Supplements/Handbook

MGT460

Lecture 1: Introduction to Operations Management

What is Management?

Management is the scientific study concerning the different activities (like POSDCORB) in order to maximize profit, minimizing cost and to optimize productivity.

This abbreviation was coined by 'Luther Gullique' in order to define management. POSDCORB is abbreviated for Planning, Organizing, Staffing, Directing, Coordinating, Reporting and Budgeting. These are the different activities of management.

What is 'Operations'?

Operations' consists of activities related to the production of goods and services. There are two broad categories of operations in organizations i.e. Goods oriented operations and Service Oriented Operations.

'Goods Oriented Operations' consists of manufacturing and assembly operations

'Service Oriented Operations' consists of, health care, transportation, Education, retailing etc.

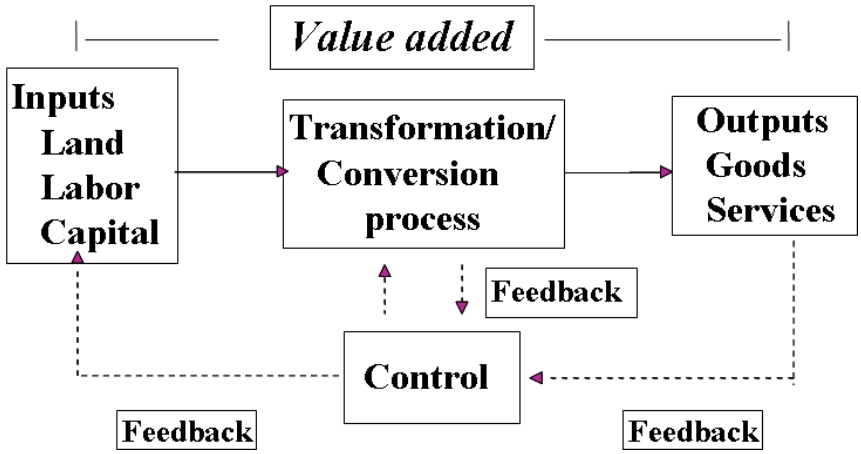
Operations as core function

Operations' function is the core of most business organizations. All other functions are interconnected with Operations' function in some way or other. In operations, inputs are converted to Valuable outputs after transformation process

Value-Added

The strength of operations can be analyzed with value addition i.e. the difference between the cost of inputs and the value or price of outputs. The more is the

difference, the more valuable operations are. Controlling refers to finding out deviation between actual and desired performance and then taking corrective action to manage this deviation. Feedback is also provided throughout operations process to get the desired outputs.



Following are some examples of Food Processing operation and operations in hospital:

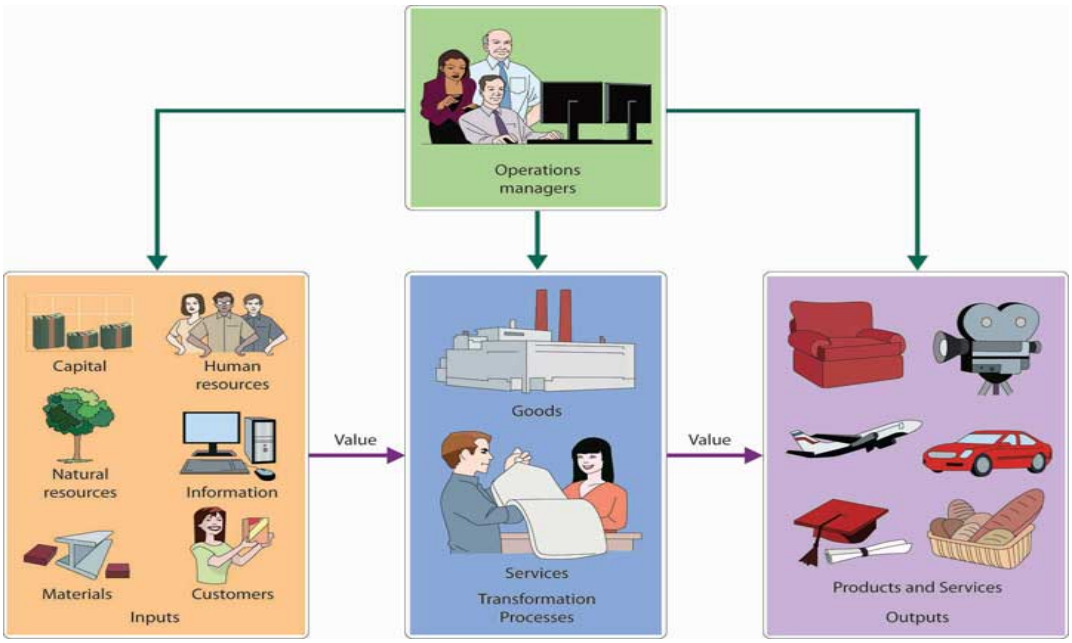
1. Food Processor

Inputs	Processing	Outputs
Raw Vegetables	Cleaning	Canned
Metal Sheets	Making cans	vegetables
Water	Cutting	
Energy	Cooking	
Labor	Packing	
Building	Labeling	
Equipment		

2. Hospital Process

Inputs	Processing	Outputs
Doctors, nurses	Examination	Healthy
Hospital	Surgery	patients
Medical Supplies	Monitoring	
Equipment	Medication	
Laboratories	Therapy	

So major responsibility of operations manager is to create value in inputs through transformation process so that valuable outputs can be produced



Why Organizations need Operations Manager

An operations Manager controls the processes by which value is added from conversion of inputs to outputs.

Production and Operations Management

Production is the creation of goods and services

Goods and Services

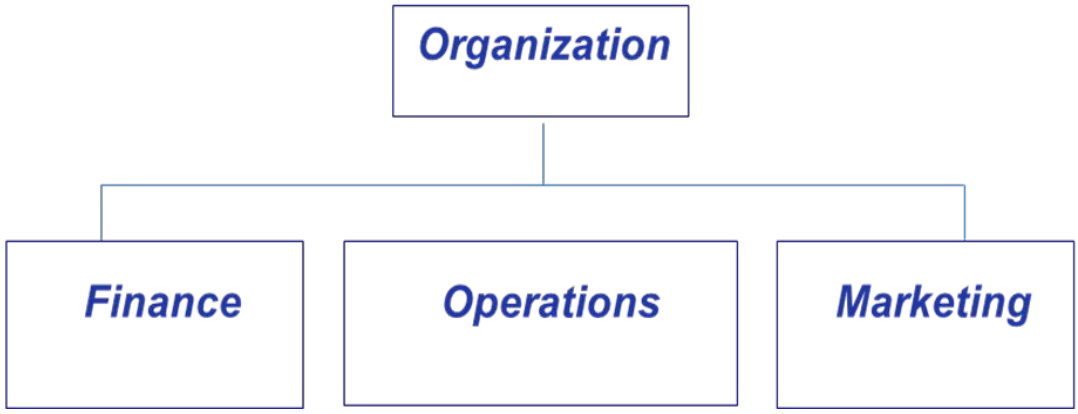
What's the difference between Goods and Services?

