Demand Forecasting in a Supply Chain

Learning Objectives

- Understand the role of forecasting for both an enterprise and a supply chain.
- Identify the components of a demand forecast.
- Forecast demand in a supply chain given historical demand data using time-series methodologies.
- Analyze demand forecasts to estimate forecast error.

Role of Forecasting in a Supply Chain

- It forms the basis of all supply chain planning
- Push/pull processes
- Push processes in the supply chain are performed in anticipation of customer demand, whereas all pull processes are performed in response to customer demand.
- Push process- planning of level of activity like production, transportation, or any other planned activity
- Pull process-planning the level of available capacity and inventory but not the actual amount to be executed.

Role of Forecasting in a Supply Chain

Examples:

- Dell orders PC components in anticipation of customer orders, whereas it performs assembly in response to customer orders. It uses a forecast of future demand to determine the quantity of components to have on hand
- When all stages of a supply chain work together to produce a collaborative forecast, it tends to be much more accurate.

Role of Forecasting in a Supply Chain

- Leaders have improved their ability to match supply and demand by moving toward collaborative forecasting.
- Example:

Coca-Cola decides on the timing of various promotions based on the demand forecast over the coming quarter. Promotion decisions are then incorporated into an updated demand forecast. A bottler operating without an updated forecast based on the promotion is unlikely to have sufficient supply available for Coca-Cola

Role of Forecasting in a Supply Chain

- Mature product with stable demand are easy to forecast. ex. Milk, paper towel
- Products with unpredictable supply/demand are difficult to forecast.

ex: fashion goods and high-tech items

Characteristics of Forecasts

1. Forecasts are not exact and it should include both the expected value of the forecast and a measure of forecast error.

- Example: 2 car dealers. One of them expects sales to range between 100 and 1,900 units, whereas the other expects sales to range between 900 and 1,100 units. Though both dealers anticipate average sales of 1,000, the sourcing policies for each dealer should be very different given the difference in forecast accuracy

Characteristics of Forecasts

2. Long-term forecasts are usually less accurate than short-term forecasts. Long term forecasts have more standard deviation.

- Example: Seven eleven Japan has instituted a replenishment process that enables it to respond to an order within hours. If a store manager places an order by 10 A.M., the order is delivered by 7 P.M. the same day. The short lead time allows a manager to take into account current information, such as the weather, which could affect product sales

Characteristics of Forecasts

3. Aggregate forecasts are usually more accurate than disaggregate forecasts, as they tend to have a smaller standard deviation of error relative to the mean.

Example: It is easy to forecast the Gross Domestic Product of the United States for a given year with less than a 2 percent error whereas it is difficult to forecast yearly revenue for a company with less than a 2 percent error and it is even harder to forecast revenue for a given product with the same degree of accuracy.

- Here aggregations are different in 3 situations. More aggregation leads to more accurate forecast

Characteristics of Forecasts

4. the farther the supply chain is from the consumer, the greater is the distortion of information it receives.

- Example: Bullwhip effect- Order variation is amplified as orders move farther from the end customer. Forecast error increases. Collaborative forecasting based on sales to the end customer helps upstream enterprises reduce forecast error

Components and Methods

- "Predictions are usually difficult, especially about the future.“
- Customer demand is influenced by a variety of factors.
- To forecast demand, companies must first identify the factors that influence future demand and then ascertain the relationship between these factors and future demand.

Components and Methods

- Companies must include human input when they make their final forecast.
- Example: Seven-Eleven Japan provides its store managers with a state-of-the-art decision support system that makes a demand forecast and provides a recommended order. The store manager is responsible for making the final decision and placing the order. If the store manager knows that the weather is likely to be rainy and cold the next day, he or she can reduce the size of an ice cream order to be placed with an upstream supplier

Components and Methods

- A company must be knowledgeable about numerous factors that are related to the demand forecast.

Some factors are

- Past demand
- Lead time of product
- Planned advertising or marketing efforts
- State of the economy
- Planned price discounts
- Actions that competitors have taken

Components and Methods

- A company must understand the factors before it can select an appropriate forecasting methodology

Forecasting methods are classified according to the following four types

1. Qualitative
2. Time series
3. Causal
4. Simulation

Classification

1. ***Qualitative:***

- Qualitative forecasting methods are primarily subjective and rely on human judgment.
- Most appropriate when little historical data is available or when experts have market intelligence that may affect the forecast.
- Necessary to forecast demand several years into the future in a new industry.

Classification

2. Time series:

- Time-series forecasting methods use historical demand to make a forecast.
- Based on the assumption that past demand history is a good indicator of future demand.
- Most appropriate when the basic demand pattern does not vary significantly from one year to the next.
- Simplest methods to implement and can serve as a good starting point for a demand forecast.

Classification

3. Causal:

- Assumes that the demand forecast is highly correlated with certain factors in the environment (the state of the economy, interest rates, etc.).
- Finds the correlation between demand and environmental factors and use estimates of what environmental factors will be to forecast future demand.
- Companies can thus use causal methods to determine the impact of price promotions on demand.

Classification

4. Simulation:

- Imitates the consumer choices that give rise to demand to arrive at a forecast.
- Using simulation, a firm can combine time-series and causal methods to answer such questions as: What will be the impact of a price promotion? What will be the impact of a competitor opening a store nearby?
- Airlines simulate buying behaviour to forecast demand for higher-fare seats when there are no seats available at the lower fares.

Components of an Observation

- Time-series methods are most appropriate when future demand is related to historical demand, growth patterns, and any seasonal patterns. With any forecasting method, there is always a random element that cannot be explained by historical demand patterns.
- Therefore, any observed demand can be broken down into a systematic and a random component

Observed demand (o) = systematic component (S) + random component (R)

Components of an Observation

- **The systematic component:**

Measures the expected value of demand and consists of level, the current deseasonalized demand; trend, the rate of growth or decline in demand for the next period; and seasonality, the predictable seasonal fluctuations in demand.

Components of an Observation

- **The random component :**

  It is that part of the forecast that deviates from the systematic part. A company can only predict the random component's size and variability, which provides a measure of forecast error

- A good forecasting method has an error whose size is comparable to the random component of demand. The objective of forecasting is to filter out the random component (noise) and estimate the systematic component

Basic Approach

Six-step approach helps an organization perform effective forecasting.

1. Understand the objective of forecasting.

2.Integrate demand planning and forecasting throughout the supply chain.

3. Understand and identify customer segments.

4. Identify the major factors that influence the demand forecast.

5. Determine the appropriate forecasting technique.

6. Establish performance and error measures for the forecast

Basic Approach

1.UNDERSTAND THE OBJECTIVE OF FORECASTING

- Examples of such decisions include how much of a particular product to make, how much to inventory, and how much to order
- All parties affected by a supply chain decision should be aware of the link between the decision and the forecast
- **Example:** Wal-Mart's plans to discount detergent during the month of July must be shared with the manufacturer, the transporter, and others involved in filling demand, as they all must make decisions that are affected by the forecast of demand

Basic Approach

2. INTEGRATE DEMAND PLANNING AND FORECASTING THROUGHOUT THE SUPPLY CHAIN

- Forecast should be linked to all planning activities throughout the supply chain. These include capacity planning, production planning, promotion planning, and purchasing, among others. This link should exist at both the information system and the human resources management level.

