ISOM 2700: Operations Management
Session 7.1. Demand forecasting

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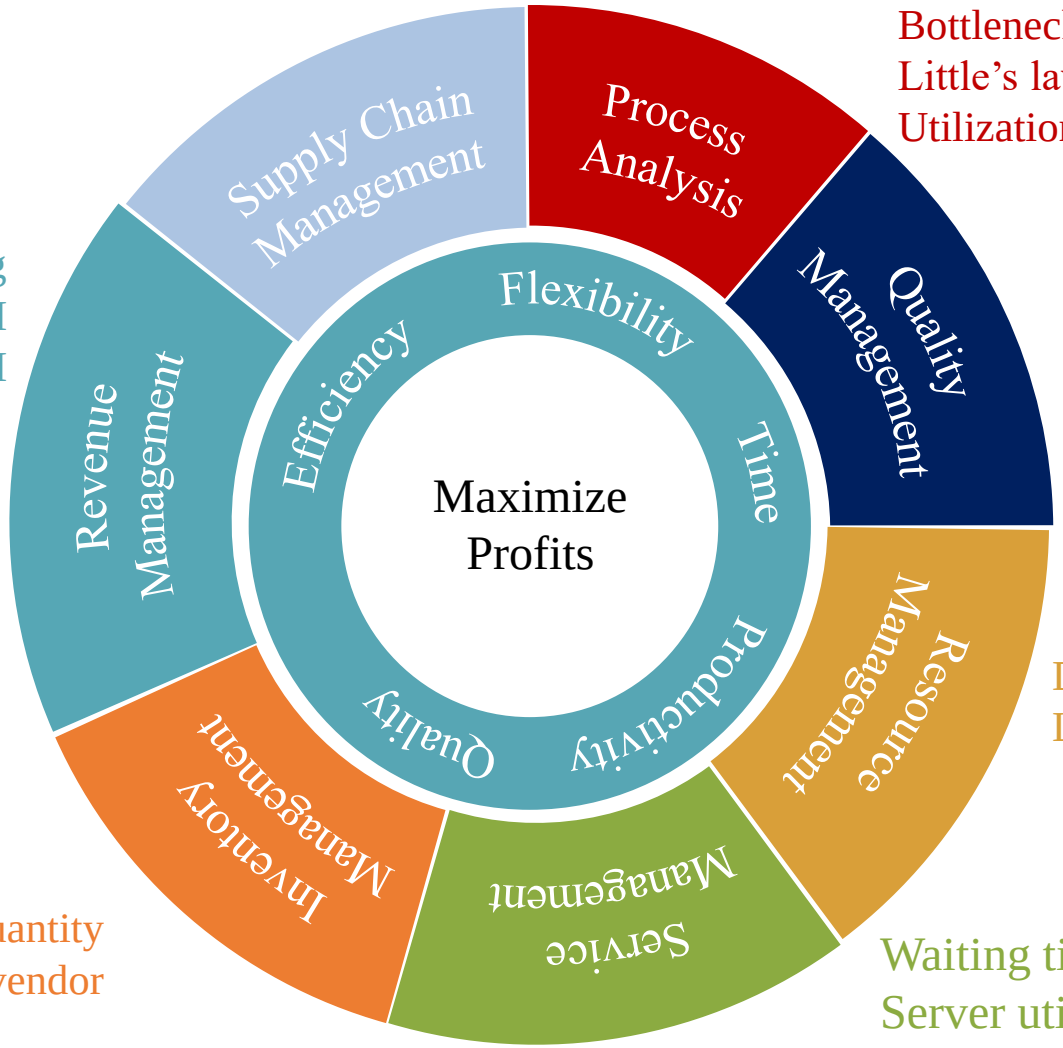
Course Roadmap



Bottleneck
Little's law
Utilization

Control chart
Acceptance sampling
Six sigma

Decision tree method
Linear programming

Waiting time
Server utilization

Economic order quantity
Newsvendor

Demand forecasting
Capacity-based RM
Price-based RM

2

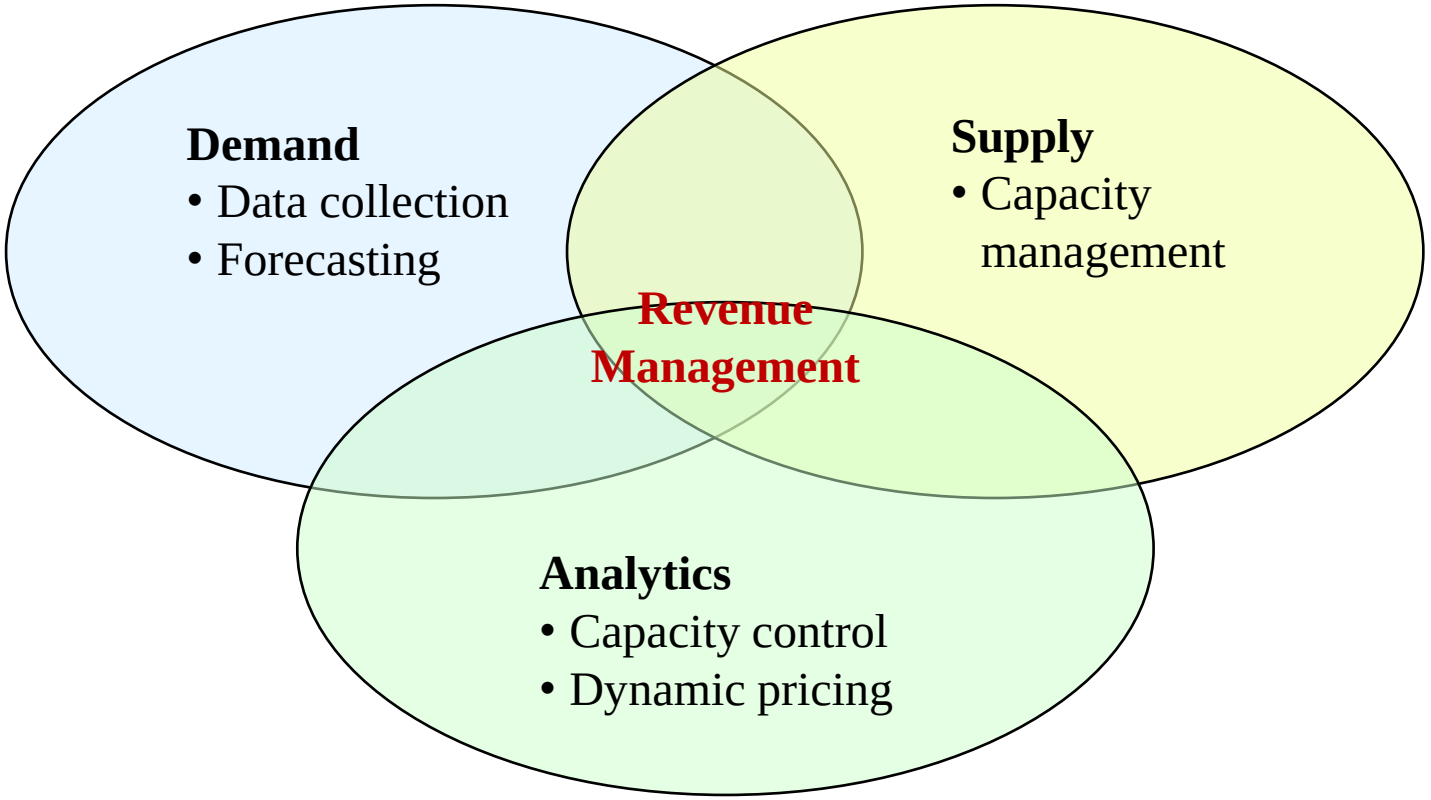
Revenue Management

- Revenue management is the application of disciplined analytics that predict consumer behavior and optimize capacity and price to maximize revenue

RM Big Picture

Revenue Management in a Bird's-Eye View

Sell the Right product to the Right customer at the Right price and the Right time