Goods	Services
Can be resold	Reselling is unusual
Can be inventoried	Cannot be inventoried
Some aspect of quality are measurable	Many aspect are difficult to measure
Selling is distinct from production	Selling is often part of the services
Product is transportable	Provider is transportable
Site of facility is important for cost	Site of facility is important for customer contact
Easy to automate	Difficult to automate
Revenue generated from tangible product	Revenue generated from intangible services

Operations management (OM) is the set of activities that creates value in the form of goods and services by transforming inputs into outputs.

What Is Operations Management?

The management of systems or processes that create goods and/or provide services



Business organizations typically have three basic functional areas i.e. Finance, marketing, and operations, as depicted in Figure. It doesn't matter if the business is a retail store, a hospital, a manufacturing firm, a car wash, or some other type of business; it is true for all business organizations.

Finance is responsible for securing financial resources at favorable prices and allocating those resources throughout the organization, as well as budgeting, analyzing investment proposals, and providing funds for operations.

Marketing is responsible for assessing consumer wants and needs, and selling and promoting the organization's goods or services. Operations' is primarily responsible for producing the goods or providing the services offered by the organization. To put this into perspective, if a business organization were a car; operations would be its engine. And just as the engine is the core of what a car does, in a business organization, operations is the core of what the organization does.

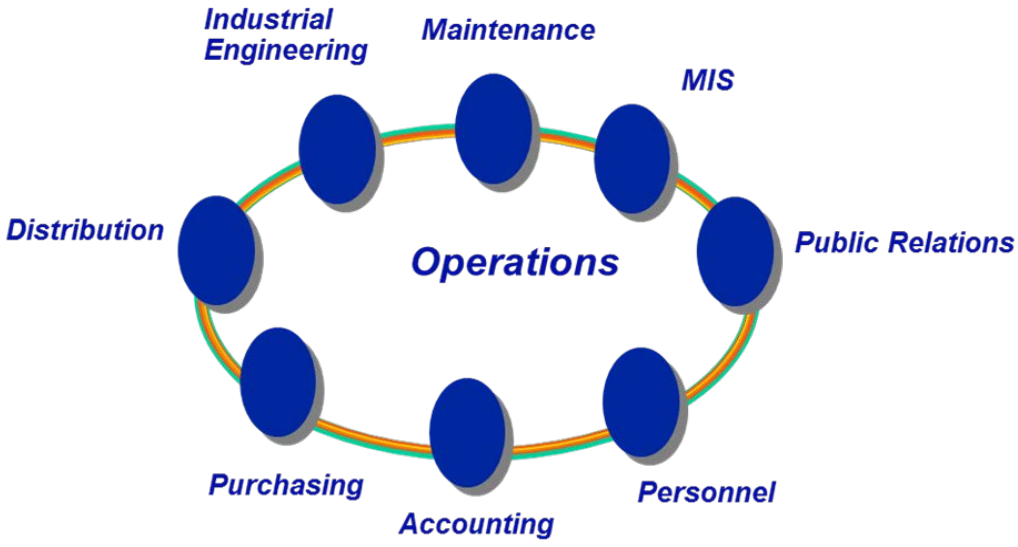
Operations management is responsible for managing that core. Hence, operations management is the management of systems or processes that create goods and/or provide services. The creation of goods or services involves

transforming or converting inputs into outputs. Various inputs such as capital, labor, and information are used to create goods or services using one or more transformation processes (e.g., storing, transporting, and cutting). To ensure that the desired outputs are obtained, measurements are taken at various points in the transformation process (feedback) and then compared with previously established standards to determine whether corrective action is needed (control). The essence of the operations function is to add value during the transformation process: Value-added is the term used to describe the difference between the cost of inputs and the value or price of outputs.

Organizing to Produce Goods and Services

Operations Interfaces

All the organizational functions have to interface with operations function in order to achieve their desired objectives. In this way, Operations function serves as a link and bridge to carry out the different other functions in the organizations.



What Is Operations Management?

Operations management (OM) is the area of management which is concerned with administration of business practices especially overseeing, designing and controlling the process of production set of activities that creates value in the form of goods and services by transforming inputs into outputs with maximum level of efficiency ensuring profitability for the organization. Or

Operation management is defined as the design, operation, and improvement of the systems that create and deliver the firms primary products and services. Like marketing and finance, OM is functional field of business with clear line management responsibilities. This point is important because operations management is frequently confused with operations research and management science and industrial engineering (IE).

The essential difference is that OM is a field of management, whereas OR/MS is the application of quantitative methods to decision making in all fields and IE is an engineering discipline. Thus while operation managers use the decision making tools of OR/MS (such as critical path scheduling) and are concerned with many of same issues as IE.

OM is concerned with the management of entire system that produces a good or delivers a product. Producing a product such as a cell phone, or providing a service such as cellular phone account, involves a complex series of transformation process.

Nomenclature

Following different terminologies and nomenclature have been used for operations management

- Production Management
- Production and Operations Management (POMA)

- Operations Management
- Operations Research (Interdisciplinary Subject)

Initially this subject was taught in industrial engineering as ‘Production Management’. Later, theorists suggest that operations are not only limited to production of physical goods but also intangible services. So this subject was then taught as POMA. Other nomenclature used for the subject is operations management and operations research. There is a difference between both of these subjects but there are many grey areas and topics which may be included in both.

Operations Research

Operations research is the development and collection of techniques based on mathematics and other scientific approaches that finds solutions to your problems**.**

Difference between Operations Management and Research

1. OR relies on mathematical modeling and OM relies on practical scenarios/industrial cases.
2. OR is domain and tool of Engineers while OM is considered to be one of the critical tools of Managers**.**

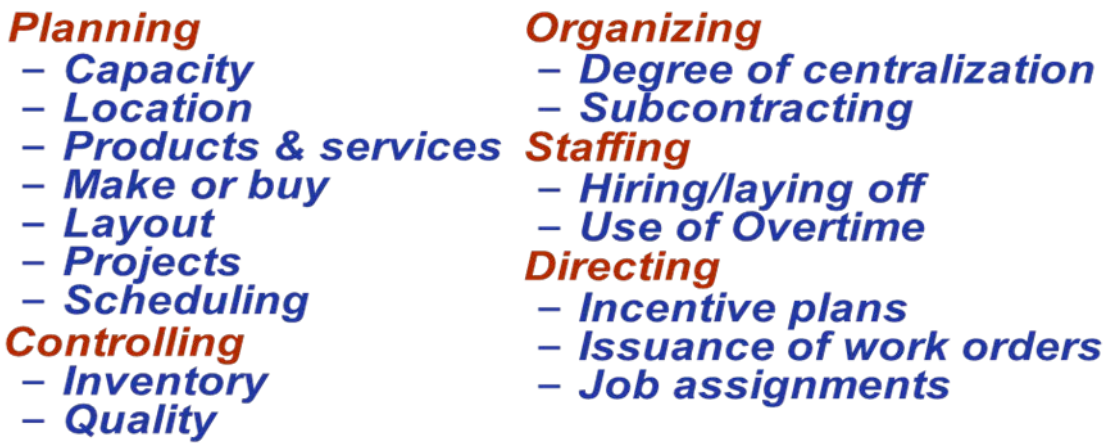
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Why Study OM?

- OM is one of three major functions (marketing, finance, and operations) of any organization
- We want (and need) to know how goods and services are produced
- We want to understand what operations managers do
- OM is such a costly part of an organization

Responsibilities of Operations Management

Responsibilities of Operations manager can be divided in to the following broad and specific categories.



