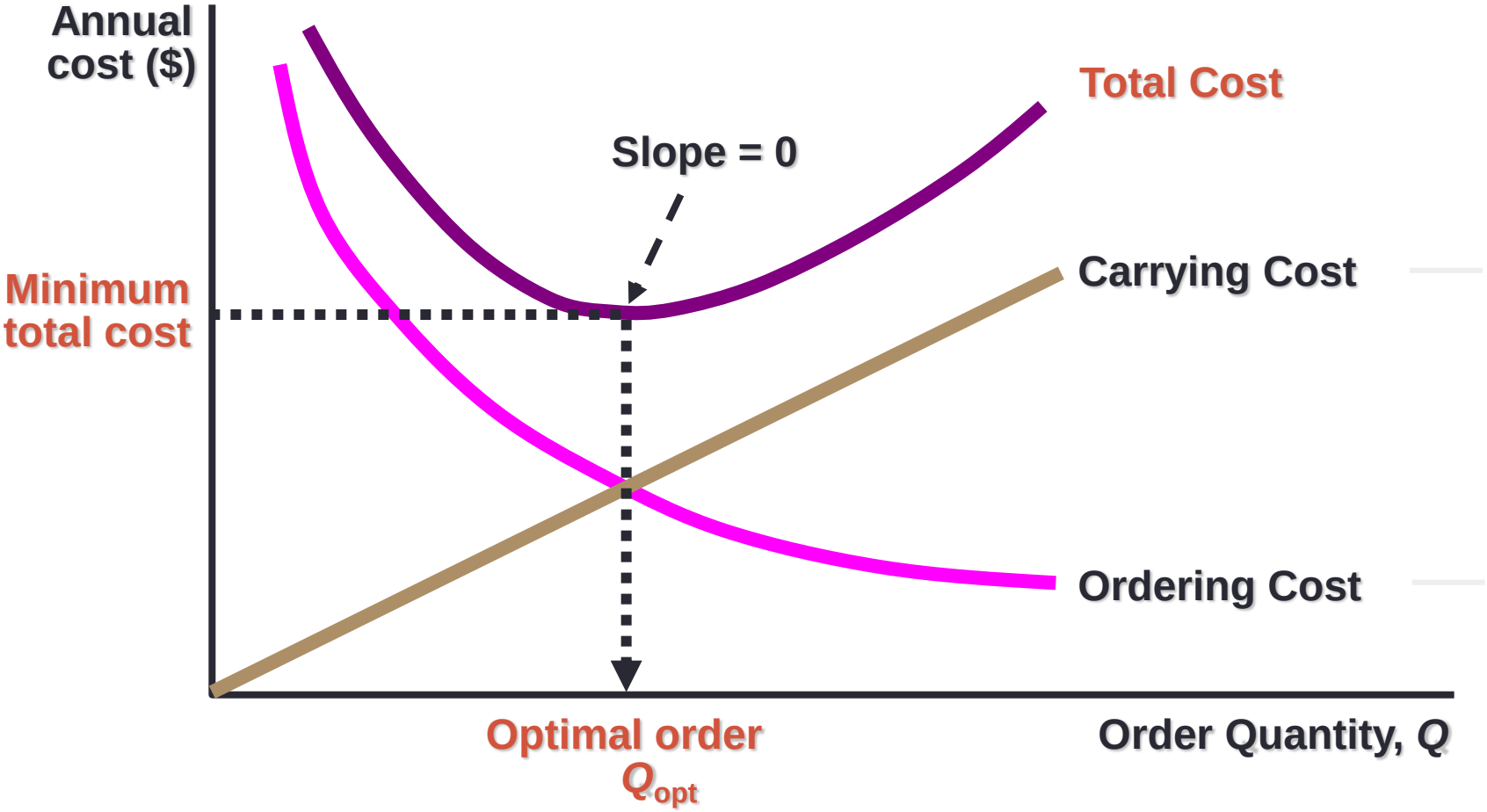


How the Costs Behave

- Total Cost (TC)

$$TC = \frac{Q}{2}H + \frac{D}{Q}S$$

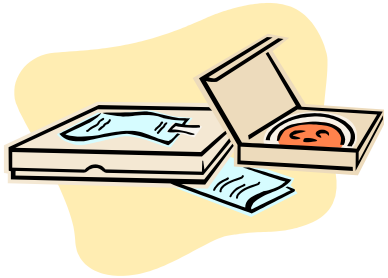
- 1. Total Cost Function Has Slope of Zero at Best (Optimal) Value of Q
- 2. Taking First Derivative of *TC* and Setting Equal to Zero Gives the Square Root Equation