Continue…

Basic Approach

- **Example:**

  A retailer develops forecasts based on promotional activities, whereas a manufacturer, unaware of these promotions, develops a different forecast for its production planning based on historical orders. This leads to a mismatch between supply and demand, resulting in poor customer service

- Integration can be achieved by cross-functional team, with members from each affected function responsible for forecasting demand

Basic Approach

3. UNDERSTAND AND IDENTIFY CUSTOMER SEGMENTS

- Customers may be grouped by similarities in service requirements, demand volumes, order frequency, demand volatility, seasonality
- Companies may use different forecasting methods for different segments.

Basic Approach

4. IDENTIFY MAJOR FACTORS THAT INFLUENCE THE DEMAND FORECAST

- A company must ascertain whether demand is growing, declining, or has a seasonal pattern based on demand and not sales data.
- **Example:** A supermarket promoted a certain brand of cereal in July 2005. As a result, the demand for this cereal was high while the demand for other, comparable cereal brands was low in July. The supermarket should not use the sales data from 2005 to estimate that demand for this brand will be high in July 2006, because this will occur only if the same brand is promoted again in July 2006 and other brands respond as they did the previous year.

Continue…

Basic Approach

- On the supply side, a company must consider the available supply sources to decide on the accuracy of the forecast desired. If alternate supply sources with short lead times are available, a highly accurate forecast may not be especially important.
- On the product side, a firm must know the number of variants of a product being sold and whether these variants substitute for or complement each other. If demand for a product influences or is influenced by demand for another product, the two forecasts are best made jointly.

Continue…

Basic Approach

- **Example:** When a firm introduces an improved version of an existing product, it is likely that the demand for the existing product will decline because new customers will buy the improved version. Although the decline in demand for the original product is not indicated by historical data, the historical demand is still useful in that it allows the firm to estimate the combined total demand for the two versions

Basic Approach

5. DETERMINE THE APPROPRIATE FORECASTING TECHNIQUE

- A company should first understand the dimensions (geographic area, product groups, and customer groups) that are relevant to the forecast.
- A firm selects an appropriate forecasting method from among the four methods however, using a combination of these methods is often most effective.

Basic Approach

6. **ESTABLISH PERFORMANCE AND ERROR MEASURES FOR THE FORECAST**

- Establishing performance measures that are correlated with the objectives of business decisions based on the forecast
- **Example:** A mail-order company that uses a forecast to place orders with its suppliers up the supply chain. Suppliers take two months to send in the orders. The mail-order company must ensure that the forecast is created at least two months before the start of the sales season because of the two-month lead time for replenishment. At the end of the sales season, the company must compare actual demand to forecasted demand to estimate the accuracy of the forecast.

Time-Series Forecasting Methods

- The goal of any forecasting method is to predict the systematic component of demand and estimate the random component
- The systematic component of demand data contains a level, a trend, and a seasonal factor.
- The equations for calculating the systematic component
- **Multiplicative:**

  Systematic component = level X trend X seasonal factor
- **Additive:**

  Systematic component = level + trend + seasonal factor
- **Mixed:**

  Systematic component = (level + trend) X seasonal factor

Static method

- It assumes that the estimates of level, trend, and seasonality within the systematic component do not vary as new demand is observed
- Each of the parameters are estimated based on historical data

Systematic component = (level + trend) X seasonal factor

Static method

$$F_{t+l} = [L + (t+l)T]S_{t+l}$$

where

L	=	Estimate of level at $t = 0$
T	=	Estimate of trend
S_t	=	Estimate of seasonal factor for Period t
D_t	=	Actual demand observed in Period t
F_t	=	Forecast of demand for Period t

Static method

- Example: Tahoe Salt

Year	Quarter	Period, t	Demand, D_t
1	2	1	8,000
1	3	2	13,000
1	4	3	23,000
2	1	4	34,000
2	2	5	10,000
2	3	6	18,000
2	4	7	23,000
3	1	8	38,000
3	2	9	12,000
3	3	10	13,000
3	4	11	32,000
4	1	12	41,000

Table 7-1

Static method

- In figure observe that demand for salt is seasonal, increasing from the second quarter of a given year to the first quarter of the following year. The second quarter of each year has the lowest demand. Each cycle lasts four quarters, and the demand pattern repeats every year.

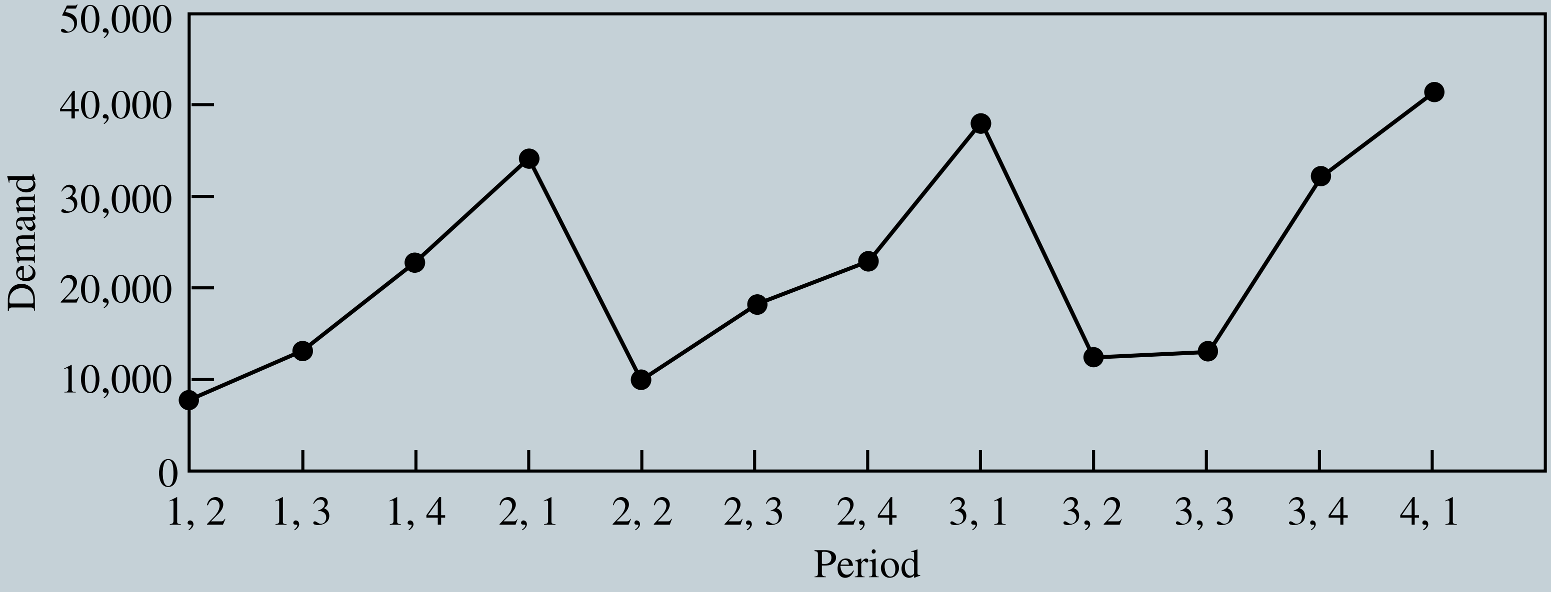

Figure 7-1

Estimate Level and Trend

- The objective of this step is to estimate the level at Period 0 and the trend.
- Starting from deseasonalizing the demand data. Deseasonalized demand represents the demand that would have been observed in the absence of seasonal fluctuations.
- The periodicity p is the number of periods after which the seasonal cycle repeats. For Tahoe Salt's demand, the pattern repeats every year.