The Critical Decisions in operations management

Design of goods and services

- What good or service should we offer?
- How should we design these products and services?

Managing quality

- How do we define quality?
- Who is responsible for quality?

Process and capacity design

- What process and what capacity will these products require?
- What equipment and technology is necessary for these processes?

Location strategy

- Where should we put the facility?
- On what criteria should we base the location decision?

Layout strategy

- How should we arrange the facility?
- How large must the facility be to meet our plan?

Human resources and job design

- How do we provide a reasonable work environment?
- How much can we expect our employees to produce?

Supply chain management

- Should we make or buy this component?
- Who are our suppliers and who can integrate into our e-commerce program?

Inventory, material requirements planning, and JIT

- How much inventory of each item should we have?
- When do we re-order?

Intermediate and short–term scheduling

- Are we better off keeping people on the payroll during slowdowns?
- Which jobs do we perform next?

Maintenance

- Who is responsible for maintenance?
- When do we do maintenance?

New Challenges in OM

Form		To
Local or National Focus		Global Focus
Batch Shipment		Just in Time
Low Bid Purchasing		Supply Chain partnering
Lengthy Product Development		Rapid Product development, Alliance
Standard Products		Mass Customization
Job Specialization		Empowered employees, Teams

There had been drastic changes in operations management today because of globalization and intense competition. The reason is to manage the operations efficiently and effectively. There has been more focus on global operations instead of domestic production and national focus in order to target world market and economies of scale. JIT i.e. 'Just In Time' focuses on reducing the inventory level in organizations and produce goods just when they are needed in order to manage cost. There is emerging trend of outsourcing important functions in supply chain to the specialized organizations. Product Life Cycle has been reduced due to continuous improvement and modification trend. The product

change and improvement is now being carried out on continuous basis. There is another important demand on the part of operations i.e. to produce products according demand of specific customers instead of producing standardized products. Organizations now empower their employees to be more motivated and productive. No organization can survive without teamwork. Increased focus prevails now on team effort rather than individualized contributions.

Characteristics of Goods

- Tangible product
- Consistent product definition
- Production usually separate from consumption
- Can be inventoried
- Low customer interaction

Service Definitions

Services are deeds, processes or performances. OR

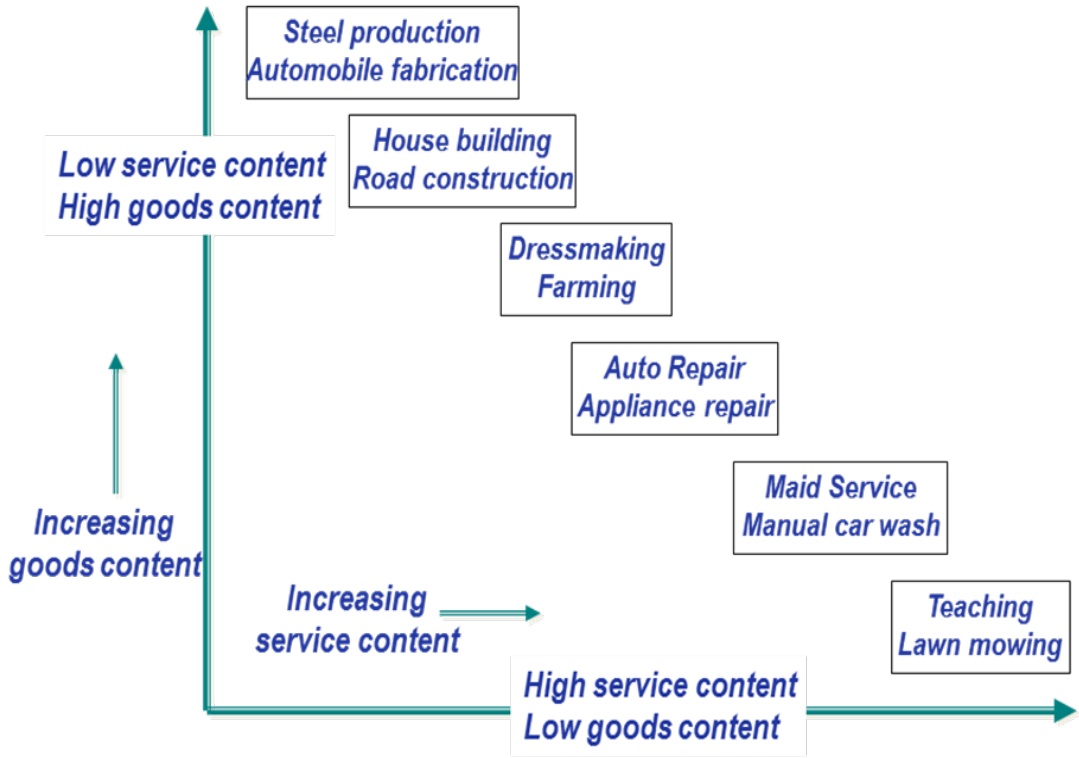
A service is a time-perishable, intangible experience performed for a customer acting in the role of a co-producer.

Characteristics of Service

- Intangible product
- Produced and consumed at same time
- Often unique
- High customer interaction
- Inconsistent product definition
- Often knowledge-based

- Frequently dispersed

Goods-service continuum



In actual, sometimes it is difficult to segregate the goods and services content. Intangible services are also involved in the provision of tangible products to the customers. . For instance, in auto repair physical products tangible goods such as spares are also being provided along with the services and we cannot segregate both of them. Similarly in some cases there are more services content such as teaching. In other cases, there may be more physical and tangible product involved such as steel production and automobile fabrication.

Ethics and Social Responsibility

There is also an increasing responsibility of operations managers in respect of ethical and social requirements. This may not have short term benefits but do

have long term and strategic benefits for the organizations. Some of the important challenges faced by today's operations managers are:

- Developing and producing safe, quality products
- Maintaining a clean environment
- Providing a safe workplace
- Honouring community commitments

Lecture 2: Productivity and Measurement

Productivity Challenge

Productivity is the ratio of outputs (goods and services) divided by the inputs (resources such as labor and capital).

Productivity = Outputs/inputs

There is another way to define productivity in terms of efficiency and effectiveness. Both efficiency and effectiveness define productivity.

Input is actually related to efficiency that how well the organizational resources are utilized. Efficiency is therefore related to do job well with minimum resources and waste. Effectiveness is related to the quality of output. It refers doing the right thing. We can increase the productivity by reducing and managing inputs with constant outputs. Alternatively, we can increase outputs with constant inputs.

The objective is to improve productivity!

Important Note!

Production is a measure of output only and not a measure of efficiency

Factors Affecting Productivity

1) Capital: From manual packing to automated packing but requires capital investment for auto packing comparing to manual.

2) Quality: Will it be 100% inspection which is time consuming or just random sampling?

3) Technology: the fact is that many productivity gains in the past have come from technological change such as automation, computers, calculators and so on…

4) Management: A supportive management will boost morale of employees come on time?

Productivity

$$\text{Productivity} = \frac{\text{Units produced}}{\text{Input used}}$$

- Measure of process improvement: Productivity is an important measure to improve the process. The strength of any process and operations is how much productive it is.

