ISOM 2700: Operations Management

Session 6.1. Inventory Management

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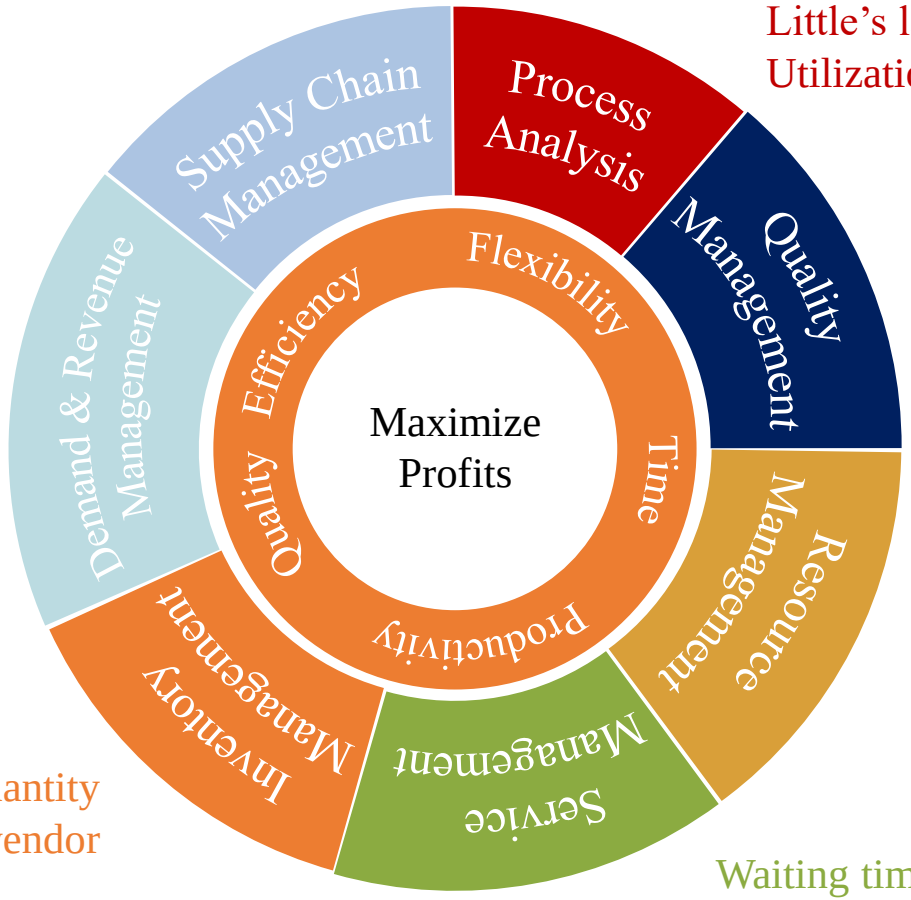
Course roadmap



Bottleneck
Little's law
Utilization

Control chart
Acceptance sampling
Six sigma

Decision tree method
Linear programming

Waiting time
Server utilization

Economic order quantity
Newsvendor

Inventory Management

Goal: Matching supply with demand

Recall from the very beginning…

- The stock price of Zale (the second-largest U.S. jewelry retailer) plunged 12.7 percent on Dec 18, 2009, when it was revealed, it refused to take millions of dollars of **inventory** at the end of November 2009.
  - Analysts: "It means they are in trouble, that they're not expecting sales to be as good as expected" (Wahba 2009).

Investors do respond to the firm's operational decisions!

Recall from the very beginning

Berman Capital Management in New York

- Berman's experience with Saucony, a shoemaker based near Boston
  - In 2003, sales were flattish, but **inventories** had declined about 20% per year; Berman bought shares at $14 in 2003; A year later, the stock had doubled.

- Berman's experience with Bombay, a furniture retailer
  - In Nov of 2003, the revenue had risen a healthy 19%. But Berman noticed that **inventories** had increased 50% per year. Berman dumped his shares of Bombay. The stock fell 50% in just one and a half months.

Inventory

- **Inventory** is a stock of goods awaiting consumption
  - Something the company has paid for but customers have not yet paid for

- Examples of inventory:
  - Raw materials
  - Work in process
  - Supplies
  - Finished goods

Why Hold Inventory?

