Production Management

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Production/manufacturing is the process of converting raw materials or semi-finished products into finished products that have value in the market place. This process involves the contribution of labor, equipment, energy, and information.
The Production System

- Raw materials
- Energy
- Labor
- Equipment
- Information

Production System

- Finished products
- Scrap
- Waste
Production Management

Production management is focus on managing production operations and resources throughout the production system.
Example Performance Measures

Cost (are products being created at minimum or acceptable cost?)

Quality (what are the specifications of the products? What percentages of shipped products meet specification?)

Variety (how many types of products are - or can be - simultaneously produced?)

Service (how long does it take to fulfill a customer order? how often are quoted lead times met?)

Flexibility (how quickly can existing resources be reconfigured to produce new products?)
Process capabilities & business strategy

- Example product attributes: price, quality, variety, service, demand uncertainty

- Example process attributes: cost, quality, flexibility, lead time
Value-Added/Production Control

- The difference between the cost of inputs and the value or price of outputs.
Example Decisions

- What should we produce, how much, and when (forecasting)?
- How much can we produce (capacity planning)?
- How much do we have and how much do we need (inventory management)?
- When should we produce (production planning and scheduling)?
Cycle of Production System

- Forecast
- Aggregate Production Plan
- Master Production Schedule
- Material Requirements Plan
- Inventory Record
- Bills of Materials
- Purchase Orders
- Manufacturing Orders
- Scheduling
- Demand
- Orders
- Resource Capacity Planning
- Rough-cut Capacity Planning
- Capacity Requirements Planning
Forecasts

- A statement about the future

- Used to help managers
  - Plan the system
# Uses of Forecasts

<table>
<thead>
<tr>
<th>Department</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounting</td>
<td>Cost/profit estimates</td>
</tr>
<tr>
<td>Finance</td>
<td>Cash flow and funding</td>
</tr>
<tr>
<td>Human Resources</td>
<td>Hiring/recruiting/training</td>
</tr>
<tr>
<td>Marketing</td>
<td>Pricing, promotion, strategy</td>
</tr>
<tr>
<td>MIS</td>
<td>IT/IS systems, services</td>
</tr>
<tr>
<td>Operations</td>
<td>Schedules, MRP, workloads</td>
</tr>
<tr>
<td>Product/service design</td>
<td>New products and services</td>
</tr>
</tbody>
</table>
Assumes causal system
past ==> future

Forecasts rarely perfect because of randomness

Forecasts more accurate for groups vs. individuals

Forecast accuracy decreases as time horizon increases
Steps in the Forecasting Process

- Step 1 Determine purpose of forecast
- Step 2 Establish a time horizon
- Step 3 Select a forecasting technique
- Step 4 Gather and analyze data
- Step 5 Prepare the forecast
- Step 6 Monitor the forecast
Types of Forecasts

- **Judgmental** - uses subjective inputs
- **Time series** - uses historical data assuming the future will be like the past
- **Associative models** - uses explanatory variables to predict the future
Forecasting Approaches

**Qualitative Methods**
- Used when situation is vague & little data exist
  - New products
  - New technology
- Involves intuition, experience
  - e.g., forecasting sales on Internet

**Quantitative Methods**
- Used when situation is ‘stable’ & historical data exist
  - Existing products
  - Current technology
- Involves mathematical techniques
  - e.g., forecasting sales of color televisions
Judgmental Forecasts

- Executive opinions
- Sales force composite
- Consumer surveys
- Outside opinion
- Opinions of managers and staff
  - Delphi method
Overview of Quantitative Approaches

- Naïve approach
- Moving averages
- Exponential smoothing
- Trend projection

Time-series Models

- Linear regression

Causal models
Quantitative Forecasting Methods (Non-Naive)

- Quantitative Forecasting
  - Time Series Models
    - Moving Average
    - Exponential Smoothing
  - Causal Models
    - Trend Projection
    - Linear Regression
Example of forecasting

Forecasting using linear trend. Demonstration

<table>
<thead>
<tr>
<th>Week</th>
<th>Number of library visitors</th>
<th>1. Calculating correlation: 0.995741</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1063</td>
<td>Significant correlation</td>
</tr>
<tr>
<td>2</td>
<td>2369</td>
<td>2. Plotting a chart (XY scatter)</td>
</tr>
<tr>
<td>3</td>
<td>3159</td>
<td>3. Adding a linear trend line</td>
</tr>
<tr>
<td>4</td>
<td>3964</td>
<td>Options: display equation</td>
</tr>
<tr>
<td>5</td>
<td>5001</td>
<td>4. Calculating the forecast</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>(by inserting number of the week x=6 into the equation)</td>
</tr>
</tbody>
</table>

Forecasted number of visitors: 5953

Very good fitting

![Chart showing number of library visitors over weeks with linear trend line and equation: y = 947.1x + 269.9, R^2 = 0.9915]
What is a Time Series?

- Set of evenly spaced numerical data
  - Obtained by observing response variable at regular time periods

- Forecast based only on past values
  - Assumes that factors influencing past, present, & future will continue

Example

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>78.7</td>
<td>63.5</td>
<td>89.7</td>
<td>93.2</td>
<td>92.1</td>
</tr>
</tbody>
</table>
Patterns of the time-series data

A forecasting method should comply with the data pattern. There are 4 basic data patterns:

- Horizontal (random, irregular variation)
- Trend (linear)
- Periodical (cyclical, seasonal)
- Complex (a combination of part or all listed above)
Forecast Variations

- Irregular variation
- Trend
- Seasonal variations
  - 90
  - 89
  - 88
Trend Component

- Persistent, overall upward or downward pattern
- Due to population, technology etc.
- Several years duration

Response

Mo., Qtr., Yr.
Cyclical Component

- Repeating up & down movements
- Due to interactions of factors influencing economy
- Usually 2-10 years duration