- Represents output relative to input

Only through productivity increase can our standard of living improve

- How can we improve?
  Labor, Technology, Management are important considerations which can help us increasing our level of productivity and thus our standard of living.

It is important to know that how we can measure productivity. Productivity Measures are useful to the following:

1. To track performance over time

2. To determine what has changed and then devise means of improving productivity in the subsequent periods.

3. To judge the performance of an entire industry or the productivity of a country as a whole.

Productivity Calculations

We can measure single factor productivity and multifactor productivity.

Labor Productivity:

$$\text{Productivity} = \frac{\text{Units produced}}{\text{Labor-hours used}}$$

If 250 labor hours are used to produce 1000 units of a product then labor productivit will be:

$$= \frac{1{,}000}{250} = 4 \text{ units/labor-hour}$$

This is single factor productivity because we use only labor hours as input. Single-factor productivity indicates the ratio of one resource (input) to the goods and services produced (outputs)

Multi-Factor Productivity

Multifactor productivity indicates the ratio of many or all resources (inputs) to the goods and services produced (outputs).

$$\text{Productivity} = \frac{\text{Output}}{\text{Labor} + \text{Material} + \text{Energy} + \text{Capital} + \text{Miscellaneous}}$$

- Also known as total factor productivity i.e. if all the possible inputs are used in denominator for productivity calculation

Labor Productivity at national level

At national level:

Labor productivity can be computed by taking entire economically active population as input

Total value of goods & services produced as output.

National productivity = ***GNP / Population***

Productivity Measurement

Productivity Measurement is important for productivity improvement. It Very effective tool for decision-making at all economic levels.

Success of productivity measurement & analysis depends largely upon clear understanding by all parties concerned (enterprise managers, worker, employers, trade union orgs & government; institutions) of why productivity measurement is important for effectiveness of organizations.

Productivity Analysis in Enterprise

Simple & practical approaches to productivity analysis are:

- Measurement of workers productivity
- Measurement systems for planning & analyzing unit labor requirements.
- Measurement system of labor productivity aimed at structure of labor resource use.
- Value added productivity at enterprise level.

Three of most common purposse are:

1. Comparing enterprise with its competitors.
2. Determining relative performance of departments & workers
3. Comparing relative benefits of various types of input for collective bargaining & gain sharing.

Example: Collins Title Productivity

Collins title wants to evaluate its labor and multifactor productivity with a new computerized title-search system. The company has a staff of four, each working eight hours per day (for a payroll of cost of $640/day) and overhead expenses of 400$ per day. Collins processes and closes on eight titles each day. The new computerized title-search system will allow the processing of 14 titles per day. Although the staff, their work hours and pay are the same, the overhead expenses are now 800$ per day. What is the labor productivity and multifactor productivity with old and new system?

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

New System:

14 titles/day Overhead = $800/day

$$\text{Old labor productivity} = \frac{8 \text{ titles/day}}{32 \text{ labor-hrs}} = .25 \text{ titles/labor-hr}$$

$$\text{New labor productivity} = \frac{14 \text{ titles/day}}{32 \text{ labor-hrs}}$$

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

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$$\text{Old labor productivity} = \frac{8 \text{ titles/day}}{32 \text{ labor-hrs}} = .25 \text{ titles/labor-hr}$$

$$\text{New labor productivity} = \frac{14 \text{ titles/day}}{32 \text{ labor-hrs}} = .4375 \text{ titles/labor-hr}$$

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

New System:

14 titles/day Overhead = $800/day

$$\text{Old multifactor productivity} = \frac{8 \text{ titles/day}}{\$640 + 400}$$

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

New System:

14 titles/day Overhead = $800/day

$$\text{Old multifactor productivity} = \frac{8 \text{ titles/day}}{\$640 + 400} = .0077 \text{ titles/dollar}$$

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

New System:

14 titles/day Overhead = $800/day

$$\text{Old multifactor productivity} = \frac{8 \text{ titles/day}}{\$640 + 400} = .0077 \text{ titles/dollar}$$

$$\text{New multifactor productivity} = \frac{14 \text{ titles/day}}{\$640 + 800}$$

Old System:

Staff of 4 works 8 hrs/day 8 titles/day
Payroll cost = $640/day Overhead = $400/day

New System:

14 titles/day Overhead = $800/day

$$\text{Old multifactor productivity} = \frac{8 \text{ titles/day}}{\$640 + 400} = .0077 \text{ titles/dollar}$$

$$\text{New multifactor productivity} = \frac{14 \text{ titles/day}}{\$640 + 800} = .0097 \text{ titles/dollar}$$

Measurement Problems

- Quality may change while the quantity of inputs and outputs remains constant
- External elements may cause an increase or decrease in productivity
- Precise units of measure may be lacking

Productivity Variables

A research survey indicated that:

- *Labor - contributes about* 10% *of the annual increase*
- *Capital - contributes about* 38% *of the annual increase*
- *Management - contributes about* 52% *of the annual increase*

Problem 1

The Production Manager at a Textile Mills, can currently expect his operation to produce 1000 square yards of fabric for each ton of raw cotton. Each ton of raw cotton requires 5 labor hours to process. He believes that he can buy a better quality raw cotton, which will enable him to produce 1200 square yards per ton of raw cotton with the same labor hours.

What will be the impact on productivity (measured in square yards per labor-hour) if he purchases the higher quality raw cotton?

Solution

Current Labor Productivity =*100 sq yds* = 200 sq yds per hour

1 ton*5 Hours

New Labor Productivity= *1200 sq yds* = 240 sq yards per hour

1 ton * 5 hours

Productivity improves 20%= (240-200) / 200 = 0.2 (20%)

Problem 2

A local auto mechanic finds that it usually takes him 2 hours to diagnose and fix a typical problem. What is his daily productivity (assume an 8 hour day)?

He believes he can purchase a small computer trouble-shooting device, which will allow him to find and fix a problem in the incredible (at least to his customers!) time of 1 hour. He will, however, have to spend an extra hour each morning adjusting the computerized diagnostic device. What will be the impact on his productivity if he purchases the device?

Solution

Current Productivity = 8 hrs per day/ 2 hrs per problem = *4 problems per hour*

Productivity with computer= 8 hrs per day / 2 hrs per problem= 7 problems per day

Productivity improves 75% (7-4) / 4 = 0.75 (75%)

Problem 3

Susan has a part-time "cottage industry" producing seasonal plywood yard ornaments for resale at local craft fairs and bazaars. She currently works 8 hours per day to produce 16 ornaments.

a. What is her productivity?

b. She thinks that by redesigning the ornaments and switching from use of a wood glue to a hot-glue gun she can increase her total production to 20 ornaments per day. What is her new productivity?

c. What is her percentage increase in productivity?

Solution:

a.16 ornaments/8 hours = 2 ornaments/hour

b. 20 ornaments/8 hours = 2.5 ornaments/hour

c. Change in productivity = 0.5 ornaments/hour; percent change = 0.5/2= 25%

Problem 4

A firm cleans chemical tank cars. With standard equipment, the firm typically cleaned 70 chemical tank cars per month. They utilized 10 gallons of solvent, and two employees worked 20 days per month, 8 hours a day. The company decided to switch to a larger cleaning machine. Last April, they cleaned 60 tank cars in only 15 days. They utilized 12 gallons of solvent, and the two employees worked 6 hours a day.

