

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



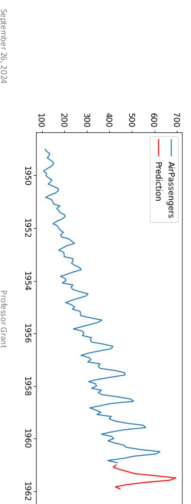
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Time Series Forecasting Framework

- **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



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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.



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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.

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

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

4-day moving average example

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

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Evaluating the Quality of a Forecast

- **Mean squared error (MSE)**
- **Mean absolute error (MAE)**
- **Mean absolute percentage error (MAPE)**

$$\text{MSE} = \frac{\sum_{i=1}^N \text{FE}_i^2}{N}$$

$$\text{MAE} = \frac{\sum_{i=1}^N |\text{FE}_i|}{N}$$

$$\text{MAPE} = \frac{\sum_{i=1}^N \left| \frac{\text{FE}_i}{y_i} \right|}{N}$$

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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.

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Time Series Analysis – Seasonality

- **Desasonalize** – to remove the seasonal effect from past data.
- **Reasonalize** – to reintroduce the seasonal effect to the forecasted data.

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

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

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

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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?

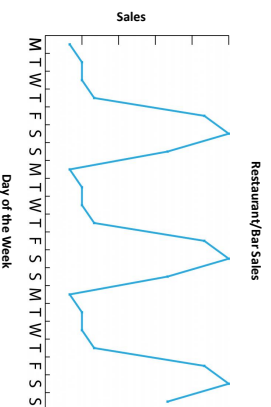
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Time Series Analysis – Seasonality

- **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.



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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.



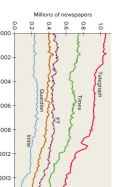
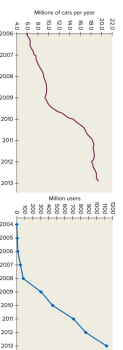
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Time Series Analysis – Trends

- **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.

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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.

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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?

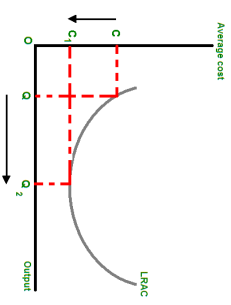
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Economies of Scale

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



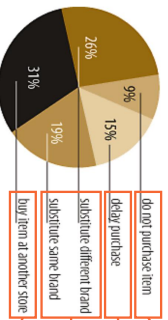
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Inventory Stockouts

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.



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

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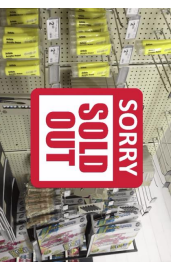
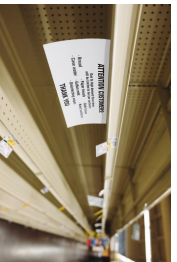
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Customer Response to a Stockout	How costly is the Stockout?
do not purchase item	High cost of stockout: loss of profit from the sale of them.
delay purchase	Low cost of stockout: total profit doesn't change much, as long as the delay isn't too long.
substitute different brand	Moderate cost of stockout: loss of profit from one item is replaced, maybe in part or in full, by the profit of another item.
substitute same brand	Moderate cost of stockout: loss of profit from one item is replaced, maybe in part or in full, by the profit of another item.
buy item at another store	Very high cost of stockout: loss of future profit from the customer.

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Stockouts – a major reason to hold inventory

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



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The Economic Order Quantity

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

$$\text{Average inventory} = \frac{\text{Order quantity}}{2} = \frac{Q}{2} \quad \text{Holding Cost Per Unit of time} = \frac{Q}{2}h$$

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

$$\text{Orders per unit of time} = \frac{R}{Q} \quad \text{Ordering Cost Per Unit of Time} = \frac{R}{Q}K$$

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

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

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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

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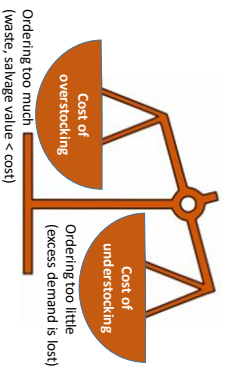
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The Newsvendor Model