Graph showing cyclical component with terms 'Cycle', 'Response', 'Mo., Qtr., Yr.'
Seasonal Component

- Regular pattern of up & down fluctuations
- Due to weather, customs etc.
- Occurs within 1 year
Random Component

- Erratic, unsystematic, ‘residual’ fluctuations
- Due to random variation or unforeseen events
  - Union strike
  - Tornado
- Short duration & nonrepeating
Components of an observation

Observed demand (O) = Systematic component (S) + Random component (R)

Level (current deseasonalized demand)

Trend (growth or decline in demand)

Seasonality (predictable seasonal fluctuation)
General Time Series Models

- Any observed value in a time series is the product (or sum) of time series components

- Multiplicative model
  \[ Y_i = T_i \cdot S_i \cdot C_i \cdot R_i \] (if quarterly or mo. data)

- Additive model
  \[ Y_i = T_i + S_i + C_i + R_i \] (if quarterly or mo. data)
Techniques for Averaging

- Moving average
- Weighted moving average
- Exponential smoothing
Main idea of the method

The moving average uses the average of a given number of the most recent periods' value to forecast the value for the next period.

Moving average smoothes down the fluctuations in the data
Smoothing

Smoothing the data variation: a graphical presentation

- Data
- Smoothed data
- Moore smoothed data
A formula for the Moving Average

If forecast for t period is denoted by $F_t$, and the actual value of the time-series was $A_{t-1}$ during period t-1, $A_{t-2}$ during period t-2, etc., then n period simple moving average is expressed as:

$$F_t = (A_{t-1} + A_{t-2} + \ldots A_{t-n}) / n$$
## Calculation of a moving average: an Example

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of clients</th>
<th>Moving average (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>April</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>May (forecast)</td>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>
Choosing the averaging period

The averaging period (value of n) must be determined by the decision-maker. It is important to try to select the best period to use for the moving average.

As a general rule, the number of periods used should relate to the amount of random variability in the data.

Specifically, the bigger the moving average period, the greater the random elements are smoothed.
Evaluation of MA

- Advantage: very simple method.
- Shortcomings:
- The new and the old data are treated in the same way (while, in fact, the old data should be treated as less being significant). (Method of exponential smoothing does not have this shortcoming).
Modification of Moving Average method

Weighted Moving Average:

Simple moving average technique assigns equal weights to each period of historical data; the weighted moving average technique assigns different weights to historical data allowing the model to respond quickly to any shift in the series being studied.
Weighted Moving Average Method

- Used when trend is present
  - Older data usually less important
- Weights based on intuition
  - Often lay between 0 & 1, & sum to 1.0

Equation

\[ \text{WMA} = \frac{(\text{Weight for period n}) \times (\text{Demand in period n})}{\text{Weights}} \]
Disadvantages of Moving Average Method

- Increasing $n$ makes forecast less sensitive to changes
- Do not forecast trend well
- Require much historical data

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Exponential Smoothing

\[ F_t = F_{t-1} + \alpha (A_{t-1} - F_{t-1}) \]

- Main idea of the method: smoothing down variations in the data. Forecast error for the previous period is taken into account.

- **Premise**--The most recent observations might have the highest predictive value.

  Therefore, we should give more weight to the more recent time periods when forecasting.
Exponential Smoothing Method

- Form of weighted moving average
  - Weights decline exponentially
  - Most recent data weighted most
- Requires smoothing constant (\( \theta \))
  - Ranges from 0 to 1
  - Subjectively chosen
- Involves little record keeping of past data
Exponential Smoothing Equations

\[ F_t = \beta \cdot A_{t-1} + (1-\beta) \cdot A_{t-2} + (1-\beta)^2 \cdot A_{t-3} + (1-\beta)^3 \cdot A_{t-4} + \ldots + (1-\beta)^{t-1} \cdot A_0 \]

- \( F_t \) = Forecast value
- \( A_t \) = Actual value
- \( \beta \) = Smoothing constant

\[ F_t = F_{t-1} + \beta \cdot (A_{t-1} - F_{t-1}) \]

- Use for computing forecast
**Exponential Smoothing Example**

You’re organizing a Kwanza meeting. You want to forecast attendance for 1998 using exponential smoothing ($\alpha = .10$). The 1993 forecast was 175.

<table>
<thead>
<tr>
<th>Year</th>
<th>Attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>180</td>
</tr>
<tr>
<td>1994</td>
<td>168</td>
</tr>
<tr>
<td>1995</td>
<td>159</td>
</tr>
<tr>
<td>1996</td>
<td>175</td>
</tr>
<tr>
<td>1997</td>
<td>190</td>
</tr>
</tbody>
</table>
### Exponential Smoothing Solution

The formula for exponential smoothing is given by:

\[ F_t = F_{t-1} + a \cdot (A_{t-1} - F_{t-1}) \]

where:
- \( F_t \) is the forecast for time period \( t \)
- \( F_{t-1} \) is the previous forecast
- \( A_{t-1} \) is the actual value for time period \( t-1 \)
- \( a \) is the smoothing factor

For \( a = 0.10 \), the forecast values are calculated as follows:

<table>
<thead>
<tr>
<th>Time</th>
<th>Actual</th>
<th>Forecast, ( F_t ) (Given)</th>
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<tbody>
<tr>
<td>1993</td>
<td>180</td>
<td>175.00 (Given)</td>
</tr>
<tr>
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<td>168</td>
<td>175.00 +</td>
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<tr>
<td>1995</td>
<td>159</td>
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Exponential Smoothing Solution

\[ F_t = F_{t-1} + a \cdot (A_{t-1} - F_{t-1}) \]

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\[ F_t = F_{t-1} + a \cdot (A_{t-1} - F_{t-1}) \]

(a = 0.10)