Example: *Papa Joe's Pizza (Atlanta store)*

- Uses 18,000 pizza cartons / year
- Ordering lead time is 1 month

Decisions:

- **1. How many cartons should Papa Joe order? i.e., Q**
- **2. When should Papa Joe order? R**



Data:

- Inventory carrying cost is
  $ .022 carton / year
- Ordering cost is $10 / order

EOQ for Papa Joe's

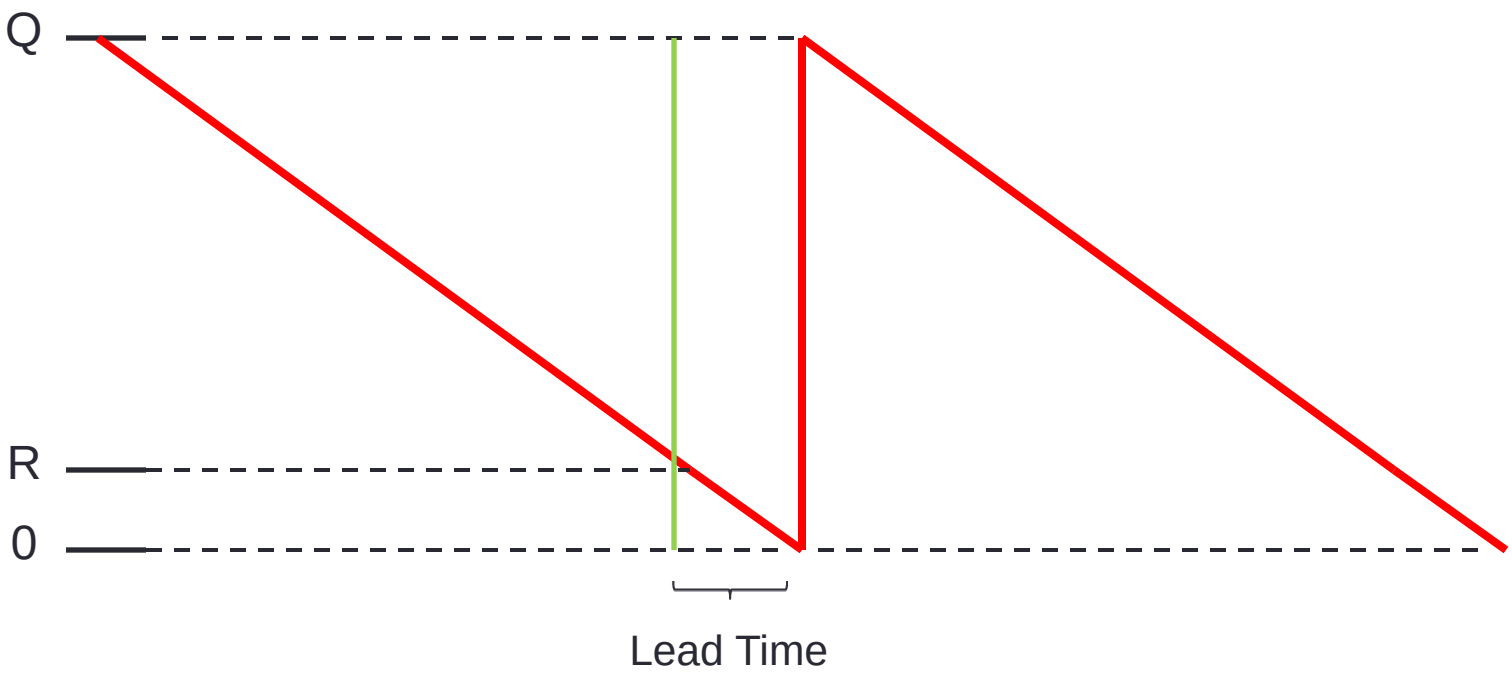
$$\text{EOQ} = \sqrt{\frac{2 \times 10 \times 18{,}000}{0.022}} = 4{,}045.2$$

