

# Forecasting Framework

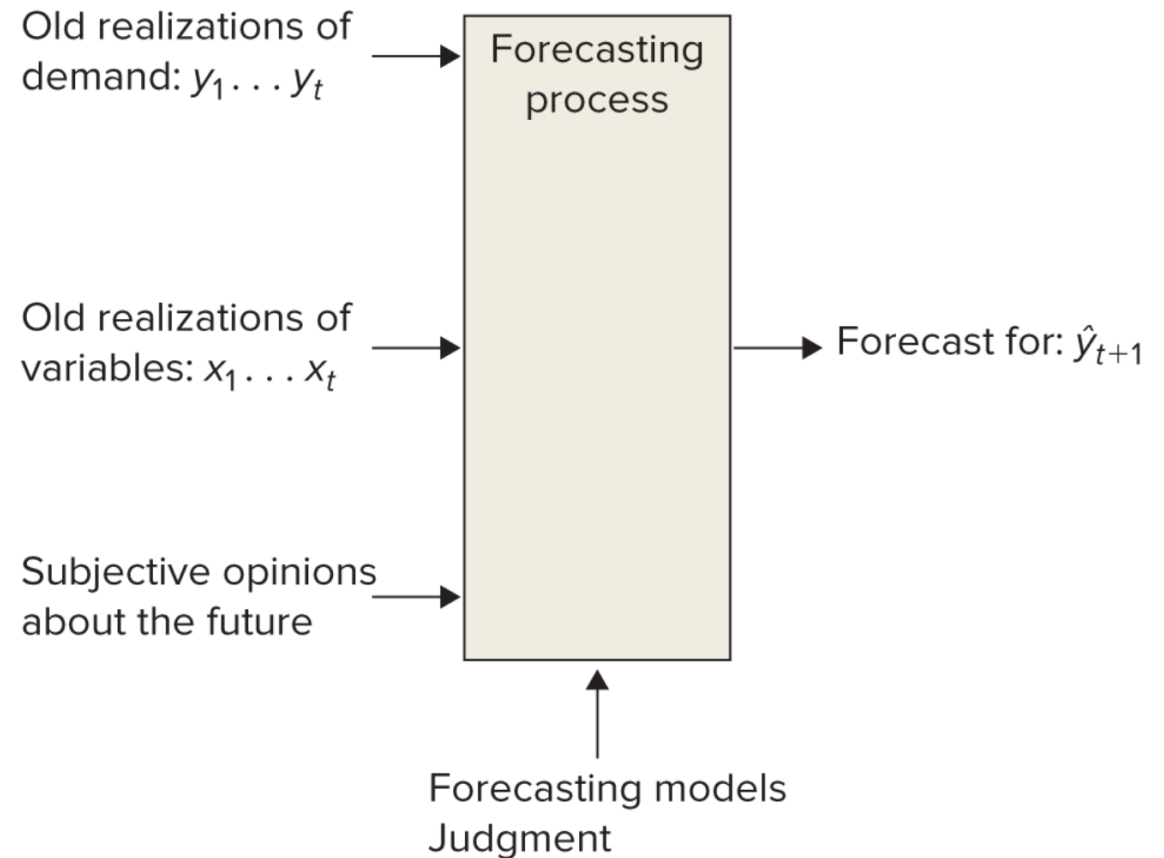
**Forecasting** – the process of creating statements about outcomes of variables that presently are **uncertain** and will only be realized in the future.

**Demand forecasting** – the process of creating statements about future realizations of demand.



# Five-step Approach to Implementing a Forecasting Process

1. Collect data
2. Establish the forecasting method and models to use
3. Forecast future demand using a forecasting method
4. Make decision based on step 3
5. Measure the forecast error; look for biases and improve the process

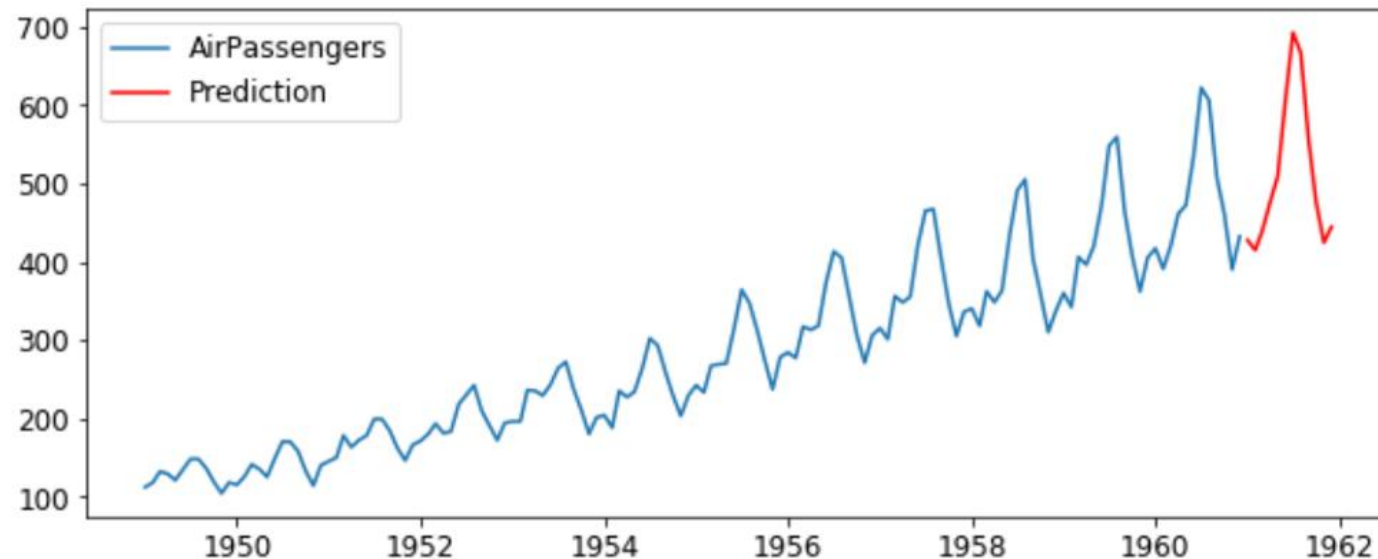


# Comments About Forecasts

- Forecasts are always wrong!
- Long-term forecasts are worse than short-term forecasts
- Aggregate forecasts (both time and location) are more accurate
- Forecast should always be checked with common sense

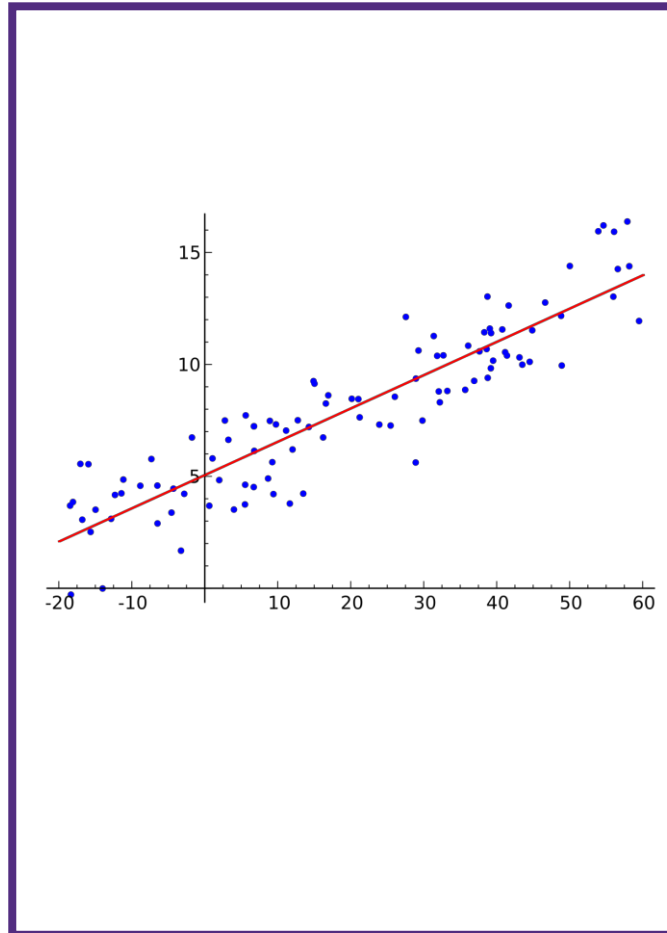
# Time Series Forecasting Framework

- **Time series analysis** – analysis of old demand data
- **Time series-based forecast** –forecasting that only uses old demand data
- **Extrapolation** – estimation of values beyond the range of the original observations

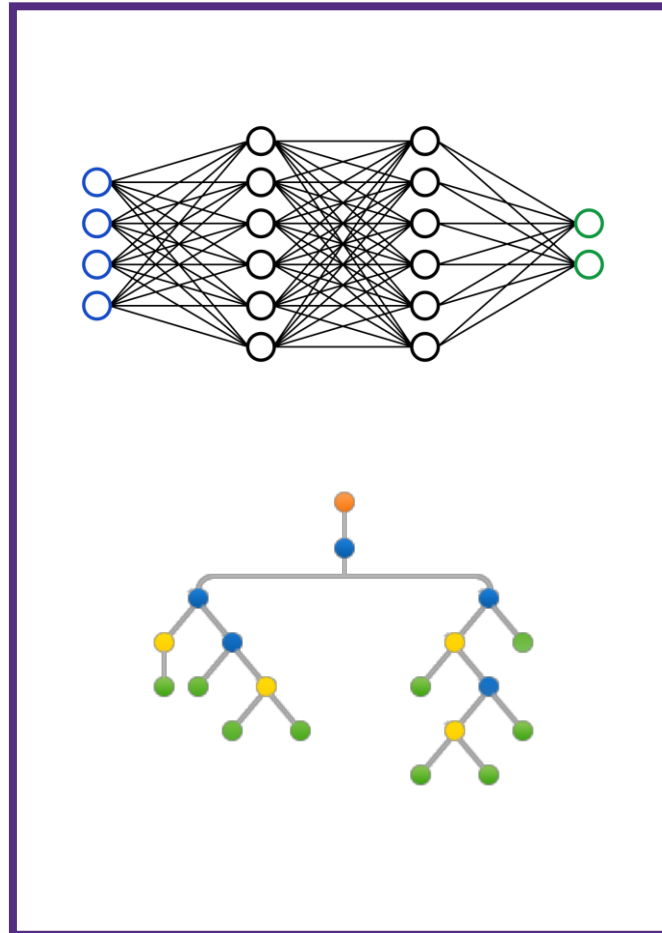


# Other Forecasting Methods

Regression analysis



Machine Learning



Expert panel forecasting



# Forecasting Time Horizon

- **Short-term forecasts**

- support tactical decision-making
- hours to weeks



- **Mid-term forecasts**

- support capacity planning and financial accounting
- weeks to a year



- **Long-term forecasts**

- support strategic decisions
- multiple years



# Evaluating the Quality of a Forecast

A good forecast should be:

1. Unbiased – that is, correct on average
2. Close to the real outcomes

**Forecast error (FE)** – the difference between a forecasted value and the realized value.

# Evaluating the Quality of a Forecast

- **Mean squared error (MSE)**

$$\text{MSE} = \frac{\sum_{t=1}^N \text{FE}_t^2}{N}$$

- **Mean absolute error (MAE)**

$$\text{MAE} = \frac{\sum_{t=1}^N |\text{FE}_t|}{N}$$

- **Mean absolute percentage error (MAPE)**

$$\text{MAPE} = \frac{\sum_{t=1}^N \left| \frac{\text{FE}_t}{y_t} \right|}{N}$$

# Some simple forecast methods

- **Naïve forecasting method** – predicts that the next value will be like the last realized value.
- **Moving average forecasting method** – predicts that the next value will be the average of the last realized values.
- **Exponential smoothing forecasting method** – predicts the next value will be a weighted average between the last realized value and the old forecast.

$$\hat{y}_{t+1} = y_t$$

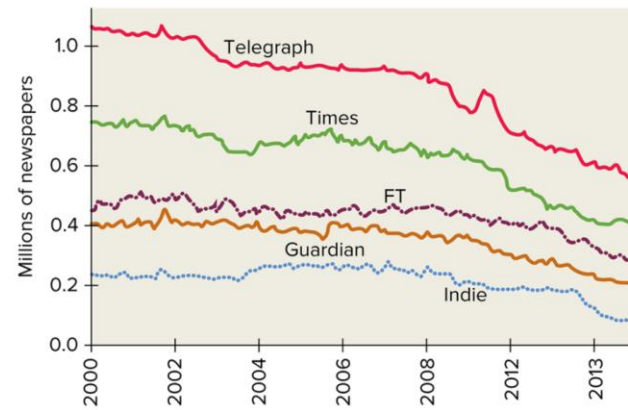
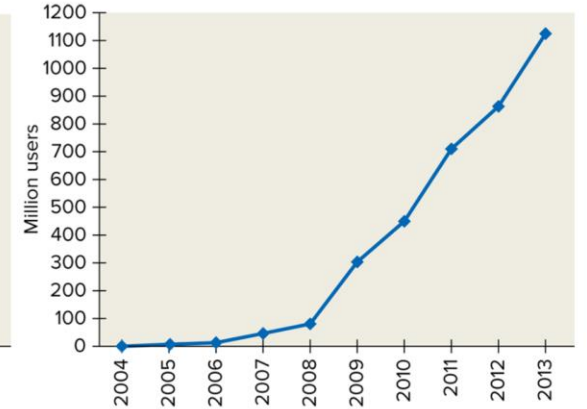
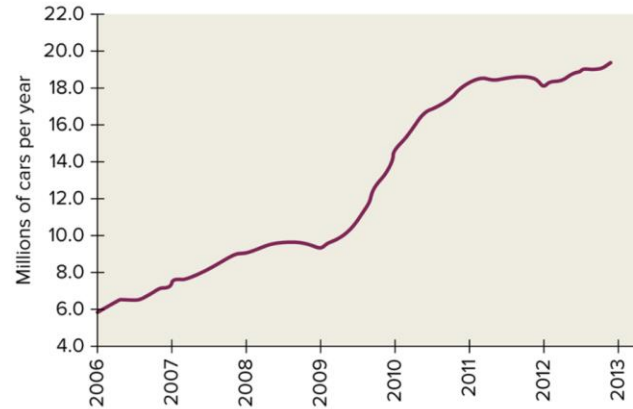
4-day moving average example

$$\hat{y}_{t+1} = \text{Average}(y_t, y_{t-1}, y_{t-2}, y_{t-3})$$

$$\hat{y}_{t+1} = (\alpha \times y_t) + (1 - \alpha) \times \hat{y}_t$$

# Time Series Analysis – Trends

- **Trend** – a continuing increase or decrease in a variable that is consistent over a long period of time.
- **Momentum-based forecasts** – an approach to forecasting that assumes that the trend in the future will be similar to the trend in the past.



# Forecasting Trends: Double exponential smoothing

$y_t$ : realized demand in period  $t$

$\hat{y}_{t+1}$ : forecasted demand for period  $t+1$  obtained via exponential smoothing using smoothing parameter  $\alpha$

$\hat{T}_t$ : forecasted trend for period  $t+1$  obtained via exponential smoothing using smoothing parameter  $\beta$

With this notation, we write the demand rate exponential smoothing as

$$\hat{y}_{t+1} = (\alpha \times y_t) + [(1 - \alpha) \times \hat{y}_t] + \hat{T}_t$$

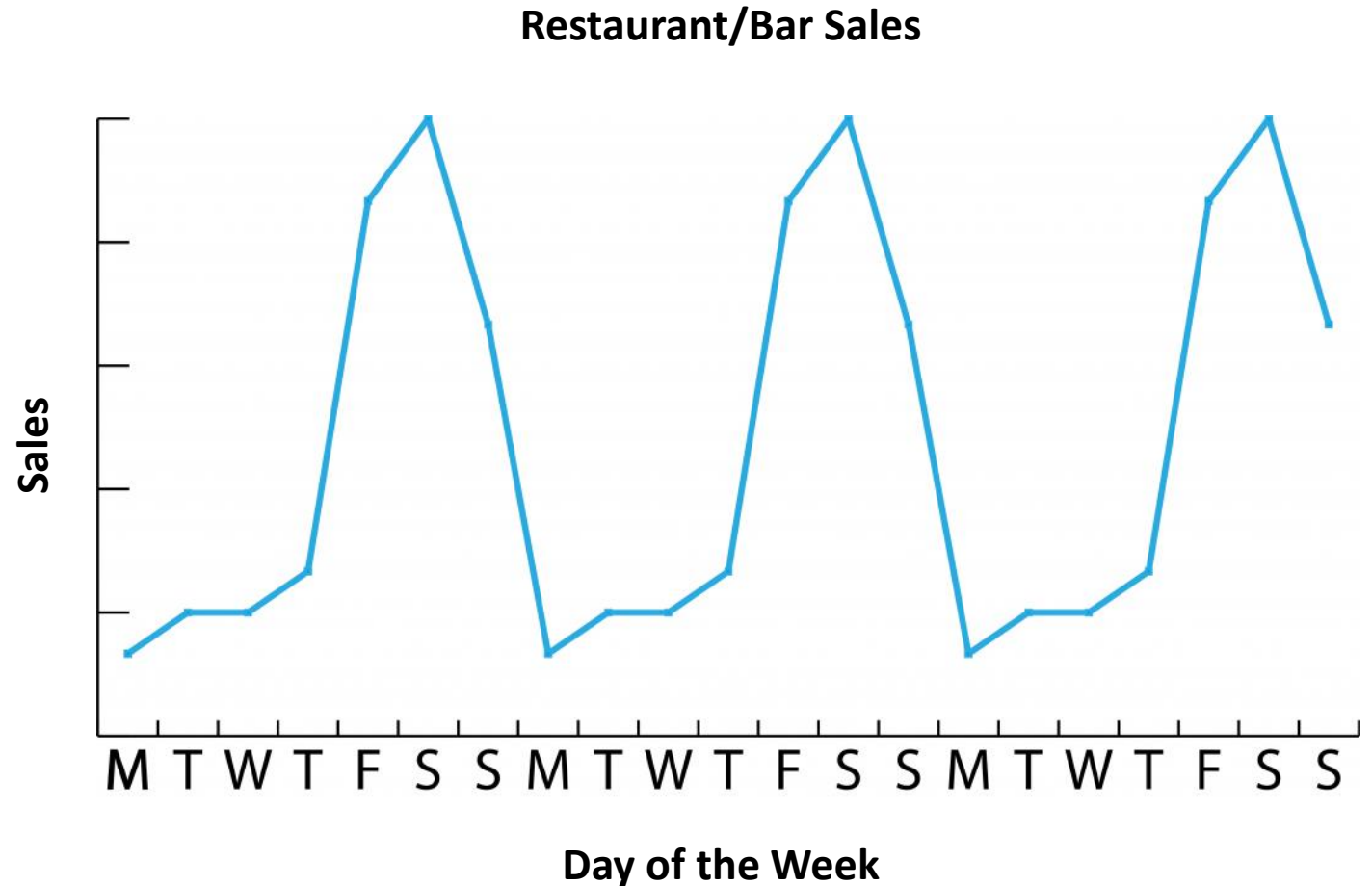
and the exponentially smoothed trend as

$$\hat{T}_{t+1} = [\beta \times (\hat{y}_{t+1} - \hat{y}_t)] + (1 - \beta) \hat{T}_t$$