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<td>175.50 + .10(168 - 175.50) = 174.75</td>
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<td></td>
</tr>
<tr>
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</tr>
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<td>159</td>
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</tr>
<tr>
<td>1996</td>
<td>175</td>
<td>174.75 + .10(159 - 174.75) = 173.18</td>
</tr>
<tr>
<td>1997</td>
<td>190</td>
<td>NA</td>
</tr>
<tr>
<td>1998</td>
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\[ F_t = F_{t-1} + a \cdot (A_{t-1} - F_{t-1}) \]

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<tr>
<td>1996</td>
<td>175</td>
<td>174.75 + .10(159 - 174.75) = 173.18</td>
</tr>
<tr>
<td>1997</td>
<td>190</td>
<td>173.18 + .10(175 - 173.18) = 173.36</td>
</tr>
<tr>
<td>1998</td>
<td>NA</td>
<td></td>
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# Exponential Smoothing Solution

\[ F_t = F_{t-1} + a \cdot (A_{t-1} - F_{t-1}) \]

| Time | Actual | Forecast, \( F_t \)  
<table>
<thead>
<tr>
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</tr>
<tr>
<td>1997</td>
<td>190</td>
<td>173.18 + .10(175 - 173.18) = 173.36</td>
</tr>
<tr>
<td>1998</td>
<td>NA</td>
<td>173.36 + .10(190 - 173.36) = 175.02</td>
</tr>
</tbody>
</table>
Exponential Smoothing Graph

Sales

Year

Actual

Forecast

190
180
170
160
150
140

93 94 95 96 97 98
Forecast Effects of Smoothing Constant?

\[ F_t = a \cdot A_{t-1} + a \cdot (1-a) \cdot A_{t-2} + a \cdot (1-a)^2 \cdot A_{t-3} + \ldots \]

<table>
<thead>
<tr>
<th>a is...</th>
<th>Prior Period</th>
<th>Weight 2 Periods Ago</th>
<th>Weight 3 Periods Ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>a</td>
<td>a (1- a )</td>
<td>a (1- a )^2</td>
</tr>
<tr>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
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Forecast Effects of Smoothing Constant?

\[ F_t = a \cdot A_{t-1} + a \cdot (1-a) \cdot A_{t-2} + a \cdot (1-a)^2 \cdot A_{t-3} + \ldots \]

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<th>3 Periods Ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>10%</td>
<td></td>
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<tr>
<td>0.90</td>
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Forecast Effects of Smoothing Constant

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<tbody>
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<td>a</td>
<td>a</td>
<td>a (1-a)</td>
<td>a (1-a)^2</td>
</tr>
<tr>
<td>0.10</td>
<td>10%</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Forecast Effects of Smoothing Constant?

\[ F_t = a \cdot A_{t-1} + a \cdot (1-a) \cdot A_{t-2} + a \cdot (1-a)^2 \cdot A_{t-3} + ... \]

<table>
<thead>
<tr>
<th>a is...</th>
<th>Prior Period</th>
<th>Weight 2 Periods Ago</th>
<th>Weight 3 Periods Ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>a</td>
<td>a (1- a )</td>
<td>a (1- a )^2</td>
</tr>
<tr>
<td>0.10</td>
<td>10%</td>
<td>9%</td>
<td>8.1%</td>
</tr>
<tr>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Forecast Effects of Smoothing Constant?

\[ F_t = a \cdot A_{t-1} + a \cdot (1-a) \cdot A_{t-2} + a \cdot (1-a)^2 \cdot A_{t-3} + \ldots \]

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<thead>
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<th>3 Periods Ago</th>
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<td>8.1%</td>
</tr>
<tr>
<td>0.90</td>
<td>90%</td>
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Forecast Effects of Smoothing Constant?

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</tr>
</thead>
<tbody>
<tr>
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<td>a (1-a)</td>
<td>a (1-a)^2</td>
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<td>10%</td>
<td>9%</td>
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<td>9%</td>
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Forecast Effects of Smoothing Constant?

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<td>a (1- a )</td>
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<tr>
<td>0.90</td>
<td>90%</td>
<td>9%</td>
<td>0.9%</td>
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</tbody>
</table>
Example of Exponential Smoothing

<table>
<thead>
<tr>
<th>Period</th>
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<th>Alpha = 0.1</th>
<th>Error</th>
<th>Alpha = 0.4</th>
<th>Error</th>
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<tr>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>40</td>
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<td>42</td>
<td>-2</td>
</tr>
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<td>3</td>
<td>43</td>
<td>41.8</td>
<td>1.20</td>
<td>41.2</td>
<td>1.8</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>41.92</td>
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<td>-1.92</td>
</tr>
<tr>
<td>5</td>
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<td>-0.73</td>
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<td>-0.15</td>
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<td>-2.66</td>
<td>41.09</td>
<td>-2.09</td>
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<td>4.61</td>
<td>40.25</td>
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<td>44</td>
<td>41.85</td>
<td>2.15</td>
<td>42.55</td>
<td>1.45</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
<td>42.07</td>
<td>2.93</td>
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<td>1.87</td>
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<td>-5.88</td>
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<td>-1.53</td>
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<td>41.73</td>
<td></td>
<td></td>
<td>40.92</td>
<td></td>
</tr>
</tbody>
</table>
Picking a Smoothing Constant

![Graph showing demand over periods with a line indicating actual values. The graph has a y-axis labeled 'Demand' with values ranging from 35 to 50, and an x-axis labeled 'Period' with values from 1 to 12. There is a line labeled 'Actual' showing the trend of the demand over time. The graph also includes a few marked points with related numbers.]
Choosing?