$$Q = 4{,}045$$

$$\begin{aligned} \text{TC}(4{,}045) &= 180{,}000/4{,}045 + 0.011 \times 4{,}045 \\ &= \$88.99/\text{year} \end{aligned}$$

$$\begin{aligned} \text{TC}(4{,}000) &= 180{,}000/4{,}000 + 0.011 \times 4{,}000 \\ &= \$89.00/\text{year} \end{aligned}$$

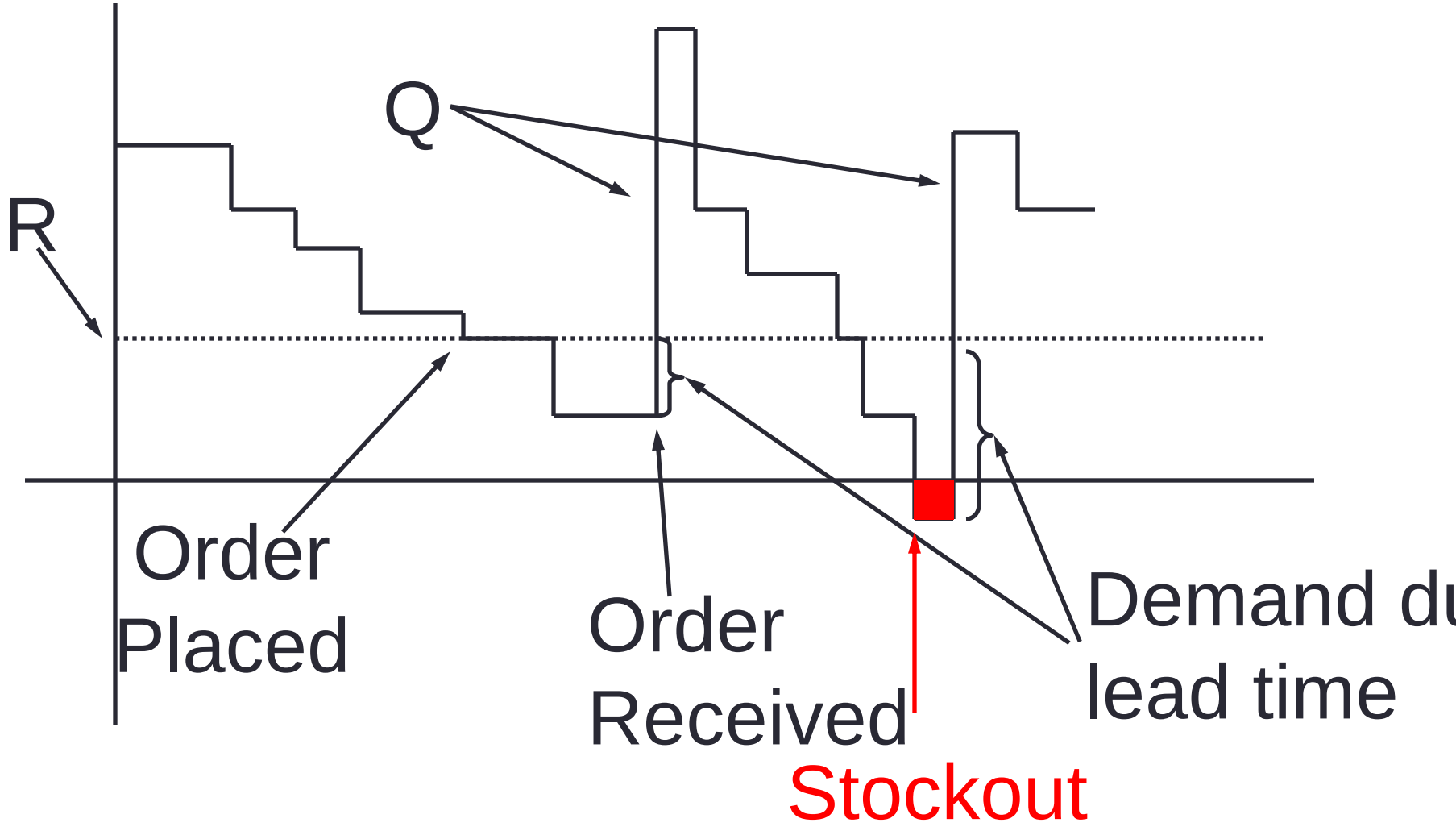
Reorder Point



Reorder Point Calculation

- 1. D x L = demand during lead time
- 2. Set reorder point, R, equal to demand during lead time
- 3. R = D x L
- 4. For Papa Joe's
  - A. R = (18,000 cartons / yr) x (1 / 12 yr)
    = 1,500 cartons
- 5.State Inventory Policy As:
  - A. Order 4,000 cartons When the Inventory Level Reaches 1,500 cartons

Variable Demand & Safety Stock



The Relationship Between SS, R, & L

1. **R = enough stock to cover:**

A. **What you *expect* to happen during a lead time**

plus

B. What *might* happen during the lead time

C. R = dL + SS

EOQ with Discounts

- Many companies offer discounted pricing for items that they sell.

Procedure:

- Arrange the prices from lowest to highest. Starting with the lowest price, calculate the EOQ for each price until a feasible EOQ is found.