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



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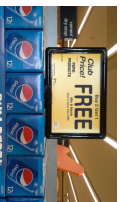
Quantity Constraints and Discounts

- 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 PICK & MATCH DESIGNS AND COLORS TO GET QUANTITY DISCOUNTS

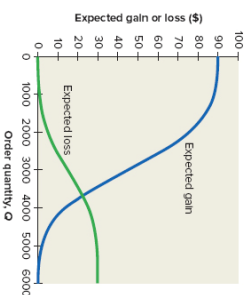
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The moral of the (less likely) I would sell one extra unit... So, my expected gain from ordering more and more units goes down, whereas my expected loss goes up.

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 lose \$90

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

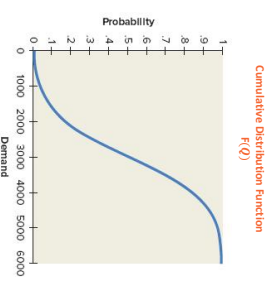
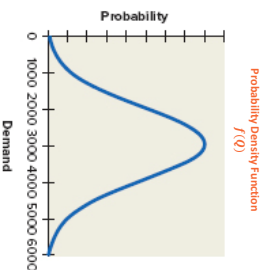
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Quantity Constraints and Discounts

- **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.

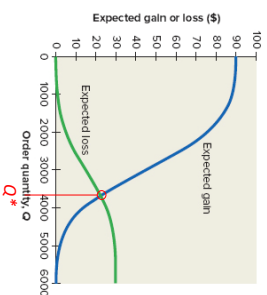


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We increase Q until the expected loss is equal to the expected gain



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

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

The Critical Ratio (Fractile)

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

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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.

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

$$\text{In-stock probability} = F(Q)$$

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

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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.

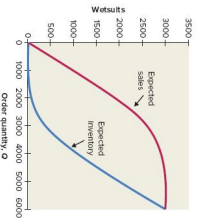
- The standard deviation is only an absolute measure of uncertainty.
- Captures that difference in uncertainty
- Can vary considerably low – high

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Expected Sales, Inventory (leftover), and Profit



If: Sales + Inventory = Q

Then: Expected sales + Expected inventory = Q

And: Expected profit = (Price $\times$ Expected sales)

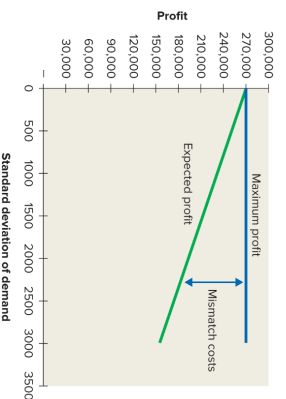
– (Cost per unit $\times Q$)

Expected inventory = $\sigma \times I(z)$

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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 =

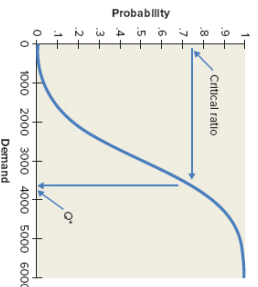
Maximum profit – Mismatch costs

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What is the optimal order Quantity Q^* ?



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

[Equation 13.2]

where

z = the quantity in the standard normal distribution

μ = the mean of the true demand distribution

σ = 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 $C_u/(C_u+C_o) = \$9/(90+30) = 90/120 = 0.75$

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

Or we can use Excel's NORM.S.INV(Critical Ratio).

We find that $z = 0.7$ (using table B.4), or 0.674 (using Excel, which is more precise).

We should order Quants:

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

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Mismatch Costs in the Newsvendor Model

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.

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

Wet suit example:

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

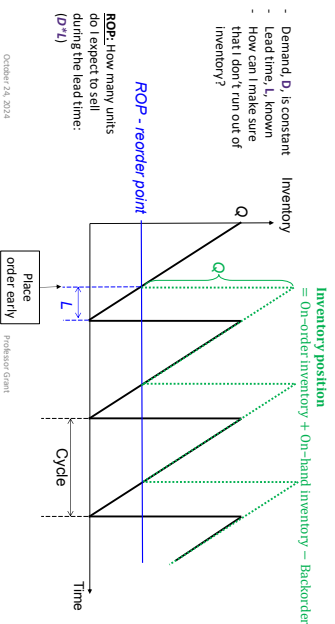
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Constant demand with a lead time...