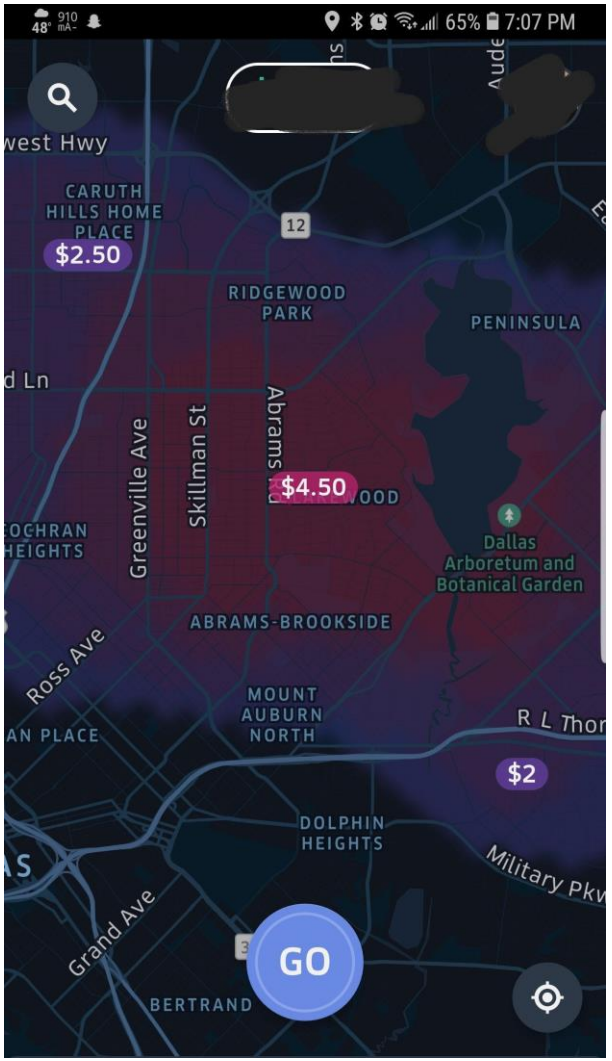
⇒ improve the net revenue while matching supply and demand

⇒ by changing the price or capacity allocation to different customer segmentation

Example: ride-hailing industry

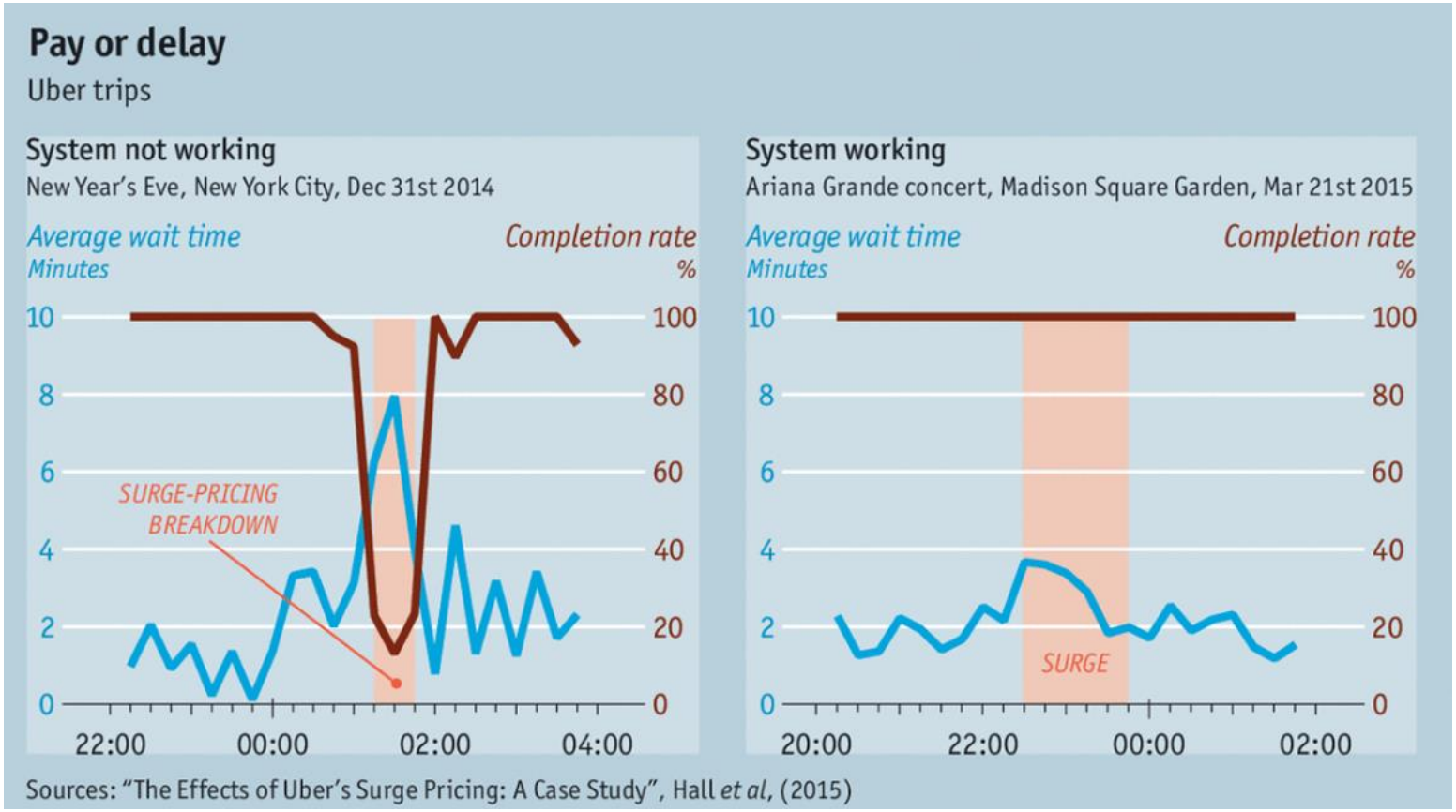
Uber and lyft

- With their dynamic pricing model Uber and Lyft raise the price when there is high demand and not enough drivers.
- Passengers will pay higher rates, the price of a ride can even jump 50 percent or more.

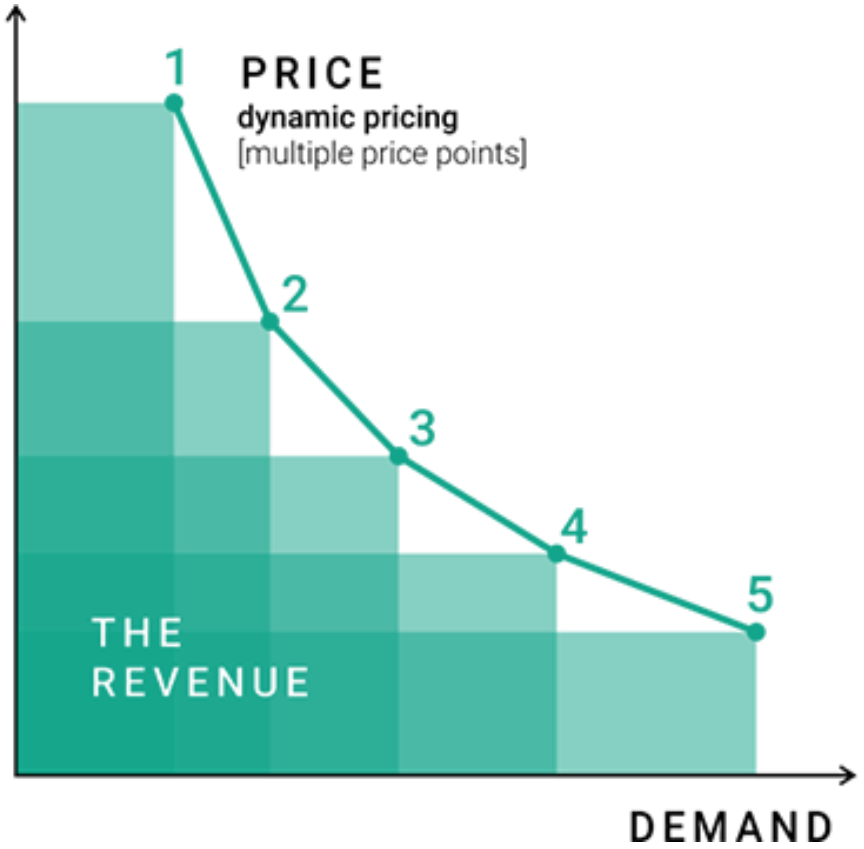


Example: Uber's dynamic pricing system

- Demand forecast factors: the global news events, weather, historical data, holidays, time, traffic…



Why revenue management works?



When dynamic pricing backfires?

- A vending machine with temperature-scanning capability was introduced, charging variable price depending on the weather
- "Charge higher price for more thirsty customers"
- Result: Failure
  - Angry Coke drinkers denounced the idea
  - The company's stock dove from $37 to $18 in 5 months.
  - Pepsi gleefully accused its rival of exploiting customers

When dynamic pricing backfires?

- Uber and Lyft: Following a mass shooting at a subway station in Sunset Park, Brooklyn on April 12. people attempting to avoid public transit by hailing an Uber or a Lyft were met with an infuriating, if unsurprising, result.