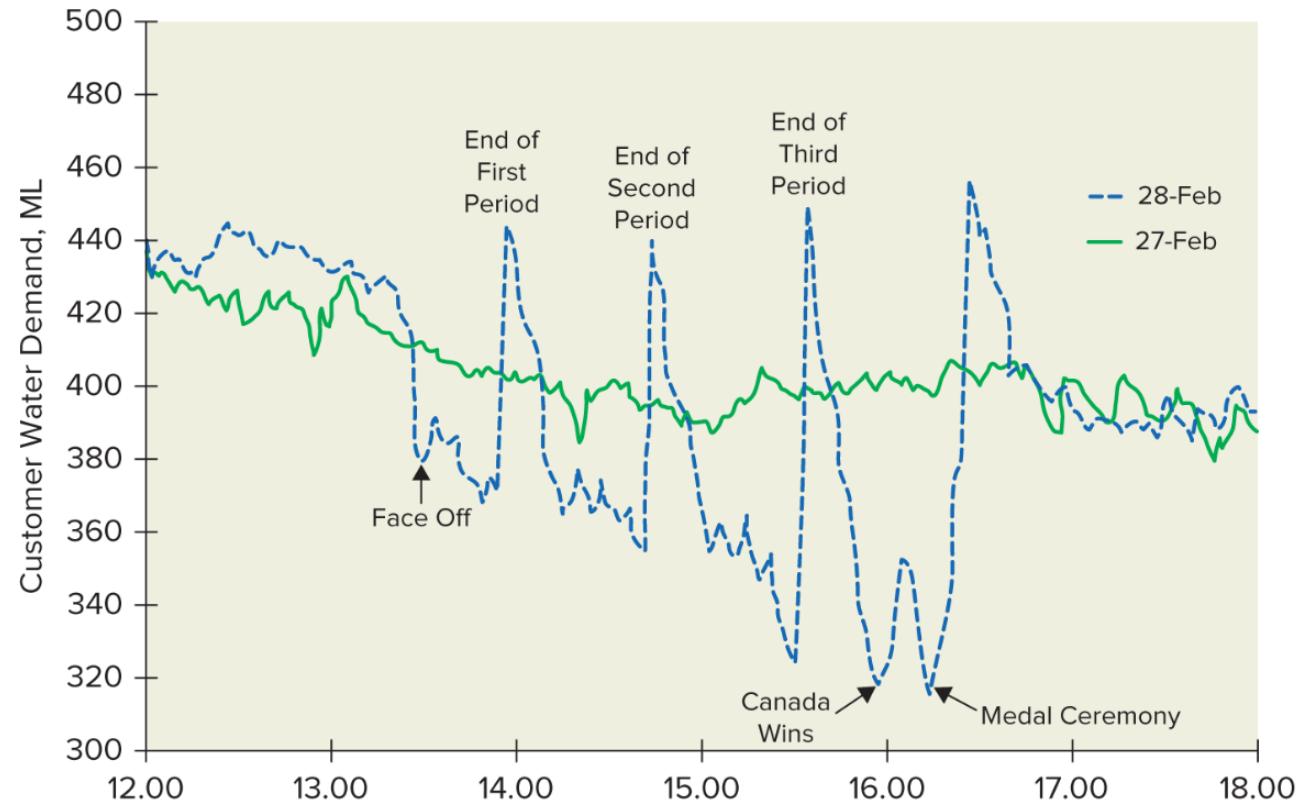
where  $(\hat{y}_{t+1} - \hat{y}_t)$  can be thought of as our latest estimate of our trend.

# Time Series Analysis – Seasonality

- **Seasonality** – a significant demand change that constitutes a repetitive fluctuation over time.
- **Seasonality index (SI)** – the estimated adjustment factor that allows us to move from the average overall demand to the average demand for a particular season.



# Time Series Analysis – Seasonality



**Figure 15.7** Water consumption in Edmonton (Canada) during the Olympic Gold medal hockey game (Source: <http://www.smartplanet.com/blog/smart-takes/infographic-water-consumption-in-edmonton-canada-during-olympic-gold-medal-hockey-game/>)

# Time Series Analysis – Seasonality

- **Deseasonalize** – to remove the seasonal effect from past data.
- **Reseasonalize** – to reintroduce the seasonal effect to the forecasted data.

$$\text{Seasonality index for season } x = SI_{\text{Season } x} = \frac{\text{Average season } x \text{ demand}}{\text{Average total demand}}$$

$$\text{Deasonalized demand in } t = \frac{\text{Demand in } t}{\text{Seasonality index}}$$

Forecast for next season  $x$  = Smoothed forecast for an average day (use the last value in the deseasonalized smoothed exponential forecast)  $\times SI_{\text{Season } x}$

# Expert Panels and Subjective Forecasts

## Methods

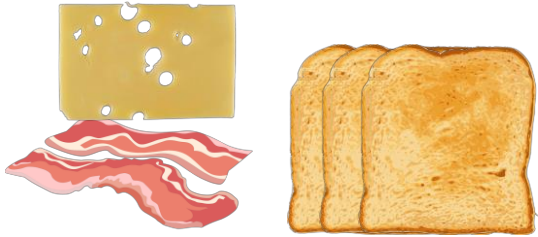
- **Forecast combination** – combining multiple forecasts that have been generated by different forecasters into one single value.
- **Forecast with consensus building** – an iterative discussion among experts about their forecasts and opinions that leads to a single forecast.
- **Prediction markets** – a betting game in which forecasters can place financial bets on their forecasts.

## Some Considerations

- **Overconfidence bias** – the fact that human decision makers are overly confident in their ability to shape a positive outcome.
- **Anchoring bias** – the fact that human decision makers are selective in their acquisition of new information, looking for what confirms their initially held beliefs.
- **Forecast gaming** – a purposeful manipulation of a forecast to obtain a certain decision outcome for a decision that is based on the forecast.

# Inventory - the number of flow units within the process. There are three types

**Raw material**



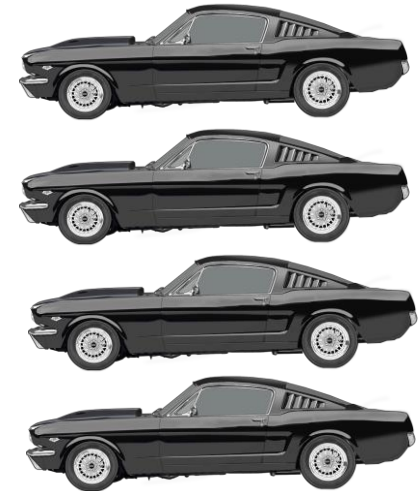
**Work-in-process (WIP)**



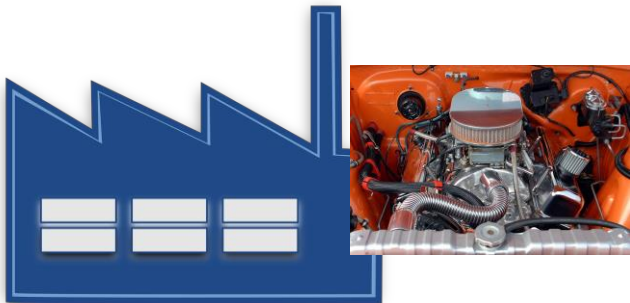
**Finished goods**



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# The same components can be different types of inventory for different levels of the supply chain



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|                       | Engine plant       | Assembly plant                  | Dealership (sales) |
|-----------------------|--------------------|---------------------------------|--------------------|
| Raw material          | Castings           | Finished engines, chassis, etc. | Automobile         |
| Work-in-process (WIP) | Unfinished engines | Unfinished automobile           | Automobile         |
| Finished goods        | Finished engines   | Automobile                      | —                  |

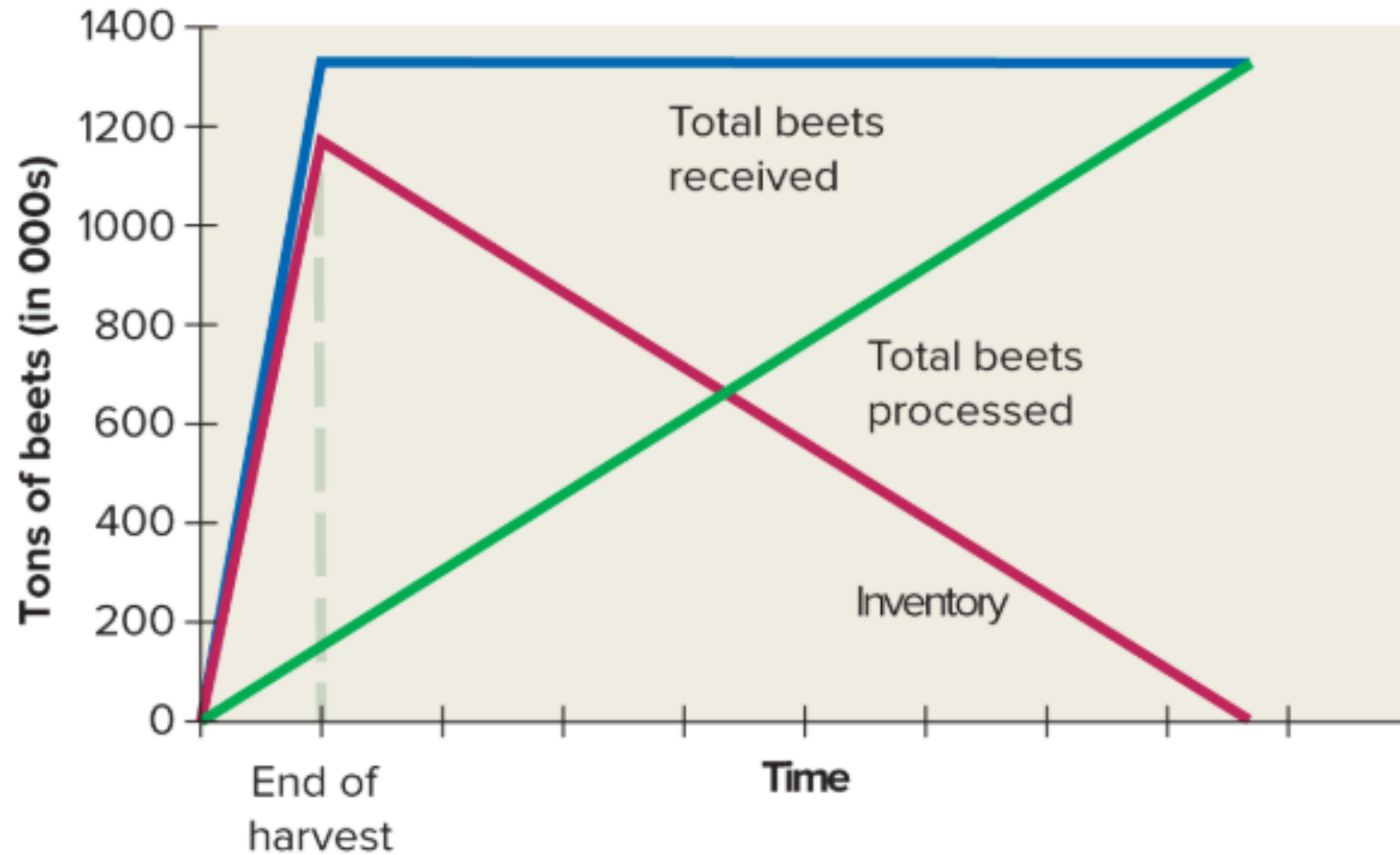
# Inventory Management

**Inventory Management** – the practice of regulating the quantity, location, and type of inventory in a process.

- **Forecasting** – predicting future demand.
- **Data tracking and analysis** – maintaining accurate inventory and demand data.
- **Mandate's investments** – building, equipment etc.



# Production Smoothing



# Two Key Metrics of Inventory

**Days-of-supply =  $T = I/R$**  – the average amount of time (in days) it takes for a unit to flow through the system

- Example: *I have \$65,000 worth of inventory on average; I sell \$1,000 per day. What are the days-of-supply*

**Inventory Turns =  $1/T = R/I$**  – the number of times the average inventory flows through a process in a designated interval of time.

- Example: *I have \$65,000 worth of inventory on average; I sell \$1,000 per day. What are the annual inventory turns?*

# Examples: Days-of-Supply and Turns

**TABLE 10.1** Inventory Turns for Selected Retail Segments

| Retail Segment                  | Examples                      | Annual Inventory Turns | Days-of-Supply |
|---------------------------------|-------------------------------|------------------------|----------------|
| Jewelry                         | Tiffany                       | 1.68                   | 217            |
| Hobby, toy/game stores          | Toys R Us                     | 2.99                   | 122            |
| Department store                | Sears, JCPenney               | 3.87                   | 94             |
| Radio, TV, consumer electronics | Best Buy                      | 4.10                   | 89             |
| Variety stores                  | Kohl's, Target                | 4.45                   | 82             |
| Apparel and accessory           | Ann Taylor, Gap               | 4.57                   | 80             |
| Drug and proprietary stores     | Rite Aid, CVS                 | 5.26                   | 69             |
| Home furniture/equipment        | Bed Bath & Beyond             | 5.44                   | 67             |
| Catalog, mail-order             | Spiegel, Lands' End           | 8.60                   | 42             |
| Food stores                     | Albertson's, Safeway, Walmart | 10.78                  | 34             |

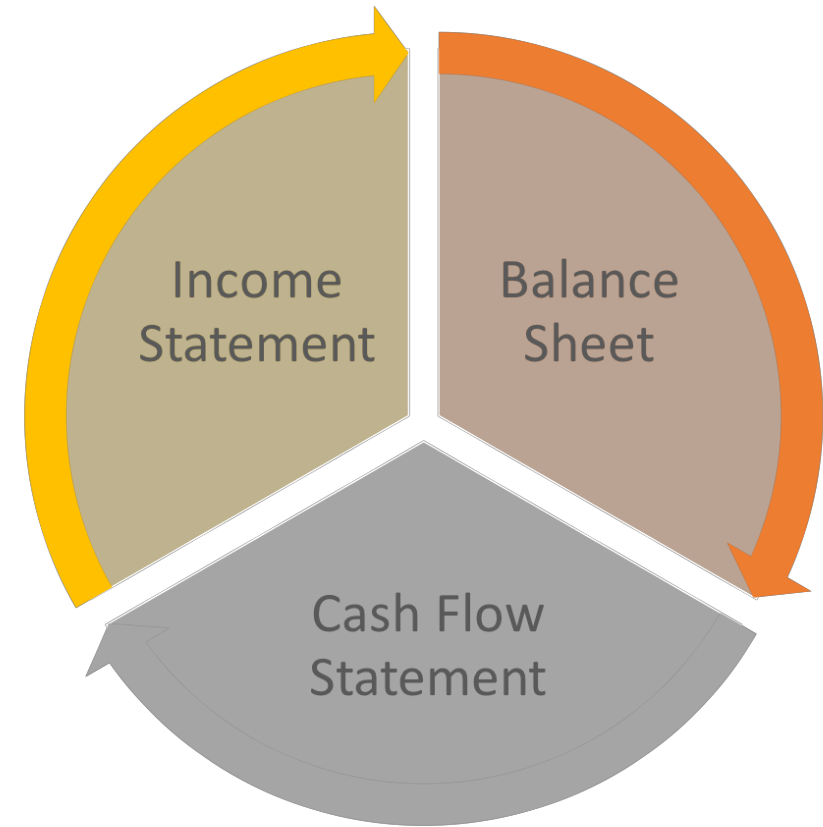
| Online Retailers                 | Annual Inventory Turns | Days of Supply |
|----------------------------------|------------------------|----------------|
| <b>Amazon.com, Inc. (AMZN)</b>   | 8.34                   | 43.76          |
| <b>Walmart Inc. (WMT)</b>        | 9.35                   | 39.04          |
| <b>Best Buy Co., Inc. (BBY)</b>  | 6.54                   | 55.81          |
| <b>The Home Depot, Inc. (HD)</b> | 5.25                   | 69.52          |
| <b>Target Corporation (TGT)</b>  | 6.21                   | 58.78          |

<https://www.alphaquery.com/>

# We can Evaluate Inventory Turns and Days-of-Supply from Financial Reports

Both turns and days-of-supply measure how long items remain in inventory.

- Should this information be revealed to the public?
  - If the stock is publicly traded, the company is legally required to report financial information to evaluate its inventory turns.
  - If the stock is privately held, financial information is usually withheld.