  - If the first feasible EOQ is for the lowest price, this quantity is optimal and should be used.
  - If not, proceed until feasible EOQ found.
  - If feasible EOQ found, check ALL breakpoints above the value of the feasible Q

EOQ w/ Quantity Discounts

- Example
  - D = 16,000 boxes of gloves/year
  - S = $5/order
  - h = 0.25 (25% of cost)
  - C = cost per unit
    - $5.00 for 1 to 99 boxes
    - $4.00 for 100 to 499 boxes
    - $3.00 for 500+ boxes

$$C = \$3.00$$

$$Q = \sqrt{\frac{(2)(16,000)(5)}{(0.25)(3)}} = 461.9$$

Not Feasible

$$C = \$4.00$$

$$Q = \sqrt{\frac{(2)(16,000)(5)}{(0.25)(4)}} = 400$$

Feasible

EOQ w/ Quantity Discounts

For Q = 400

$$TC = \frac{16,000}{400}(5) + \frac{400}{2}(0.25)(4) + (4)(16,000) = \$64,400$$

For Q = 500

$$TC = \frac{16,000}{500}(5) + \frac{500}{2}(0.25)(3) + (3)(16,000) = \$48,347.5$$

Decision: Buy with Q = 500 for
Lowest Possible Cost

EPQ

- You want to review your inventory continually
- You want to replenish your inventory when the level falls below a minimum amount, and order the same Q each time
- **Your replenishment does *NOT* occur all at once**
- Typical of a WIP item, typical of manufacturing