Learning objective

- Introduction of revenue management
- Demand forecasting
  - Qualitative and quantitative method
  - Accuracy metrics
- Revenue management with capacity control
  - Airline industry
  - Hotel industry
- Revenue management with price control

Demand Management

- Demand management is a process for optimizing the customer demand with available capacity to **maximize** a company's **profit**
  - Revenue: How much to sell and at what price?
  - Cost: How much capacity to maintain and at what cost?

- Common approaches and tactics
  - Take a passive role to forecast and respond to customer demand
  - Take an active role to influence or prioritize customer demand

Forecasting is Essential to Supply Chain Planning

Why forecasting?

Video

- **Strategic Forecasts**
  - Medium- and Long-term forecasts used to make decisions related to strategy and estimating aggregate demand

- **Tactical Forecasts**
  - Short-term forecasts used as input for making day-to-day decisions related to meeting demand

Principles of Demand Forecasting

- Forecasting is only forecasting
  - **Not perfect**
- The longer the forecast horizon, the worse the forecast
- Aggregate forecasts are more accurate
- Good forecasts do not always require the use of complex forecasting models
  - "Simplicity is the ultimate sophistication"
    Leonardo da Vinci

Forecasting framework

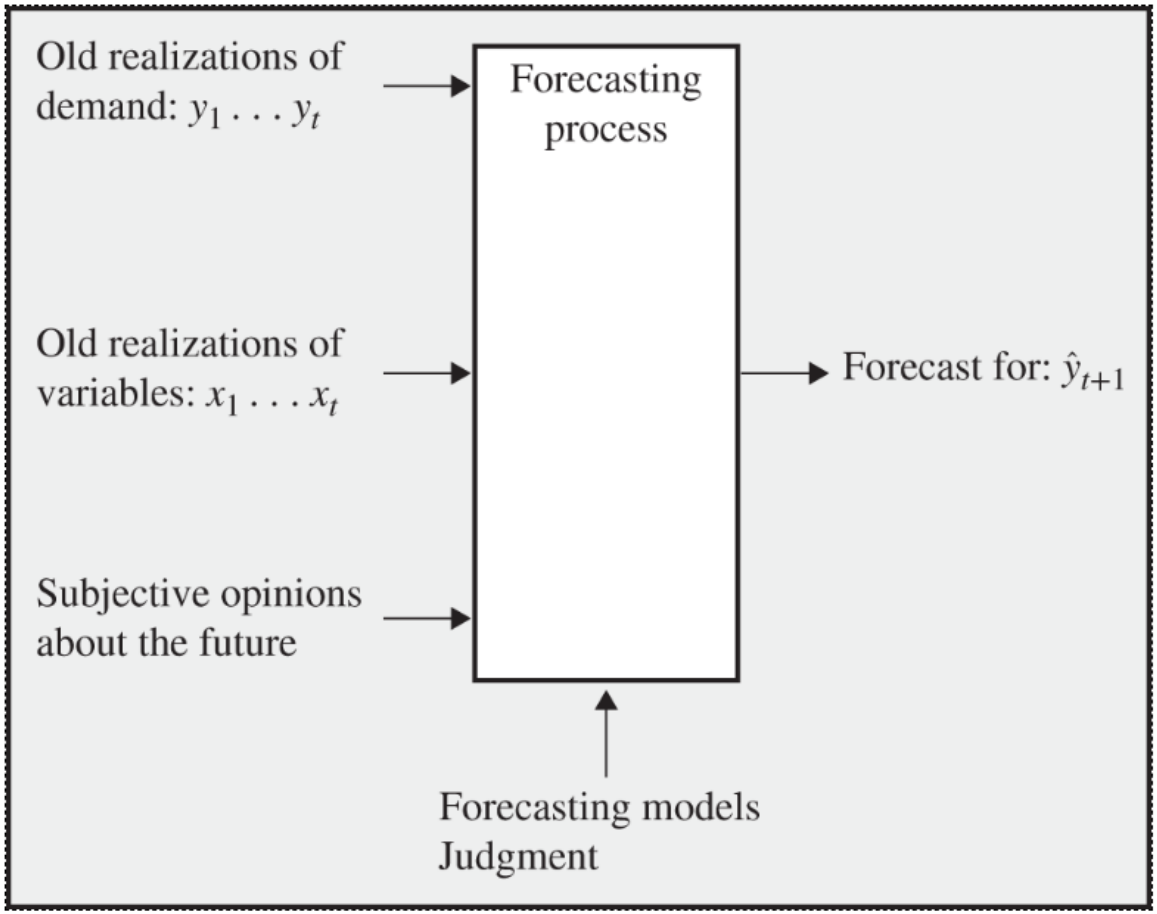


FIGURE 13.2 Forecasting Framework

Forecasting Methods

- Qualitative Forecasting Methods
  - Market research
  - Historical analogy
  - Panel consensus
  - Delphi method

- Quantitative techniques for forecasting
  - Simple and weighted moving averages
  - Exponential smoothing
  - Linear regression

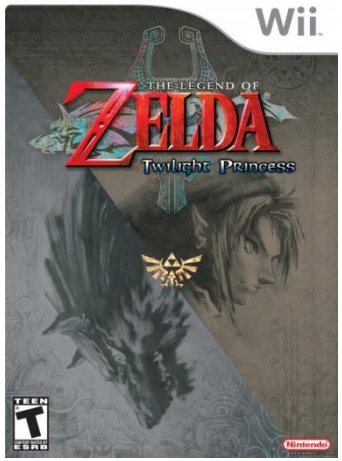
- Measuring forecast accuracy

Qualitative Forecasting Methods (1)

- **Market research**
  - Sets out to collect data in a variety of ways (surveys, interviews, etc.) to test hypothesis about the market
  - Typically used to forecast long-range and new-product sales

Qualitative Forecasting Methods (2)

- **Historical analogy**
  - Ties what is being forecast to an existing product (such as complementary product, substitutable product)
  - Important in planning new products where a forecast may be derived by using the history of a similar product



Qualitative Forecasting Methods (3) and (4)

- **Panel consensus**
  - Free open exchange at meetings
  - The idea is that discussion by the group will produce better forecasts than any one individual
  - Participants may be executives, salespeople or customers

- **Delphi method**
  - Experts respond to questions
  - A moderator compiles results and formulates a new questionnaire which is submitted to the group (perhaps with new set of questions)
  - There is a learning process for the group as it receives new information and there is no influence of group pressure or dominating individuals

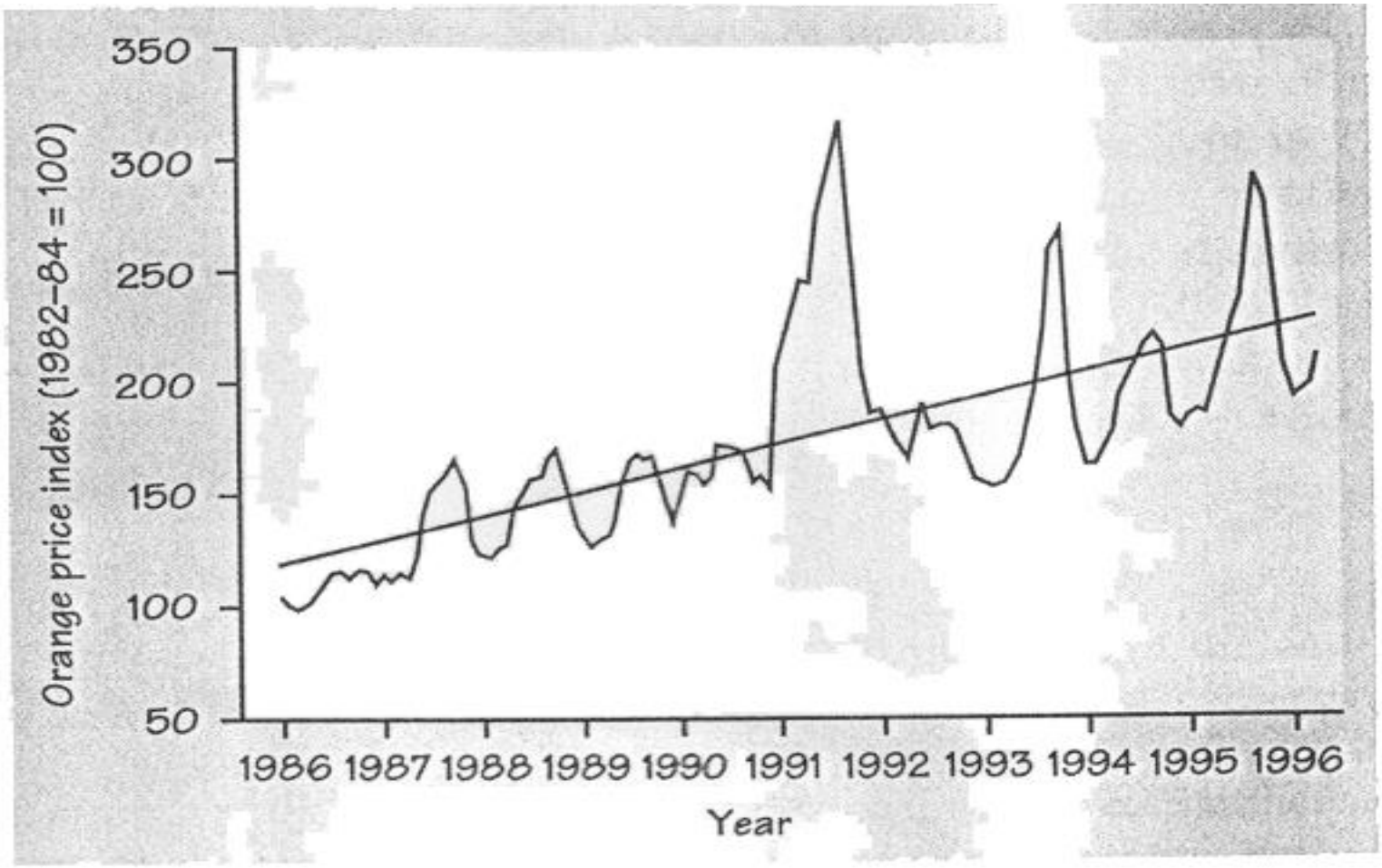
Qualitative Forecasting Methods – Pros and Cons