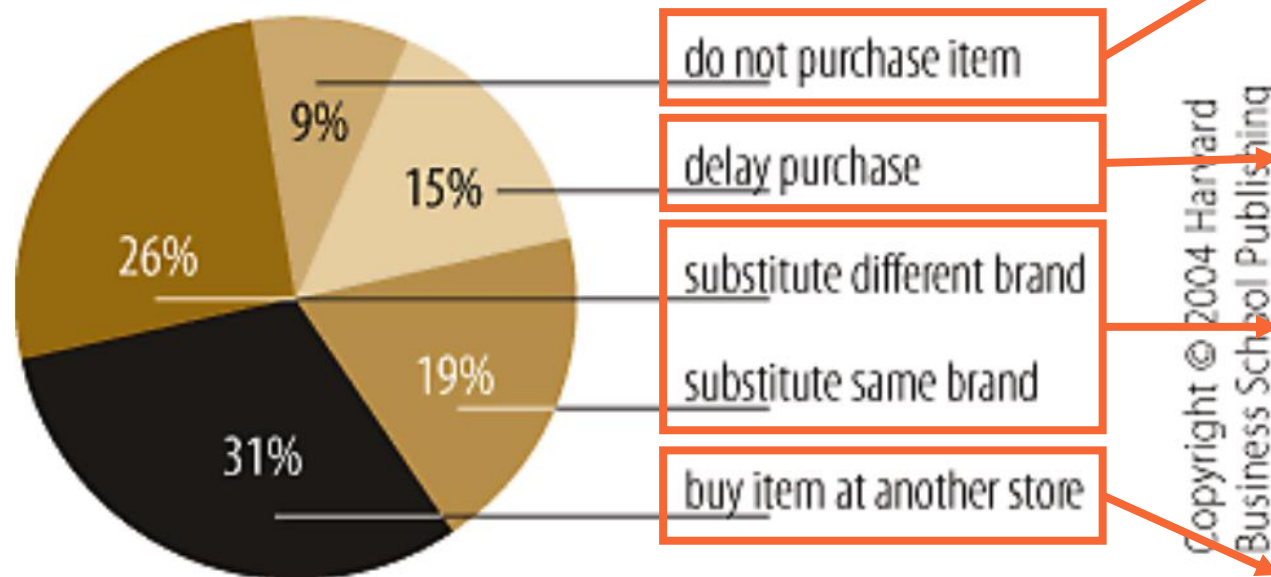
# Stockouts – a major reason to hold inventory

**Stockout** – a stockout occurs when a customer demands an item that is not available in inventory.



# Inventory Stockouts

A study of more than 71,000 consumers worldwide shows that they have little patience for stock-outs. When consumers can't find the precise product they're looking for, fewer than half, on average, will make a substitute purchase, and nearly a third will buy the item elsewhere.



| Customer Response to a Stockout                                    | How Costly Is the Stockout?                                                                                                   |
|--------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Lose the sale                                                      | High cost of stockout: loss of profit from the sale of them.                                                                  |
| Customer waits for the item to become available                    | Low cost of stockout: total profit doesn't change much, as long as the delay isn't too long.                                  |
| Lose the sale of one item, but the customer purchases another item | Moderate cost of stockout: loss of profit from one item is replaces, maybe in part or in full, by the profit if another item. |
| Lose the sale and lose the customer                                | Very high cost of stockout: loss of future profit from the customer.                                                          |

Reference: <https://hbr.org/2004/05/stock-outs-cause-walkouts>

# Inventory Holding Costs

## Inventory Costs

- **Inventory storage cost**



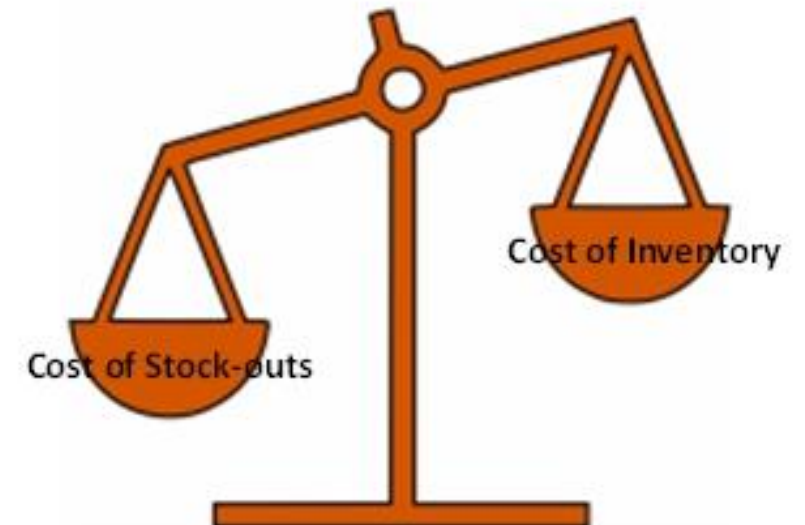
- Material Handling
- IT
- Purchase
- Rental
- Operational costs
- Communication
- Utilities

- **Opportunity cost of capital**



- **Spoilage and shrinkage costs**

- Investments
- Interests on working capital
- Taxes on inventory paid
- Insurance costs



# Inventory Holding Cost

Most companies assess their inventory holding costs as a percentage of the cost to purchase an item. We call this percentage the **holding cost percentage**

- For example: If a dress costs \$50 and the firm assigns a holding cost percentage of 35%, what is the cost to hold a dress in inventory for the entire year?
- The retailer's annual turns are 3. How much inventory holding cost should be assigned to each dress sold?

# A typical inventory setting



What quantity ( $Q$ ) of inventory should I order when I place an order?

**Economic order quantity (EOQ) model** – a model used to select an order quantity that minimizes the sum of inventory ordering and inventory holding costs per unit of time.

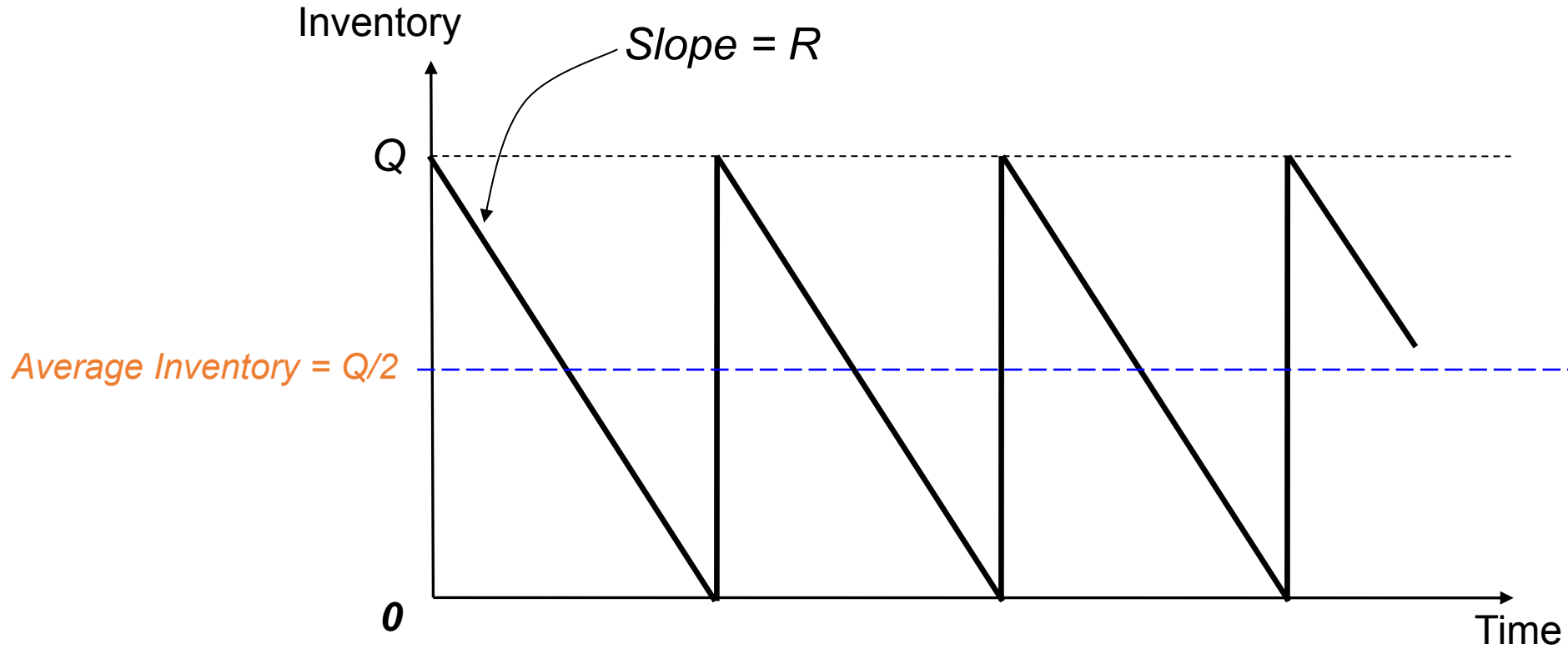
# The Economic Order Quantity Model

## Assumptions and Inventory Depletion

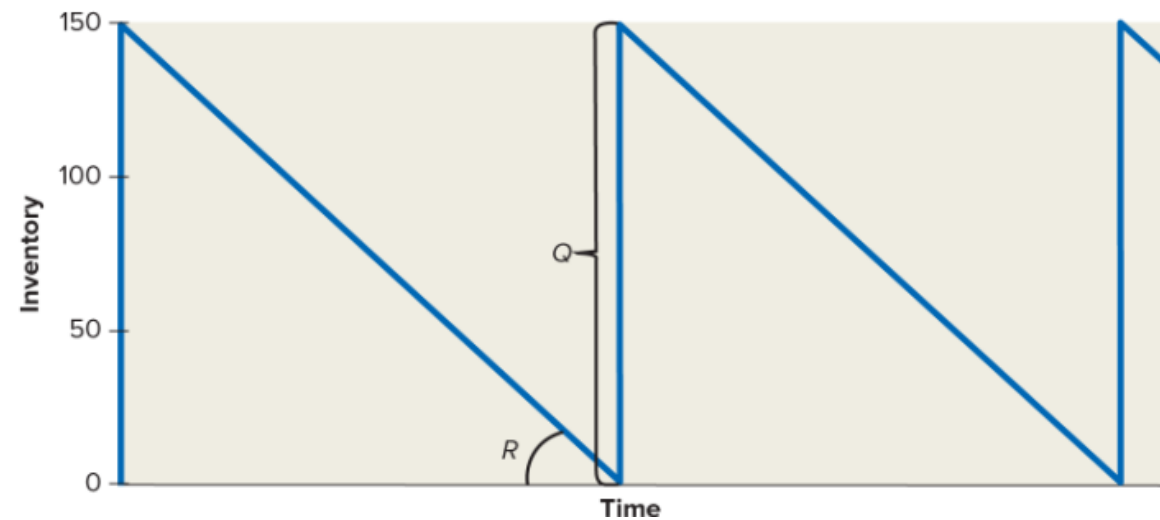
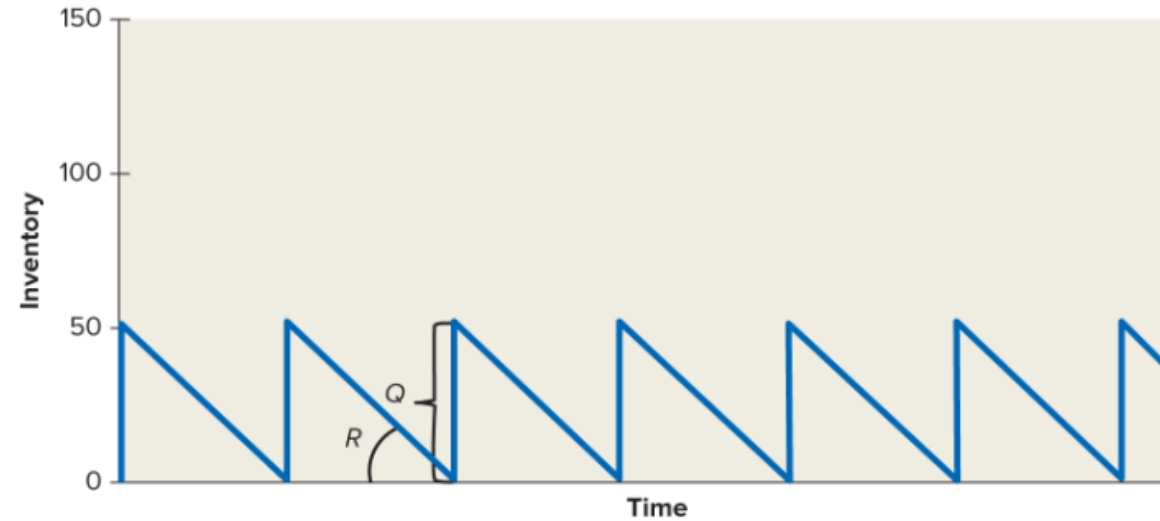
### Assumptions:

- Demand occurs at a constant rate  $R$
- There is a fixed order cost  $K$  per order
- There is a holding cost per unit of time  $h$
- All demand is satisfied from inventory (no backlogs)
- Inventory never spoils, degrades, or is lost
- Orders are delivered with a reliable lead time
- There is a purchase price per unit that is independent of the quantity purchased

# Inventory Depletion



# Inventory Depletion for different Policies (order quantities)



# The Economic Order Quantity

- **Holding cost per unit of time** – the total cost to hold inventory for a period of time.

$$\text{Average inventory} = \frac{\text{Order quantity}}{2} = \frac{Q}{2}$$

$$\text{Holding Cost Per Unit of time} = \frac{Q}{2} h$$

- **Ordering cost per unit of time** – the cost to purchase inventory in a period of time.

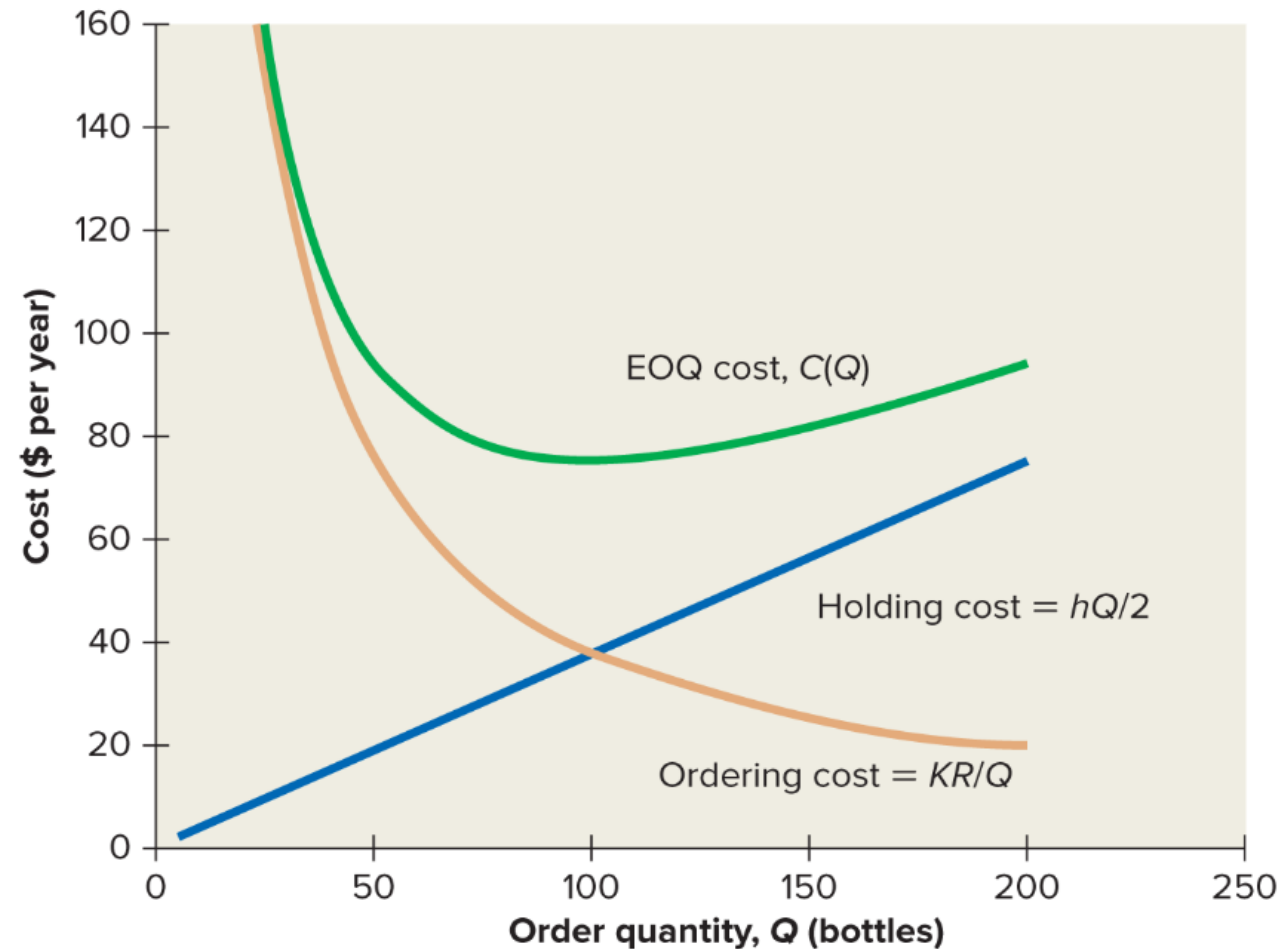
$$\text{Orders per unit of time} = \frac{R}{Q}$$

$$\text{Ordering Cost Per Unit of Time} = \frac{R}{Q} K$$

- **Total Inventory Ordering and Holding Cost per unit of time** – the sum of ordering and holding costs per unit of time.