- **The transaction motive**
  - Economies of scale: production, transportation, discount, replenishment, …
  - Competition purpose

- **The precautionary motive**
  - Demand uncertainty: unpredictable events
  - Supply uncertainty: lead time, random yield, …

- **The speculative motive**
  - Fluctuating value: ordering cost, selling price
  - Demand increase: seasonality, promotion, …

Importance of Inventory

Evidence from the industry -- Based on an empirical analysis over 353 publicly listed U.S. retailers for the period 1985-2003

- Inventory is the **largest asset** on the balance sheet for 57% of publicly traded retailers in U.S
- Ratio inventory/total assets averages 35.1%
- Managers and analysts use inventory turnover, inventory growth rate, and payables to inventory ratio to determine how well a retailer is managing its inventory

Source: Gaur & Kesavan, 2009. Data obtained from Standard & Poor's Compustat database

Disadvantage of Inventory

- **High costs**
  - Ordering cost (per order)
  - Holding cost (per unit of inventory per unit time)
    - Building lease, insurance, taxes etc.
  - Stock-out or shortage cost (per unit of lost sales)
    - Occurs when the demand for exceed its supply
    - Customer's goodwill cost, delivery cost or penalty cost

- **Difficult to control**
  - Variation in the demand
  - Lead-time
  - …

Managing Inventory

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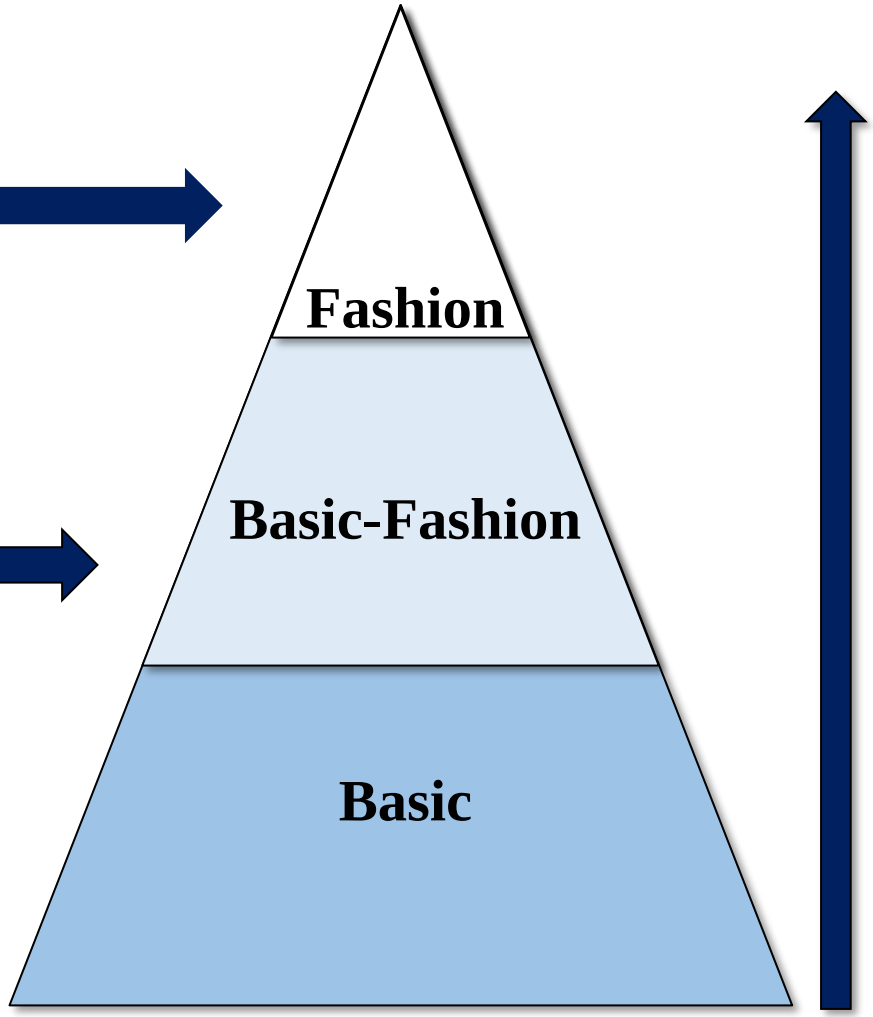
MADE FOR ALL



Demand uncertainty & Unit margin

Inventory Models

- **Economic Order Quantity (EOQ) Model**
  - **Long lifecycle** products
  - Tradeoff between setup and holding costs, driven by the frequency of ordering

- **Newsvendor Model**
  - **Short lifecycle** products
  - Tradeoff between costs of excess leftover inventory and excess demand

Video

EOQ Model

- **EOQ Model**
  - **Long lifecycle** products
  - Tradeoff between setup and holding costs, driven by the frequency of ordering

- **Key questions**
  - How much to order?
  - When to order?