Seek to minimize the Mean Absolute Deviation (MAD)

If: Forecast error = demand - forecast

Then: MAD = \frac{\sum |\text{forecast errors}|}{n}$
Main idea of the trend analysis forecasting method

Main idea of the method: a forecast is calculated by inserting a time value into the regression equation. The regression equation is determined from the time-series data using the “least squares method”
Prerequisites: 1. Data pattern: Trend

Trend (close to the linear growth)
The trend line is the “best-fit” line: an example

\[ Y_i = a + b \, X_i + \text{Error} \]

Regression line

\[ \hat{Y}_i = a + b \, X_i \]

Observed value
Linear Regression Model

- Shows linear relationship between dependent & explanatory variables
- Example: Sales & advertising (not time)

\[ \hat{Y}_i = a + b \times X_i \]

Dependent (response) variable \quad Independent (explanatory) variable
Linear Regression Equations

Equation: \( \hat{Y}_i = a + bx_i \)

Slope: \( b = \frac{\sum_{i=1}^{n} x_i y_i - n \bar{x} \bar{y}}{\sum_{i=1}^{n} x_i^2 - n \bar{x}^2} \)

Y-Intercept: \( a = \bar{y} - b \bar{x} \)
Statistical measures of goodness of fit

In trend analysis the following measures will be used:

- The Correlation Coefficient
- The Determination Coefficient
Prerequisites: 2. Correlation

There should be a sufficient correlation between the time parameter and the values of the time-series data
The Correlation Coefficient

The correlation coefficient, $R$, measure the strength and direction of linear relationships between two variables. It has a value between $-1$ and $+1$.

A correlation near zero indicates little linear relationship, and a correlation near one indicates a strong linear relationship between the two variables.
Coefficient of Correlation and Regression Model

$r = 1$

$Y = a + b X_i$

$r = -1$

$Y_i = a + b X_i$

$r = 0.89$

$Y_i = a + b X_i$

$r = 0$

$Y_i = a + b X_i$
Sample Coefficient of Correlation

\[
r = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - \left(\sum x_i\right)^2} \sqrt{n \sum y_i^2 - \left(\sum y_i\right)^2}}
\]
Non-linear trends

Excel provides easy calculation of the following trends

- Logarythmic
- Polynomial
- Power
- Exponential
Logarithmic trend

\[ y = 4.6613 \ln(x) + 1.0724 \]

\[ R^2 = 0.9963 \]
Trend (power)

\[ y = 0.4826x^{1.5097} \]

\[ R^2 = 0.9919 \]
Trend (exponential)

\[ y = 0.0509e^{1.0055x} \]

\[ R^2 = 0.9808 \]
Trend (polynomial)

\[ y = -0.1142x^3 + 1.6316x^2 - 5.9775x + 7.7564 \]

\[ R^2 = 0.9975 \]
Choosing the trend that fits best

1) Roughly: Visually, comparing the data pattern to the one of the 5 trends (linear, logarithmic, polynomial, power, exponential)

2) In a detailed way: By means of the determination coefficient
Guidelines for Selecting Forecasting Model

You want to achieve:

∑ No pattern or direction in forecast error
   ∑ Error = (Y_i - \hat{Y}_i) = (Actual - Forecast)
   ∑ Seen in plots of errors over time
∑ Smallest forecast error
   ∑ Mean square error (MSE)
   ∑ Mean absolute deviation (MAD)
Pattern of Forecast Error

Trend Not Fully Accounted for

Desired Pattern

Error

Time (Years)

Error

Time (Years)
Forecast Error Equations

Mean Square Error (MSE)

\[ \text{MSE} = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = \frac{\sum \text{(forecast errors)}^2}{n} \]

Mean Absolute Deviation (MAD)

\[ \text{MAD} = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y}_i| = \frac{\sum |\text{forecast errors}|}{n} \]
You’re a marketing analyst for Hasbro Toys. You’ve forecast sales with a linear model & exponential smoothing. Which model do you use?

<table>
<thead>
<tr>
<th>Year</th>
<th>Actual Sales</th>
<th>Linear Model Forecast</th>
<th>Exponential Smoothing Forecast (.9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>1</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>1993</td>
<td>1</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>1994</td>
<td>2</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>1995</td>
<td>2</td>
<td>2.7</td>
<td>2.0</td>
</tr>
<tr>
<td>1996</td>
<td>4</td>
<td>3.4</td>
<td>3.8</td>
</tr>
</tbody>
</table>
## Linear Model Evaluation

| Year | $Y_i$ | $\hat{Y}_i$ | Error | Error$^2$ | $|\text{Error}|$ |
|------|------|-------------|-------|-----------|-----------------|
| 1992 | 1    | 0.6         | 0.4   | 0.16      | 0.4             |
| 1993 | 1    | 1.3         | -0.3  | 0.09      | 0.3             |
| 1994 | 2    | 2.0         | 0.0   | 0.00      | 0.0             |
| 1995 | 2    | 2.7         | -0.7  | 0.49      | 0.7             |
| 1996 | 4    | 3.4         | 0.6   | 0.36      | 0.6             |
| Total|      |             | 0.0   | 1.10      | 2.0             |
# Linear Model Evaluation

| Year | $Y_i$ | $\hat{Y}_i$ | Error | $\text{Error}^2$ | $|\text{Error}|$ |
|------|-------|-------------|-------|-----------------|----------------|
| 1992 | 1     | 0.6         | 0.4   | 0.16            | 0.4            |
| 1993 | 1     | 1.3         | -0.3  | 0.09            | 0.3            |
| 1994 | 2     | 2.0         | 0.0   | 0.00            | 0.0            |
| 1995 | 2     | 2.7         | -0.7  | 0.49            | 0.7            |
| 1996 | 4     | 3.4         | 0.6   | 0.36            | 0.6            |
| Total|       |             | 0.0   | 1.10            | 2.0            |

\[ \text{MSE} = \frac{\sum \text{Error}^2}{n} = \frac{1.10}{5} = .220 \]

\[ \text{MAD} = \frac{\sum |\text{Error}|}{n} = \frac{2.0}{5} = .400 \]
## Exponential Smoothing Model Evaluation

| Year | $Y_i$ | $\hat{Y}_i$ | Error | $\text{Error}^2$ | $|\text{Error}|$ |
|------|-------|-------------|-------|-----------------|----------------|
| 1992 | 1     | 1.0         | 0.0   | 0.00            | 0.0            |
| 1993 | 1     | 1.0         | 0.0   | 0.00            | 0.0            |
| 1994 | 2     | 1.9         | 0.1   | 0.01            | 0.1            |
| 1995 | 2     | 2.0         | 0.0   | 0.00            | 0.0            |
| 1996 | 4     | 3.8         | 0.2   | 0.04            | 0.2            |
| Total|       |             | 0.3   | 0.05            | 0.3            |

\[
\text{MSE} = \frac{\sum \text{Error}^2}{n} = \frac{0.05}{5} = 0.01
\]
\[
\text{MAD} = \frac{\sum |\text{Error}|}{n} = \frac{0.3}{5} = 0.06
\]
# Exponential Smoothing