1. What was their productivity with the standard equipment?

2. What is their productivity with the larger machine?

3. What is the change in productivity?

Solution

Resource	Standard Equipment	Larger Machine	Percent Change
Solvent	$\frac{70}{10} = 7$	$\frac{60}{12} = 5$	$\frac{5-7}{7} = -28.57\%$
Labor	$\frac{70}{320} = 0.22$	$\frac{60}{180} = .33$	$\frac{.33-.22}{.22} = 50\%$

Problem 5

Joanna French is currently working a total of 12 hours per day to produce 240 dolls. She thinks that by changing the paint used for the facial features and fingernails that she can increase her rate to 360 dolls per day. Total material cost for each doll is approximately $3.50; she has to invest $20 in the necessary supplies (expendables) per day; energy costs are assumed to be only $4.00 per day; and she thinks she should be making $10 per hour for her time. Viewing this from a total (multifactor) productivity perspective, what is her productivity at present and with the new paint?

Solution

Currently			**Using the new paint**	
Labor	**12 hrs * $10**	**= $120**	**12 hrs * $10**	**= $ 120**
Material	**240 * $3.50**	**= $840**	**360 * $3.50**	**= $1260**
Supplies		**= $ 20**		**= $ 20**
Energy		**= $ 4**		**= $ 4**
Total Inputs		**= $984**		**= $1404**
Productivity	**240/984**	**= 0.24**	**360/1404**	**= .26**

Problem 6

(Refer Problem 5) How would total (multifactor) productivity change if using the new paint raised Ms. French's material costs by $0.50 per doll?

Solution

If the material costs increase by $0.5 per doll:

	Using the new paint	
Labor	**12 hrs * $10**	**= $ 120**
Material	**360 * $4**	**= $1440**
Supplies		**= $ 20**
Energy		**= $ 4**
Total Inputs		**= $1584**
Productivity	**360/1584**	**= .23**

Problem 7

(Refer Problem 6) If she uses the new paint, by what amount could Ms. French's material costs increase keeping the total (multifactor) productivity same as 0.24?

Solution

We want to know how high the material cost could go, using the new paint, before the productivity drops to the current level of 0.24. In mathematical terms we make the material cost a variable (X), set the new multifactor productivity value to the current level, 0.24, and solve for X.

360 /(12x10) + (360X) + 20 +4 = .24

360= 0.24(120 + 360X + 20 + 4

360= 28.8 + 86.4X + 4.8 + 0.96 X =3.77 $

It follows then that the new paint could raise Materials cost by no more than approximately $0.27 (the difference between $3.77 and $3.50) before Ms. French would experience a decrease in multifactor productivity.

Problem 8

Gibson Products produces cast bronze valves for use in offshore oil platforms. Currently, Gibson produces 1600 valves per day. The 20 workers at Gibson work from 7 a.m. until 4 p.m., with 30 minutes off for lunch and a 15 minute break during the morning work session and another at the afternoon work session. Gibson is in a competitive industry, and needs to increase productivity to stay competitive. They feel that a 20 percent increase is needed.
Gibson's management believes that the 20 percent increase will not be possible without a change in working conditions, so they change work hours. The new schedule calls on workers to work from7:30 a.m. until 4:30 p.m., during which workers can take one hour off at any time of their choosing. Obviously, the number of paid hours is the same as before, but production increases, perhaps because workers are given a bit more control over their workday. After this change, valve production increased to 1800 units per day.

a. Calculate labor productivity for the initial situation
b. Calculate labor productivity for the hypothetical 20 percent increase
c. What is the productivity after the change in work rules?
d. Write a short paragraph analyzing these results.

Solution

(a) ***Total output is 1600 valves per day. 20 workers are active for eight hours per day. So Total working hours per day are 20x8=160. So Labor Productivity is 1600/160 i.e. 10 valves/hour.***

(b) Productivity rises by 20 percent, to 12 valves/hour. output will be 12x8x20 = 1920

(c) New productivity is 1800 / (20 x 8) = 11.25 valves/hour

(d) Gibson did not gain the desired 20 percent increase in productivity, but they did gain over ten percent, without extra equipment or energy, and without increasing the wage bill.

Problem 9

The Dulac Box plant produces wooden packing boxes to be used in the local seafood industry. Current operations allow the company to make 500 boxes per day, in two 8-hour shifts (250 boxes per shift). The company has introduced some moderate changes in equipment, and conducted appropriate job training, so that production levels have risen to 300 boxes per shift. Labor costs average $10 per hour for each of the 5 full-time workers on each shift. Capital costs were previously $3,000 per day, and rose to $3,200 per day with the equipment modifications. Energy costs were unchanged by the modifications, at $400 per day. What is the firm's multifactor productivity before and after the changes?

Solution

MFP before: 500 boxes / ($10x5x16 + $3000 + $400) = 500 / 4200 = 0.119 boxes/dollar

MFP after: 600 boxes / ($10x5x16 + $3200 + $400) = 600 / 4400 = 0.136 boxes/dollar

Problem 10

A farmer grows crop in his 100 by 100 foot garden. He then sells the crop at the local farmers' market. Two summers ago, he was able to produce and sell 1200 pounds of crop. Last summer, he tried a new fertilizer that promised a 50% increase in yield. He harvested 1900 pounds. Did the fertilizer live up to its promise?

Solution

Two summer ago	**Last Sumer**	**Change**
1200/1000=0.12 lbs/sq ft	1900/1000=0.19 lbs/sq ft	(0.19 - 0.12)/0.12 = 58.3%

Since the productivity gain was 58.3%, not 50%, the fertilizer was at least as good as advertised.

Lecture 3: COMPETITIVENESS and STRATEGY

Competitiveness

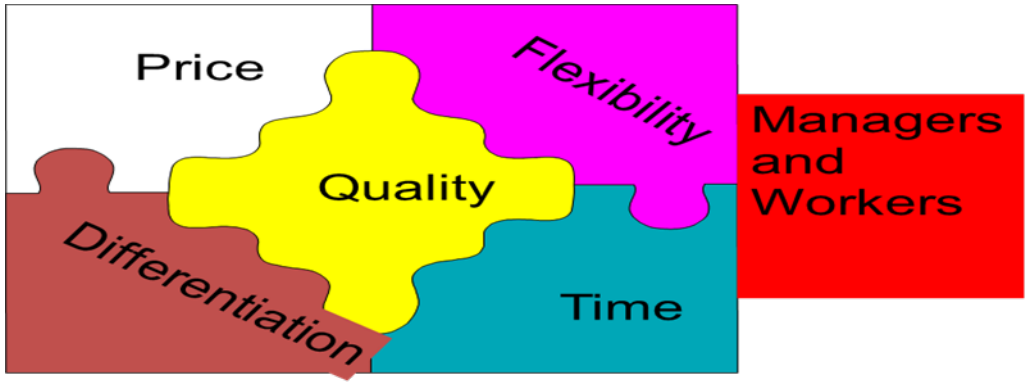
Competitiveness is important to a company because it determines organizations' profits.

- Competitiveness is process by which one entity strives to outperform another.
- The allocation of resources to obtain the organization's long term objectives in the most efficient and effective way.
- Competitiveness depends on productivity

Dimensions of Competitiveness

There are different dimensions of competitiveness such as price, quality, flexibility, differentiation and time. These are the factors and dimensions on the basis of which different organization Compete against each other.