Example: Sweater

- M&S has a stable demand for a line of sweater it offers. Each week there is a demand for 100 sweaters. M&S incurs a fixed cost of $5000 every time it places an order. The marginal cost of a sweater is $400, and the shop's cost of capital is approximately 1% per week.

How often should M&S order?

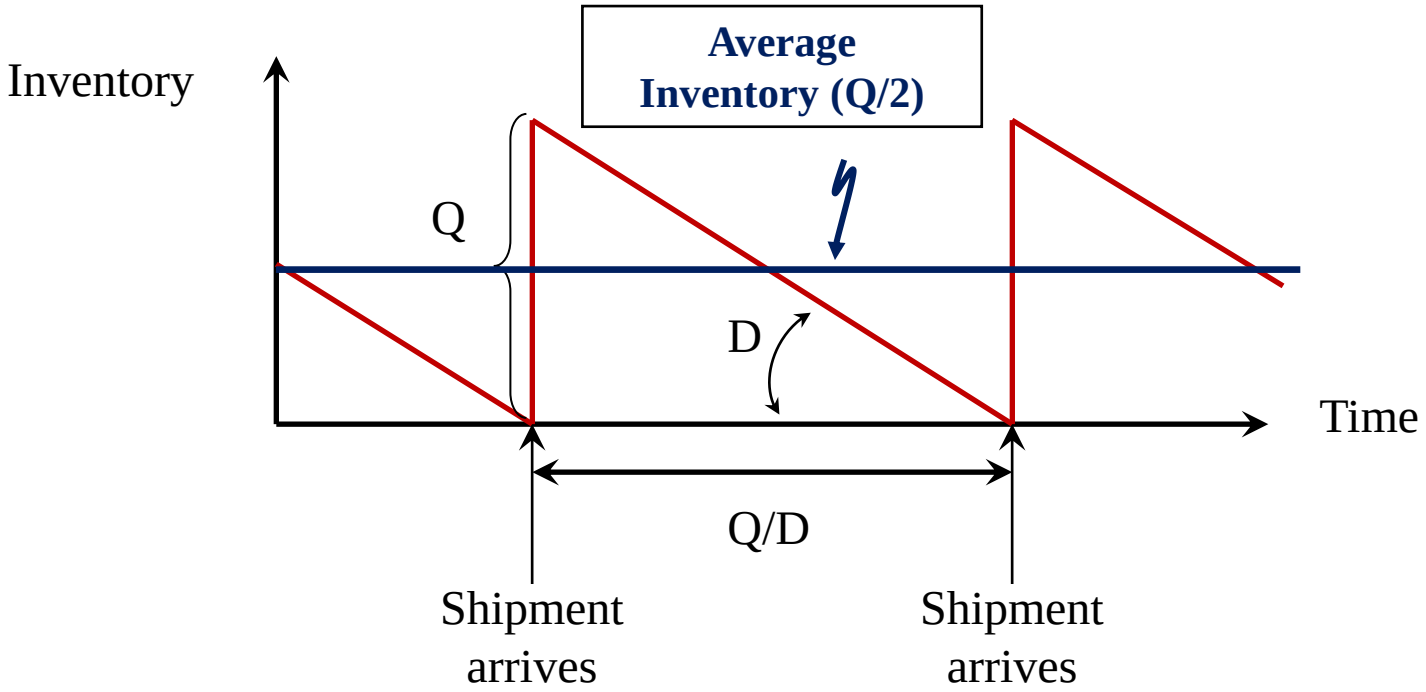
How many units should be ordered each time?