**Microsoft Excel - T3-2.xls**

<table>
<thead>
<tr>
<th>Period</th>
<th>Data</th>
<th>Forecast</th>
<th>Error</th>
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</table>

**Alpha = 0.40**  
**MAD = 4.62**  
**MSE = 34.44**

![Graph showing data and forecast](image)
### Linear Trend Equation

**T3-3: Linear Trend Equation**

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<td>18</td>
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</tbody>
</table>

**Excel Output**

- **Slope** = 1.7500
- **MAD** = 1.86
- **Intercept** = 45.47222
- **MSE** = 5.23
Trend Adjusted Exponential Smoothing

<table>
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<th>Error</th>
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Alpha1 = 0.40, MAD = 4.84
Alpha2 = 0.30, MSE = 55.99
Simple Linear Regression

Microsoft Excel - T3-5.xls

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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Graph showing the relationship between x and y with a line of best fit and error bars.
Inventory Management

Type of Inventory

- Raw materials & purchased parts
- Partially completed goods called *work in progress*
- Finished-goods inventories
  
  (manufacturing firms) or merchandise  
  (retail stores)
Types of Inventories (Cont’d)

- Replacement parts, tools, & supplies
- Goods-in-transit to warehouses or customers
Functions of Inventory

- To meet anticipated demand
- To smooth production requirements
- To take advantage of order cycles
- To help hedge against price increases or to take advantage of quantity discounts
- To permit operations
Inventory hides problems in a process.

Water Level = Inventory
Rocks = Problems in the system
Boat = Company Operations
Inventory Management Questions

- What should be the order quantity \((Q)\)?
- When should an order be placed, called a reorder point \((ROP)\)?
- How much safety stock \((SS)\) should be maintained?
Inventory Cost

- Holding costs - associated with holding or “carrying” inventory over time
- Ordering costs - associated with costs of placing order and receiving goods
- Setup costs - cost to prepare a machine or process for manufacturing an order
Inventory Models

- Fixed order quantity models
  - Economic order quantity
  - Production order quantity
  - Quantity discount
- Probabilistic models
- Fixed order period models

Help answer the inventory planning questions!

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T/Maker Co.
Inventory Levels For EOQ Model
Why Holding Costs Increase

More units must be stored if more ordered
Why Order Costs Decrease

Cost is spread over more units

Example: You need 1000 microwave ovens

1 Order (Postage $ 0.32) 1000 Orders (Postage $320)
EOQ Model
How Much to Order?

Annual Cost

Total Cost Curve
Holding Cost Curve
Order (Setup) Cost Curve

Optimal Order Quantity (Q*)

Order Quantity
Deriving an EOQ

- Develop an expression for setup or ordering costs
- Develop an expression for holding cost
- Set setup cost equal to holding cost
- Solve the resulting equation for the best order quantity
Total Cost

Total cost = Annual carrying cost + Annual ordering cost

\[ TC = \frac{Q}{2} H + \frac{D}{Q} S \]
Annual Order Cost

\[ \frac{U}{Q}c_0 \]
Annual Holding Cost

\[ \frac{Q}{2} C_H \]

$ \quad Q$
Graph of Annual Inventory Costs

- TAC
- Annual holding cost, \((C_H/2)Q\)
- Annual order cost, \((U_CQ)/Q\)
Deriving the EOQ

Using calculus, we take the derivative of the total cost function and set the derivative (slope) equal to zero and solve for $Q$.

$$Q_{\text{OPT}} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(\text{Annual Demand })(\text{Order or Setup Cost })}{\text{Annual Holding Cost}}}$$
The Inventory Cycle

Profile of Inventory Level Over Time

Quantity on hand

Reorder point

Receive order

Place order

Receive order

Lead time

Usage rate

Q

Profile of Inventory Level Over Time

Time
EOQ Example

Given:
- 25,000 annual demand
- $3 per unit per year holding cost
- $100 ordering costs

EOQ = \sqrt{\frac{2(25,000)(100)}{3}} \approx 1291
EOQ Model Equations

Optimal Order Quantity

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

Expected Number of Orders

\[ N = \frac{D}{Q^*} \]

Expected Time Between Orders

\[ T = \frac{\text{Working Days}}{N} \]

\[ d = \frac{D}{\text{Working Days}} \]

\[ ROP = d \times L \]

\( D = \text{Demand per year} \)

\( S = \text{Setup (order) cost per order} \)

\( H = \text{Holding (carrying) cost} \)

\( d = \text{Demand per day} \)

\( L = \text{Lead time in days} \)
Production Order Quantity Model

- Answers how much to order and when to order
- Allows partial receipt of material
  - Other EOQ assumptions apply
- Suited for production environment
  - Material produced, used immediately
  - Provides production lot size
- Lower holding cost than EOQ model
POQ Model Inventory Levels

Production portion of cycle

Demand portion of cycle with no supply

Supply Begins

Supply Ends

Time

Inventory Level
POQ Model Equations

Optimal Order Quantity \( Q_p^* = \sqrt{\frac{2DS}{Hd}} \)

Max. Inventory Level \( Q^* = \frac{Ds}{p} \)

Setup Cost \( = \frac{D}{Q} \times S \)

Holding Cost \( = 0.5 \times H \times Q \)

\( D = \) Demand per year
\( S = \) Setup cost
\( H = \) Holding cost
\( d = \) Demand per day
\( p = \) Production per day
When to Reorder with EOQ Ordering

- **Reorder Point** - When the quantity on hand of an item drops to this amount, the item is reordered.