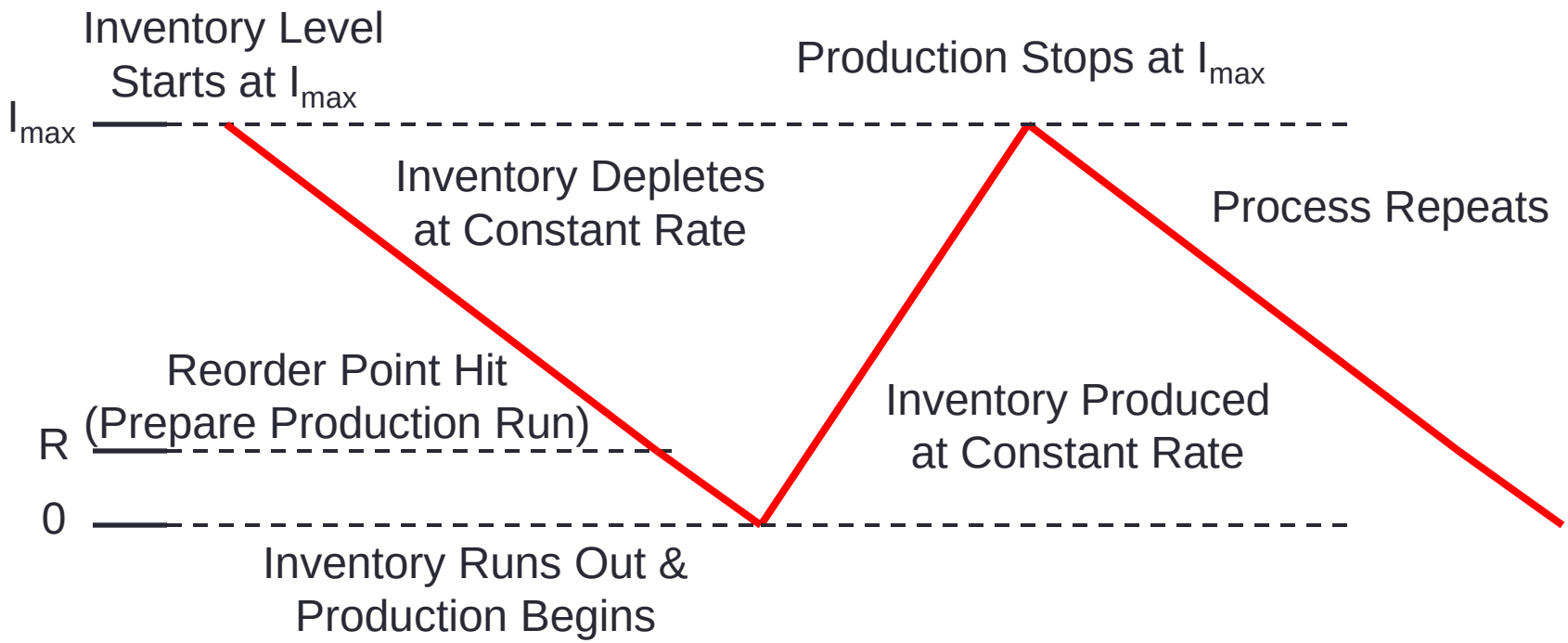
Illustration - -
Papa Joe's Pizza

- Joe orders in batches of Q = 4000 cartons at a time

- He uses a "low bid" vendor (cheap)
  - It takes about 1 month to get the order in
  - Due to limited staffing, **only 1000 cartons can be made and sent to Joe each week**

How is the inventory build up different than the Base Case (EOQ scenario)?

EPQ Inventory Behavior



Major Difference: Maximum Inventory Level

EPQ Equations

- **Total cost:** $$TC = \left(\frac{D}{Q}S\right) + \left(\frac{I_{MAX}}{2}H\right)$$

- **Maximum inventory:**
  - d =avg. daily demand rate
  - p =daily production rate

$$\mathbf{I_{MAX} = Q\left(1 - \frac{d}{p}\right)}$$

- **Calculating EPQ:**

$$Q = \sqrt{\frac{2DS}{H\left(1 - \frac{d}{p}\right)}}$$

EPQ Example

And when should Papa Joe reorder his cartons ?

R = Demand during the resupply lead time

= d x L

Reorder point is determined in the same way as for the EOQ policy

Other Types of Inventory Systems

Variations on the basic types of continuous and periodic reviews:

- ABC Systems
- Bin Systems
- Can Order Systems
- Base Stock Systems
- The Newsvendor Problem

ABC Systems

- **1. ABC systems**: inventory systems that utilize some measure of importance to classify inventory items and allocate control efforts accordingly