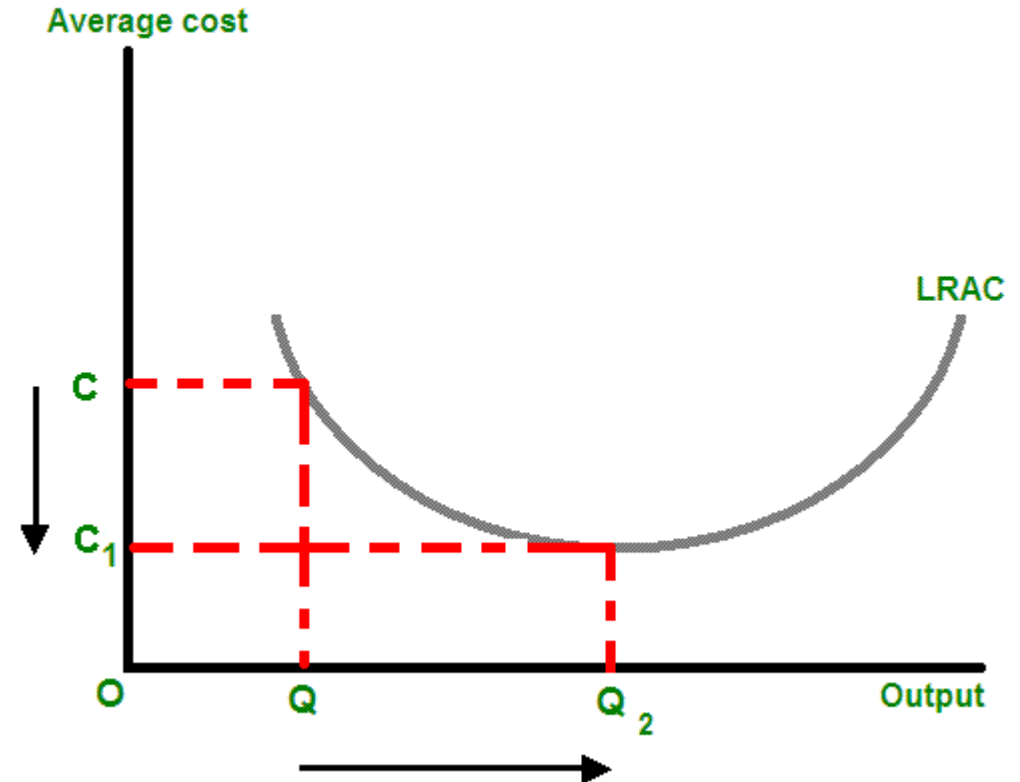
$$\text{Total Inventory Ordering and Holding Cost Per Unit of Time} = C(Q) = \frac{R}{Q} K + \frac{Q}{2} h$$

# How do inventory costs change based on the order quantity, $Q$ ?



# Economies of Scale

**Economies of scale** – describes a relationship between operational efficiency and demand in which greater demand leads to a more efficient process.



# Economies of Scale

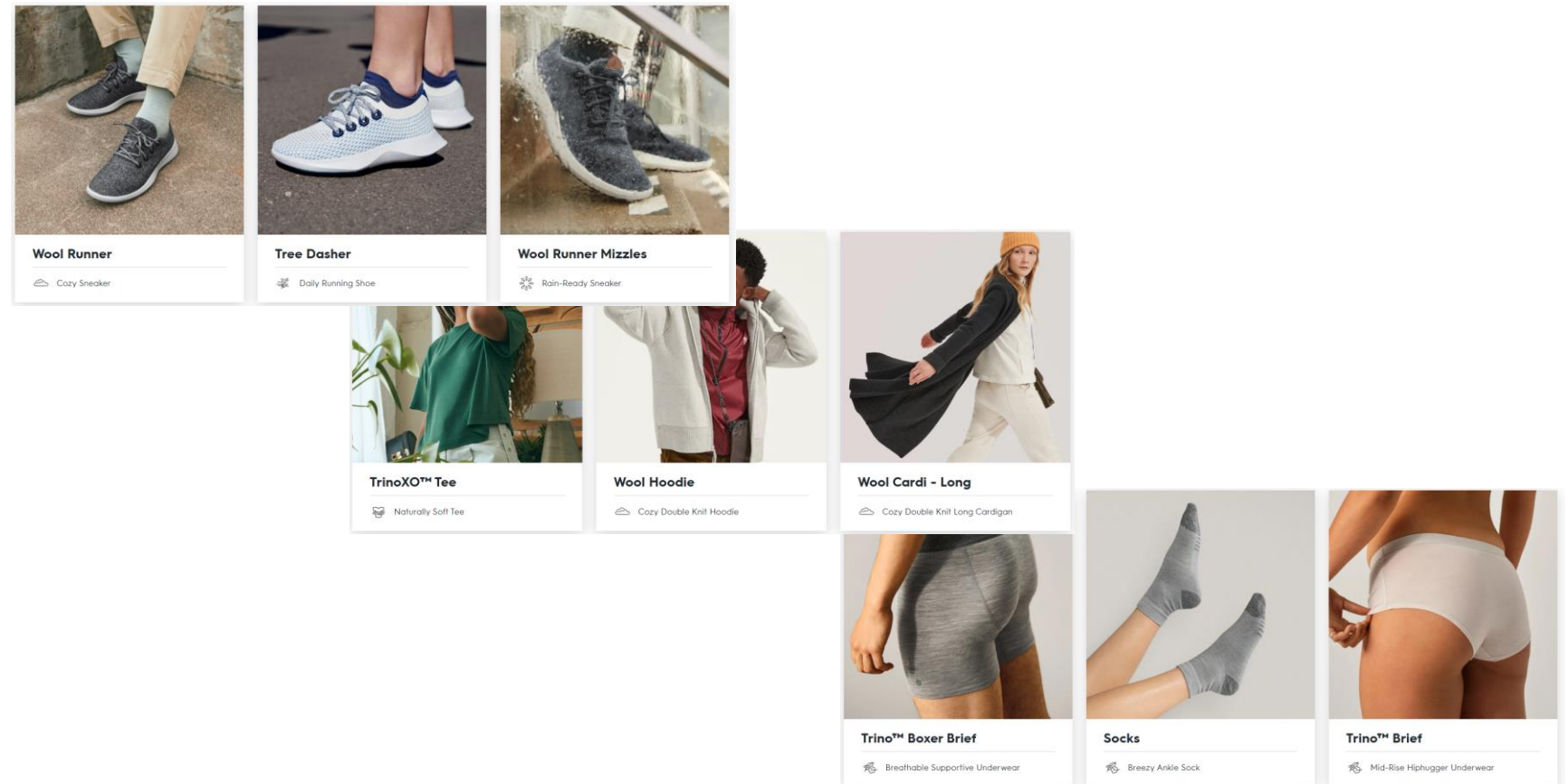
**TABLE 12.2** How Changes in Demand Influence Costs

| Scenario  |                                              | I       | II      | III     | IV       | V        |
|-----------|----------------------------------------------|---------|---------|---------|----------|----------|
|           | Demand rate, $R$ (bottles per year)          | 156     | 312     | 624     | 1248     | 2496     |
|           | Demand multiple                              | 1/4     | 1/2     | 1       | 2        | 4        |
|           | EOQ, $Q^*$ (bottles)                         | 50      | 71      | 100     | 141      | 200      |
| (a)       | Annual EOQ cost, $C(Q^*)$ (\$)               | \$37.50 | \$53.00 | \$74.90 | \$106.00 | \$149.90 |
| (b)       | Annual purchase cost ( $\$3 \times R$ )      | \$468   | \$936   | \$1872  | \$3744   | \$7488   |
| (c = a/b) | Annual EOQ cost as % of annual purchase cost | 8.0%    | 5.7%    | 4.0%    | 2.8%     | 2.0%     |

- As the demand rate  $R$  increases, the annual EOQ cost as a percentage of annual purchasing cost goes down, because the annual EOQ cost does not increase as fast as the purchase cost.
  - Note: this is also known as a *square root law*
- Hence, it is better to have higher sales, in that it gives you **economies of scale**.

# Product Variety

If adding the product reduces the demand of existing products, the existing products lose scale and become less efficient.



# Quantity Constraints and Discounts

- **Pallet** – either a platform which is used to stack inventory or the quantity of inventory that is stacked on the platform.
- **Tier** – the quantity of product in one layer of a pallet.



# Quantity Constraints and Discounts

- A quantity discount can be used as a motivator to order larger quantities.
- Larger quantities increases the sum of ordering and holding costs (above minimum).
- The purchasing cost is reduced.
- A very large quantity may be optimal even if the discount appears to be small.
- Firms are more price sensitive than consumers.

**QUANTITY DISCOUNTS:**  
YOU CAN NOW MIX & MATCH DESIGNS AND COLORS TO GET QUANTITY DISCOUNTS

|                                                                                            |                                                                                              |                                                                                              |                                                                                              |                                                                                             |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| <b>15% OFF</b><br>WHEN ORDERING<br><b>5-9 DECALS</b><br>MIX & MATCH<br>DESIGNS AND OPTIONS | <b>20% OFF</b><br>WHEN ORDERING<br><b>10-19 DECALS</b><br>MIX & MATCH<br>DESIGNS AND OPTIONS | <b>30% OFF</b><br>WHEN ORDERING<br><b>20-49 DECALS</b><br>MIX & MATCH<br>DESIGNS AND OPTIONS | <b>50% OFF</b><br>WHEN ORDERING<br><b>50-99 DECALS</b><br>MIX & MATCH<br>DESIGNS AND OPTIONS | <b>60% OFF</b><br>WHEN ORDERING<br><b>100+ DECALS</b><br>MIX & MATCH<br>DESIGNS AND OPTIONS |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|

DISCOUNTS WILL BE AUTOMATICALLY CALCULATED IN YOUR SHOPPING CART...



# Quantity Constraints

**TABLE 12.3** Ordering and Inventory Costs for Order Quantities Equal to the EOQ; also One Case (72 Bottles) and Two Cases (144 Bottles)

|                                                 | One Case | EOQ     | Two Cases |
|-------------------------------------------------|----------|---------|-----------|
| $Q$ (bottles)                                   | 72       | 100     | 144       |
| Holding cost per year                           | \$27.00  | \$37.50 | \$54.00   |
| Ordering cost per year                          | \$52.00  | \$37.40 | \$26.00   |
| Annual EOQ (ordering and holding cost, $C(Q)$ ) | \$79.00  | \$74.90 | \$80.00   |
| Annual purchasing cost                          | \$1872   | \$1872  | \$1872    |
| EOQ cost as % of purchase cost                  | 4.2%     | 4.0%    | 4.3%      |

- In most cases, ordering a quantity relatively smaller or larger than the EOQ does not have much effect on the annual ordering and holding costs.
- To find the best option, evaluate the cost with the quantity below and the quantity above the EOQ and pick the option with the lowest cost.

# Quantity Constraints

**TABLE 12.4** Relevant Data for Walmart's DC Order Quantity Decision

|                                                   | Walmart/Tylenol Value                   |
|---------------------------------------------------|-----------------------------------------|
| Demand rate, $R$ (bottles per year)               | 65,000                                  |
| Order cost, $K$ (\$ per order)                    | \$8                                     |
| Regular price per bottle                          | \$3                                     |
| Order quantity multiple                           | One tier = 20 cases = 1440 bottles      |
| Minimum order quantity for discount               | One pallet = 140 cases = 10,080 bottles |
| Discount                                          | 4%                                      |
| Annual holding cost percentage                    | 20%                                     |
| Holding cost per unit (\$ per unit per year), $h$ | Depends on $Q$                          |
| Order quantity (units), $Q$                       | To be determined                        |

# Quantity Constraints

**TABLE 12.5** Cost Calculations for Different Order Quantities at the Walmart DC

|                                                             | 1 Tier    | 1 Pallet  | 2 Pallets | 3 Pallets |
|-------------------------------------------------------------|-----------|-----------|-----------|-----------|
| $Q$ (bottles)                                               | 1440      | 10,080    | 20,160    | 30,240    |
| Order cost, $K$ (\$)                                        | \$8       | \$8       | \$8       | \$8       |
| Annual holding cost %                                       | 20%       | 20%       | 20%       | 20%       |
| Discount                                                    | 0%        | 4%        | 4%        | 4%        |
| Holding cost per unit (\$ per year), $h$                    | \$0.60    | \$0.576   | \$0.576   | \$0.576   |
| Holding cost (\$ per year) = $1/2 hQ$                       | \$432     | \$2903    | \$5806    | \$8709    |
| Ordering cost (\$ per year) = $KR/Q$                        | \$361     | \$52      | \$26      | \$17      |
| Annual purchasing cost (\$)                                 | \$195,000 | \$187,200 | \$187,200 | \$187,200 |
| Total annual cost (purchasing + ordering + holding) \$      | \$195,793 | \$190,155 | \$193,032 | \$195,926 |
| Annual cost savings relative to the one-tier order quantity |           | -2.9%     | -1.4%     | 0.1%      |

# Timing of Decisions



For the same odds, when would you rather place your bet?

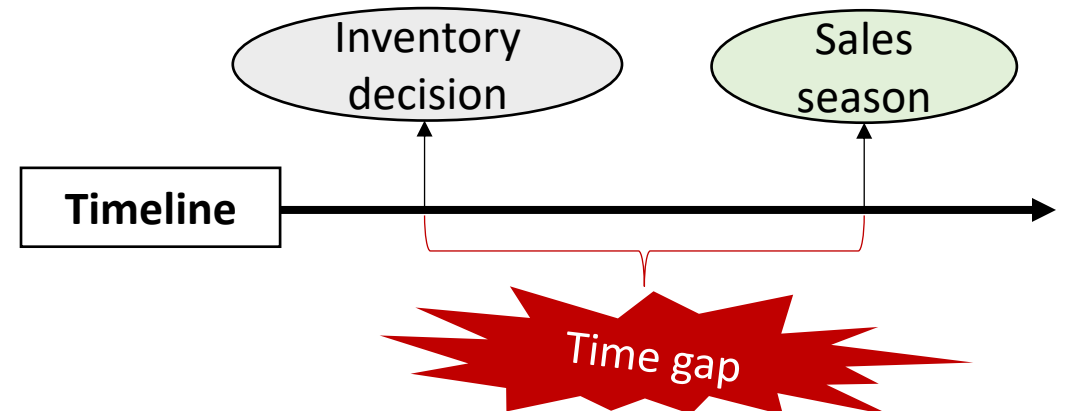


- A: A month before start of Derby
- B: The Monday before start of Derby
- C: The morning of start of Derby
- D: The winner is an inch from the finish line

# The Newsvendor Model

This model represents one of the canonical (recognized or fundamental) challenges faced in operations. We need to make a decision on inventory but face:

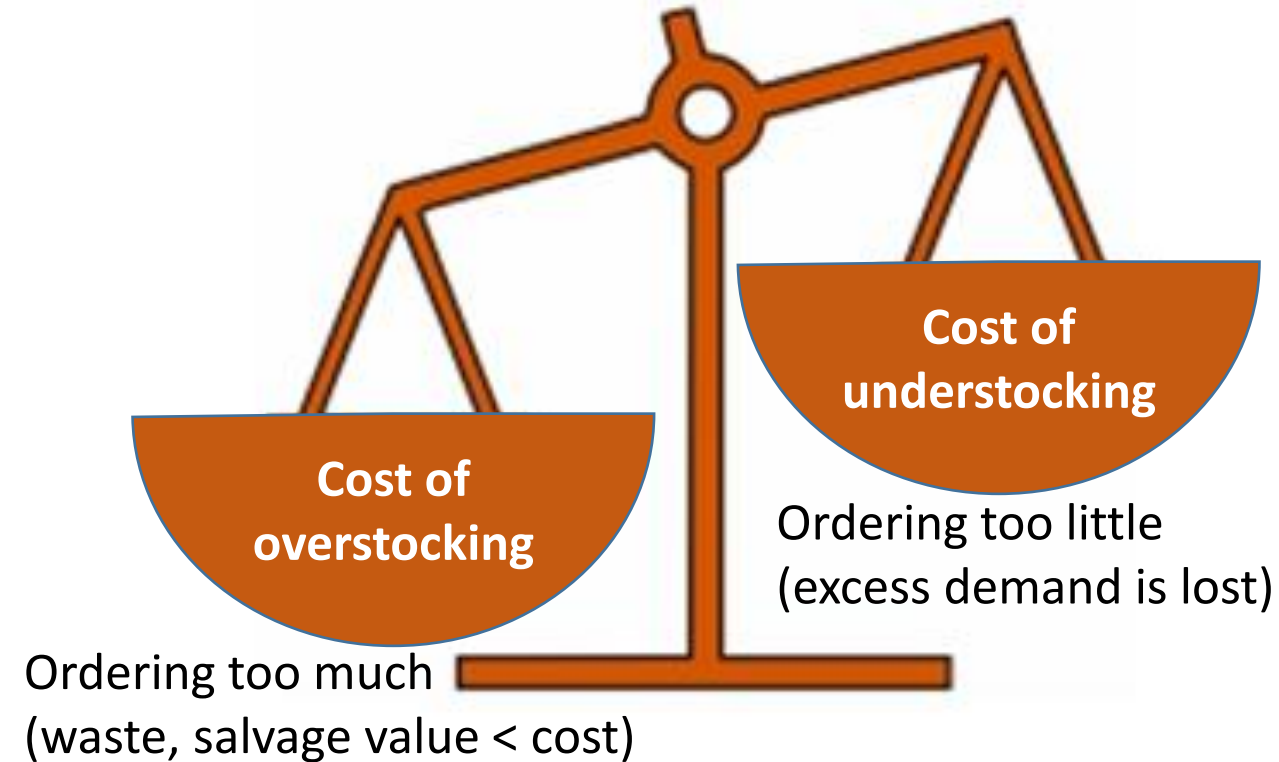
1. **Uncertain demand**
2. **Inflexible supply**
3. **Perishable inventory**



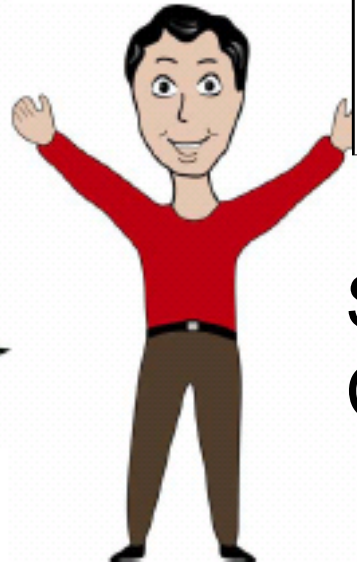
# The Newsvendor Model

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1. **Uncertain demand**
2. **Inflexible supply**
3. **Perishable inventory**



# THE CHRISTMAS TREE PROBLEM



| December |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|
| 1        | 2  | 3  | 4  | 5  | 6  | 7  |
| 8        | 9  | 10 | 11 | 12 | 13 | 14 |
| 15       | 16 | 17 | 18 | 19 | 20 | 21 |
| 22       | 23 | 24 | 25 | 26 | 27 | 28 |
| 29       | 30 | 31 |    |    |    |    |

Sell price  $p = 100$   
Cost  $c = 20$

2002 - Jérémie Gallien

# ORDERING TOO MUCH...



| December |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|
| 1        | 2  | 3  | 4  | 5  | 6  | 7  |
| 8        | 9  | 10 | 11 | 12 | 13 | 14 |
| 15       | 16 | 17 | 18 | 19 | 20 | 21 |
| 22       | 23 | 24 | 25 | 26 | 27 | 28 |
| 29       | 30 | 31 |    |    |    |    |