- **Safety Stock** - Stock that is held in excess of expected demand due to variable demand rate and/or lead time.

- **Service Level** - Probability that demand will not exceed supply during lead time.
Safety Stock

- Expected demand during lead time
- Maximum probable demand during lead time
- ROP
- LT
- Safety stock
- Time
- Quantity
Demand During Lead Time

Example

Four Days Lead Time

Demand During Lead Time
Reorder Point

Service level

Probability of no stockout

Risk of a stockout

Expected demand

ROP

Safety stock

Quantity

0  z  z-scale
Safety Stock (SS)

- Demand During Lead Time (LT) has Normal Distribution with
  - \( \text{Mean}(d_L) \) ? ? \( (LT) \)
  - \( \text{Std. Dev.}(\sigma_L) \) ? ? \( \sqrt{LT} \)

- SS with r% service level
  - \( SS \) ? \( z_r \) ? \( \sqrt{LT} \)

- Reorder Point

\[ ROP \text{ ? } SS \text{ ? } d_L \]
Fixed-Period Model

- Answers how much to order
- Orders placed at fixed intervals
  - Inventory brought up to target amount
  - Amount ordered varies
- No continuous inventory count
  - Possibility of stockout between intervals
- Useful when vendors visit routinely
  - Example: P&G rep. calls every 2 weeks
Fixed-Period Model: When to Order?

- Inventory Level
- Target maximum
- Period
- Time
Fixed-Period Model: When to Order?

Inventory Level

Target maximum

Period

Period

Time
Fixed-Period Model: When to Order?

Inventory Level

Target maximum

Time

Period

Period
Fixed-Period Model: When to Order?

Inventory Level

Target maximum

Period Period Period

Time
Fixed-Period Model: When to Order?

Inventory Level

Target maximum

Period Period Period

Time
Fixed-Period Model: When to Order?
Material Requirements Planning (MRP)

- Manufacturing computer information system
- Determines quantity & timing of dependent demand items
Collins Industries

- Largest manufacturer of ambulances in the world
- International competitor
- 12 major ambulance designs
  - 18,000 different inventory items
    - 6,000 manufactured parts
    - 12,000 purchased parts
  - MRP: IBM’s MAPICS
Collins Industries

Collins requires:

- Material plan must meet both the requirements of the master schedule and the capabilities of the production facility
- Plan must be executed as designed
- Effective “time-phased” deliveries, consignments, and constant review of purchase methods
- Maintenance of record integrity
Purposes, Objectives and Philosophy of MRP

_theme of MRP_

- getting the right materials to the right place at the right time.

_objectives of MRP_

- Improve customer service, minimize inventory investment, and maximize production operating efficiency

_philosophy of MRP_

- Materials should be expedited if needed to keep the MPS on target and de-expedited when we are behind schedule and don’t need the materials.
MRP and The Production Planning Process

- Forecast & Firm Orders
- Aggregate Production Planning
- Resource Availability
- Material Requirements Planning
- Master Production Scheduling
- No, modify CRP, MRP, or MPS
- Capacity Requirements Planning
- Realistic?
- Yes
- Shop Floor Schedules
Inputs to the Standard MRP System

- Actual Customer Orders
- Aggregate Product Plan
- Forecasted Demand
- Master Production Schedule
- Inventory Records File
- MRP Program
- Bill of Materials File
Structure of the MRP System

- BOM (Bill-of-Material)
- Lead Times (Item Master File)
- Inventory Data
- Purchasing data

Master Production Schedule

- MRP by period report
- MRP by date report
- Planned orders report
- Purchase requirements
- Exception reports
Master Production Schedule

- Shows items to be produced
  - End item, customer order, module
- Derived from aggregate plan
- Example

<table>
<thead>
<tr>
<th>Item/Week</th>
<th>Oct 3</th>
<th>Oct 10</th>
<th>Oct 17</th>
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<td>450</td>
<td>310</td>
<td>330</td>
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</table>
Bill-of-Material

- List of components & quantities needed to make product
- Provides product structure (tree)
  - Parents: Items above given level
  - Children: Items below given level
- Shows low-level coding
  - Lowest level in structure item occurs
  - Top level is 0; next level is 1 etc.
Bill-of-Material
Product Structure Tree

Bicycle (1)
P/N 1000

Handle Bars (1)
P/N 1001

Frame Assy (1)
P/N 1002

Wheels (2)
P/N 1003

Frame (1)
P/N 1004
Start production of D

Must have D and E completed here so production can begin on B

2 weeks to produce B
MRP Example- Shutter Mfg. Company

Master Production Schedule

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
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</table>

Bill of Materials (Product Structure Tree)

Shutter

- Frames (2)
  - Lead Time = 2 weeks

- Wood Sections (4)
  - Lead Time = 1 week

Lead Time = 1 week
<table>
<thead>
<tr>
<th>Item</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
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</tbody>
</table>
MRP Benefits

- Increased customer satisfaction due to meeting delivery schedules
- Faster response to market changes
- Improved labor & equipment utilization
- Better inventory planning & scheduling
- Reduced inventory levels without reduced customer service
MRP Requirements

- Computer system
- Mainly discrete products
- Accurate bill-of-material
- Accurate inventory status
  - 99% inventory accuracy
- Stable lead times
MRP Planning

Develop a tentative master production schedule → Use MRP to simulate material requirements

Convert material requirements to resource requirements → Revise tentative master production schedule

Is shop capacity adequate? No → Can capacity be changed to meet requirements No

Firm up a portion of the MPS → Change capacity Yes
<table>
<thead>
<tr>
<th>Week</th>
<th>Order Number</th>
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<th>Lead Time</th>
<th>Processing Time/ piece</th>
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Capacity Loading Chart
MRP II

- Expanded MRP with an emphasis placed on integration

  - Financial planning
  - Marketing
  - Engineering
  - Purchasing
  - Manufacturing
MRP Core Inside ERP

Global Strategy

Business Plan

Sales & Operations Plan

MPS

Detailed Material & Capacity Planning

Plant & Supplier Communication

Schedule Execution

Financial & Accounting

Treasury & Activity

Costing

Rough-Cut Capacity Plan

Inventory

Work Centers

Demand Management

SFA & CRM

Bills of Material

Routings

Engineering CAD/Configurators
What is Scheduling?