Many organizations are driven by competition. To be successful in today's competitive business environment, companies must know what combinations of factors are most important to satisfy all of their shareholders while also helping to fulfill their mission. These factors may include, but are not limited to: price, quality, services, time or special features. It is critical that organizations as a whole develop goals and strategies to fulfill their mission. Further, each functional area in the business should also have goals and strategies that coincide with accomplishing the larger goals. Employees of the organization should also focus on using all resources efficiently to maximize the productivity of the organization. Productivity has implications not only for the organization at stake, but society as a whole. Managers and workers are yet another important dimension which can effect competitiveness. Efficient and hardworking employees are important source of competitiveness for the organizations.



Indicators of Competitiveness

Productivity: Productivity is efficiency and effectiveness with which goods & services are produced & provided.

Innovation involves the creation of product, service or process that is new to an organization

- Product Innovation (new product development)
- Process Innovation (improved and efficient process modification)
- Incremental (marginal innovation not radical)
- Radical (dramatic and major innovation not incremental and marginal)
- Technological Innovation (Development and usage of improved and innovative technology)

New Competitiveness Paradigm

There is a change in competitiveness focus all over world. Word is now moving from Product competitiveness to Process competitiveness. Further, organizations are also striving for change from process competitiveness to structure/society competitiveness to have a strategic view and focus.

Competitive Advantage

Types of competitive advantages a nation's companies enjoy must shift from comparative advantage (low cost labor or natural resources) to competitive advantages due to unique products or processes.

Low Competitiveness –Drawbacks

Lack of competitiveness is leading to:

- reducing sales
- Stagnation in business
- Underutilization of Capacities & low productivity

Important Concepts

- Policy-Guideline for decision making
- Rule-Do’s and Dont's
- Strategy-Comprehension plan to achieve mission
- Procedure-Steps in chronological order to achieve
- Mission

  The reason for existence for an organization

  - A clear statement of purpose
- Vision-Where you want to see your organization in future

Elements of Strategy

1. Scope

   There are three types of scope for strategy. i.e. Corporate level strategy, Business level strategy and Operations level strategy. A good strategy should define the scope that at what level an organization is making strategy.

2. Goals/Objectives

   A good strategy should define the desired level of accomplishment i.e. goals and objectives.

3. Resource Deployment

   A good strategy should give the idea that how the organizational resources will be deployed across the organization to achieve the desired objectives.

4. Synergy

   A good strategy should create synergy among the different department at horizontal level and also with organizational mission and vision at vertical level.

5. Sustainable Competitive Advantage
   A good strategy should create a sustainable competitive advantage. Human resource is most important source of competitive advantage which is most sustainable with respect to technology, process and management style.

Strategy, Tactics and Operations

- **Strategy (To do)**
  - Plan for achieving organizational goals
  - Long term focus (road map)
  - Organizational vs. functional (Hierarchical)
- **Tactics (How to)**
  - Actions and methods to accomplish strategies
  - Short term focus
- **Operations (Doing)**
  - Day-to-day execution

Strategy Example:

You are a business student at COMSATS Institute of Information Technology. You would like to have a career in business, have a good job, and earn enough income to live comfortably.

Mission: **Live a good life**

Goal: Successful career, good income.

Strategy: Obtain a Business Degree from COMSATS

Tactics: Select a business field of your interest and high market value.

Operations: Register, Buy books, Take courses, Study, Graduate, Apply & get job

Quality and Time Strategies

Quality-based strategies:

- Focuses on quality in all phases of an organization
- Quality at the source

Time-based strategies

- Focuses on reduction of time needed to accomplish tasks

There are 6 time based strategies namely:-

1. Planning Time The time required to react to a competitive threat, or to adopt new technologies, or to approve changes to an existing facility

2. Products/Service Design Time The time needed to develop or market new or redesigned products or services

3. Processing Time The time required to produce goods or services, includes repairing equipment, quality training, inventory etc

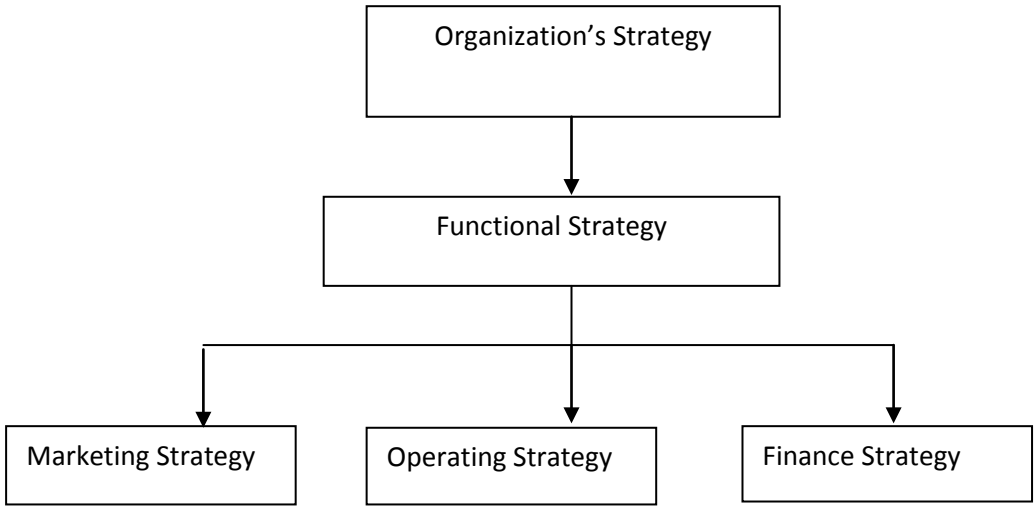
4. Changeover Time is the time needed to change from producing one type of product or service to another i.e. new model, new insurance /health service.

5. Delivery Time is the time needed to fill orders.

6. Response Time for complaints is the required to improve the model or service features according to customer inputs and improving employee working conditions.

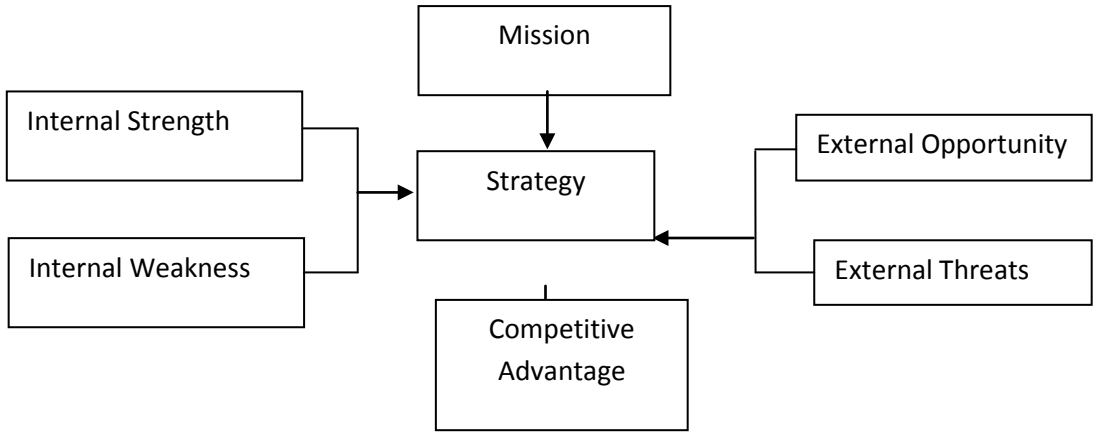
OM Strategic Fit for synergy

In order to achieve strategic fit, operations strategy should have synergy at horizontal level with all other functional strategies such as marketing strategy and finance strategy etc. Further, it should have vertical fit i.e. it should create synergy with organization's overall strategy such as vision, mission etc.