- Advantage of qualitative forecasting methods
  - Does not require extensive historical data
- Disadvantage of qualitative forecasting methods
  - Subjective
- **When to use?**
  - When historical data are scarce or not available at all
  - Use expert and/or customers opinion to predict future events subjectively
  - Example: sales of new product, environment and technology change over the long term

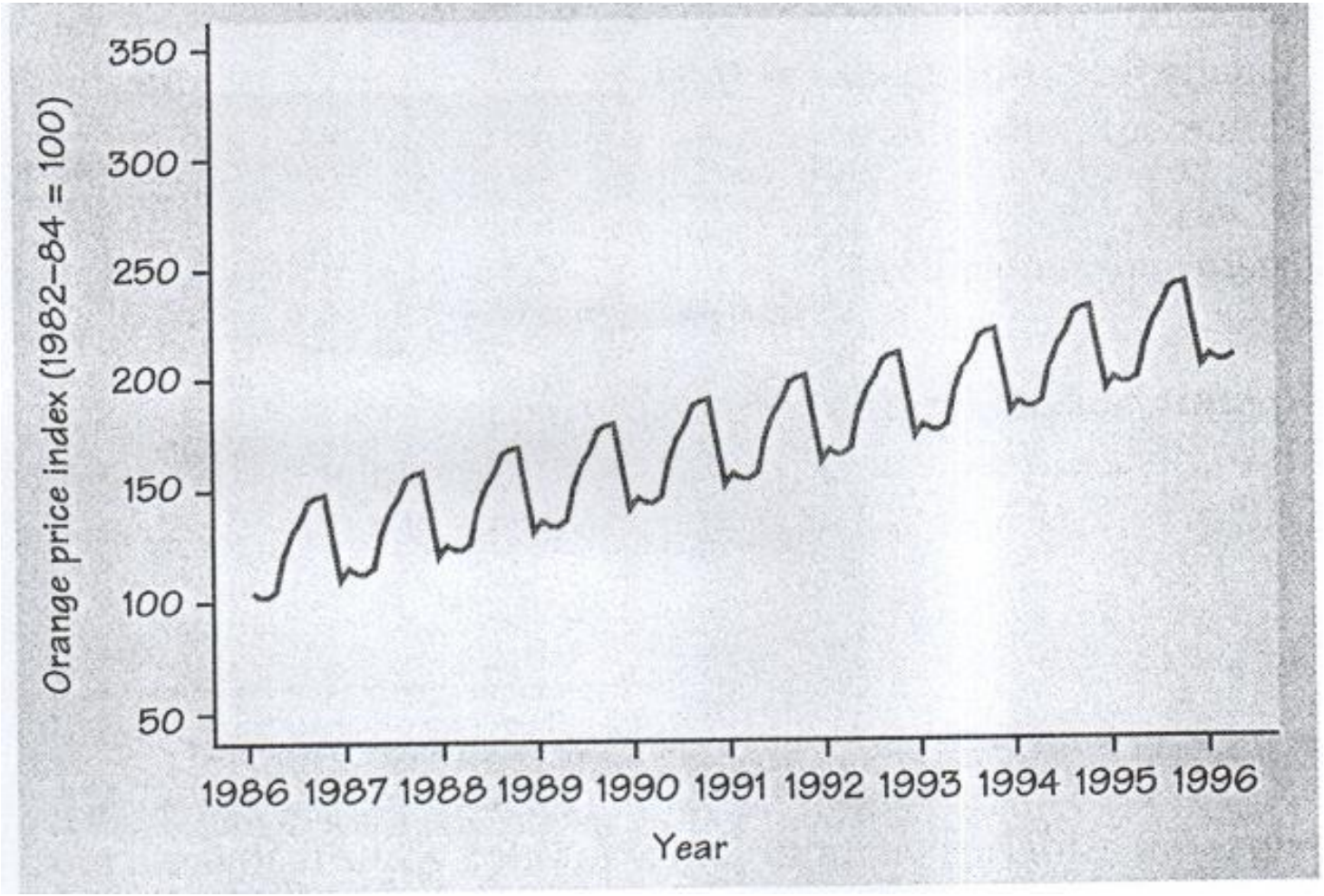
Qualitative method: time series

- Decomposition of time series
  - Trend
  - Seasonality
  - Random variation (noise)
- Assumption: past=> future
- Method
  - Moving (weighted) averages
  - Exponential Smoothing

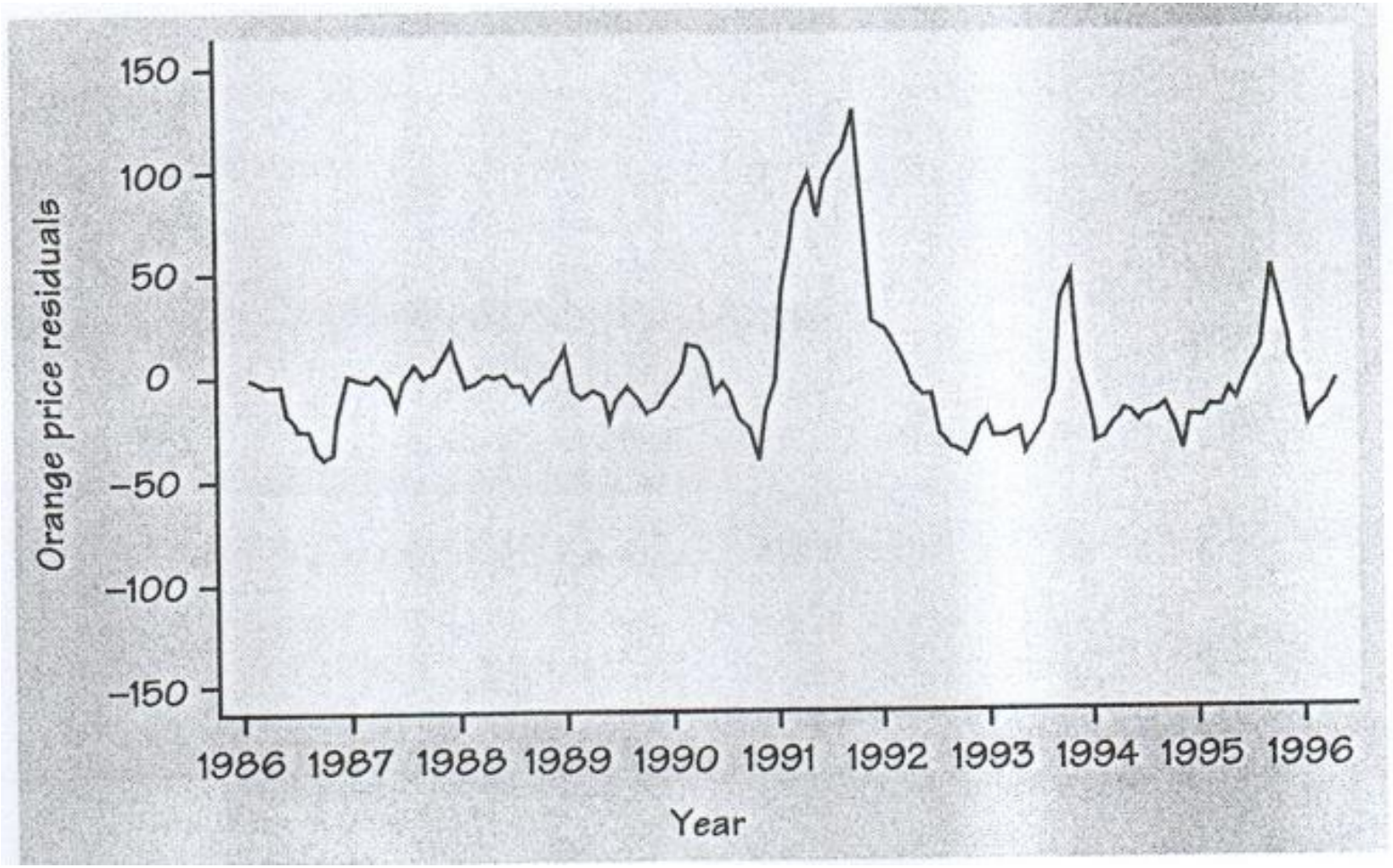
Components of demand: Trend + Random Variation