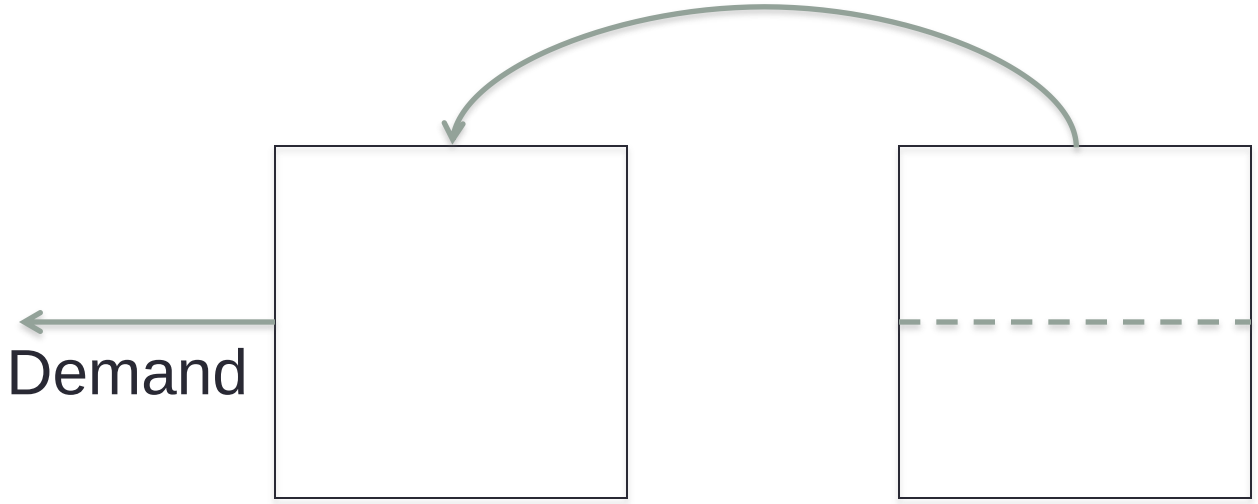
- 2. They take advantage of what is commonly called the 80/20 rule, which holds that 20 percent of the items usually account for 80 percent of the value.
  - A. Category **A** contains the most important items.
  - B. Category **B** contains moderately important items.
  - C. Category **C** contains the least important items.

ABC Systems

- **1. A** items make up only 10 to 20 percent of the total number of items, yet account for *60 to 80 percent of annual dollar value.*
- **2. C** items account for 50 to 70 percent of the total number of items, yet account for only *10 to 20 percent of annual dollar value.*
- **3. C** items may well be of high importance, but because they account for relatively little annual inventory cost, it may be preferable to order them in large quantities and carry excess safety stock.

Bin Systems

- **1. Bin system**: a type of inventory system that uses either one or two bins to hold a quantity of the item being inventoried; an order is placed when one of two bins is empty or a line on a single bin is reached



Can Order & Base Stock Systems

- **1. Can order system**: a type of inventory system that reviews the inventory position at fixed time intervals and places orders to bring the inventory up to an expected target level, but only if the inventory position is below a minimum quantity, similar to the reorder point in a continuous review system
- **2. Base stock system**: a type of inventory system that issues an order whenever a withdrawal is made from inventory

“Newsvendor” Problem

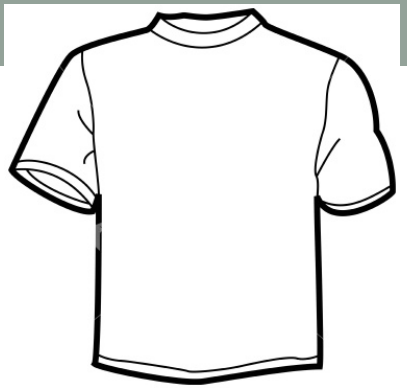
- 1. Order inventory for only a one-time stocking of an item the **“Single-Period” Inventory model**

- 2. Examples:
  - A. Xmas tree lots
  - B. Newspaper stands

- 3. Objective: maximize profit

- ***4. Why not just stock as many units as possible?***

Example:



Tee shirts are purchased in multiples of 10 for a charity event for $8 each. When sold during the event the selling price is $20. After the event their salvage value is just $2.