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

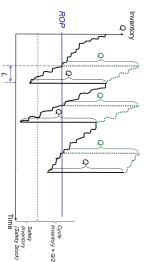


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How much Safety Stock should we have?

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



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

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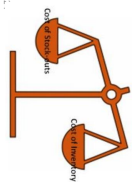
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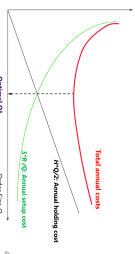
Inventory Models

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

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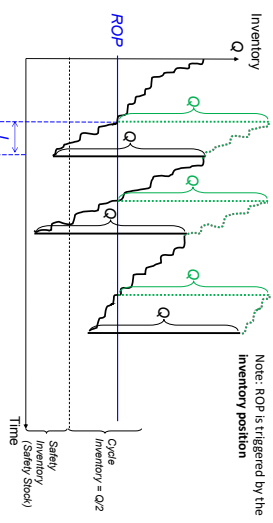


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Variable demand with a lead time...

- 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?



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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 loss from a stock out**
 - Arrange for backup sourcing or provide substitute product
 - Reduce the margin loss from a stock out
 - Satisfy the customer demand during a stock out
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 cycle
 - **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

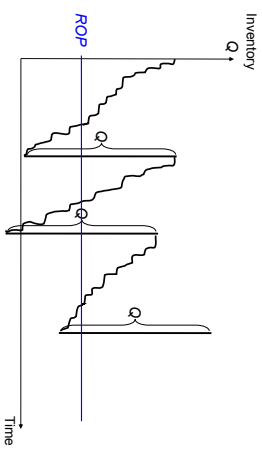
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Variable demand with a lead time...

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

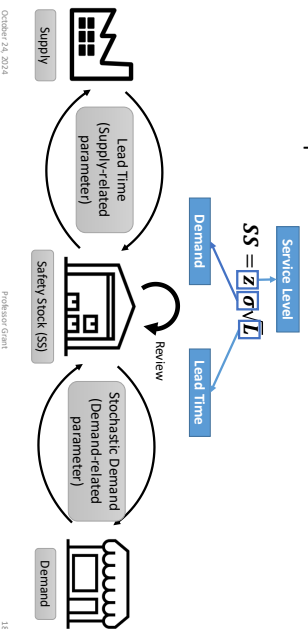


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Relationship between inventory levels and the other parameters:



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 .

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 $z = 2.4$
- $$SS = z\sigma\sqrt{L}$$

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

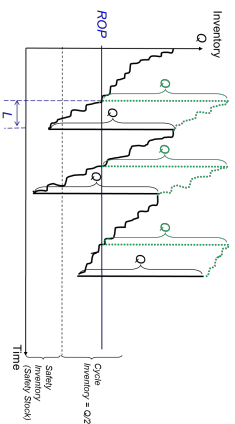
So we set the ROP to the sum of these:

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

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

How much to order?

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

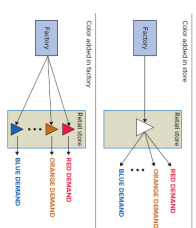


Improving the Supply Chain:

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

Figure 14.14

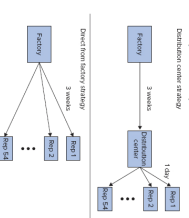
Two strategies for selling paint to customers. In the top panel, generic paint is shipped to the store and color is added in the store to serve demand. In the bottom panel, color is added in the factory before shipping to the store, where no further processing occurs.



Improving the Supply Chain:

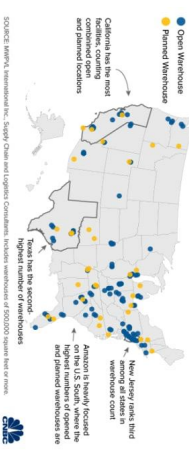
1. location and/or lead time pooling

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



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 $S = ROP + Q$