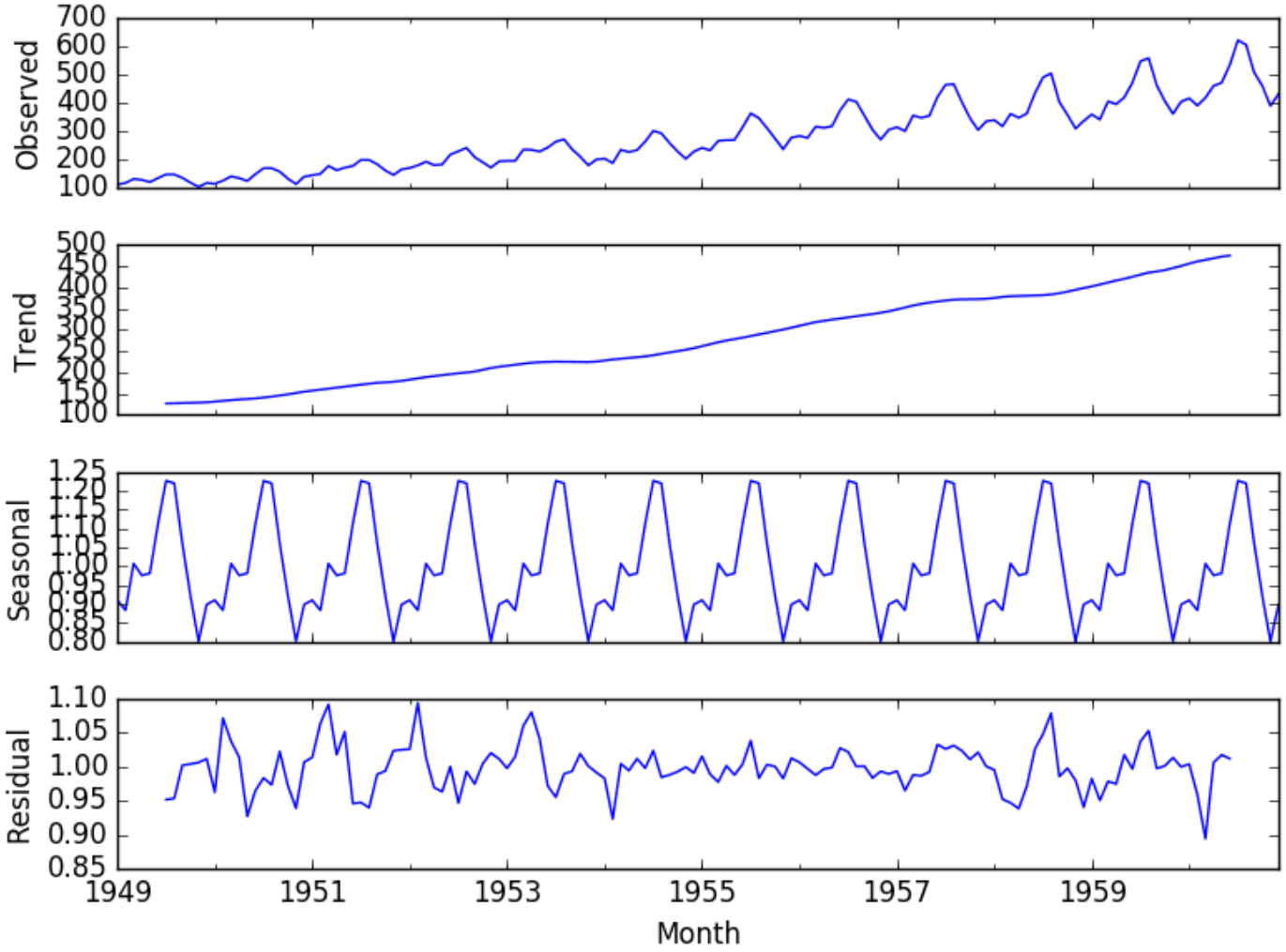
Components of demand: Trend+ Seasonality



Components of demand: Random Variation



Time series decomposition



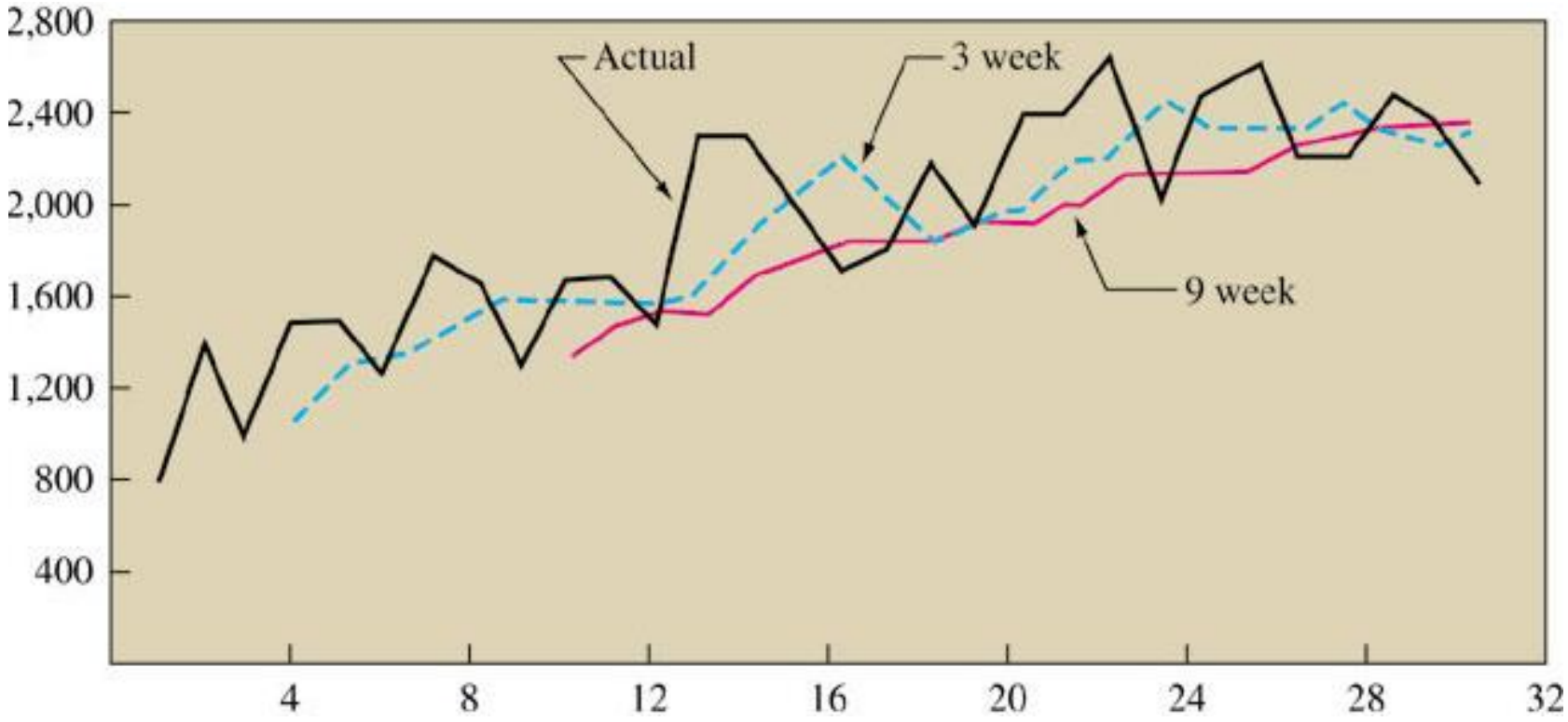
Simple Moving Average

Week	Demand
1	650
2	678
3	720
4	785
5	859
6	920
7	850
8	758
9	892
10	920
11	789
12	844

$$F_t = \frac{A_{t-1} + A_{t-2} + A_{t-3} + \ldots + A_{t-n}}{n}$$

Question: What are the 3-week and 6-week moving average forecasts for demand week 13?