Estimate Level and Trend

- The periodicity for the demand in Table 7-1 is $p = 4$.
- The average of demand from Period $l + 1$ to Period $l + p$ provides deseasonalized demand for Period $l + (p + 1)/2$.
- If p is odd, this method provides deseasonalized demand for an existing period
- If p is even, this method provides deseasonalized demand at a point between Period $l + (p/2)$ and $l + 1 + (p/2)$.
- By taking the average of deaseasonalized demand provided by Periods $l + 1$ to $l + p$ and $l + 2$ to $l + p + 1$, we obtain the deseasonalized demand for Period $l + 1 + (p/2)$.

Estimate Level and Trend

Procedure:

Periodicity $p = 4$, $t = 3$

$$\bar{D}_t = \begin{cases} \left[D_{t-(p/2)} + D_{t+(p/2)} + \sum_{i=t+1-(p/2)}^{t-1+(p/2)} 2D_i \right] / (2p) & \text{for } p \text{ even} \\ \sum_{i=t-[(p-1)/2]}^{t+[(p-1)/2]} D_i / p & \text{for } p \text{ odd} \end{cases}$$

$$\bar{D}_t = \left[D_{t-(p/2)} + D_{t+(p/2)} + \sum_{i=t+1-(p/2)}^{t-1+(p/2)} 2D_i \right] / (2p)$$

$$= D_1 + D_5 + \sum_{i=2}^{4} 2D_i / 8$$

Estimate Level and Trend-Tahoe Salt

- With the procedure we can obtain deseasonalized demand between Periods 3 and 10 as shown in Figure 7-2 and Figure 7-3.

	A	B	C
1	Period t	Demand D_t	Deseasonalized Demand
2	1	8,000	
3	2	13,000	
4	3	23,000	19,750
5	4	34,000	20,625
6	5	10,000	21,250
7	6	18,000	21,750
8	7	23,000	22,500
9	8	38,000	22,125
10	9	12,000	22,625
11	10	13,000	24,125
12	11	32,000	
13	12	41,000	

Cell	Cell Formula	Equation	Copied to
C4	=(B2+B6+2*SUM(B3:B5))/8	7.2	C5:C11

Figure 7-2

Estimate Level and Trend-Tahoe Salt

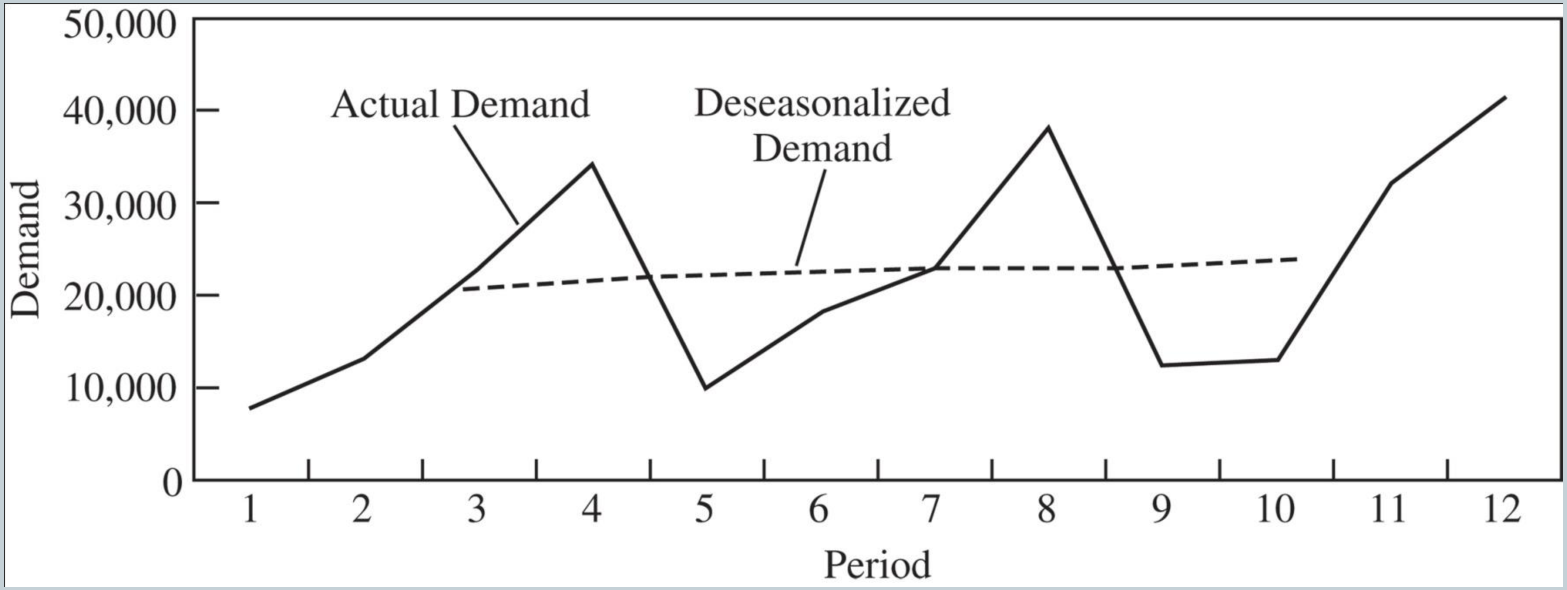

Figure 7-3

A linear relationship exists between the deseasonalized demand and time based on the change in demand over time

$$\bar{D}_t = L + Tt$$

Estimating Seasonal Factors

	A	B	C	D
1	*Period* t	*Demand* D_t	*Deseasonalized Demand (Eqn 7.4)* $\bar{D}_t$	*Seasonal Factor (Eqn 7.5)* $\bar{S}_t$
2	1	8,000	18,963	0.42
3	2	13,000	19,487	0.67
4	3	23,000	20,011	1.15
5	4	34,000	20,535	1.66
6	5	10,000	21,059	0.47
7	6	18,000	21,583	0.83
8	7	23,000	22,107	1.04
9	8	38,000	22,631	1.68
10	9	12,000	23,155	0.52
11	10	13,000	23,679	0.55
12	11	32,000	24,203	1.32
13	12	41,000	24,727	1.66

Cell	Cell Formula	Equation	Copied to
C2	=18439+A2*524	7.4	C3:C13
D2	=B2/C2	7.5	D3:D13

$$\bar{S}_t = \frac{D_i}{\bar{D}_t}$$

Figure 7-4

Estimating Seasonal Factors

- Given the periodicity, p, we obtain the seasonal factor for a given period by averaging seasonal factors that correspond to similar periods

$$S_i = \frac{\sum_{j=0}^{r-1} \bar{S}_{jp+1}}{r}$$

$$S_1 = (\bar{S}_1 + \bar{S}_5 + \bar{S}_9) / 3 = (0.42 + 0.47 + 0.52) / 3 = 0.47$$

$$S_2 = (\bar{S}_2 + \bar{S}_6 + \bar{S}_{10}) / 3 = (0.67 + 0.83 + 0.55) / 3 = 0.68$$

$$S_3 = (\bar{S}_3 + \bar{S}_7 + \bar{S}_{11}) / 3 = (1.15 + 1.04 + 1.32) / 3 = 1.17$$

$$S_4 = (\bar{S}_4 + \bar{S}_8 + \bar{S}_{12}) / 3 = (1.66 + 1.68 + 1.66) / 3 = 1.67$$

Estimating Seasonal Factors

- Without the sharing of sell-through information between the retailers and the manufacturer, this supply chain would have a less accurate forecast and a variety of production and inventory inefficiencies would result.