- Scheduling deals with the allocation of scarce resources to tasks over time. It is a decision-making process with the goal of optimizing one or more objectives.

- Consists of planning and prioritizing activities that need to be performed in an orderly sequence of operation.

- Scheduling leads to increased efficiency and capacity utilization, reducing time required to complete jobs and consequently increasing the profitability of an organization.

- Resource scheduling, such as machines, labor, and material.
The role of scheduling

The resources and tasks in an organization has many forms, the resources such as:
- machines in a workshop, runways at an airport
- crews at a construction site, processing units in a computing environment.

The tasks may be:
- operations in a production process, take-offs and landing at an airport.
- stages in a construction project, executions of computer programs.
Process-Focused Planning System

1. Forecast & Firm Orders
2. Aggregate Production Planning
3. Resource Availability
4. Material Requirements Planning
5. Master Production Scheduling
6. Realistic?
   - Yes: Shop Floor Schedules
   - No: modify CRP, MRP, or MPS
7. Capacity Requirements Planning

Yes
## Order Release Begins Shop Loading

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</tbody>
</table>

- **Priority & Capacity OK?**
  - Yes: Release Order
  - No: Hold Release

Order Release Begins Shop Loading
### Gantt Load Chart

- **Shows relative workload in facility**
- **Disadvantages**
  - Does not account for unexpected events
  - Must be updated regularly

<table>
<thead>
<tr>
<th>Work Center</th>
<th>M</th>
<th>T</th>
<th>W</th>
<th>Th</th>
<th>F</th>
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<td>Job D</td>
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<td>Job G</td>
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<td>Job C</td>
<td>Job E</td>
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<td>Job I</td>
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</tr>
</tbody>
</table>
Scheduling Objectives

- Meet due dates
- Minimize lead time
- Minimize setup time or cost
- Minimize work-in-process inventory
- Maximize machine utilization ...
Scheduling Examples

Carton manufacturing operations: High mixed products and on time delivery.

Order delay: How to minimize the penalties?
Product similarity: How to produce with same setup?
How to plan the production?
Scheduling Examples

A machine shop has only stamping machine: With different dye and a different processing time.

How to generate weekly schedule to minimize the number of late shipments?

How should these schedules be developed?
Scheduling and Control of Job Shops

Allocate orders, equipment, and personnel to work centers or other specified locations

Dispatch orders

Shop-floor control
  - Reviewing the status and controlling the progress of orders as they are being worked
  - Expediting late and critical orders

Revising the schedule in light of changes in order status ....
Job-Shop Scheduling Issues

- Job arrival patterns
- Number and variety of machines
- Ratio of workers to machines
- Flow patterns of jobs
- Worker-to-machine priority rules
- Schedule evaluation criteria
Methodology

Practically, schedules are generated using scheduling algorithms or knowledge-based rules ("If-Then").

Scheduling algorithms tend to optimize a measuring criterion such as the minimizing deviations from due dates, tardiness penalty, or the maximum delay.

The rule-, or knowledge-based tries to find a feasible solution under the operating environment. “If machine A and operator X are available, Then load job Z”
Priority Rules for Job Sequencing

1. First-come, first-served (FCFS)

2. Shortest operating time

3. Earliest due date first

4. Earliest start date first (due date-lead time)

5. Least slack time remaining first ....
Priority Rules for Job Sequencing

6. Least slack time remaining (per operation as opposed to per job) first

7. Smallest critical ratio first
   (due date - current date)/(number of days remaining)

8. Smallest queue ratio first
   (slack time remaining in schedule)/(planned remaining queue time)

9. Last come, first served

10. Random order ....
### Example

Work Schedule: 7 days a week  
Single Work Station  
Today’s Date: October 1  
Planning Horizon: October and November

#### October’s Plan

<table>
<thead>
<tr>
<th>Job</th>
<th>Time Required</th>
<th>Due Date</th>
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</thead>
<tbody>
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<td>5 days</td>
<td>Oct 10</td>
</tr>
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<td>B</td>
<td>10 days</td>
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<tr>
<td>C</td>
<td>2 days</td>
<td>Oct 5</td>
</tr>
<tr>
<td>D</td>
<td>8 days</td>
<td>Oct 12</td>
</tr>
<tr>
<td>E</td>
<td>6 days</td>
<td>Oct 8</td>
</tr>
</tbody>
</table>

Note: Jobs are listed in order as taken by the Sales department
### Scheduling Alternative: Earliest Due Date (DDATE)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Start Time</th>
<th>Processing Time</th>
<th>Completion Time</th>
<th>Due Date</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>5</td>
<td>13</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>8</td>
<td>21</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>21</td>
<td>10</td>
<td>31</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

Mean = **15.0**  
Mean Late = **5.6**
Scheduling Alternative: Minimum Critical Ratio (CR)

Critical ratio = \( \frac{\text{Time Remaining}}{\text{Work Remaining}} = \frac{\text{due date - today's date}}{\text{remaining processing time}} \)

If \( CR > 1 \) job is *ahead of schedule*
If \( CR < 1 \) job is *behind schedule*