Inventory cost

- **Fixed ordering (setup) costs**
  - Handling charges, preparing purchase order
  - Supplier selection, negotiations
  - Freight and insurance

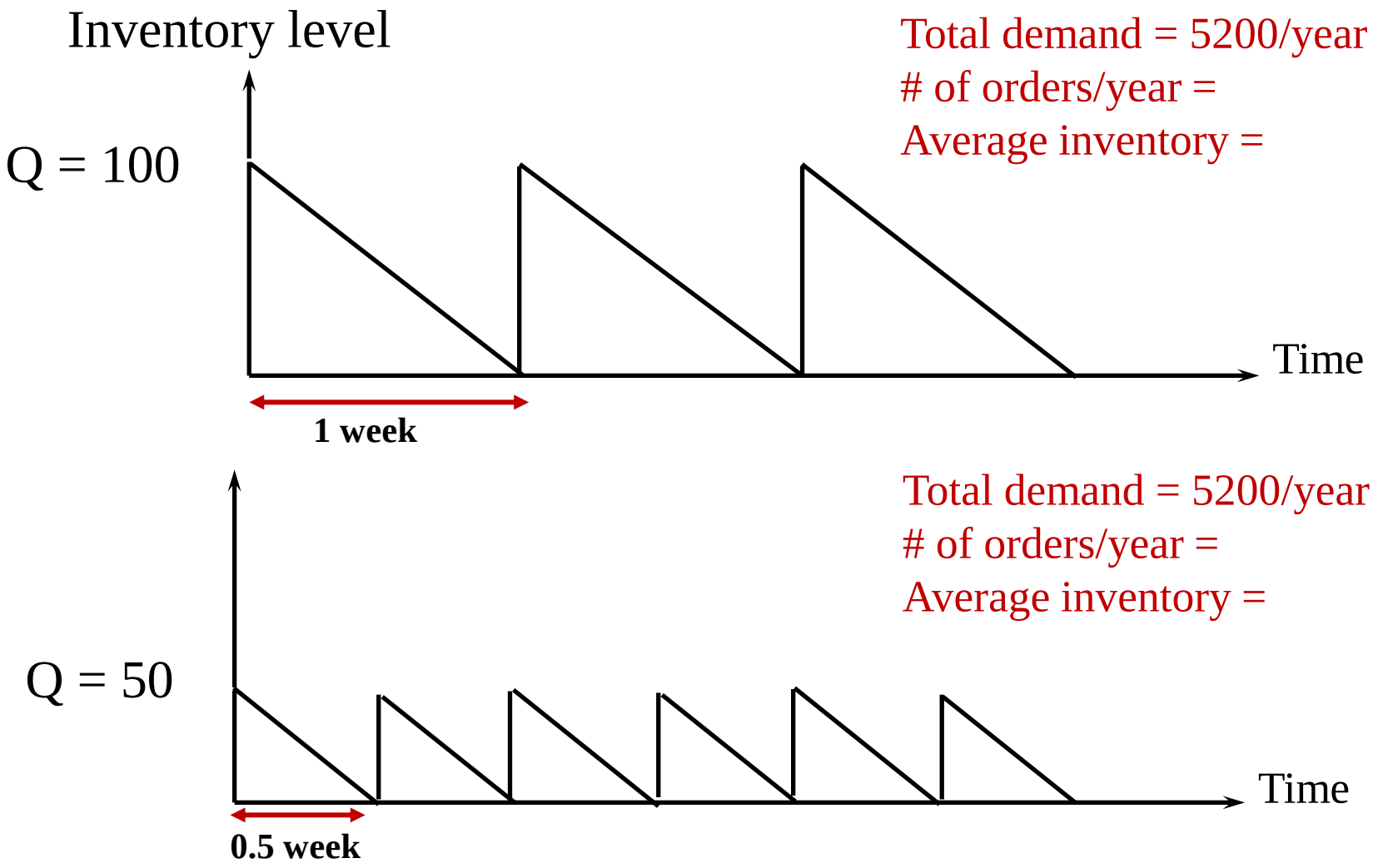
- **Inventory carrying costs**
  - Insurance cost
  - Maintenance cost
  - Opportunity cost of alternative investment

The Inventory "Saw-Tooth" Pattern



- Q = Quantity in each order (what we need to choose)
- D = Demand Rate
- Q/D = Time between shipments
- D/Q = Order frequency per unit time

Tradeoffs


Inventory level
Q = 100
Time
1 week
Total demand = 5200/year
# of orders/year =
Average inventory =
Q = 50
Time
0.5 week
Total demand = 5200/year
# of orders/year =
Average inventory =

EOQ Model: How Much to Order?