Forecasts:

$$F_{13} = (L + 13T)S_{13} = (18{,}439 + 13 \times 524)0.47 = 11{,}868$$

$$F_{14} = (L + 14T)S_{14} = (18{,}439 + 14 \times 524)0.68 = 17{,}527$$

$$F_{15} = (L + 15T)S_{15} = (18{,}439 + 15 \times 524)1.17 = 30{,}770$$

$$F_{16} = (L + 16T)S_{16} = (18{,}439 + 16 \times 524)1.67 = 44{,}794$$

Adaptive Forecasting

- The estimates of level, trend, and seasonality are updated after each demand observation
- The framework is provided in the most general setting, when the systematic component of demand data contains a level, a trend, and a seasonal factor.
- The framework can also be specialized for the case in which the systematic component contains no seasonality or trend

Adaptive Forecasting

$$F_{t+1} = (L_t + lT_t)S_{t+1}$$

where

L_t = estimate of level at the end of Period t

T_t = estimate of trend at the end of Period t

S_t = estimate of seasonal factor for Period t

F_t = forecast of demand for Period t (made Period t – 1 or earlier)

D_t = actual demand observed in Period t

E_t = $F_t - D_t$ = forecast error in Period t

Adaptive Forecasting-Steps

1. **Initialize:** Compute initial estimates of the level (Lo), trend (To), and seasonal factors (S1, … , Sp) from the given data
2. **Forecast:** Given the estimates in Period t, forecast demand for Period t + 1
3. **Estimate error:** Compute error $(E_{t+1}) = F_{t+1} - D_{t+1}$
4. **Modify estimates:** Modify the estimates of level L_{t+1}, trend T_{t+1}, and seasonal factor S_{t+p+1}, given the error E_{t+1}

Moving Average

- The moving-average method is used when demand has no observable trend or seasonality

Systematic component of demand = level

- The level in Period t is estimated as the average demand over the most recent N periods.

$$L_t = (D_t + D_t\text{-}1 + \ldots + D_{t-N+1}) / N$$

$$F_{t+1} = L_t \text{ and } F_{t+n} = L_t$$

After observing the demand for period t + 1, revise the estimates as

$$L_{t+1} = (D_{t+1} + D_t + \ldots + D_{t\text{-}N+2}) / N, F_{t+2} = L_{t+1}$$

Moving Average Example

- A supermarket has experienced weekly demand of milk of 120, 127, 114, and 122 gallons over the last four weeks. Forecast demand for Period 5 using a four-period moving average. What is the forecast error if demand in Period 5 turns out to be 125 gallons?

Continue…

Moving Average Example

- We make the forecast for Period 5 at the end of Period 4. First objective is to estimate the level in Period 4.

$$L_4 = (D_4 + D_3 + D_2 + D_1)/4$$
$$= (122 + 114 + 127 + 120)/4 = 120.75$$

- Forecast demand for Period 5

$$F_5 = L_4 = 120.75 \text{ gallons}$$

- Error if demand in Period 5 = 125 gallons

$$E_5 = F_5 - D_5 = 125 - 120.75 = 4.25$$

- Revised demand

$$L_5 = (D_5 + D_4 + D_3 + D_2)/4$$
$$= (125 + 122 + 114 + 127)/4 = 122$$

Simple Exponential Smoothing

- This method is appropriate when demand has no observable trend or seasonality

Systematic component of demand = level

- The initial estimate of level L_o, is taken to be the average of all historical data because because demand has been assumed to have no observable trend or seasonality.

Simple Exponential Smoothing

Given data for Periods 1 to n

$$L_0 = \frac{1}{n}\sum_{i=1}^{n} D_i$$

Current forecast

$$F_{t+1} = L_t \quad \text{and} \quad F_{t+n} = L_t$$

Revised forecast using smoothing constant $0 < \alpha < 1$

$$L_{t+1} = \alpha D_{t+1} + (1-\alpha)L_t$$

Thus

$$L_{t+1} = \sum_{n=0}^{t-1} \alpha(1-\alpha)^n D_{t+1-n} + (1-\alpha)^t D_1$$

Simple Exponential Smoothing

- **Example 7-2** Consider the supermarket in Example 7-1, where weekly demand for milk has been 120, 127, 114, and 122 gallons over the last four weeks. Forecast demand for Period 1 using simple exponential smoothing with $\alpha = 0.1$

Initial estimate of level $L_0 = \sum_{i=1}^{4} D_i / 4 = 120.75$

The forecast for Period 1 $F_1 = L_0 = 120.75$

Simple Exponential Smoothing

The observed demand for Period 1 is D1 = 120. The forecast error for Period 1 is given by

$$E_1 = F_1 - D_1 = 120.75 - 120 = 0.75$$

the revised estimate of level for Period 1

$$L_1 = \alpha D_1 + (1-\alpha)L_0 \;\; = 0.1 \times 120 + 0.9 \times 120.75 = 120.68$$

- Continuing in this manner, we obtain F3 = 121.31, F4 = 120.58, and F5 = 120.72. Thus, the forecast for period 5 is 120.72

Trend-Corrected Exponential Smoothing (Holt's Model)

- This method is appropriate when demand is assumed to have a level and a trend in the systematic component but no seasonality. Here,

  Systematic component of demand = level + trend

- Initial estimate of level and trend is obtained by running a linear regression between demand Dr and time Period t of the form $D_t = a_t + b$

  $T_o = a, L_o = b$

Trend-Corrected Exponential Smoothing (Holt's Model)

- In Period t, the forecast for future periods is

  $$F_{t+1} = L_t + T_t \text{ and } F_{t+n} = L_t + nT_t$$

- Revised estimates for Period t

  $$L_{t+1} = \alpha D_{t+1} + (1 - \alpha)(L_t + T_t)$$

  $$T_{t+1} = \beta\,(L_{t+1} - L_t) + (1 - \beta)T_t$$

where α is smoothing constant for the level,

$0 < \alpha < 1$, and is β a smoothing constant for the trend,

$0 < \beta < 1$

Trend-Corrected Exponential Smoothing (Holt's Model)

- **Example 7-3** An electronics manufacturer has seen demand for its latest MP3 player increase over the last six months. Observed demand (in thousands) has been 8415, 8732, 9014, 9808, 10413, and 11961. Forecast demand for Period 7 using trend-corrected exponential smoothing with $\alpha = 0.1$, $\beta = 0.2$
- Using regression analysis