How to choose n?



Weighted Moving Average

- A weighted moving average allows any weights to be placed on each element.
- Model:

$$F_t = w_1 A_{t-1} + w_2 A_{t-2} + \ldots + w_n A_{t-n}$$

$$\sum_{i=1}^{n} w_i = 1$$

- Choosing weights:
  - Most recent data with higher weighting
  - If the data are seasonal, weights should reflect this appropriately
  - Experience and trial and error

Example

- **Question: Given the weekly demand and weights, what is the forecast for the 4th period or Week 4?**

Week	Demand
1	650
2	678
3	720
4	

Weights:
t-1 0.5
t-2 0.3
t-3 0.2

Note that the weights place more emphasis on the most recent data, that is time period "t-1"

Simple vs. Weighted Moving Average

- **Simple Moving Average**
  - A forecast based on average past demand
  - Assign equal importance to each component

- **Weighted Moving Average**
  - A forecast made with past data where more recent data are usually given more significance than older data

- **Major Drawback for both methods**
  - Need to continually carry a large amount of historical data

Exponential Smoothing

- Model: $F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$

Where :

F_t = Demand Forcast for the coming time period

F_{t-1} = Demand forecast in the past time period

A_{t-1} = Actual demand in the past time period

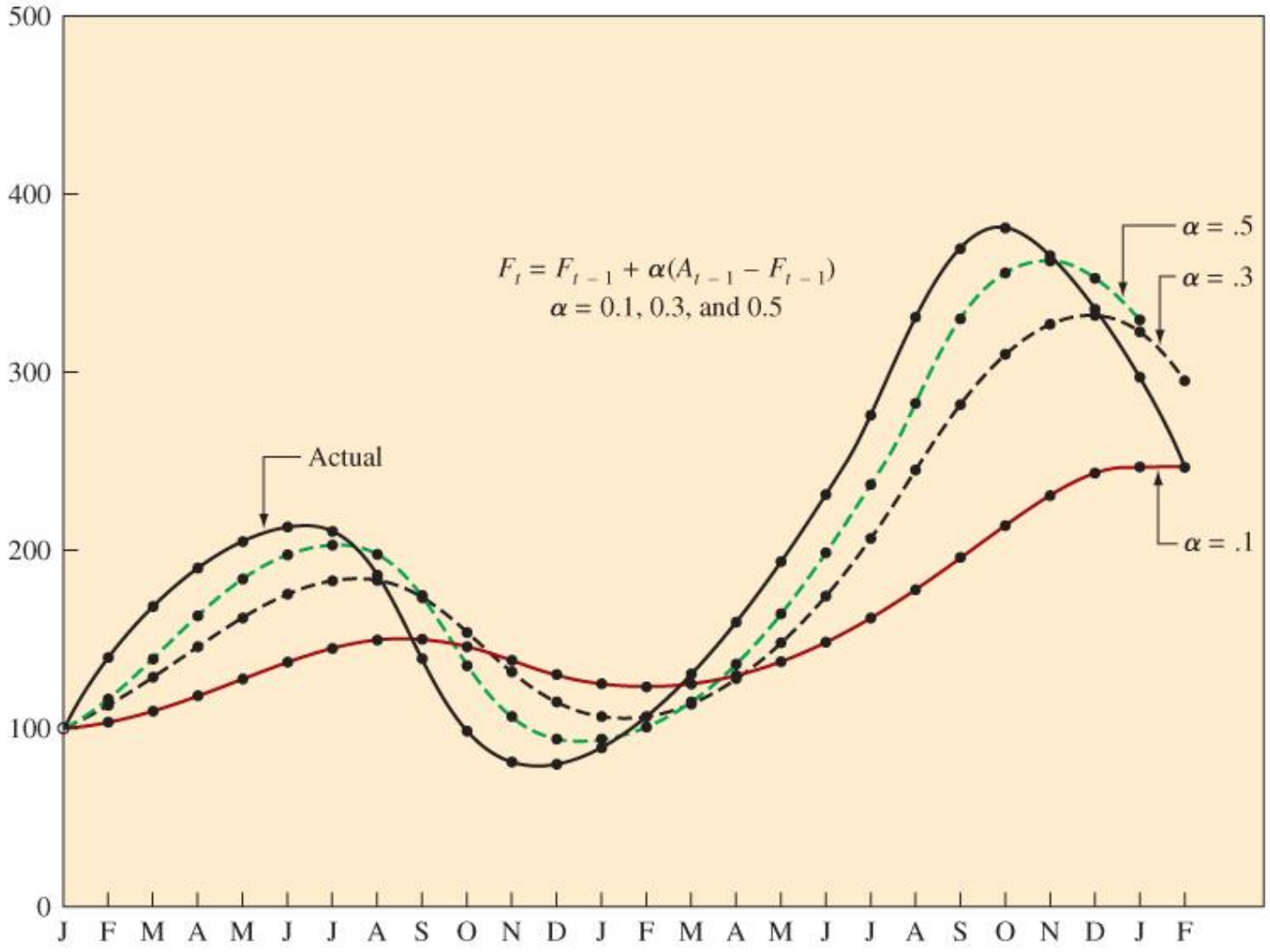
α = Alpha smoothing constant

- Data
  - The most recent forecast
  - The most recent demand
  - A smoothing constant α

Example

- Assume that the last month's forecast was 1050 units
- It turns out that 1000 units were actually demanded
- Assume smoothing constant α=0.05
- Forecast for this month:

Effect of α


500
400
300
200
100
0
$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$
α = 0.1, 0.3, and 0.5
Actual
α = .5
α = .3
α = .1
J F M A M J J A S O N D J F M A M J J A S O N D J F

Does Exponential Smoothing use Distant Data?

$$
\begin{aligned}
F_t &= F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \\
&= (1-\alpha)F_{t-1} + \alpha A_{t-1} \\
&= (1-\alpha)[(1-\alpha)F_{t-2} + \alpha A_{t-2}] + \alpha A_{t-1} \\
&= (1-\alpha)^2 F_{t-2} + \alpha(1-\alpha)A_{t-2} + \alpha A_{t-1} \\
&= (1-\alpha)^3 F_{t-3} + \alpha(1-\alpha)^2 A_{t-3} + \alpha(1-\alpha)A_{t-2} + \alpha A_{t-1}
\end{aligned}
$$

α	Past period	Two periods ago	Three periods ago
0.1	0.1	0.09	0.081
0.5	0.5	0.25	0.125
0.9	0.9	0.09	0.009

Question for student

Given the following sales data, use a simple exponential smoothing model with $\alpha = 0.4$ to update the forecasts. (Assume that the actual sales for month 2 is observed only after making a forecast for that month.)

What is the forecast sales figure (round to the nearest integer) for month 3?

a. 550

b. 555

c. 560

d. 565

e. 570

Month	1	2	3
Actual sales	534	576	
Forecast sales	560		

Qualitative method: linear regression

- Regression: $y \sim f(x)$
- Linear regression: $y = a + bx$
  - Use x to predict y
  - Based on observable data
  - How to estimate a, b
- Using data (x_i, y_i)
  - Plot scatter plot to check linear assumption
  - Get the linear regression estimation
  - Interpret the coefficient as well as the goodness of fit

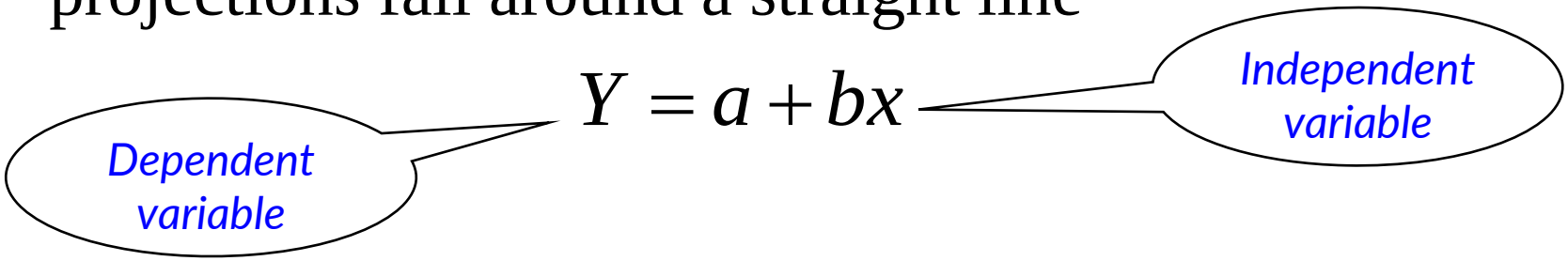
Example: Credit Analysis

- A bank wants to know whether the credit amount is higher for new customers or for old customers