Sell price  $p = 100$

Cost  $c = 20$

Salvage value  $s = 5$

Cost of overstocking

$$C_o = c - s$$

2002 - Jérémie Gallien

# VERSUS ORDERING TOO LITTLE...



| December |    |    |    |    |    |    |
|----------|----|----|----|----|----|----|
| 1        | 2  | 3  | 4  | 5  | 6  | 7  |
| 8        | 9  | 10 | 11 | 12 | 13 | 14 |
| 15       | 16 | 17 | 18 | 19 | 20 | 21 |
| 22       | 23 | 24 | 25 | 26 | 27 | 28 |
| 29       | 30 | 31 |    |    |    |    |

Sell price  $p = 100$

Cost  $c = 20$

Cost of understocking

$$C_u = p - c$$

2002 - Jérémie Gallien

# Wet Suit Retail

## Timeline of events and economics for O'Neill's Hammer 3/2 wet suit

Generate forecast  
of demand and  
submit an order  
to TEC

Spring selling season

Nov Dec Jan Feb Mar Apr May Jun Jul Aug

Receive order  
from TEC at the  
end of the  
month

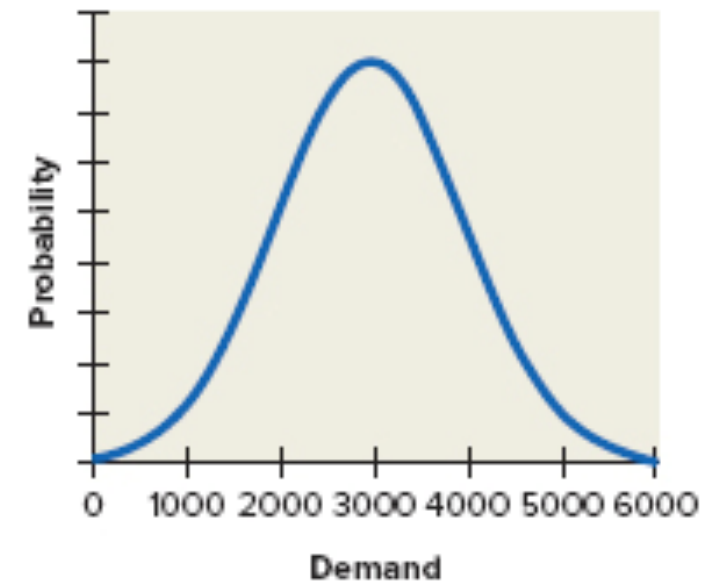
Leftover  
units are  
discounted

|                                                     |       |
|-----------------------------------------------------|-------|
| Selling price                                       | \$190 |
| Purchase price from TEC                             | \$100 |
| Discount price at end of season (the salvage value) | \$ 70 |

Demand is distributed normally:

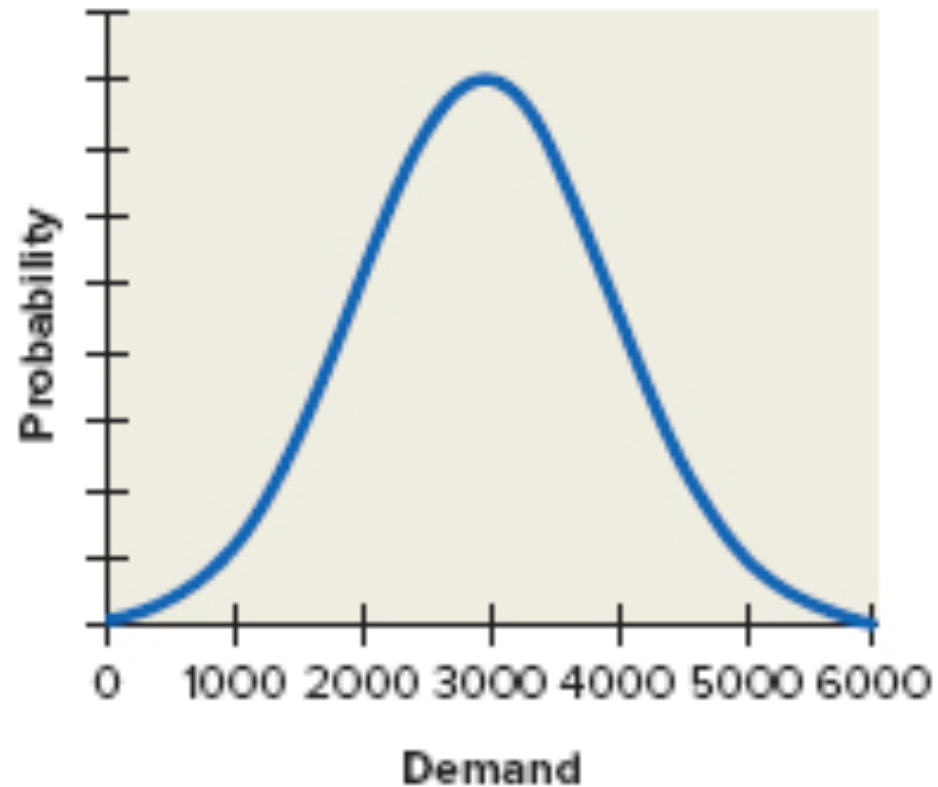
Average = 3,000 suits

Standard deviation = 1,000 suits

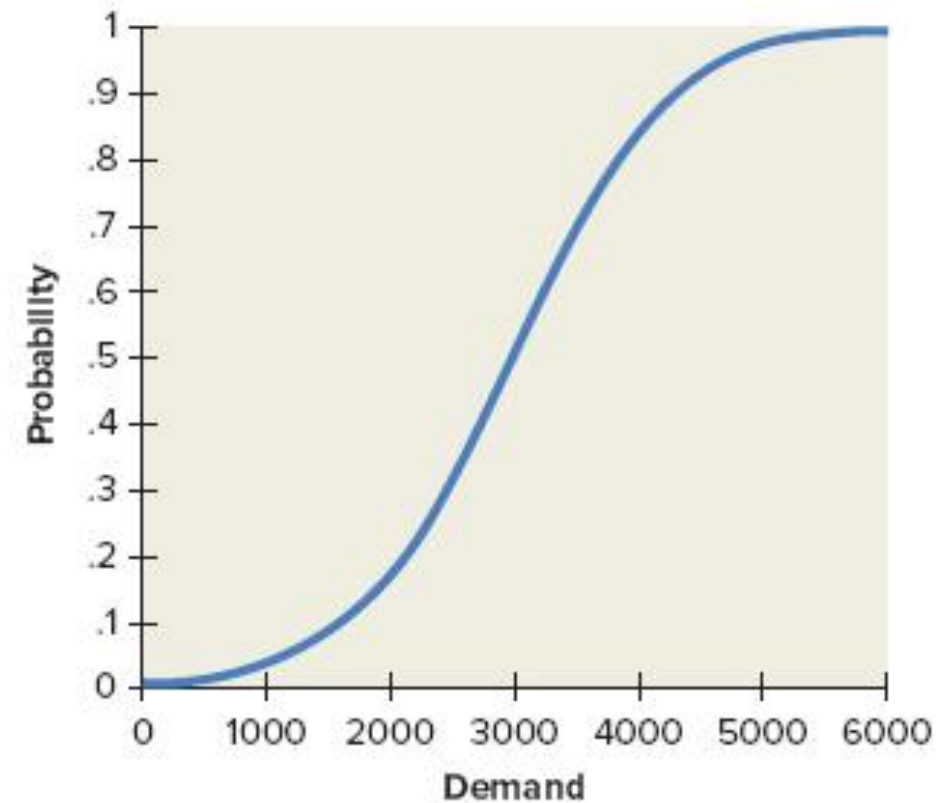


# Reminder about the normal distribution

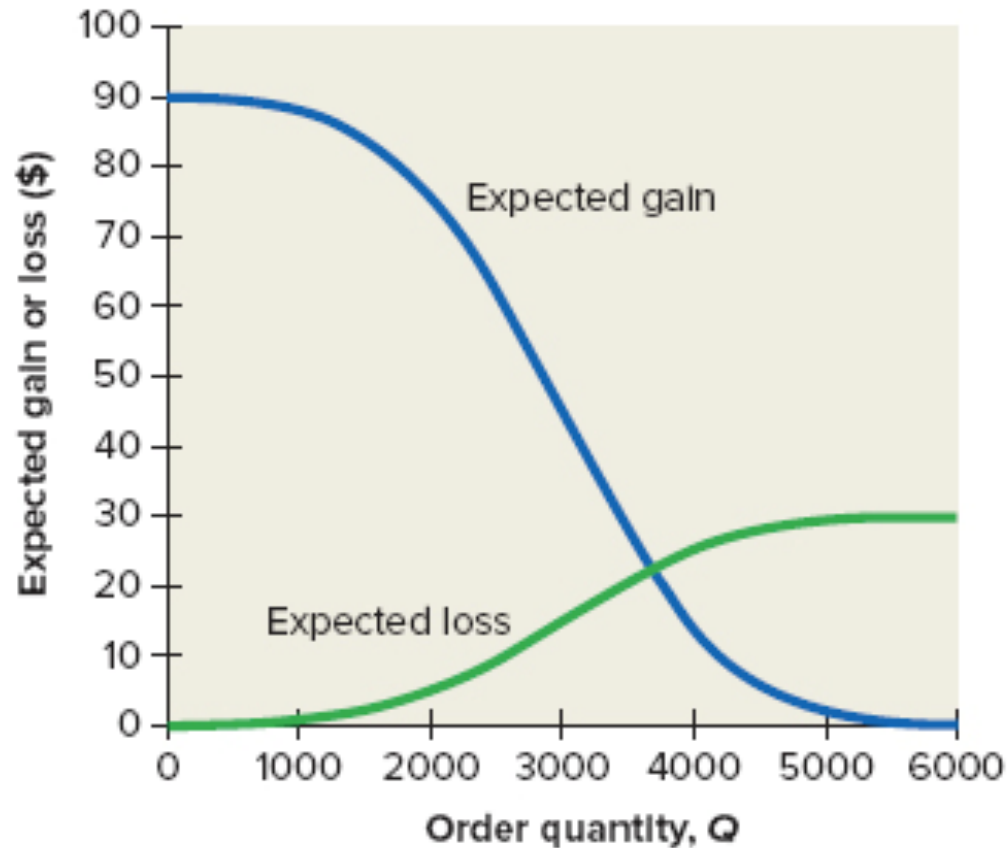
Probability Density Function  
 $f(Q)$



Cumulative Distribution Function  
 $F(Q)$



# We Want to Find the Optimal Order Quantity, $Q^*$ . What happens as I increase $Q$



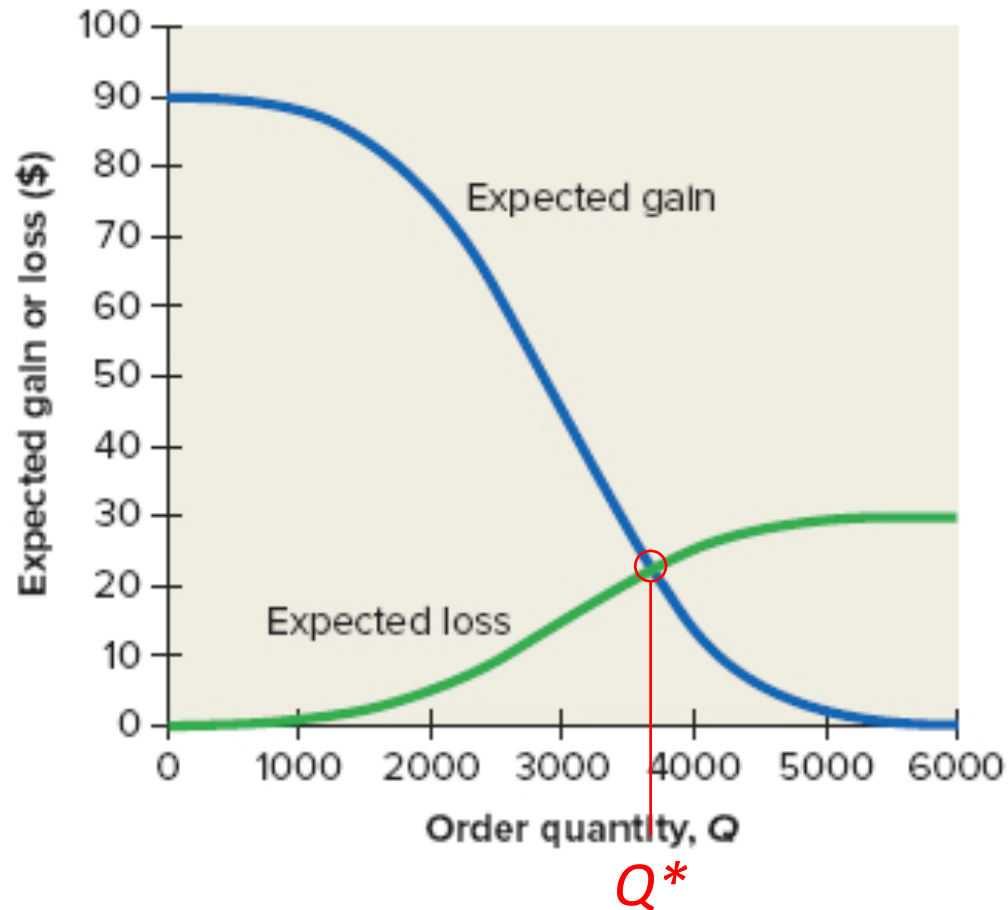
The more I order, the less likely I would sell one extra unit.... So, my expected gain from ordering more and more units goes down, whereas my expected loss goes up.

**For example:** If I order 0 units, then I would sell an extra 1 unit with almost 100% probability (almost 0% chance that I would lose money on that unit), but if I order 6,000 units, then I would sell an extra 1 unit with almost 0% probability (almost 100% chance that I would not make money on that unit)

For every item I sell, I make \$90 -> So if I understock, I loose \$90

For every item I don't sell, I loose \$30. -> So if I overstock, I loose \$30.

We increase  $Q$  until the expected loss is equal to the expected gain



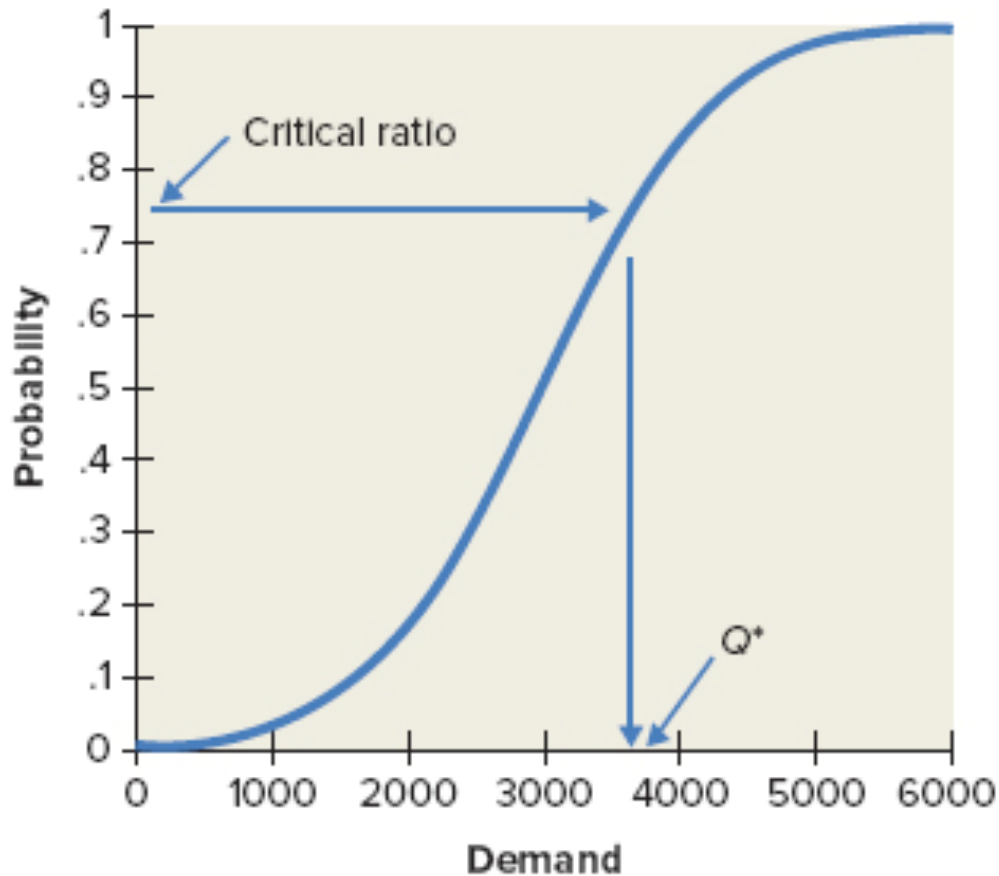
$$(1 - F(Q^*)) \times C_u = F(Q^*) \times C_o$$

$$F(Q^*) = \frac{C_u}{C_o + C_u}$$

**The Critical Ratio (Fractile)**

This gives a probability so how do we convert this into an order quantity?