$L_0 = 7367$ and $T_0 = 673$

- Forecast for Period 1

$F_1 = L_0 + T_0 = 7367 + 673 = 8040$

Trend-Corrected Exponential Smoothing (Holt's Model)

- Revised estimate

$$L_1 = \alpha D_1 + (1 - \alpha)(L_0 + T_0)$$
$$= 0.1 \text{ x } 8{,}415 + 0.9 \text{ x } 8{,}040 = 8{,}078$$
$$T_1 = \beta(L_1 - L_0) + (1 - \beta)T_0$$
$$= 0.2 \text{ x } (8{,}078 - 7{,}367) + 0.8 \text{ x } 673 = 681$$

- With new L_1

$$F_2 = L_1 + T_1 = 8{,}078 + 681 = 8{,}759$$

- Continuing

$$F_7 = L_6 + T_6 = 11{,}399 + 673 = 12{,}072$$

Trend- and Seasonality-Corrected Exponential Smoothing(Winter's Model)

- It is appropriate when the systematic component of demand has a level, a trend, and a seasonal factor.

Systematic component of demand

= (level+ trend) X seasonal factor

- Assume periodicity of demand to be p. To begin, we need initial estimates of level (L_0), trend (T_0), and seasonal factors (S_1, ... , S_p)

Trend- and Seasonality-Corrected Exponential Smoothing(Winter's Model)

- The forecast for future periods is given by

$$F_{t+1} = (L_t + T_t)S_{t+1} \text{ and } F_{t+l} = (L_t + lT_t)S_{t+l}$$

- After observing demand for period (t + 1), revise estimates for level, trend, and seasonal factors

$$L_{t+1} = \alpha\,(D_{t+1}/S_{t+1}) + (1 - \alpha)(L_t + T_t)$$

$$T_{t+1} = \beta(L_{t+1} - L_t) + (1 - \beta)T_t$$

$$S_{t+p+1} = \gamma(D_{t+1}/L_{t+1}) + (1 - \gamma)S_{t+1}$$

Where α = smoothing constant for level

β = smoothing constant for trend

γ = smoothing constant for seasonal factor

Winter's Model

- Example 7-4 Consider the Tahoe Salt demand data in Table 7-1. Forecast demand for Period 1 using trend- and seasonality-corrected exponential smoothing with $\alpha = 0.1$, $\beta = 0.2$, $\gamma = 0.1$

Continue...

Winter's Model

$L_0 = 18{,}439$, $T_o = 524$

$S_1 = 0.47$, $S_2 = 0.68$, $S_3 = 1.17$, $S_4 = 1.67$

$F_1 = (L_o + T_o)S_1 = (18{,}439 + 524)(0.47) = 8{,}913$

The observed demand for Period 1, $D_1 = 8{,}000$

Forecast error for Period 1

$$= E_1 = F_1 - D_1$$

$$= 8{,}913 - 8{,}000 = 913$$

Winter's Model

- Assume $\alpha = 0.1$, $\beta = 0.2$, $\gamma = 0.1$; revise estimates for level and trend for period 1 and for seasonal factor for Period 5

$L_1 = \alpha(D_1/S_1) + (1 - \alpha)(L_0 + T_0)$

$= 0.1 \text{ x } (8{,}000/0.47) + 0.9 \text{ x } (18{,}439 + 524) = 18{,}769$

$T_1 = \beta(L_1 - L_0) + (1 - \beta)T_0$

$= 0.2 \text{ x } (18{,}769 - 18{,}439) + 0.8 \text{ x } 524 = 485$

$S_5 = \gamma(D_1/L_1) + (1 - \gamma)S_1$

$= 0.1 \text{ x } (8{,}000/18{,}769) + 0.9 \text{ x } 0.47 = 0.47$

$F_2 = (L_1 + T_1)S_2 = (18{,}769 + 485)0.68 = 13{,}093$

Time Series Models

- The forecasting methods discussed and the situations in which they are generally applicable are as follows

Forecasting Method	Applicability
Moving average	No trend or seasonality
Simple exponential smoothing	No trend or seasonality
Holt's model	Trend but no seasonality
Winter's model	Trend and seasonality

Measures of Forecast Error

- A good forecasting method should capture the systematic component of demand but not the random component. The random component manifests itself in the form of a forecast error.
- Forecast errors contain valuable information and must be analyzed carefully for two reasons

Measures of Forecast Error

1. Managers use error analysis to determine whether the current forecasting method is predicting the systematic component of demand accurately

Example:

- If a forecasting method consistently produces a positive error, the forecasting method is overestimating the systematic component and should be corrected.

Measures of Forecast Error

2. All contingency plans must account for forecast error.

Example:

Consider a mail-order company with two suppliers. The first is in the Far East and has a lead time of two months. The second is local and can fill orders with one week's notice. The local supplier is more expensive, whereas the Far East supplier costs less. The mail-order company wants to contract a certain amount of contingency capacity with the local supplier to be used if the demand exceeds the quantity the Far East supplier provides

- The decision regarding the quantity of local capacity to contract is closely linked to the size of the forecast error.

Measures of Forecast Error

- Forecast error for Period t is given by Et , *where the following* holds $$E_t = F_t - D_t$$
- The error in Period t is the difference between the forecast for Period t and the actual demand in Period *t*.
- ***Example:*** If a forecast will be used to determine an order size and the supplier's lead time is six months, a manager should estimate the error for a forecast made six months before demand arises. In a situation with a six-month lead time, there is no point in estimating errors for a forecast made one month in advance

Measures of Forecast Error

- One measure of forecast error is mean squared error

$$MSE_n = \frac{1}{n}\sum_{t=1}^{n} E_t^2$$

- Define the absolute deviation in Period t,A1, to be the absolute value of the error in Period t; that is,

$$A_t = \left| E_t \right|$$

- Define the mean absolute deviation (MAD) to be the average of the absolute deviation over all periods, as expressed by

$$MAD_n = \frac{1}{n}\sum_{t=1}^{n} A_t$$

Measures of Forecast Error

- The MAD can be used to estimate the standard deviation of the random component assuming that the random component is normally distributed. In this case the standard deviation of the random component is

$$s = 1.25 MAD$$

- The Mean Absolute Percentage Error (MAPE) is the average absolute error as a percentage of demand and is given by

$$MAPE_n = \frac{\sum_{t=1}^{n} \left| \frac{E_t}{D_t} \right| 100}{n}$$

Measures of Forecast Error

- To determine whether a forecast method consistently over- or underestimates demand, we can use the sum of forecast errors to evaluate the bias, where the following holds:

$$bias_n = \sum_{t=1}^{n} E_t$$

- The tracking signal (TS) is the ratio of the bias and the MAD and is given as

$$TS_t = \frac{bias_t}{MAD_t}$$

Selecting the Best Smoothing Constant

	A	B	C	D	E	F	G	H
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Squared Error	Absolute Errror A_t	% Error
2	0		2017.9					
3	1	2024	2021.2	2017.9	-6.1	37	6.1	0.3%
4	2	2076	2050.8	2021.2	-54.8	3003	54.8	2.6%
5	3	1992	2019.0	2050.8	58.8	3463	58.8	3.0%
6	4	2075	2049.3	2019.0	-56.0	3135	56.0	2.7%
7	5	2070	2060.5	2049.3	-20.7	429	20.7	1.0%
8	6	2046	2052.7	2060.5	14.5	210	14.5	0.7%
9	7	2027	2038.8	2052.7	25.7	658	25.7	1.3%
10	8	1972	2002.7	2038.8	66.8	4459	66.8	3.4%
11	9	1912	1953.6	2002.7	90.7	8218	90.7	4.7%
12	10	1985	1970.6	1953.6	-31.4	985	31.4	1.6%
13		2017.9			87	2,460	42.5	2.1%
14	α =	0.54						