From past events the organizers know the probability of selling different quantities of tee shirts within a range from 80 to 120:

Customer Demand	**80**	**90**	**100**	**110**	**120**
Prob. Of Occurrence	**.20**	**.25**	**.30**	**.15**	**.10**

How many tee shirts should they buy and have on hand for the event?

Payoff Table: Setup

	Demand				
Purchase Qty	80	90	100	110	120
80					
90					
100					
110					
120					

Payoff Table: Cell Calculations

Profit = Revenues – Costs + Salvage

- Revenues = Selling Price (p) × Amount Sold
- Costs = Purchase Price (c) × Purchase Qty
- Salvage = Salvage Value (s) × Amount Leftover

Amount Sold = min (Demand, Purchase Qty)

Amount Leftover = max (Purchase Qty – Demand, 0)

Payoff Table: Cell Calculations

Let Q = Purchase Qty and D = Demand

Case 1. $Q \leq D$

Profit = $[p \times Q] - [c \times Q] + [s \times 0] = (p - c)\,Q$

Case 2. $Q > D$

Profit = $[p \times D] - [c \times Q] + [s \times (Q - D)]$

Payoff Table: Cell Calculations

Have p = \$20, c = \$8, and s = \$2.

Compute Profit when Q = 90 and D = 110.

Profit = [p × Q] – [c × Q] + [s × 0] = (p – c) Q = 12(90) = 1080

Compute Profit when Q = 100 and D = 100.

Profit = [p × Q] – [c × Q] + [s × 0] = (p – c) Q = 12(100) = 1200

Compute Profit when Q = 110 and D = 80.

Profit = [p × D] – [c × Q] + [s × (Q – D)]

= 20(80) – 8(110) + 2(30) = 1600 – 880 + 60 = 780

Payoff Table Values

	Demand				
Purchase Qty	80	90	100	110	120
80	960	960	960	960	960
90	900	1080	1080	1080	1080
100	840	1020	1200	1200	1200
110	780	960	1140	1320	1320
120	720	900	1080	1260	1440

Getting the Final Answer

- 1. For Each Purchase Quantity:
  - A. Calculated the Expected Profit
- 2. Choose Purchase Quantity With Highest Expected Profit.
- 3. Expected Profit for a Purchase Quantity:
  - A. Multiply Each Payoff by Its Probability, Then Sum
- 4. Example:
  - A. For Purchase Quantity = 100
  - B. Expected Profit = (840)(0.2) + (1020)(0.25) + (1200)(0.3) + (1200)(0.15) + (1200)(0.1) =$1083

	A	B	C	D	E	F	G	H	I	J	K
1	DATA										
2		purchase price	8	$ / tee shirt							
3		selling price	20	$ / tee shirt							
4		salvage value	2	$ / tee shirt							
5											
6		Customer demand	80	90	100	110	120				
7		Prob (demand)	0.20	0.25	0.30	0.15	0.10				
8											
9											
10	Profit Calculations		= selling price*(amt sold) - purchase price*(purchase qty) + salvage value*(amt leftover)								
11											
12		Demand	80	90	100	110	120				Expected Profit
13		Purchase Qty									
14		80	960	960	960	960	960				
15		90	900	1080	1080	1080	1080				
16		100	840	1020	1200	1200	1200				
17		110	780	960	1140	1320	1320				
18		120	720	900	1080	1260	1440				

=$C$3*MIN($B14,C$12)-$C$2*$B14+$C$4*MAX($B14-C$12,0)

	A	B	C	D	E	F	G	H	I	J	K
1	DATA										
2		purchase price	8	$ / tee shirt							
3		selling price	20	$ / tee shirt							
4		salvage value	2	$ / tee shirt							
5											
6		Customer demand	80	90	100	110	120				
7		Prob (demand)	0.20	0.25	0.30	0.15	0.10				
8											
9											
10	Profit Calculations		= selling price*(amt sold) - purchase price*(purchase qty) + salvage value*(amt leftover)								
11											
12		Demand	80	90	100	110	120				Expected Profit
13		Purchase Qty									
14		80	960	960	960	960	960				
15		90	900	1080	1080	1080	1080				
16		100	840	1020	1200	1200	1200				
17		110	780	960	1140	1320	1320				
18		120	720	900	1080	1260	1440				