Duration of credit (months): Xi	Credit amount: Yi
6	1169
48	5951
12	2096
42	7882
24	4870
36	9055
24	2835
30	5234

Simple Linear Regression

- Regression
  - identifies the relationship as a function between two or more correlated variables.
- Linear Regression: assumes that past data and future projections fall around a straight line



  - Causal relationship forecasting
  - Time series forecasting

Simple Linear Regression Analysis

- There are n data points: $\{(x_i, y_i): i = 1,\ldots,n\}$
- Minimize **square error**

$$Y = a + bx$$

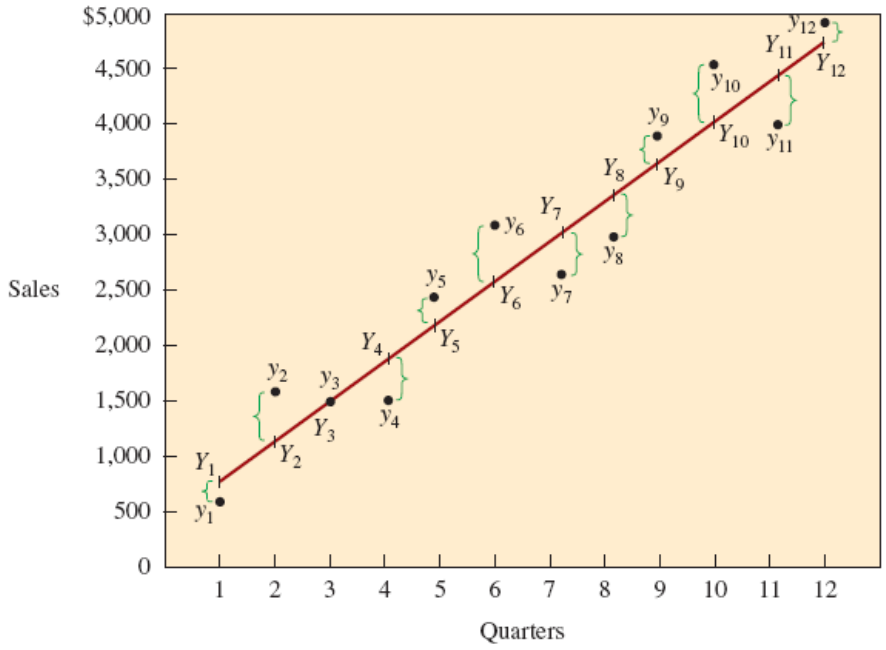
$$\min_{a,b} \sum_{i=1}^{n} (Actual - Forecast)^2$$

$$or \quad \min_{a,b} \sum_{i=1}^{n} [y_i - Y_i]^2 = \sum_{i=1}^{n} [y_i - (a + bx_i)]^2$$

Least Squares Method

- The least squares method **determines the parameters *a* and *b*** such that **the sum of the squared errors is minimized**

$$Sum\ of\ squared\ errors = (y_1 - Y_1)^2 + (y_2 - Y_2)^2 + \cdots + (y_{12} - Y_{12})^2$$



Y_i – *value of the dependent variable computed with the regression equation*

y_i – *dependent variable value at each data point*

Least Squares Method

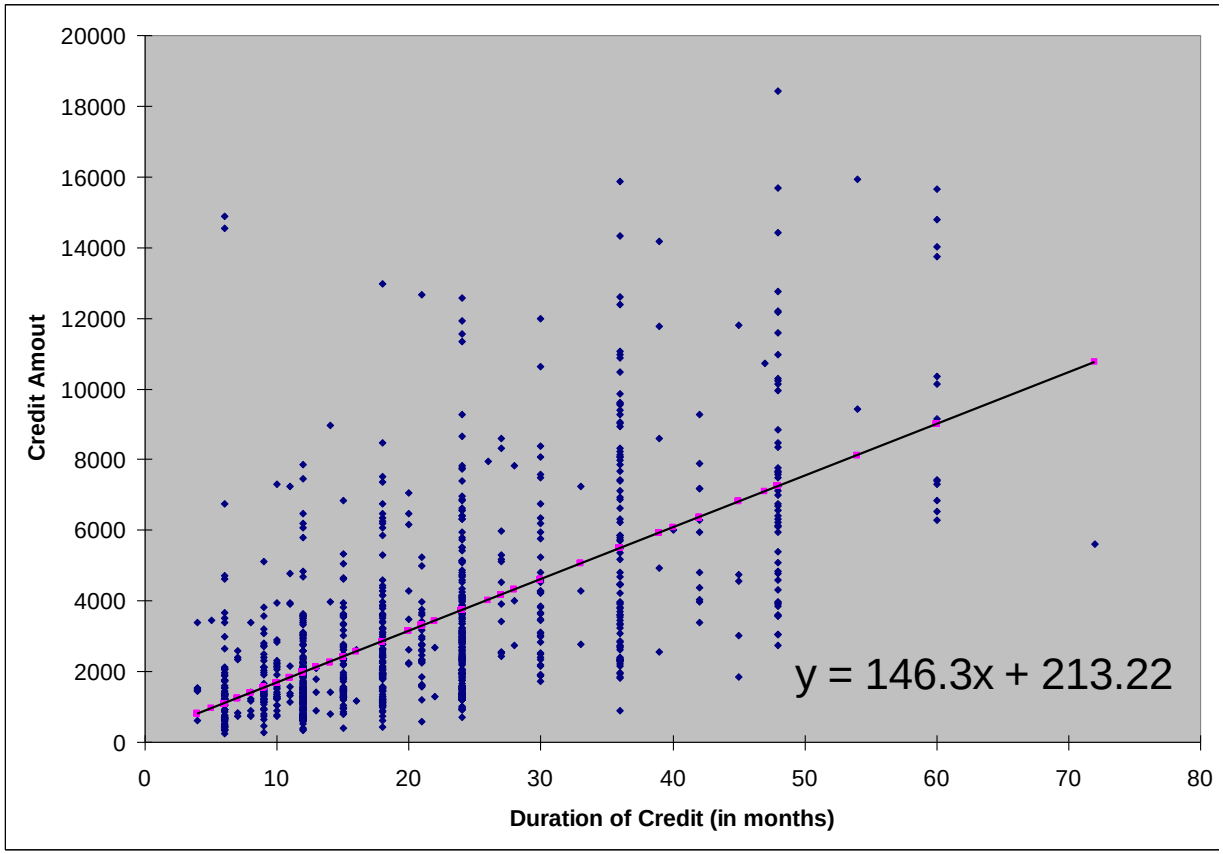
- Optimal Coefficients **a*** and **b*** that minimize the sum of the squared errors:

$$b^* = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}\,\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}$$

$$a^* = \bar{y} - b^*\bar{x}$$

- n data points: $\{(x_i, y_i): i = 1,\ldots,n\}$
- $\bar{x}$: average of x_i
- $\bar{y}$: average of y_i

Example: Credit Analysis (continued)



We can also perform multi-variable linear regression:
Credit Amount = $a + b_1(\text{Duration}) + b_2(\text{Salary}) + b_3(\text{Age})\ldots$

Discussion

- Advantages of Linear Regression

- Disadvantages of Linear Regression

Question for student

An operations management professor wants to use the number of hours a student studies for an operations management final exam (X) to predict the final exam score (Y). Which of the following models should be used?

a. Simple Moving average method
b. Linear regression model
c. Multivariate linear regression model
d. Weighted moving average method
e. Exponential smoothing

Measuring Forecast Accuracy

You are a marketing analyst for McDonalds and have the following sales forecasts ($M) using two methods.