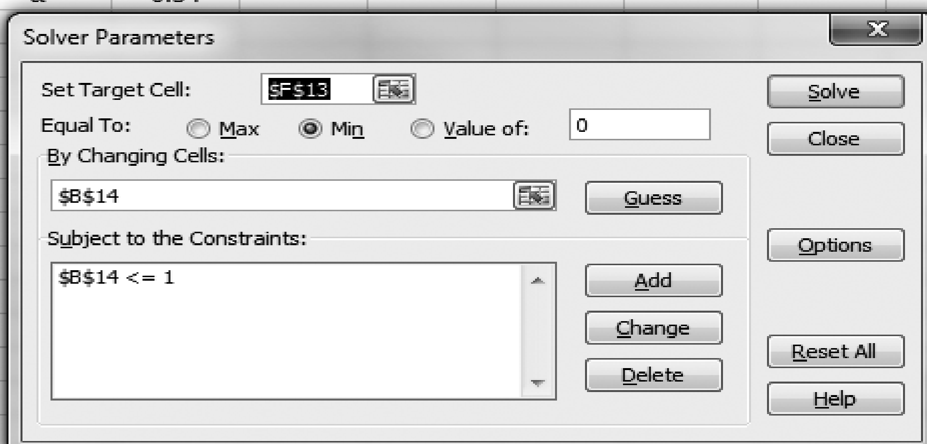

Figure 7-5

Selecting the Best Smoothing Constant

	A	B	C	D	E	F	G	H
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Squared Error	Absolute Errror A_t	% Error
2	0		2017.9					
3	1	2024	2019.8	2017.9	-6.1	37	6.1	0.3%
4	2	2076	2037.8	2019.8	-56.2	3153	56.2	2.7%
5	3	1992	2023.2	2037.8	45.8	2097	45.8	2.3%
6	4	2075	2039.7	2023.2	-51.8	2687	51.8	2.5%
7	5	2070	2049.4	2039.7	-30.3	916	30.3	1.5%
8	6	2046	2048.3	2049.4	3.4	12	3.4	0.2%
9	7	2027	2041.5	2048.3	21.3	454	21.3	1.1%
10	8	1972	2019.3	2041.5	69.5	4831	69.5	3.5%
11	9	1912	1985.0	2019.3	107.3	11511	107.3	5.6%
12	10	1985	1985.0	1985.0	0.0	0	0.0	0.0%
13		2017.9			103	2,570	39.2	2.0%
14	α =	0.32						

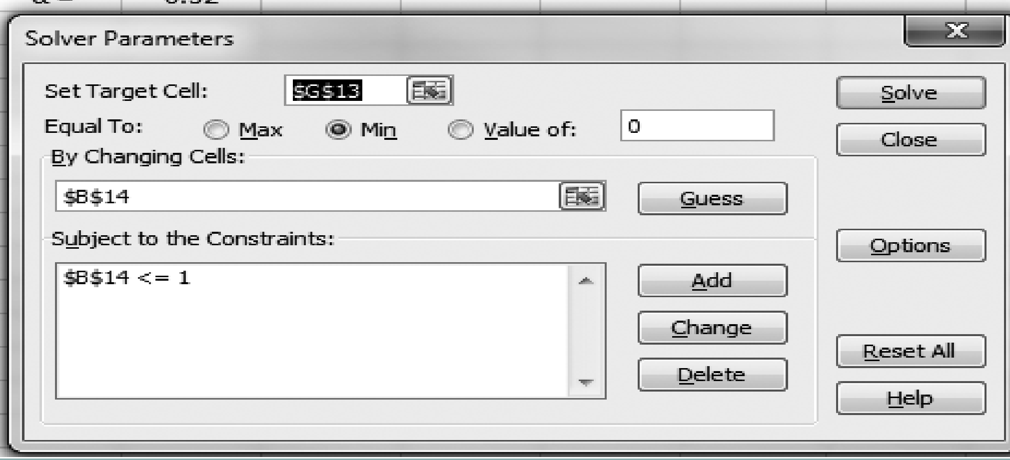

Figure 7-6

Forecasting Demand at Tahoe Salt

- Tahoe salt has assigned a team consisting of two sales managers from the retailers and the vice president of operations for Tahoe Salt to come up with the forecast.
- Each of the adaptive forecasting methods are applied on historical data and most appropriate method is to found out.
- Initially Winter's model is expected to give the best result

Forecasting Demand at Tahoe Salt

1. Moving average
2. Simple exponential smoothing
3. Trend-corrected exponential smoothing
4. Trend- and seasonality-corrected exponential smoothing

Forecasting Demand at Tahoe Salt

- **Moving average**

- It is decided to test a four-period moving average for the forecasting. All calculations are shown in the figure.
- The forecast using the four-period moving average does not contain any significant bias
- The standard deviation of forecast error is fairly large relative to the size of the forecast.

Forecasting Demand at Tahoe Salt

Moving average

	A	B	C	D	E	F	G	H	I	J	K
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Absolute Error A_t	Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	1	8,000									
3	2	13,000									
4	3	23,000									
5	4	34,000	19,500								
6	5	10,000	20,000	19,500	9,500	9,500	90,250,000	9,500	95	95	1.00
7	6	18,000	21,250	20,000	2,000	2,000	47,125,000	5,750	11	53	2.00
8	7	23,000	21,250	21,250	-1,750	1,750	32,437,500	4,417	8	38	2.21
9	8	38,000	22,250	21,250	-16,750	16,750	94,468,750	7,500	44	39	-0.93
10	9	12,000	22,750	22,250	10,250	10,250	96,587,500	8,050	85	49	0.40
11	10	13,000	21,500	22,750	9,750	9,750	96,333,333	8,333	75	53	1.56
12	11	32,000	23,750	21,500	-10,500	10,500	98,321,429	8,643	33	50	0.29
13	12	41,000	24,500	23,750	-17,250	17,250	123,226,563	9,719	42	49	-1.52

Cell	Cell Formula	Equation	Copied to
C5	=Average(B2:B5)	7.9	C6:C13
D6	=C5	7.10	D7:D13
E6	=D6-B6	7.8	E7:E13
F6	=Abs(E6)		F7:F13
G6	=Sumsq($E$6:E6)/(A6-4)	7.21	G7:G13
H6	=Sum($F$6:F6)/(A6-4)	7.22	H7:H13
I6	=100*(F6/B6)		I7:I13
J6	=Average($I$6:I6)	7.24	J7:J13
K6	=Sum($E$6:E6)/ H6	7.26	K7:K13