Decide: Order quantity Q

Given:

D - Demand per unit of time (year, week, …)

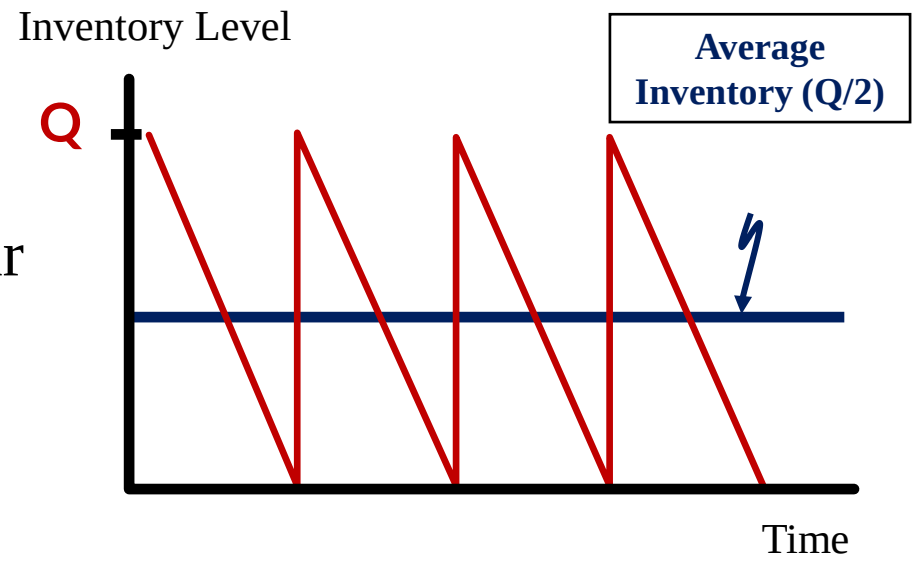
S - Setup or Order Cost ($/setup; $/order)

H - Marginal holding cost ($/per unit per unit of time)