SWOT Analysis to Strategy Formulation

Environmental scanning is most important for strategy formulation. Environmental scanning helps the organization in SWOT analysis i.e. identifying internal strengths and weaknesses and external opportunities and threats. This analysis helps to define strategy to achieve competitive advantage.



Strategic OM Decisions

Following are some of the strategic OM decisions:

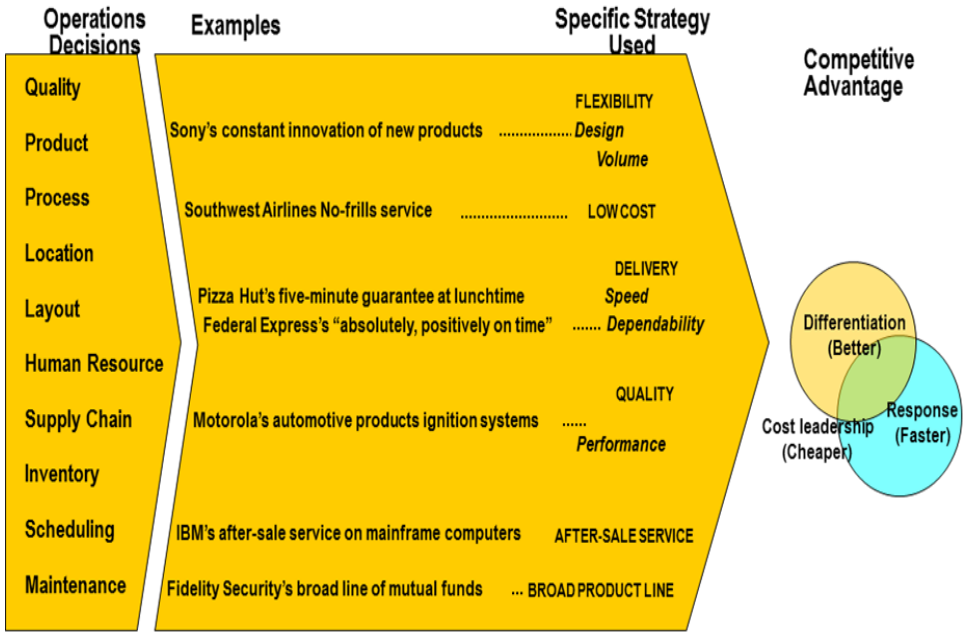
1. Goods and service design
2. Quality
3. Process and capacity design
4. Location selection
5. Layout design
6. Human resources and job design
7. Supply chain management
8. Inventory
9. Scheduling
10. Maintenance

Achieving Competitive Advantage through Operations

- **Differentiation** – better, or at least different (uniqueness in physical characteristics or service attributes
- **Cost leadership** – cheaper (doesn't imply low quality)
- **Response** – (Flexibility, Reliability, rapid response)

OM's Contribution to Strategy

Different operations decisions can use different strategies such as flexibility, price, service etc in order to achieve competitive advantage:



Preconditions -To Implement a Strategy

One must understand:

- Competitors and new entrants
- Environmental, legal, and economic issues
- The notion of product life cycle
- Available resources plus distinctive competencies

- Integration of OM strategy with company strategy and other functions

Impetus for OM Strategy Change

Operations manager should concentrate on following important points for OM strategy change:

- Changes in the organization (what changes should bring in organizations)
- Stages in the product life cycle (what strategy should be applied at particular stage of product life cycle)
- Changes in the environment (what are significant actual and potential changes in environment)

Strategy Development and Implementation

Following are some important steps for strategy development and implementation:

- Environmental (SWOT) analysis
- Distinctive competencies
    - Special attributes or abilities organizations have which can provide competitive edge
- Critical success factors (What are important factors leading to success in a particular industry)
- Build and staff the organization (Manpower should be trained and developed to cash the success factors)
- Deployment - Integration/linkage/alignment (Resources should be deployed and synergy should be created horizontally and vertically)

Operations Strategy

Summing up, a good operations strategy should have:

- Functional Focus (focus on the activities of operations function)
- Linkage and Alignment (Horizontal and Vertical focus with other functions and organization's vision and mission)

Lecture 4: Managing Quality

Introduction to Quality

- Productivity, Cost of Operations & Quality all contribute to Profitability
- Most important determinant of a company's long-term success or failure is QUALITY

What is Quality?

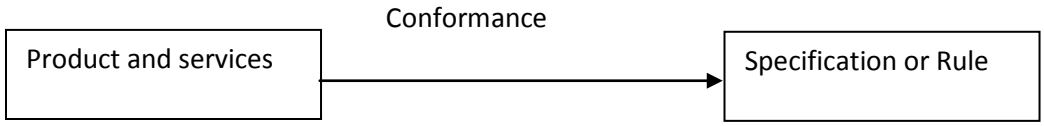
"The totality of characteristics of an entity that bear on its ability to satisfy stated & implied needs."

Quality can be interpreted as "Customer's expressed and implied requirements are met fully". This is a core statement from which some eminent definitions of quality have been derived. They include: "the totality of features and characteristics of a product or service that bears on its ability to meet a stated or implied need", "fitness for use and "conformance to requirement". It is important to note that satisfying the customers' needs and expectations is the main factor in all these definitions. Therefore it is an imperative for a company to identify such needs early in the product/service development cycle. The ability to define accurately the needs related to design, performance, price, safety, delivery, and other business activities and processes will place a firm ahead of its competitors in the market.

Classical Idea

Q: Degree of conformance to a standard

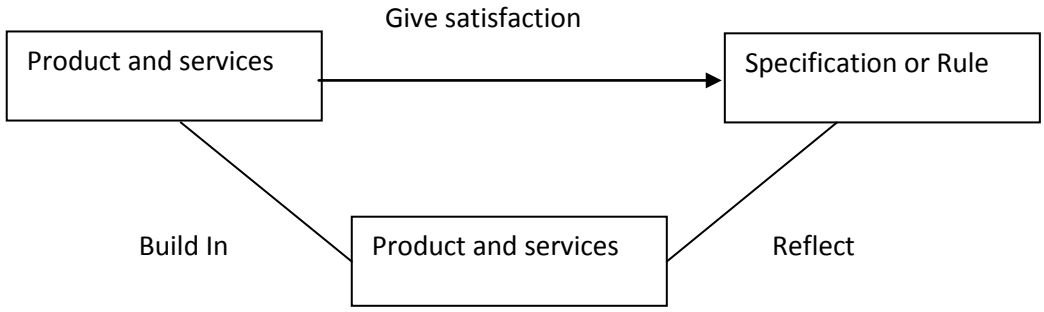
The old and classical idea about quality is how much product and service conforms to the required specifications.