Job A: \( CR = \frac{(10-1)}{5} = 1.80 \)
Job B: \( CR = \frac{(15-1)}{10} = 1.40 \)
Job C: \( CR = \frac{(5-1)}{2} = 2.00 \)
Job D: \( CR = \frac{(12-1)}{8} = 1.37 \)
Job E: \( CR = \frac{(8-1)}{6} = 1.16 \)

Schedule in order from smallest to largest CR
<table>
<thead>
<tr>
<th>Sequence</th>
<th>Start Time</th>
<th>Processing Time</th>
<th>Completion Time</th>
<th>Due Date</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>10</td>
<td>24</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>A</td>
<td>24</td>
<td>5</td>
<td>29</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>C</td>
<td>29</td>
<td>2</td>
<td>31</td>
<td>5</td>
<td>26</td>
</tr>
</tbody>
</table>

Mean = 20.8

Mean = 11.2
### Scheduling Alternative: Smallest Processing Time (SPT)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Start Time</th>
<th>Processing Time</th>
<th>Completion Time</th>
<th>Due Date</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td>6</td>
<td>13</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>8</td>
<td>21</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>21</td>
<td>10</td>
<td>31</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

Mean = **14.8**  
6.0
### Scheduling Alternatives – Summary

<table>
<thead>
<tr>
<th>Rule</th>
<th>Average Completion Time</th>
<th>Average Days Late</th>
<th>No of Late Jobs</th>
<th>Maximum Late Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCFS</td>
<td>18.60</td>
<td>9.6</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>DDATE</td>
<td>15.00</td>
<td>5.6</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>SLACK</td>
<td>16.40</td>
<td>6.8</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>CR</td>
<td>20.80</td>
<td>11.2</td>
<td>4</td>
<td>26</td>
</tr>
<tr>
<td>SPT</td>
<td>14.80</td>
<td>6.0</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>LPT</td>
<td>22.4</td>
<td>13.4</td>
<td>4</td>
<td>26</td>
</tr>
</tbody>
</table>
Scheduling Through Two Work Centers

Assume all jobs go through the process in the same order.

![Diagram showing Work Center 1 and Work Center 2 with arrows indicating the process flow.]

Example:

<table>
<thead>
<tr>
<th>Job</th>
<th>Processing Time # 1</th>
<th>Processing Time # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
Johnson’s Rule: Minimize Final Completion Time for Set of Jobs (*Makespan*)

- Set up a Column Array with the number of slots equal to the total number of jobs.
- Select the smallest processing time at either machine. If this is at work center 1, put this job as near to the beginning of the schedule as possible.
- If the smallest time is at work center 2, put this job as near the end of the schedule as possible.
- Remove the scheduled job from the list.
- Repeat steps until all jobs have been scheduled.
### Step 1

<table>
<thead>
<tr>
<th>Job</th>
<th>Processing Time # 1</th>
<th>Processing Time # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

![Diagram showing job sequence]

- The diagram shows the sequence of jobs, with C highlighted as the last job.
## Step 2

<table>
<thead>
<tr>
<th>Job</th>
<th>Processing Time # 1</th>
<th>Processing Time # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>E `</td>
<td>`</td>
<td>`(5)</td>
</tr>
</tbody>
</table>

E → C
Step 3-5

<table>
<thead>
<tr>
<th>Job</th>
<th>Processing Time # 1</th>
<th>Processing Time # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
Optimal Schedule

Completion Time = 41 hours
Work Center 1 Idle Time = 3 hours
Work Center 2 Idle Time = 7 hours
General Scheduling Guidelines

- Shortest Processing Time (SPT) is most useful when the shop is highly congested.
  - Tends to minimize mean flow time, mean number of jobs in the system (WIP), and percent of late jobs.
  - Downside is that some jobs may be finished very late.

- SLACK method works well when system is not overly constrained.

- DDATE is good when the objective is small late times
  - It does allow more late jobs but each will tend to be shorter.
Scheduling Techniques

- Software: Lindo, Arena
- Technique: Group technique, Gantt Chart, CPM
- Heuristic approach
- Artificial Intelligence: Fuzzy logic, Genetic Algorithm, Neural network, Artificial Immune System, …
Shop-Floor Control

Major Functions

1. Assigning priority of each shop order

2. Maintaining work-in-process quantity information

3. Conveying shop-order status information to the office ....
Shop-Floor Control

Major Functions

4. Providing actual output data for capacity control purposes

5. Providing quantity by location by shop order for WIP inventory and accounting purposes

6. Providing measurement of efficiency, utilization, and productivity of manpower and machines ....
Manufacturing system’s information flow

- Production planning, master scheduling
- Material requirements, planning, capacity planning
- Scheduling and rescheduling
- Dispatching
- Shopfloor management
- Detailed scheduling

- Capacity status
- Scheduling constraints
- Schedule performance
- Shop status
- Data collection
- Job loading
- Orders, demand forecasts
- Material requirements

MRP - I
Scheduling and Control of Job Shops

- Allocate orders, equipment, and personnel to work centers or other specified locations
- Dispatch orders
- Shop-floor control
  - Reviewing the status and controlling the progress of orders as they are being worked
  - Expediting late and critical orders
- Revising the schedule in light of changes in order status ....
Input/Output Control

Input: Work Center \rightarrow Output

Focuses attention on bottleneck work centers.
Principles of Job Shop Scheduling

1. There is a direct equivalence between work flow and cash flow.

2. The effectiveness of any job shop should be measured by speed of flow through the shop.

3. Schedule jobs as a string, with process steps back to back.

4. Speed of flow is most efficiently achieved by focusing on bottleneck work centers and jobs.
Principles of Job Shop Scheduling

5. Obtain feedback each day on jobs that are not completed at each work center.

6. Certainty of standards, routings, and so forth is not possible in a job shop, but always work towards achieving it ....