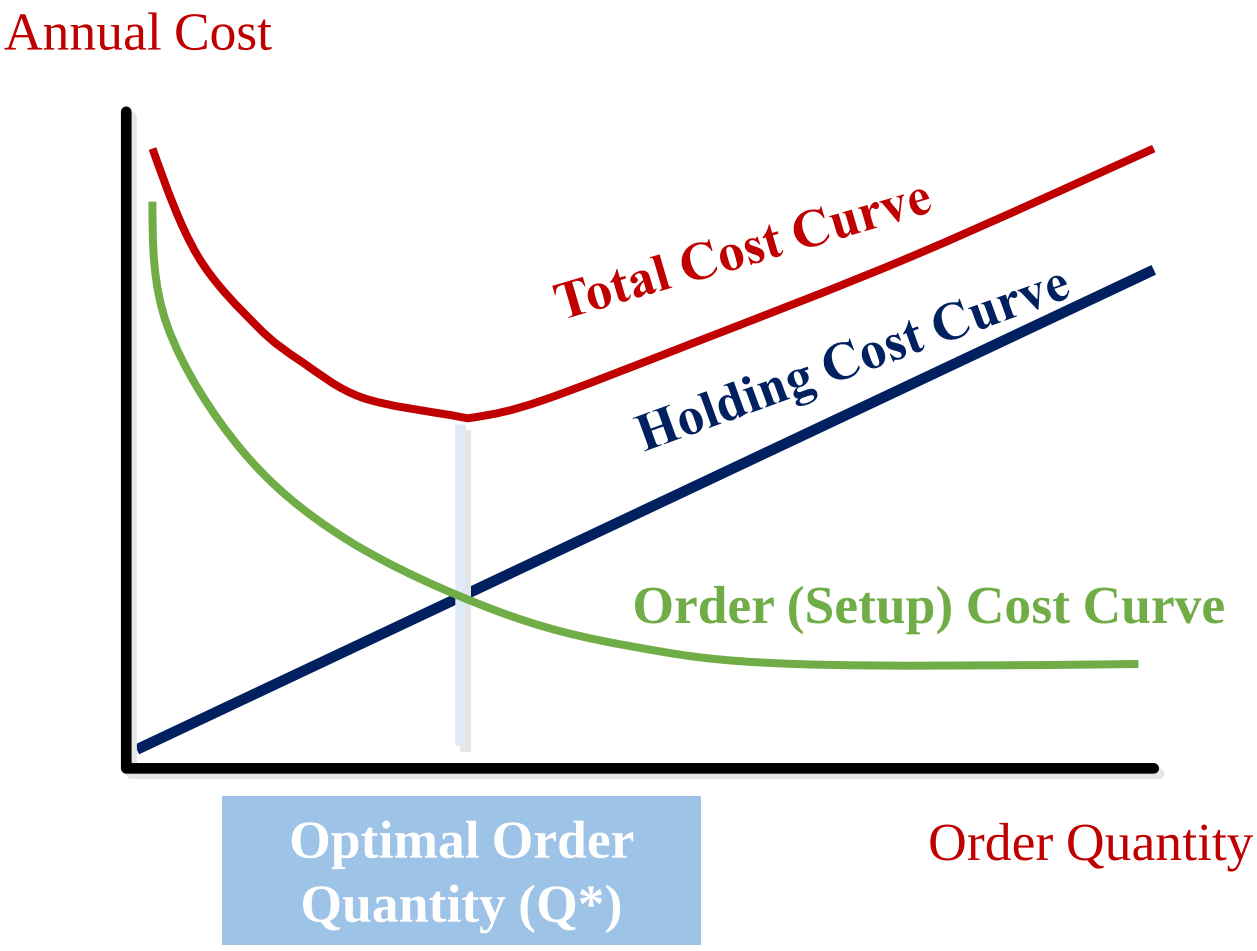
Costs

- Holding cost = HQ/2 per year
- Ordering cost = SD/Q per year
- Total cost

  HQ/2 + SD/Q per year



EOQ Model: How Much to Order?



Q* balances the setup costs with inventory holding costs

Solution to EOQ Model

$$\text{Total cost} = TC(Q) = \frac{DS}{Q} + \frac{QH}{2}$$

$$\frac{d\,TC(Q)}{d\,Q} = -\frac{DS}{Q^2} + \frac{H}{2}$$

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

Economic Order Quantity

Sweater Example EOQ

M&S has a stable demand for a line of sweater it offers. Each week there is a demand for a 100 unit. M&S incurs a fixed cost of $5000 every time it places an order. The marginal cost of a sweater is $400, and the shop's cost of capital is approximately 1% per week.

D = 100 S = $5000 H = $400 x 1% = $4

Optimal order size Q = Q_{EOQ} = 500

Time between orders = Q/D = 500/100 = 5 weeks

Weekly ordering cost = $(D/Q)S$ = (100/500)*$5000 = $1000

Weekly holding cost = $(Q/2)H$ = (500/2)*$4 = $1000

Average cycle time T = (Q/2)/D = 2.5 weeks

Characteristics of EOQ

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

- The optimal batch size trades off setup and holding costs
  - At Q=Q*, setup cost per unit time = holding cost per unit time
- Square-root relationship between Q* and (D, S):
  - If demand increases by a factor of 4, the optimal batch size increases by a factor of 2 and order twice as often
  - To reduce batch size by a factor of 2, setup cost has to be reduced by a factor of 4

EOQ Model Summary

Given D (demand rate), S (setup cost), and H (holding cost):