# What is the optimal order Quantity $Q^*$ ?



$$Q = \mu + (z \times \sigma)$$

[Equation 13.2]

where

$z$  = the quantity in the standard normal distribution

$\mu$  = the mean of the true demand distribution

$\sigma$  = the standard deviation of the true demand distribution

$Q$  = the order quantity for the true demand distribution

In our example:

We have the Critical ratio  $C_u/(C_u+C_o) = 90/(90+30) = 90/120 = 0.75$

We need to find the  $z$ -value such that  $F(z) = 0.75$

We can use Table 13.4

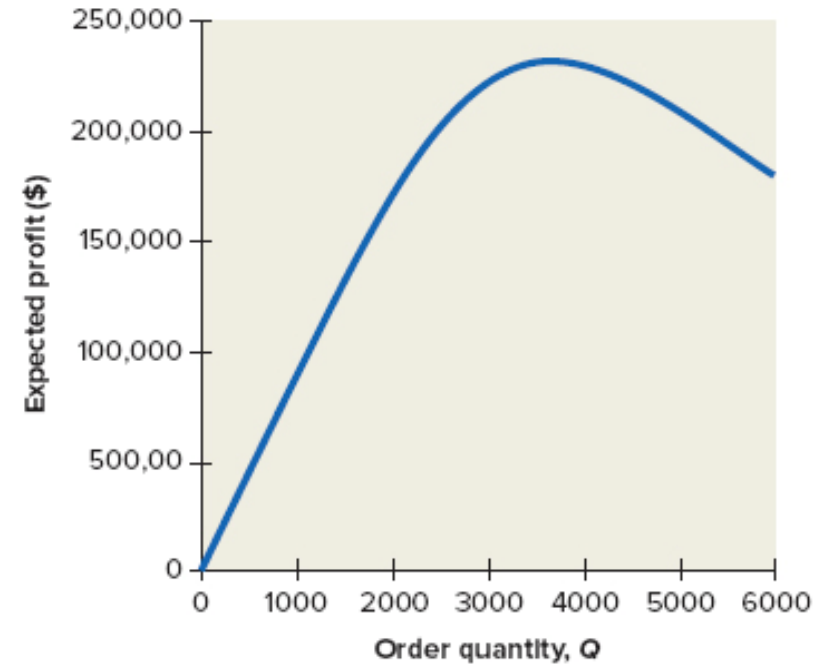
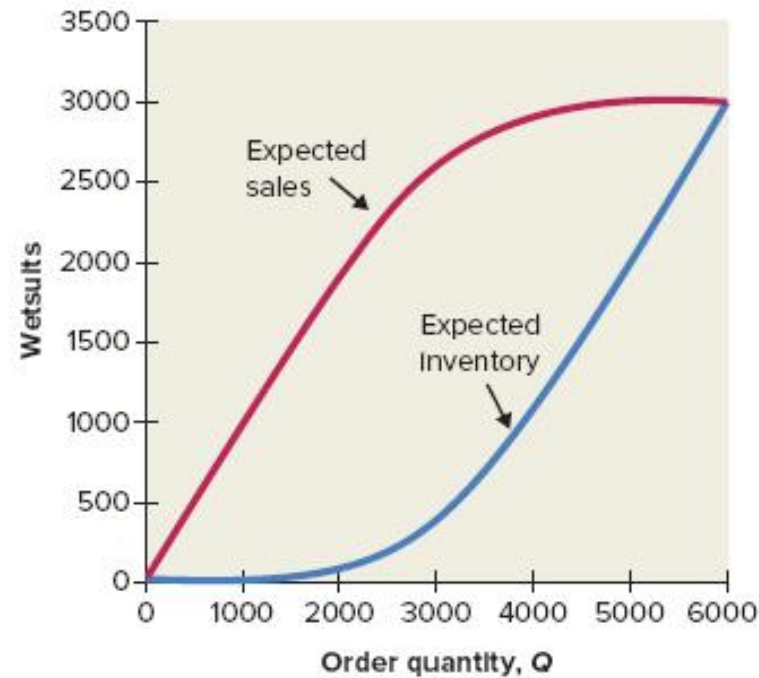
Or we can use Excel:  $z = \text{NORM.S.INV}(\text{Critical Ratio})$ .

We find that  $z = 0.7$  (using table 13.4), or 0.674 (Using Excel, which is more precise).

We should order  $Q$  units:

$$Q = 3000 + (0.7 \times 1000) = 3700$$

# Expected Sales, Inventory (leftover), and Profit



If:  $\text{Sales} + \text{Inventory} = Q$

Then:  $\text{Expected sales} + \text{Expected inventory} = Q$

And:  $\text{Expected profit} = (\text{Price} \times \text{Expected sales}) + (\text{Salvage value} \times \text{Expected inventory}) - (\text{Cost per unit} \times Q)$

$\text{Expected inventory} = \sigma \times I(z)$

What is the probability all demand can purchase an item vs. the probability someone wants the item but there is no inventory left

In-stock probability =  $F(Q)$

Stockout probability =  $1 - \text{In-stock probability}$

# Mismatch Costs in the Newsvendor Model

One benchmark to which we can compare the newsvendor profit is maximum profit.

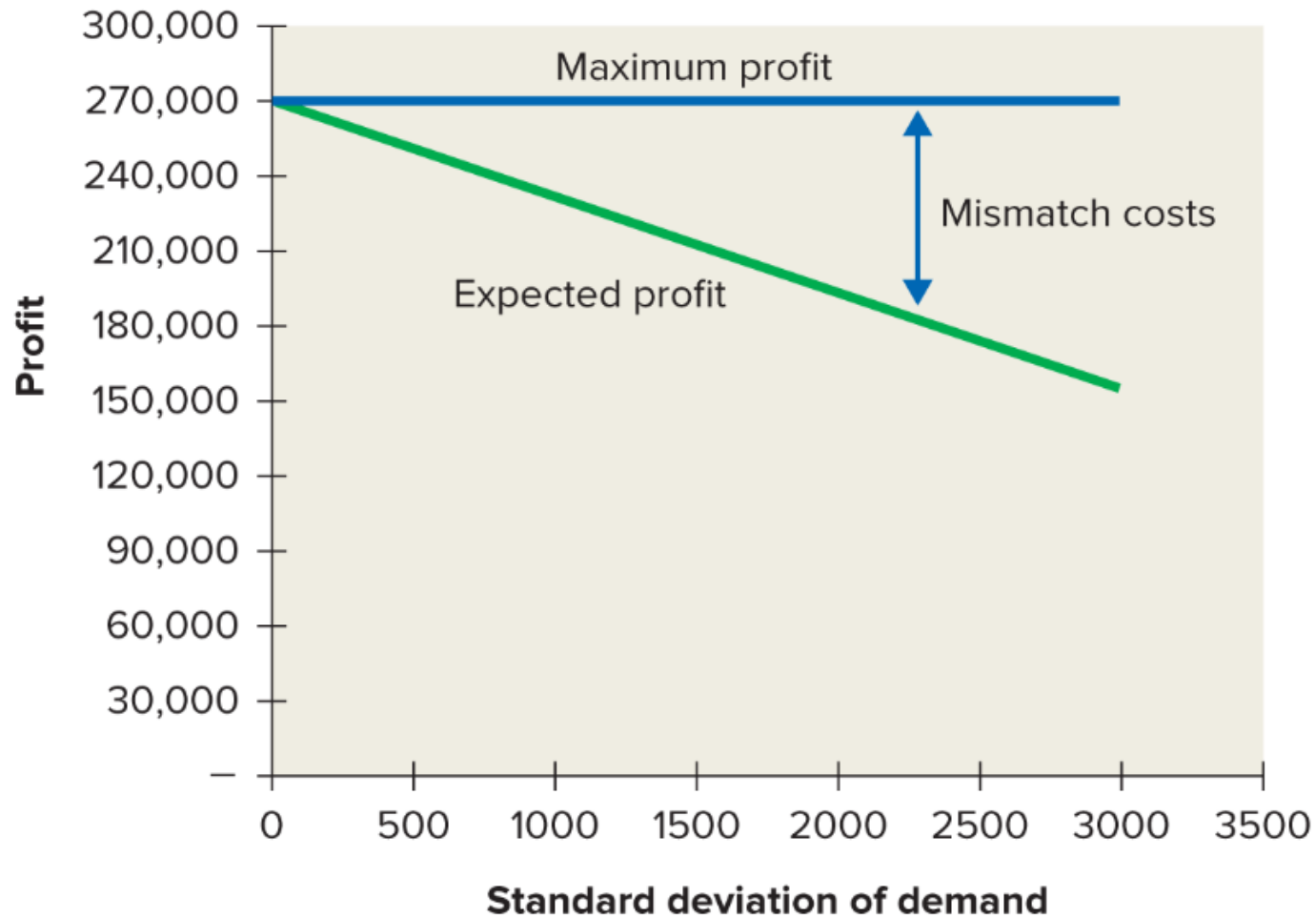
**Maximum profit** – the highest possible *expected* profit. This occurs when inventory is available for all customers.

$$\text{Maximum profit} = \text{Expected demand} \times \text{Profit per unit sold}$$

Wet suit example:

$$\text{Maximum Profit} = 3000 \text{ units} \times \$90 \text{ per unit} = \$270,000$$

# Mismatch Costs in the Newsvendor Model



**Maximum profit** – the highest possible *expected* profit. This occurs when inventory is available for all customers.

Maximum profit = Expected demand  $\times$  Profit per unit sold

Wet suit example:

Maximum Profit = 3000 units  $\times$  \$90 per unit = \$270,000

**Expected profits =**  
**Maximum profit – Mismatch costs**

# Mismatch Costs in the Newsvendor Model

## **Factors that influence mismatch costs:**

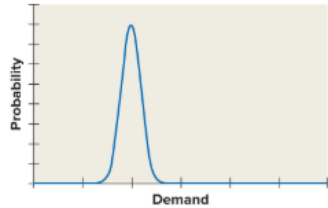
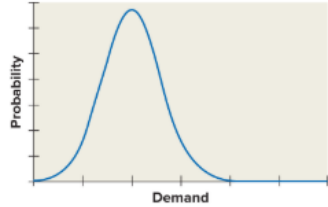
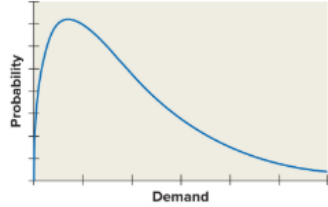
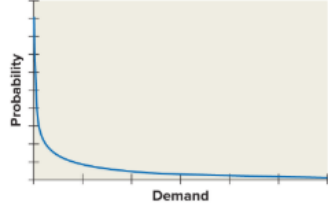
- Coefficient of variation
- Critical ratio

**Coefficient of variation** – the ratio of the standard deviation to the mean.

- The standard deviation is only an absolute measure of uncertainty.
- Captures that difference in uncertainty
- Can vary considerably low – high

# Mismatch Costs in the Newsvendor Model

**TABLE 13.5** Ranges and Examples for the Coefficient of Variation of Demand Forecasts

| Coefficient of Variation | Range   | Example                                                                                                                                                             | Probability Demand Is within 25% of the Mean | Sample Density Function                                                               |
|--------------------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|---------------------------------------------------------------------------------------|
| 0–0.2                    | Low     | A product with little year-to-year change in style or technology (e.g., black booties), so good past demand data are available                                      | .80–1.00                                     |    |
| 0.2–0.4                  | Medium  | A new product that is similar to previously sold products but has some fashion or technology change (e.g., wet suit with new color patterns)                        | .47–.80                                      |    |
| 0.4–1.0                  | High    | A completely new type of product in terms of fashion, technology, and/or function (e.g., a wet suit for a new type of water sport using a different type of fabric) | .18–.47                                      |   |
| 1.0–2.0                  | Extreme | A product for a specialized/niche market (e.g., wet suits for free divers to go beyond 100 meters deep)                                                             | .07–.18                                      |  |

# Strategies to Manage the Newsvendor Environment

## 1. Increase salvage value of each unit

- Sport Obermeyer sells winter clothing in south America during the summer.
- Buyback contracts with manufacturer

## 2. Decrease the margin lost from a stock out

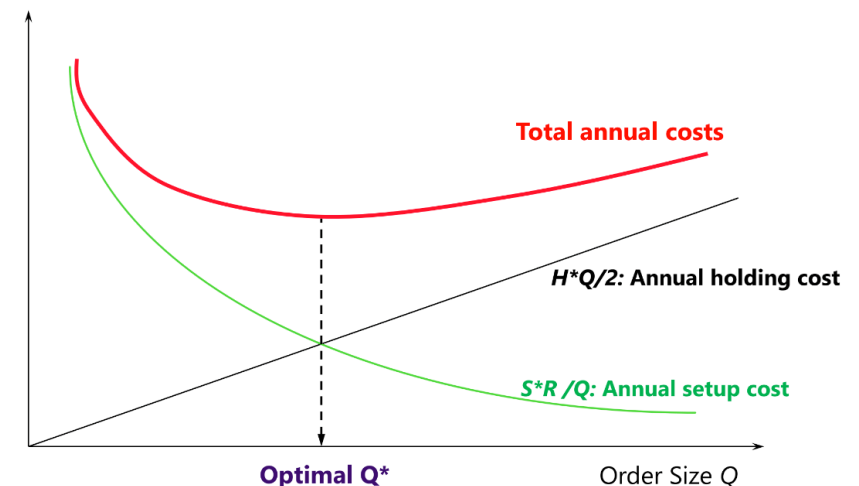
- Arrange for backup sourcing or provide substitute product
- Car part suppliers, McMaster-Carr and W.W.Grainger, are competitors but they buy from each other to satisfy the customer demand during a stockout

## 3. Reduce demand uncertainty

- **Improved forecasting:** Use better market intelligence and collaboration to reduce demand uncertainty
- **Postponement (product pooling):** In a multiproduct setting, postpone product differentiation until closer to point of sale (statistical economies of scale)
- **Quick response:** Reduce replenishment lead time so that multiple orders may be placed in a selling season
- **Make-to-order:** Produce item after product demand happens (for example: Dell computers; Amazon)
- **Tailored sourcing:** Use a low lead time, but perhaps an expensive supplier as a backup for a low-cost, but perhaps long lead time supplier

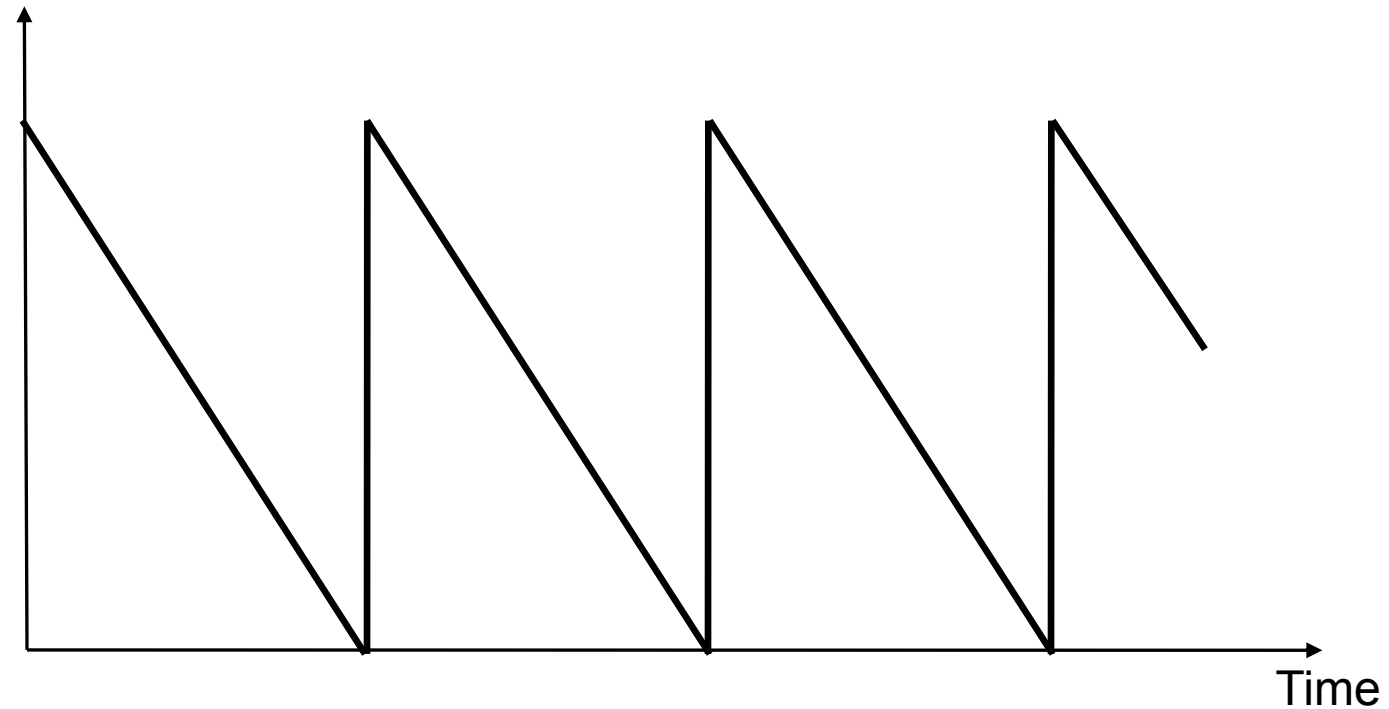
# Inventory Models

|                   | Demand            | Time Period   | Key assumptions                                                                                     | Tradeoff                               | Application                                                   |
|-------------------|-------------------|---------------|-----------------------------------------------------------------------------------------------------|----------------------------------------|---------------------------------------------------------------|
| <b>Newsvendor</b> | Stochastic demand | Single period | 1. Single order opportunity<br>2. Produce losses value at the end of season<br>3. Shortages allowed | - Order too much<br>- Order too little | Seasonal products<br>Capacity Decisions<br>Staffing Decisions |
| <b>EOQ</b>        | Constant demand   | Many periods  | 1. Inventory never spoils<br>2. No backlogs<br>3. Meet all demand                                   | - Holding cost<br>- Ordering cost      | Raw Material Inventory<br>Stable established products         |



# Constant demand with a lead time...

- Demand,  $D$ , is constant
- Lead time,  $L$ , known
- How can I make sure that I don't run out of inventory?