=SUMPRODUCT($C$7:$G$7,C14:G14)

	A	B	C	D	E	F	G	H	I	J	K
1	DATA										
2		purchase price	8	$ / tee shirt							
3		selling price	20	$ / tee shirt							
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5											
6		Customer demand	80	90	100	110	120				
7		Prob (demand)	0.20	0.25	0.30	0.15	0.10				
8											
9											
10	Profit Calculations		= selling price*(amt sold) - purchase price*(purchase qty) + salvage value*(amt leftover)								
11											
12		Demand	80	90	100	110	120				Expected
13		Purchase Qty									Profit
14		80	960	960	960	960	960				960
15		90	900	1080	1080	1080	1080				1044
16		100	840	1020	1200	1200	1200				1083
17		110	780	960	1140	1320	1320				1068
18		120	720	900	1080	1260	1440				1026

Newsvendor and Overbooking

- 1. Approximately 50% of Reservations Get Cancelled at Some Point in Time.
- 2. In Many Cases (car rentals, hotels, full fare airline passengers) There is No Penalty for Cancellations.
- 3. Problem:
  - A. The company may fail to fill the seat (room, car) if the passenger cancels at the very last minute or does not show up.
- 4. Solution:
  - A. Sell More Seats (rooms, cars) Than Capacity (Overbook)
- 5. Danger:
  - A. Some Customers May Have to be Denied a Seat Even Though They Have a Confirmed Reservation.
  - B. Passengers Who Get Bumped Off Overbooked Domestic Flights Receive :
    - a. Up-to $400 if arrive <= 2 hours after their original arrival time
    - b. Up-to $800 if arrive >= 2 hours after their original arrival time

Overbooking at Hyatt

- 1. The Cost of Denying a Room to the Customer with a Confirmed Reservation is $350 in Ill-Will (Loss of Goodwill) and Penalties.
- 2. Average Revenue From a Filled Room is $159.
- 3. Average Number of No Shows Per Night is 8.5
- 4. How Many Rooms Should be Overbooked (Sold in Excess of Capacity)?

Overbooking at Hyatt

No Shows	Probability
0	0.0002
1	0.0017
2	0.0074
3	0.0208
4	0.0443
5	0.0752
6	0.1066
7	0.1294
8	0.1375
9	0.1299
10	0.1104

No Shows	Probability
11	0.0853
12	0.0604
13	0.0395
14	0.0240
15	0.0136
16	0.0072
17	0.0036
18	0.0017
19	0.0008
20	0.0003

- How to Approach Problem?
  - Payoff Table Would Be Huge (21 by 21 = 441 Cells)

Overbooking at Hyatt

- New Trick
  - Use Critical Ratio
  - Optimal Overbooking Ratio:

$$\frac{C_u}{C_u + C_o}$$

  - C_u = Cost of Underage
  - C_o = Cost of Overage
  - For Hyatt: C_u = \$159 and C_o = \$350
  - Critcal Ratio is then:

$$\frac{C_u}{C_u + C_o} = \frac{159}{159 + 350} = 0.3124$$

Overbooking at Hyatt

- Look at Cumulative Probabilities of "No Shows"
- Find First Number of "No Shows" That Exceeds Critical Ratio
- For Critical Ratio of 0.3124 First Number of "No Shows" With Cumulative Probability That Exceeds is 7
- Overbooking by 7 Rooms Is Optimal Decision

No Shows	Cumulative Probability
0	0.0002
1	0.0019
2	0.0093
3	0.0301
4	0.0744
5	0.1496
6	0.2562
7	0.3856
8	0.5231
9	0.6530
10	0.7634
...	

Summary

- What are the types of inventory
- What are the basic inventory decisions
- What are the basic inventory questions to solve
- What are holding costs
- Understand the shortage costs
- EOQ
- EPQ
- Other types of inventory control