Time between two orders = Q/D

Order frequency per unit time = D/Q

Holding cost per unit time = $HQ/2$

Order or setup cost per unit time = SD/Q

Total cost per unit time = $HQ/2 + SD/Q$

Optimal order quantity $Q^* = \sqrt{\frac{2DS}{H}}$

Role of Lead-time in EOQ Model

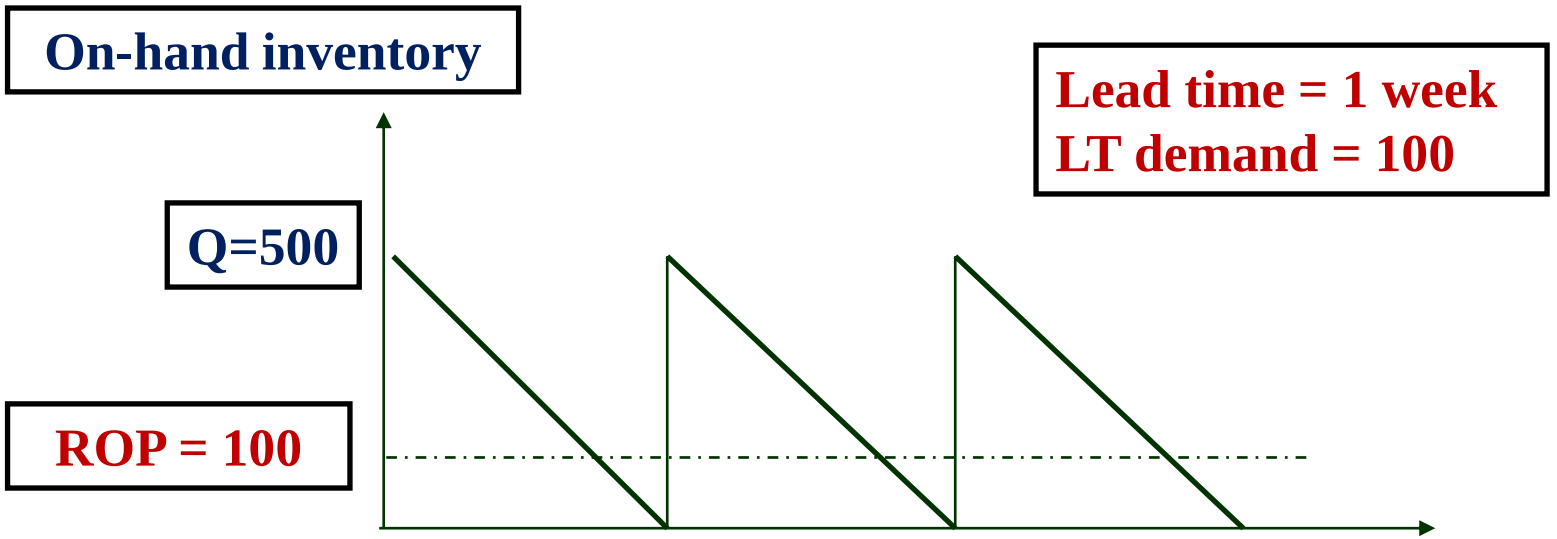
- Assumptions:
  - Constant demand rate
  - The Role of Leadtime?

- It takes 1 week from the time M&S places an order to the time the order is received. This means the lead time is 1 week. If demand is stable as before, when should the store place an order?