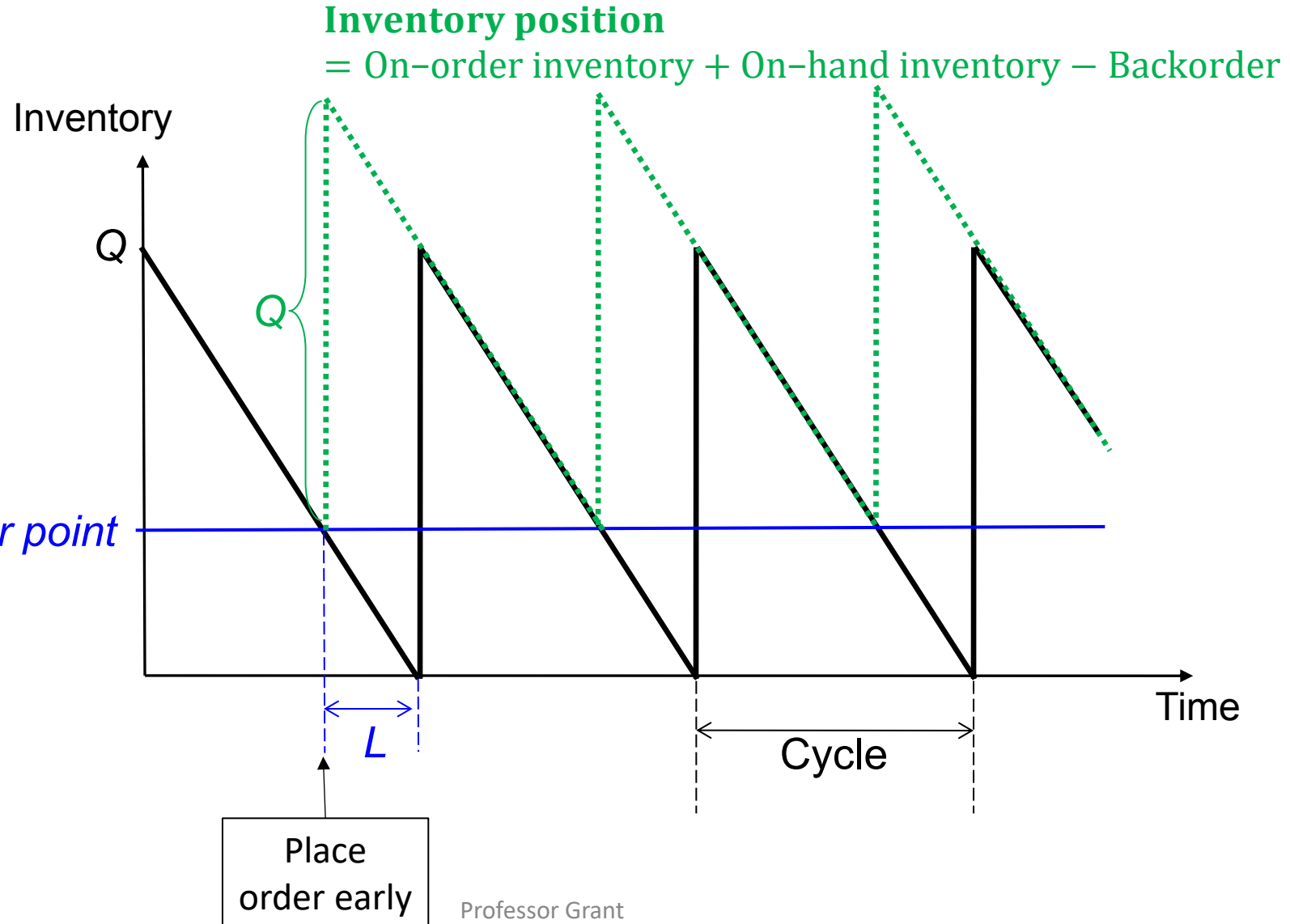


# Constant demand with a lead time...

- Demand, **D**, is constant
- Lead time, **L**, known
- How can I make sure that I don't run out of inventory?

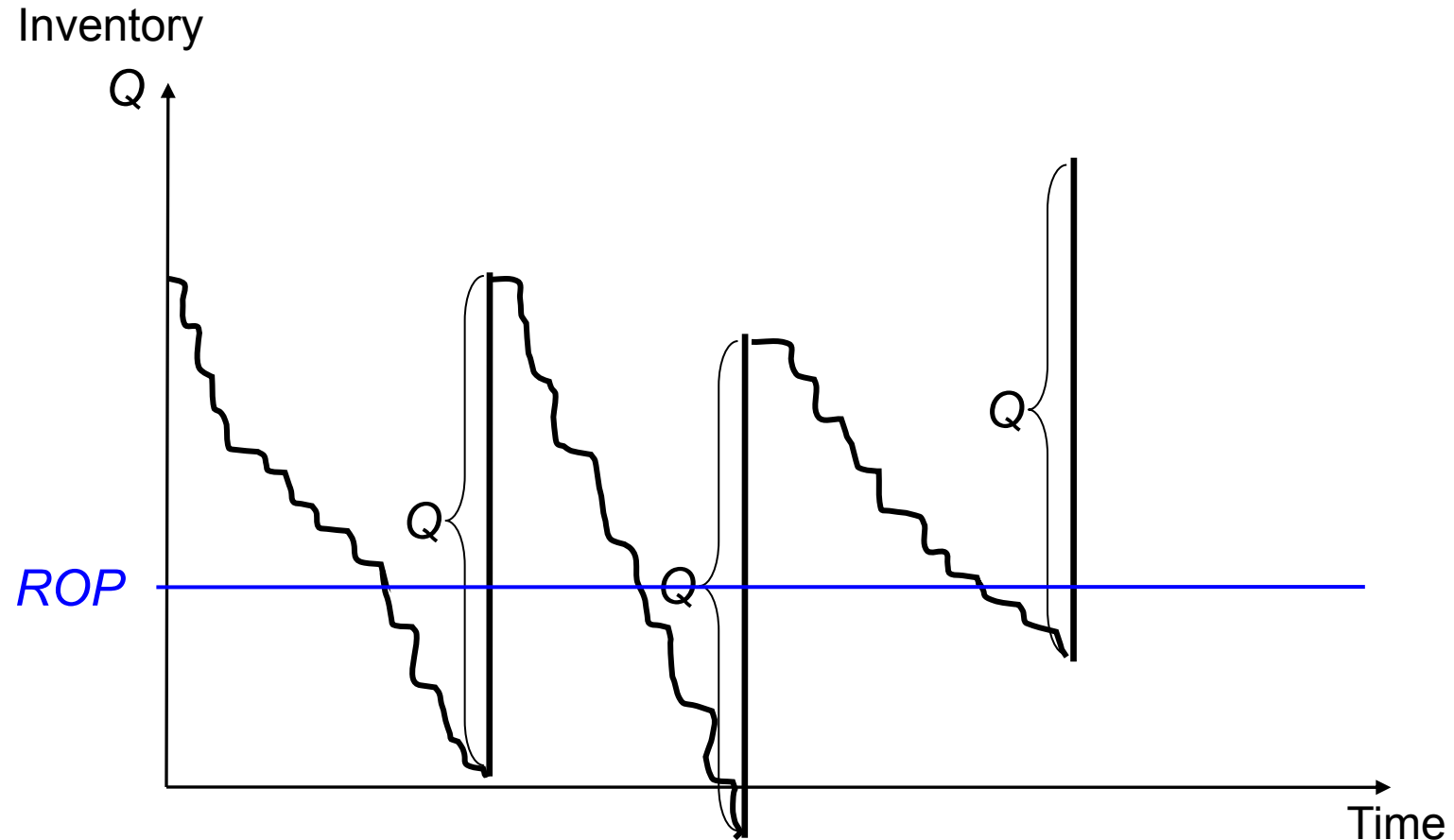
*ROP - reorder point*

**ROP:** How many units do I expect to sell during the lead time:  
( **$D \cdot L$** )



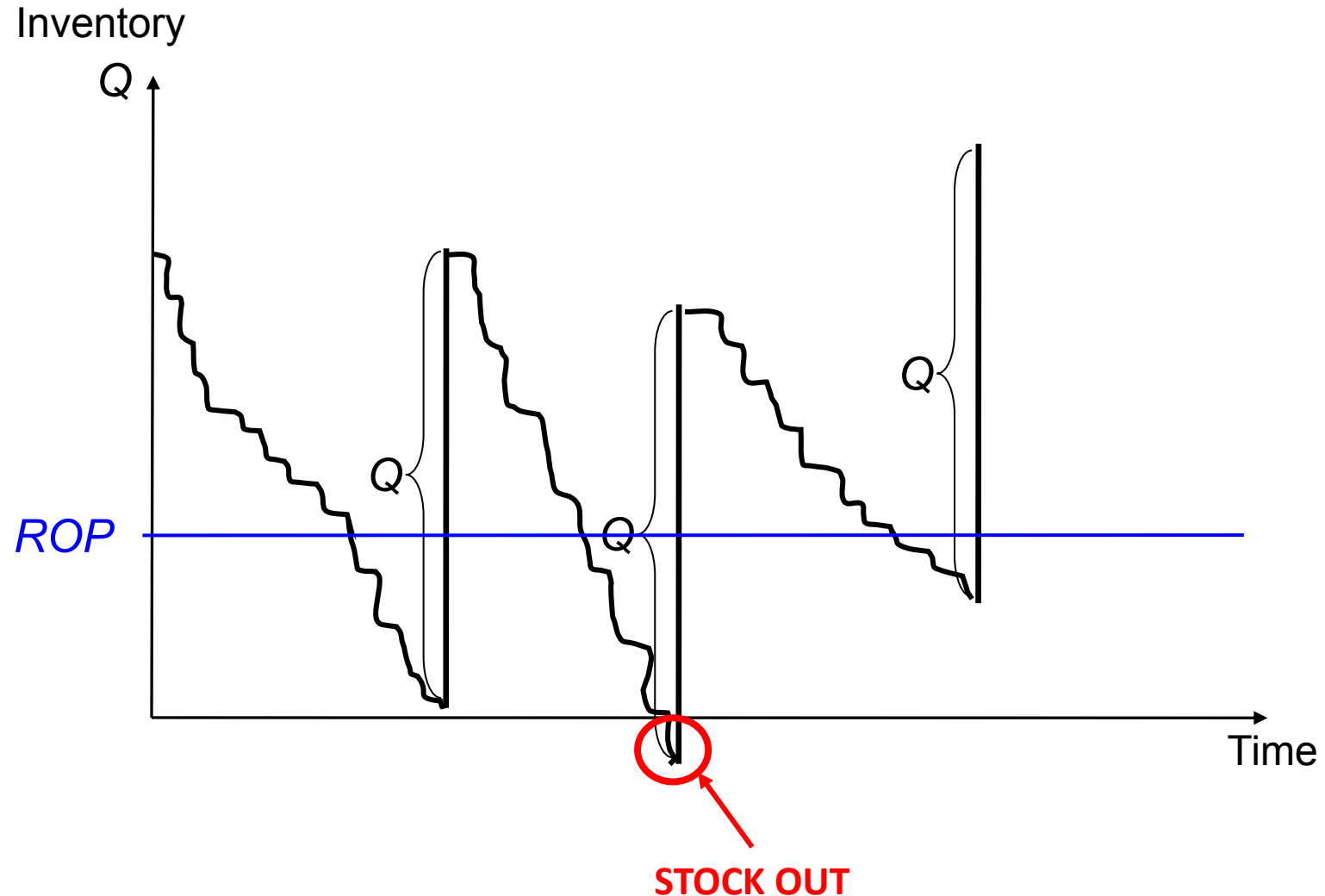
# Variable demand with a lead time...

- Demand, **D**, varies
- Lead time, **L**, known
- How can I make sure that I don't run out of inventory?



# Variable demand with a lead time...

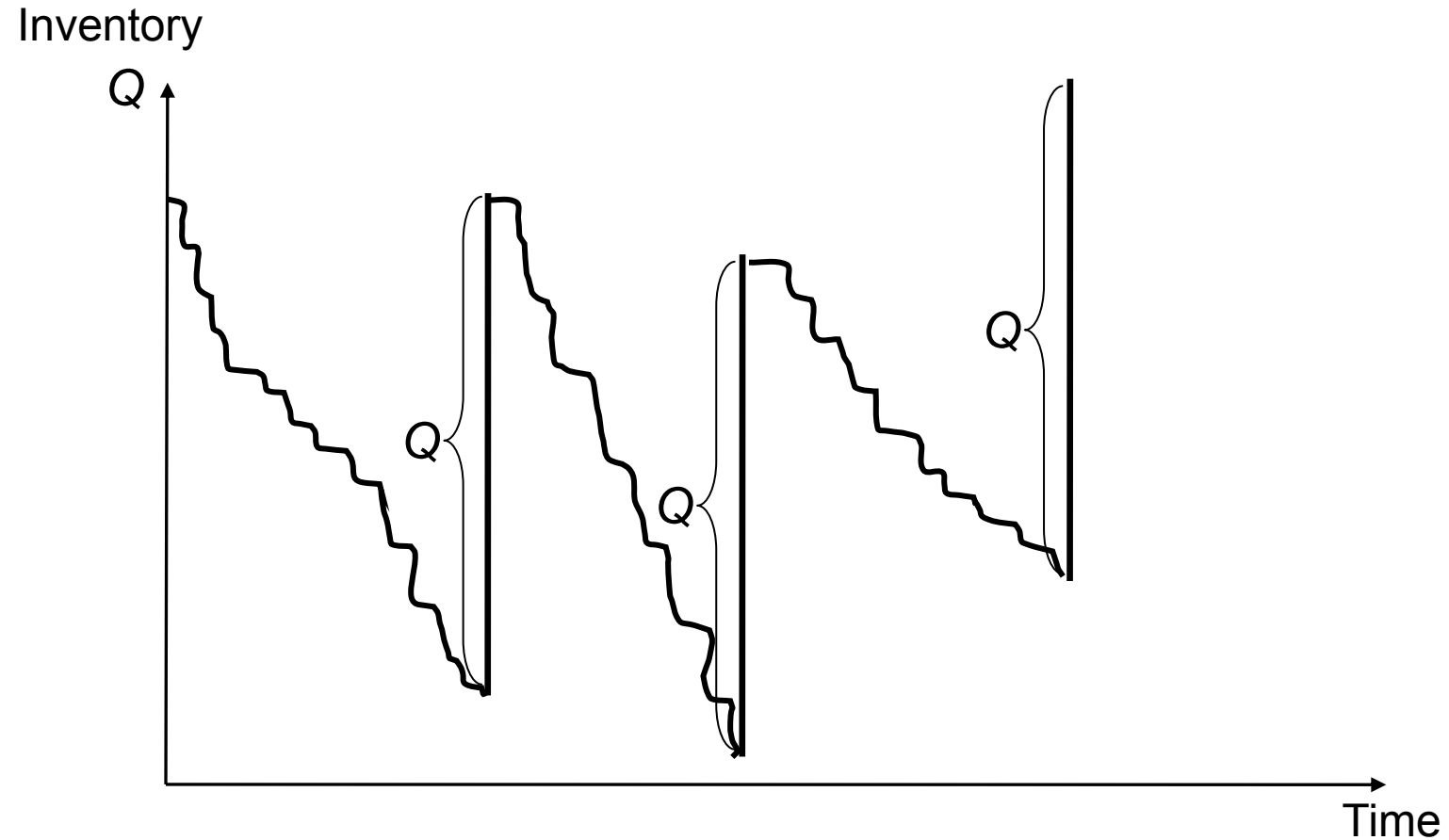
- Demand, **D**, varies
- Lead time, **L**, known
- How can I make sure that I don't run out of inventory?



# Variable demand with a lead time...

- Demand, **D**, varies
- Lead time, **L**, known
- How can I make sure that I don't run out of inventory?

Keep some extra inventory to deal with variability

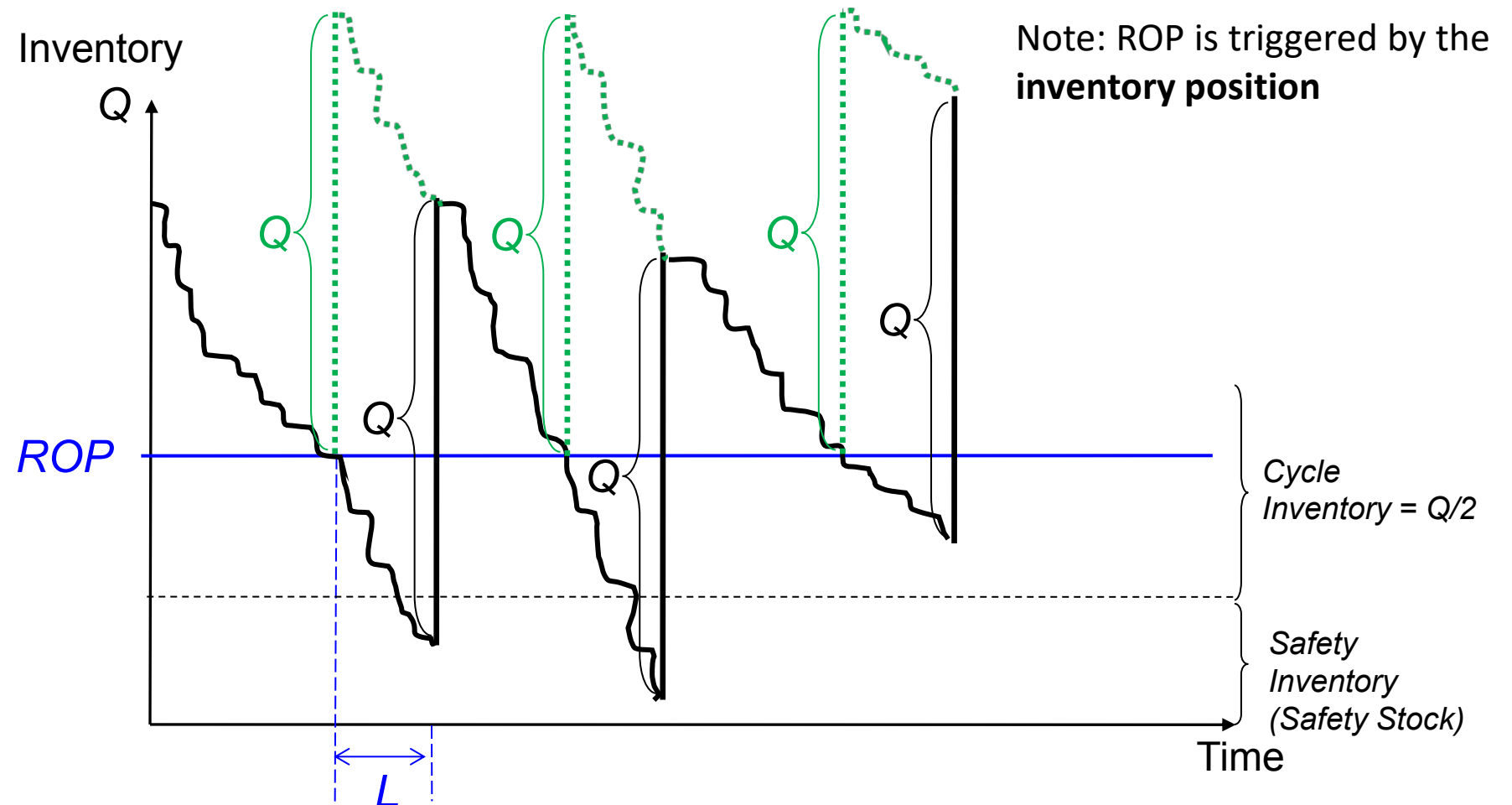


# Variable demand with a lead time...

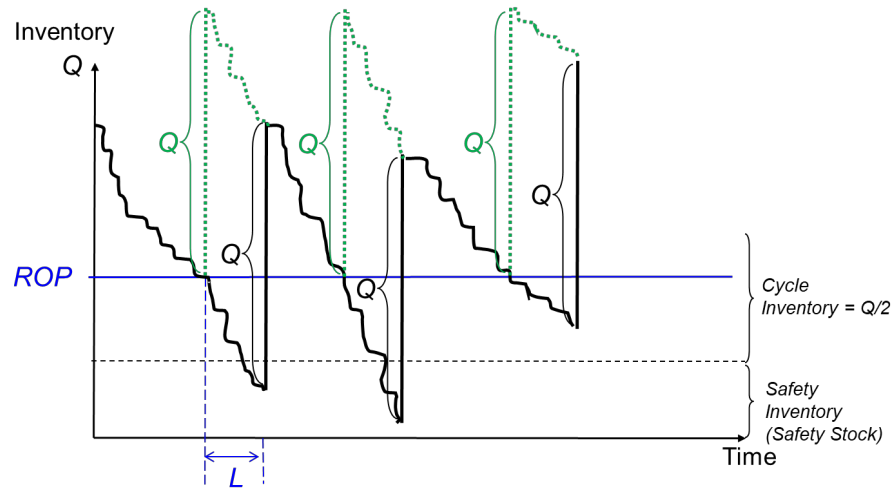
- Demand, **D**, varies
- Lead time, **L**, known
- How can I make sure that I don't run out of inventory?