Figure 7-7

Forecasting Demand at Tahoe Salt

Moving average

$$L_{12} = 24{,}500$$

$$F_{13} = F_{14} = F_{15} = F_{16} = L_{12} = 24{,}500$$

$$\sigma = 1.25 \text{ x } 9{,}719 = 12{,}148$$

Forecasting Demand at Tahoe Salt

- **Simple exponential smoothing**

- Simple exponential smoothing approach with $\alpha = 0.1$ is used to forecast demand and the method is tested on 12 quarters of historical data
- The forecast using simple exponential smoothing with $\alpha = 0.1$ does not indicate any significant bias and the standard deviation of forecast error is fairly large relative to the size of the forecast

Forecasting Demand at Tahoe Salt

Simple Exponential moving

	A	B	C	D	E	F	G	H	I	J	K
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	0		22,083								
3	1	8,000	20,675	22,083	14,083	14,083	198,340,278	14,083	176	176	1
4	2	13,000	19,908	20,675	7,675	7,675	128,622,951	10,879	59	118	2
5	3	23,000	20,217	19,908	-3,093	3,093	88,936,486	8,284	13	83	2
6	4	34,000	21,595	20,217	-13,783	13,783	114,196,860	9,659	41	72	0.51
7	5	10,000	20,436	21,595	11,595	11,595	118,246,641	10,046	116	81	1.64
8	6	18,000	20,192	20,436	2,436	2,436	99,527,532	8,777	14	70	2.15
9	7	23,000	20,473	20,192	-2,808	2,808	86,435,714	7,925	12	62	2.03
10	8	38,000	22,226	20,473	-17,527	17,527	114,031,550	9,125	46	60	-0.16
11	9	12,000	21,203	22,226	10,226	10,226	112,979,315	9,247	85	62	0.95
12	10	13,000	20,383	21,203	8,203	8,203	108,410,265	9,143	63	63	1.86
13	11	32,000	21,544	20,383	-11,617	11,617	110,824,074	9,368	36	60	0.58
14	12	41,000	23,490	21,544	-19,456	19,456	133,132,065	10,208	47	59	-1.38

Cell	Cell Formula	Equation	Copied to
C3	=0.1*B3+(1-0.1)*C2	7.13	C4:C14
D3	=C2	7.12	D4:D14
E3	=D3-B3	7.8	E4:E14
F3	=Abs(E3)		F4:F14
G3	=Sumsq($E$3:E3)/A3	7.21	G4:G14
H3	=Sum($G$3:G3)/A3	7.22	H4:H14
I3	=100*(F3/B3)		I4:I14
J3	=Average($I$3:I3)	7.24	J4:J14
K3	=Sum($F$3:F3)/H3	7.26	K4:K14

Figure 7-8

Forecasting Demand at Tahoe Salt

Single exponential smoothing

$$L_0 = 22{,}083$$

$$L_{12} = 23{,}490$$

$$F_{13} = F_{14} = F_{15} = F_{16} = L_{12} = 23{,}490$$

$$\sigma = 1.25 \text{ x } 10{,}208 = 12{,}761$$

Forecasting Demand at Tahoe Salt

- **Trend-Corrected Exponential Smoothing**

- The systematic component of demand is given by

  Systematic component of demand = level + trend

Forecasting Demand at Tahoe Salt

Trend-Corrected Exponential Smoothing

	A	B	C	D	E	F	G	H	I	J	K	L
1	Period t	Demand D_t	Level L_t	Trend T_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	0		**12,015**	**1,549**								
3	1	8,000	13,008	1,438	13,564	5,564	5,564	30,958,096	5,564	70	70	1
4	2	13,000	14,301	1,409	14,445	1,445	1,445	16,523,523	3,505	11	40	2
5	3	23,000	16,439	1,555	15,710	-7,290	7,290	28,732,318	4,767	32	37	0
6	4	34,000	19,594	1,875	17,993	-16,007	16,007	85,603,146	7,577	47	39.86	-2.15
7	5	10,000	20,322	1,645	21,469	11,469	11,469	94,788,701	8,355	115	54.83	-0.58
8	6	18,000	21,570	1,566	21,967	3,967	3,967	81,613,705	7,624	22	49.36	-0.11
9	7	23,000	23,123	1,563	23,137	137	137	69,957,267	6,554	1	42.39	-0.11
10	8	38,000	26,018	1,830	24,686	-13,314	13,314	83,369,836	7,399	35	41.48	-1.90
11	9	12,000	26,262	1,513	27,847	15,847	15,847	102,010,079	8,338	132	51.54	0.22
12	10	13,000	26,298	1,217	27,775	14,775	14,775	113,639,348	8,981	114	57.75	1.85
13	11	32,000	27,963	1,307	27,515	-4,485	4,485	105,137,395	8,573	14	53.78	1.41
14	12	41,000	30,443	1,541	29,270	-11,730	11,730	107,841,864	8,836	29	51.68	0.04

Cell	Cell Formula	Equation	Copied to
C3	=0.1*B3+(1-0.1)*(C2+D2)	7.15	C4:C14
D3	=0.2(C3-C2)+(1-0.2)D2	7.16	D4:D14
E3	=C2+D2	7.14	E4:E14
F3	=E3-B3	7.8	F4:F14
G3	=Abs(F3)		G4:G14
H3	=Sumsq($F$3:F3)/A3	7.21	H4:H14
I3	=Sum($G$3:G3)/A3	7.22	I4:I14
J3	=100*(G3/B3)		J4:J14
K3	=Average($J$3:J3)	7.24	K4:K14
L3	=Sum($F$3:F3)/I3	7.26	L4:L14

Figure 7-9

Forecasting Demand at Tahoe Salt

Trend-Corrected Exponential Smoothing

$$L_0 = 12{,}015 \text{ and } T_0 = 1{,}549$$

$$L_{12} = 30{,}443 \text{ and } T_{12} = 1{,}541$$

$$F_{13} = L_{12} + T_{12} = 30{,}443 + 1{,}541 = 31{,}984$$

$$F_{14} = L_{12} + 2T_{12} = 30{,}443 + 2 \text{ x } 1{,}541 = 33{,}525$$

$$F_{15} = L_{12} + 3T_{12} = 30{,}443 + 3 \text{ x } 1{,}541 = 35{,}066$$

$$F_{16} = L_{12} + 4T_{12} = 30{,}443 + 4 \text{ x } 1{,}541 = 36{,}607$$

$$\sigma = 1.25 \text{ x } 8{,}836 = 11{,}045$$

Forecasting Demand at Tahoe Salt

- **Trend- and Seasonality-Corrected exponential smoothening**
- The standard deviation of forecast error relative to the demand forecast is much smaller than with the other methods.
- Winter's model results in the most accurate forecast, because the demand data have both a growth trend as well as seasonality