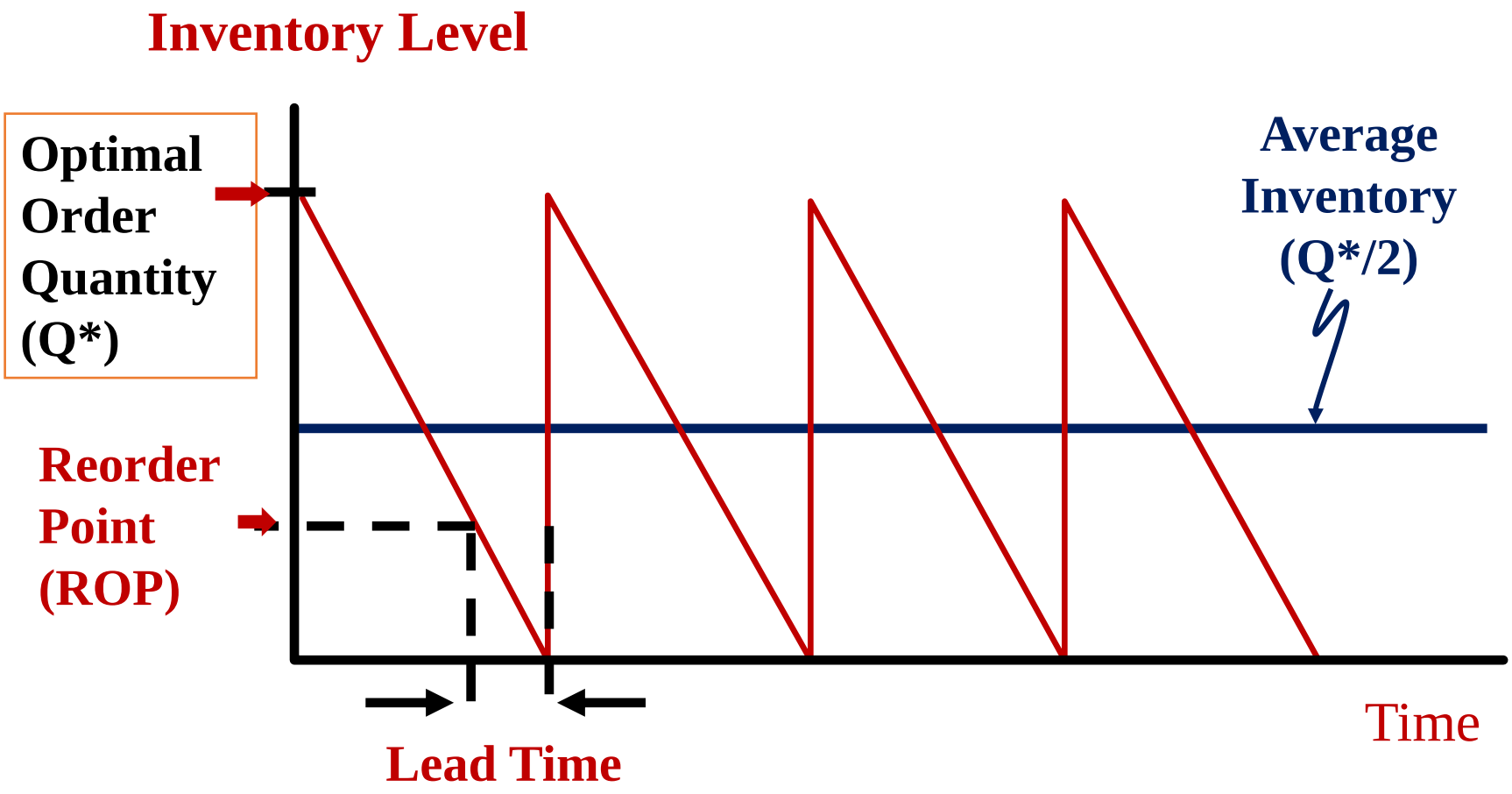
- The **two key decisions** in inventory management are:
  - How much to order?
  - When to order?

M&S Store: When to Order?

- Given the one week lead time, M&S should place an order when the on-hand inventory drops to 100, the demand during the lead time.
- The **reorder point (ROP)** equals 100.



EOQ Model: When to Order?



EOQ Model Equations

D : Demand per year d: Demand per day = D/ Working days per year

S : Setup cost per order L: Lead time in days H = Holding cost

Total cost per year

$$TC\,(Q) = \frac{DS}{Q} + \frac{QH}{2}$$

Optimal order quantity (or Economic Order Quantity)

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

Number of orders per year

$$N = \frac{D}{Q^*}$$

Reordering point

$$ROP = d \cdot L$$

EOQ Example

George Heinrich uses **18,000** units per year of a certain component. The per unit cost of this component is **$500**. Each order costs George **$100**. He operates **360** days per year and has found that an order must be placed with his supplier **4** days before he can expect to receive that order. The holding cost is **$5** per unit per year. Find:

- Economic order quantity
- Annual holding cost and annual ordering cost
- Reordering point

EOQ Example: answer

- Economic order quantity

$$Q^* = \sqrt{\frac{2 \times 18000 \times 100}{5}} = 848.5\, units$$

- Annual holding cost and annual ordering cost

$$\frac{Q^* H}{2} = \$2121.3, \qquad \frac{DS}{Q^*} = \$2121.3$$

- Reordering point

$$ROP = \frac{18000}{360} \times 4 = 200\, units$$

EOQ Example : answer

Suppose during the second year, demand has doubled, that is, George needs to use **36,000** units per year. Find:

- Economic order quantity

$$Q^* = \sqrt{\frac{2 \times 36000 \times 100}{5}} = 1200\ units$$

- Annual holding cost and annual ordering cost

$$\frac{Q^* H}{2} = \$3000, \qquad \frac{DS}{Q^*} = \$3000$$

Application of EOQ Model

An EOQ model is applicable when

- Demand does not change significantly from one ordering period to another
  - Example: long lifecycle stable products such as groceries, automobile components, chemicals, heavy industrial equipment, etc.

- Demand can be forecasted accurately.

Video: EOQ problem walkthrough