Month	Actual Demand	Method 1 Forecast	Method 2 Forecast
1	100	60	100
2	100	130	100
3	200	200	150
4	200	270	200
5	400	340	250

Measuring Forecast Accuracy

- Forecast error is the difference between the actual value and the predicted value
  - **Error = Actual – Forecast**

Measures the average magnitude of forecast errors

- Mean absolute deviation (MAD)
  - **MAD = $\sum_{i=1}^{n}$ |Actual – Forecast| / n**

Measures the bias of the forecast

- **Tracking signal**: ratio of cumulative error and MAD
  - **TS = $\sum_{i=1}^{n}(Actual - Forecast) / MAD^{n}$**

Method 1: Tracking signal

Month	Actual	Forecast	Error	∑|Error|	MAD	∑(Error)	TS
1	100	60					
2	100	130					
3	200	200					
4	200	270					
5	400	340					

Error = Actual – Forecast MAD = ∑|Error| / n TS = ∑(Error) / MAD

Method 1: Tracking signal

Month	Actual	Forecast	Error	∑|Error|	MAD	∑(Error)	TS
1	100	60	40	40	40	40	**1.00**
2	100	130	-30	70	35	10	**0.29**
3	200	200	0	70	23	10	**0.43**
4	200	270	-70	140	35	-60	**-1.71**
5	400	340	60	200	40	0	**0.00**

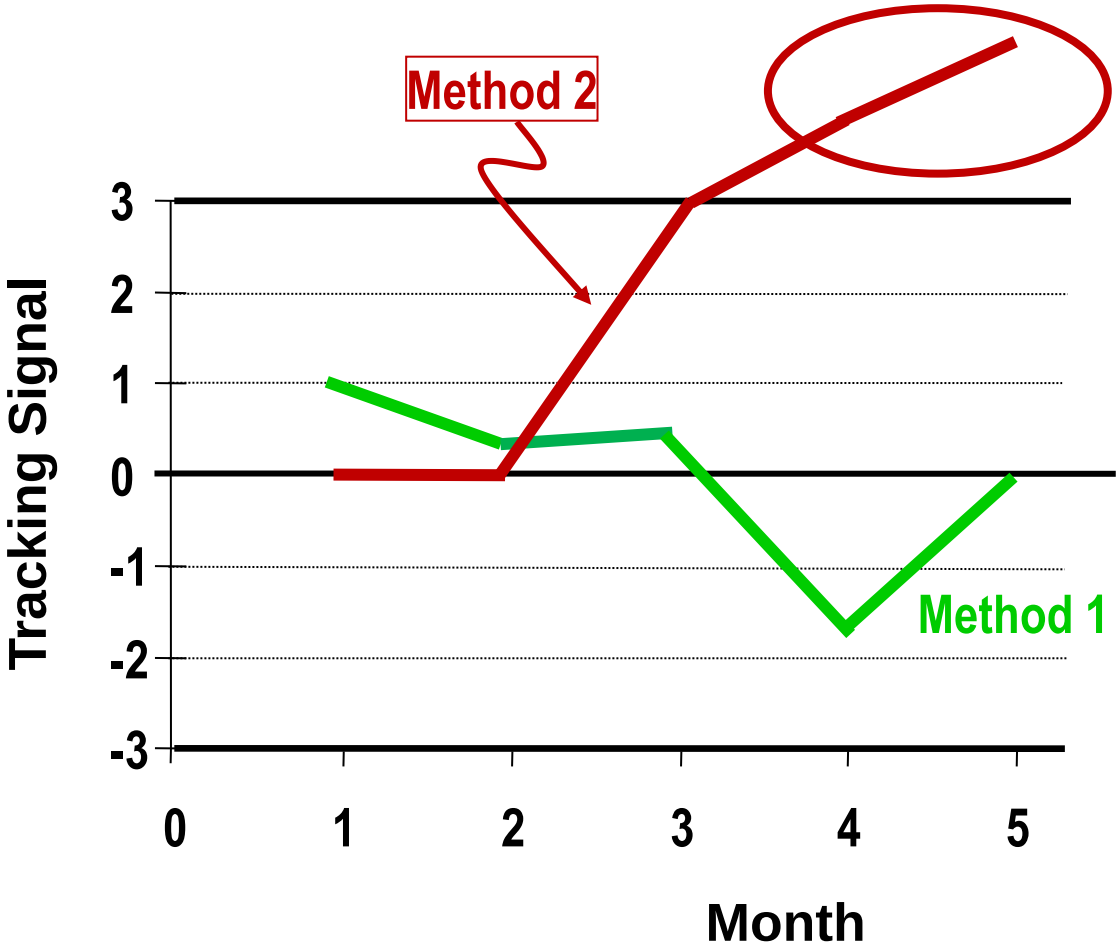
Error = Actual – Forecast MAD = ∑|Error| / n TS = ∑(Error) / MAD

Method 2: Tracking signal

Month	Actual	Forecast	Error	∑|Error|	MAD	∑(Error)	TS
1	100	100					
2	100	100					
3	200	150					
4	200	200					
5	400	250					

Error = Actual – Forecast MAD = ∑|Error| / n TS = ∑(Error) / MAD

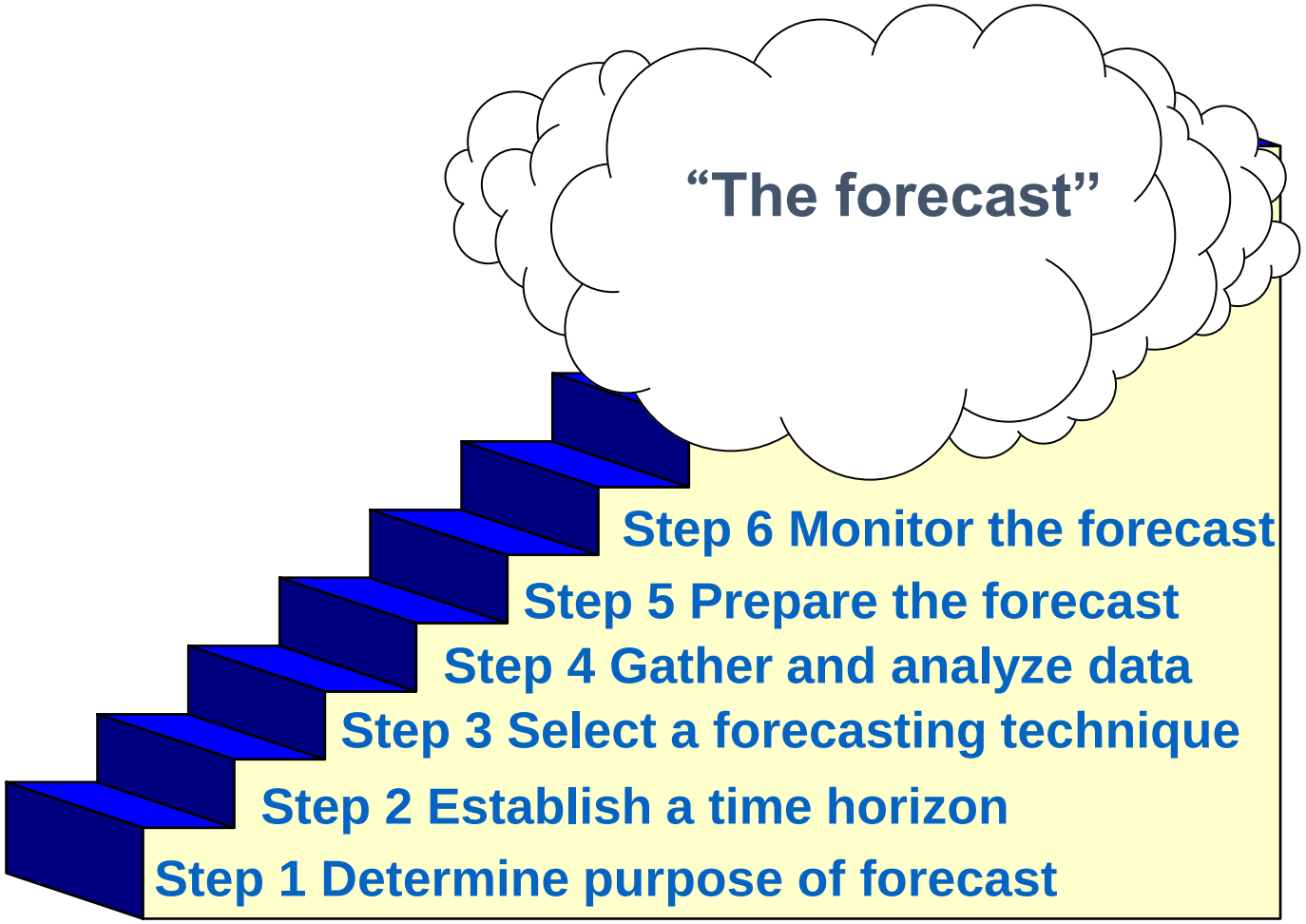
Interpreting tracking signals



Actual exceeds forecast

Actual is less than forecast

Forecasting process



Summary

- Demand forecasting
  - Why?
- Qualitative forecasting
- Quantitative forecasting method
  - Simple and weighted averages, exponential smoothing
  - Linear regression
  - Accuracy measures