Forecasting Demand at Tahoe Salt

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	*Period t*	Demand D_t	Level L_t	Trend T_t	Seasonal Factor S_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2			**18,439**	**524**									
3	1	8,000	18,866	514	**0.47**	8,913	913	913	832,857	913	11	11.41	1.00
4	2	13,000	19,367	513	**0.68**	13,179	179	179	432,367	546	1	6.39	2.00
5	3	23,000	19,869	512	**1.17**	23,260	260	260	310,720	450	1	4.64	3.00
6	4	34,000	20,380	512	**1.67**	34,036	36	36	233,364	347	0	3.50	4.00
7	5	10,000	20,921	515	0.47	9,723	-277	277	202,036	333	3	3.36	3.34
8	6	18,000	21,689	540	0.68	14,558	-3,442	3,442	2,143,255	851	19	5.98	-2.74
9	7	23,000	22,102	527	1.17	25,981	2,981	2,981	3,106,508	1,155	13	6.98	0.56
10	8	38,000	22,636	528	1.67	37,787	-213	213	2,723,856	1,037	1	6.18	0.42
11	9	12,000	23,291	541	0.47	10,810	-1,190	1,190	2,578,653	1,054	10	6.59	-0.72
12	10	13,000	23,577	515	0.69	16,544	3,544	3,544	3,576,894	1,303	27	8.66	2.14
13	11	32,000	24,271	533	1.16	27,849	-4,151	4,151	4,818,258	1,562	13	9.05	-0.87
14	12	41,000	24,791	532	1.67	41,442	442	442	4,432,987	1,469	1	8.39	-0.63
15	13				0.47	11,940							
16	14				0.68	17,579							
17	15				1.17	30,930							
18	16				1.67	44,928							

Trend- and Seasonality-Corrected exponential smoothening

Cell	Cell Formula	Equation	Copied to
C3	=0.05*(B3/E3)+(1-0.05)*(C2+D2)	7.18	C4:C14
D3	=0.1*(C3-C2)+(1-0.1)*D2	7.19	D4:D14
E7	=0.1*(B3/C3)+(1-0.1)*E3	7.20	E8:E18
F3	=(C2+D2)*E3	7.17	F4:F18
G3	=F3-B3	7.8	G4:G14
H3	=Abs(G3)		H4:H14
I3	=Sumsq($G$3:G3)/A3	7.21	I4:I14
J3	=Sum($H$3:H3)/A3	7.22	J4:J14
K3	=100*(H3/B3)		K4:K14
L3	=Average($K$3:K3)	7.24	L4:L14
M3	=Sum($G$3:G3)/J3	7.26	M4:M14

Figure 7-10

Forecasting Demand at Tahoe Salt

Trend- and Seasonality-Corrected

$$L_0 = 18{,}439 \quad T_0 = 524$$

$$S_1 = 0.47 \quad S_2 = 0.68 \quad S_3 = 1.17 \quad S_4 = 1.67$$

$$L_{12} = 24{,}791 \quad T_{12} = 532$$

$$F_{13} = (L_{12} + T_{12})S_{13} = (24{,}791 + 532)0.47 = 11{,}940$$

$$F_{14} = (L_{12} + 2T_{12})S_{13} = (24{,}791 + 2 \text{ x } 532)0.68 = 17{,}579$$

$$F_{15} = (L_{12} + 3T_{12})S_{13} = (24{,}791 + 3 \text{ x } 532)1.17 = 30{,}930$$

$$F_{16} = (L_{12} + 4T_{12})S_{13} = (24{,}791 + 4 \text{ x } 532)1.67 = 44{,}928$$

$$\sigma = 1.25 \text{ x } 1{,}469 = 1{,}836$$

Forecasting Demand at Tahoe Salt

Forecasting Method	MAD	MAPE (%)	TS Range
Four-period moving average	9,719	49	−1.52 to 2.21
Simple exponential smoothing	10,208	59	−1.38 to 2.15
Holt’s model	8,836	52	−2.15 to 2.00
Winter’s model	1,469	8	−2.74 to 4.00

The Role of IT in Forecasting

- Forecasting module within a supply chain IT system, which is called the demand planning module, is a core supply chain software product
- A variety of forecasting algorithms are provided with commercial demand planning modules , which can be quite advanced and are sometimes proprietary and we can have more accurate forecast
- Different forecasting algorithms provide different levels of quality depending on the actual demand patterns so availability of a variety of forecasting options is important

The Role of IT in Forecasting

- Not just for the firm overall, but also by product categories and markets, the IT system can be used to determine forecasting methods
- A good forecasting package - provides forecasts across a wide range of products that are updated in real time by incorporating any new demand information thus, firms respond quickly to changes in marketplace

The Role of IT in Forecasting

- Good demand planning modules link customer orders , customer sales information, thus it incorporates the most current data into the demand forecast.
- Demand planning-

✓ It facilitates the shaping of demand.

✓ Contains tools to perform **what-if analysis** regarding the impact of potential changes in prices on demand

The Role of IT in Forecasting

- Forecasts are virtually wrong sometimes. A well-structured forecast, along with a measure of error, can significantly improve decision making. It is not advisable to rely too much on the forecasting tools
- Forecasting modules are available from all the major supply chain software companies, including the ERP firms such as SAP and Oracle

Risk Management

- Errors in forecasting can cause misallocation of resources in inventory, facilities, transportation, sourcing, pricing, and even in information management. Forecast errors during network design may cause too many, too few, or the wrong type of facilities to be built.
- As one of the initial processes in each of the levels that affects many other processes, forecasting contains a significant amount of inherent risk.

Risk Management

- Long lead times require forecasts to be made further in advance, thus decreasing the reliability of the forecast
- Seasonality ,short product life cycles and very few number of customers tend to increase forecast error
- Forecast quality suffers when it is based on orders placed by intermediaries

Risk Management

- Two strategies to mitigate forecast risk

  Increasing the responsiveness of the supply chain

  Utilizing opportunities for pooling of demand.

- Example: W.W. Grainger has worked with suppliers to decrease lead times from eight weeks to less than three weeks

- Pooling helps to smooth out lumpy demand by bringing together multiple sources of demand. Thus, Amazon has a lower forecast error because it pools geographic demand into its warehouses.

Risk Management

- To achieve the right balance between risk mitigation and cost, it is important to tailor the mitigation strategies. When dealing with a commodity for which shortfalls can easily be made up for by spot market purchases, spending large amounts to increase the responsiveness of the supply chain is not warranted
- In contrast, for a product with a short life cycle, investing in responsiveness may be worth the cost

Forecasting in Practice

Collaborate in building forecasts

- Collaboration with supply chain partners can create a much more accurate forecast. Time and efforts are needed to build relationship
- Progress needs to be made before all supply chain information is accounted for and utilized

Forecasting in Practice

Share only the data that truly provide value.

- Value of data depends on where it is found.
- A retailer finds point-of-sale data to be quite valuable in measuring the performance of its stores. However, a manufacturer selling to a distributor who in turn sells to retailers does not need all the point-of-sale detail. The manufacturer finds aggregate demand data to be quite valuable, with marginally more value coming from detailed point-of-sale data

Forecasting in Practice

Be sure to distinguish between demand and sales.

- Companies make the mistake of looking at historical sales and assuming that this is what the historical demand was.
- To get true demand, adjustments need to be made for unmet demand due to stockouts, competitor actions, pricing, and promotions. Failure to do so results in forecasts that do not represent the current reality

Summary of Learning Objectives

- Understand the role of forecasting for both an enterprise and a supply chain
- Identify the components of a demand forecast
- Forecast demand in a supply chain given historical demand data using time-series methodologies
- Analyze demand forecasts to estimate forecast error