Raise the inventory level so that there is some **safety stock**.

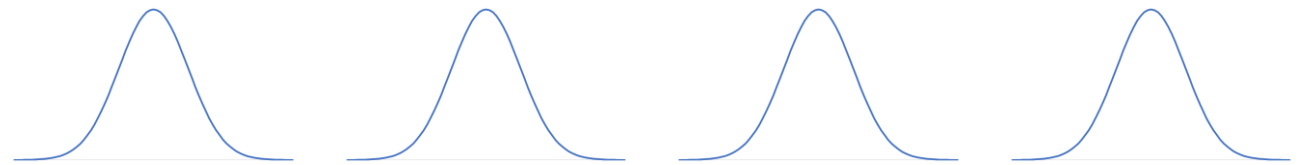
- How much safety stock?
- When should I place an order?
- For how many units?



# How much Safety Stock should we have?



Once I place an order, I must wait  $L$  time periods to receive it  
In each of those periods there will be some demand,  $D$ , that is uncertain but with a known standard deviation



$$\text{Safety stock} = z\sigma\sqrt{L}$$

# When to order and how much?

## When to order?

We know we need **safety stock**.

$$SS = z\sigma\sqrt{L}$$

We also need inventory for our expected demand during the lead time,  $L$

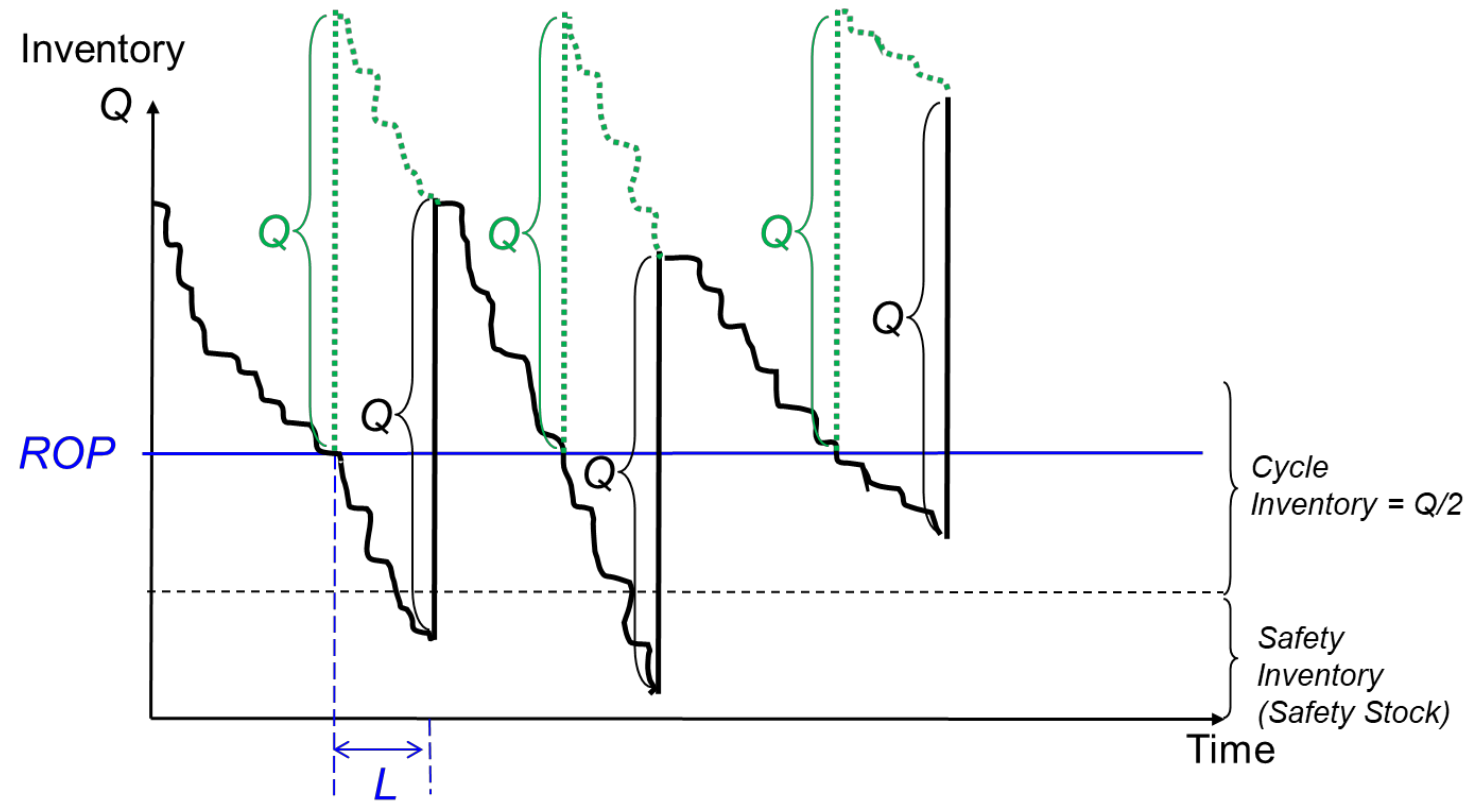
$$DL$$

So we set the ROP to the sum of these:

$$ROP = DL + z\sigma\sqrt{L}$$

## How much to order?

How should we determine the order quantity  $Q$  each time we place an order?



# Recall from Chapter 13: Target Service Level

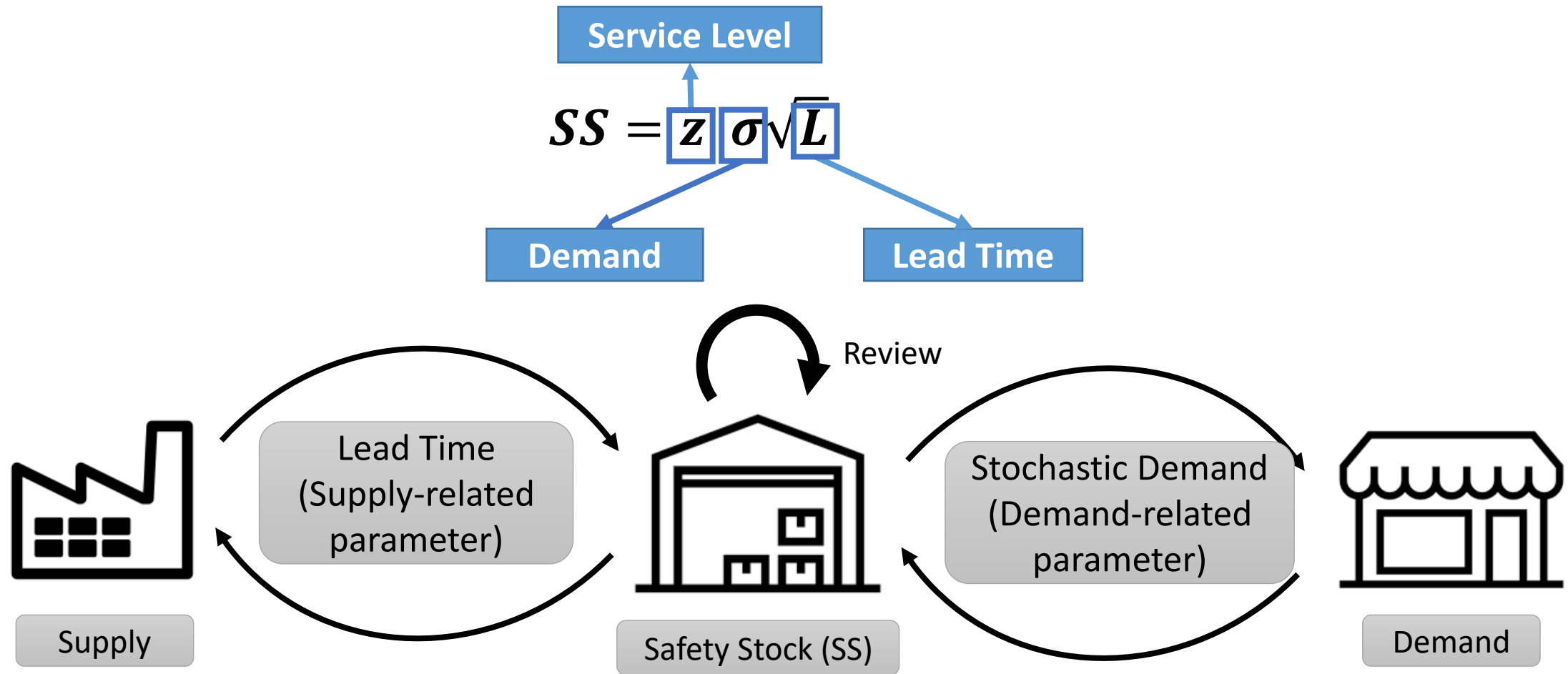
In the **News vendor** model, if I specify a target service level, I can calculate the associated order quantity:

- **Given an In-stock Probability of 0.99:**
- I look for the associated z-value:
- If  $F(z) = 0.99$ , then  $z$  is between 2.3 and 2.4.
- We round up to make sure we achieve at least the 0.99 service level.
- Using  $z = 2.4$ , we can compute  $Q$
- $Q = \mu + z\sigma$

For **safety stock** purposes, if I specify a target service level, I can calculate the associated safety stock:

- **Given an In-stock Probability of 0.99:**
- I look for the associated z-value
- If  $F(z) = 0.99$ , then  $z$  is between 2.3 and 2.4.
- We round up to make sure we achieve at least the 0.99 service level.
- Using  $z = 2.4$
- $SS = z\sigma\sqrt{L}$

# Relationship between inventory levels and the other parameters:

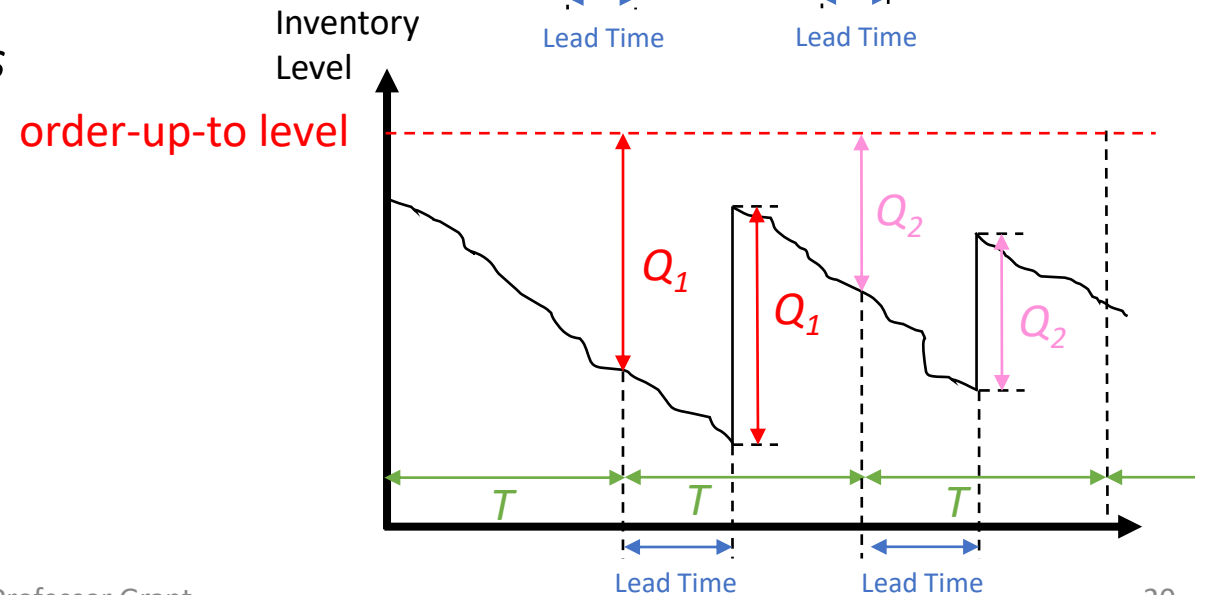
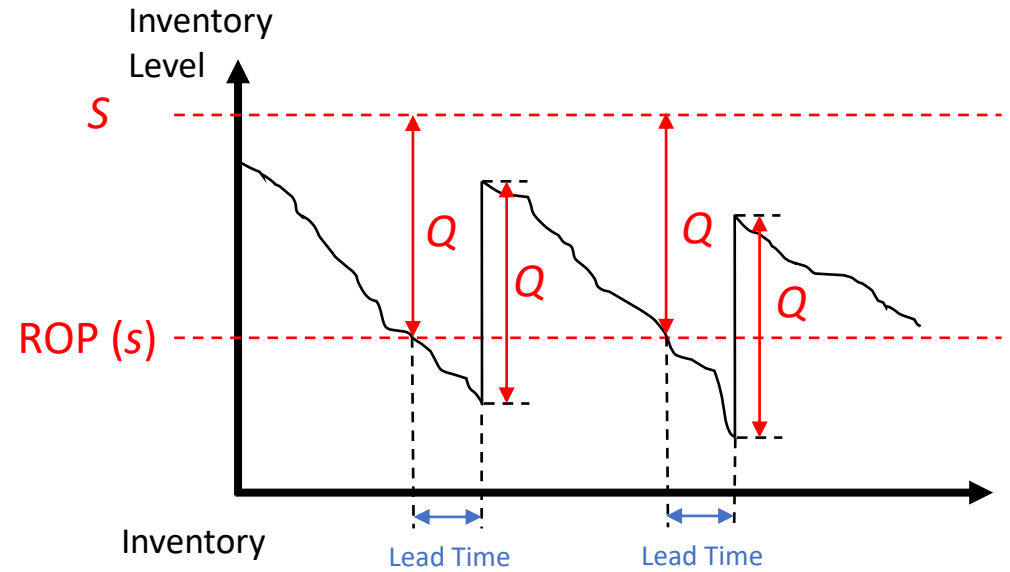


# Lets relate Continuous review to Periodic review

1. Define two inventory levels  $s$  and  $S$ :
2. During each inventory review, if the inventory position falls below  $s$ , order enough to raise the inventory position to  $S$

*This is called the  $(s, S)$  policy:*

- *Calculate the  $Q$  and  $ROP$  values as if this were a continuous review model*
- *Set  $s = ROP$  and  $S = ROP + Q$*

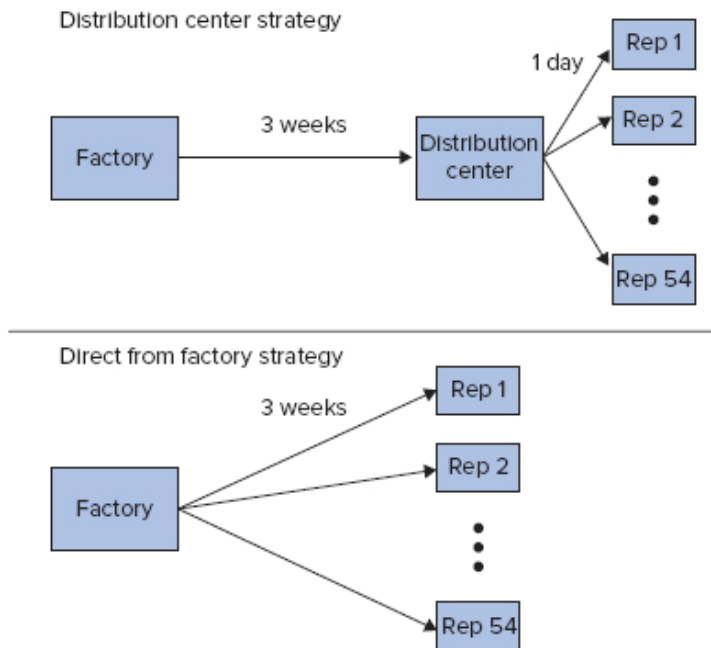


# Improving the Supply Chain:

## 1. Location and/or lead time pooling:

**Figure 14.13**

Two supply chain strategies for Medtronic. In the upper panel, product flows from the factory to a distribution center (DC) with a three-week lead time, and sales representatives order from the DC with a one-day lead time. In the lower panel, sales representatives order directly from the factory with a three-week lead time.



## Amazon fulfillment centers across the US

The company has over 100 active warehouses and dozens of planned locations



SOURCE: MWPVL International Inc., Supply Chain and Logistics Consultants. Includes warehouses of 500,000 square feet or more.



# Improving the Supply Chain:

## 2. Delayed differentiation (a.k.a. postponement):

Figure 14.14

Two strategies for selling paint to customers. In the top panel, generic paint is shipped to the store and color is added in the store to serve demand. In the bottom panel, color is added in the factory before shipping to the store, where no further processing occurs.