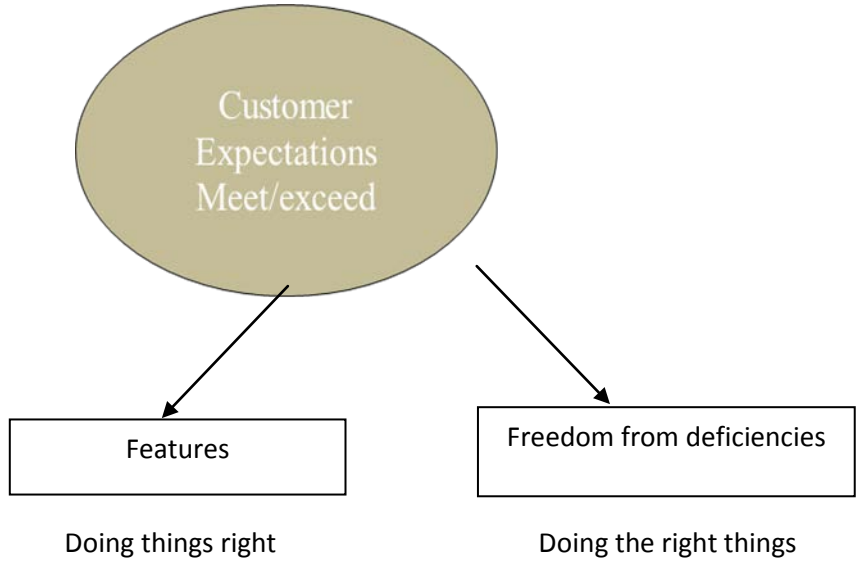
Modern Idea

Q: User's Satisfaction or fitness for use

Modern idea about quality is to link it with customer satisfaction. One has to research what customer wants then build in characteristics and features in products and services to satisfy customers.



What is Quality?

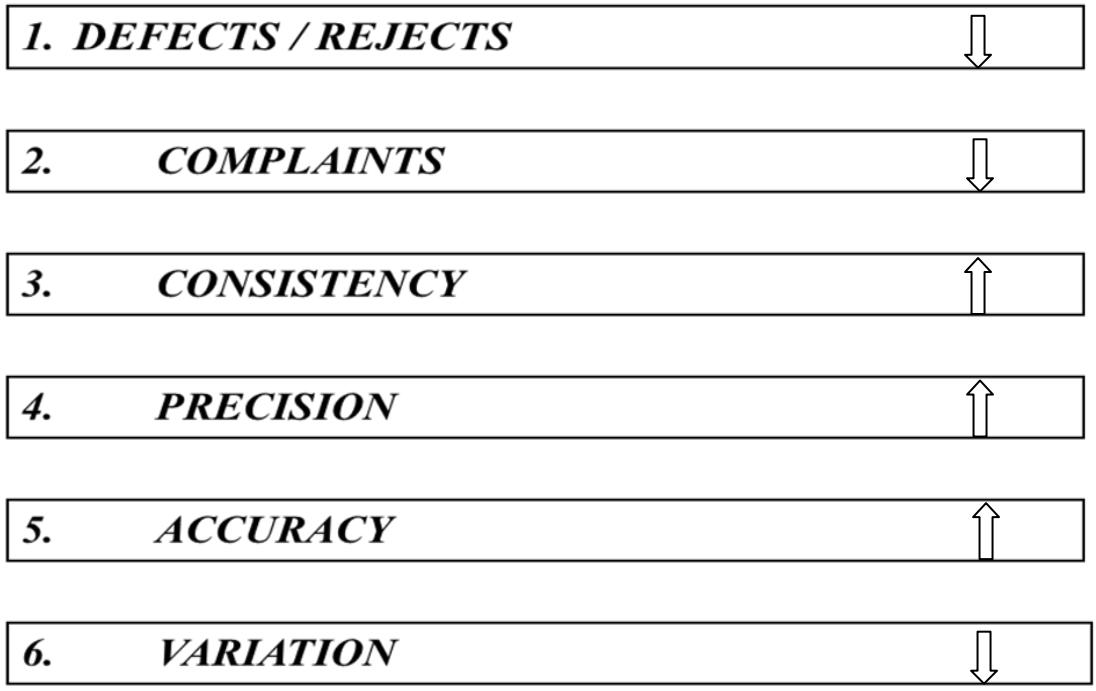


DEFINING QUALITY

Perfection, Consistency, Eliminating waste, Speed of deliver, Compliance with policies & procedures, Providing good, usable products, Doing it right the first time, Delighting or pleasing customers, Total customer service & satisfaction

Basic Quality Function

Quality is inversely proportional to defects/rejects, complaints and variation. It is directly proportional to consistency, precision and accuracy.



Quality means pleasing consumers not just protecting them from annoyances.

Criteria for Quality Assessment

There are different criteria which can be used by managers to assess quality.

JUDGEMENTAL CRITERIA

This criterion is more qualitative in nature. It depends on the personal judgment of the managers who assess quality on the basis of their personal experience. Numerical measures or statistical techniques are not used in this method of assessment.

- Quality = superiority or excellence
- “Goodness of a product”
- “You just know it when you see it”
- little practical value to managers
- No means through which quality can be measured for decision making

PRODUCT-BASED CRITERIA

This criterion depends on the assessment of measurable characteristics of the product and service.

- Quality is a function of a specific, measurable variable
- Higher amount of product characteristics = higher quality
- Quality is mistakenly related to price
- Higher the price, higher the quality (Not necessarily true)

USER-BASED CRITERIA

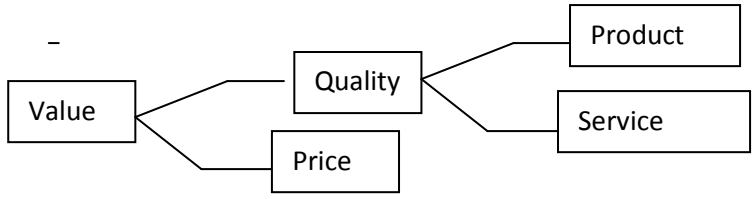
This criterion depends on the extent to which product or service is able to meet the customer demands and wants.

- Quality is determined by what customer wants
- Quality = Fitness for intended use
- How well the product:
  - Performs its intended purpose
  - Meets consumers' needs

VALUE-BASED CRITERIA

In value based criteria both the price and quality of the products are taken into account for quality assessment. "Quality is the degree of excellence at an acceptable price and the control of variability at an acceptable cost."

Gales Model of the Purchase Decision



- Purchase decision involves trading off the quality against the price
- Because many of the attributes of quality are subjective assessments, therefore most of these definitions are subjective
- Unlike manufacturing and product-based approaches
- Offering greater satisfaction at comparable price
- Procter & Gamble brought in VALUE PRICING
- Consumer brand loyalty

- More consistent sales
- Improvement of product characteristics
- Internal efficiencies

MANUFACTURING BASED CRITERIA

This criterion depends on the extent to which a product or service is able to conform to the pre-established standards and sepecifications.

- ***Quality = Conformance to specifications***
- ***Quality is*** "about manufacturing a product that people can depend on every time they reach for it"
- Achieved at Coca-Cola through rigorous quality & packaging standards

PRINCIPAL QUALITY DIMENSIONS

Following are important quality dimensions:

1. ***Performance***

   Performance: a product's primary operating characteristics. Example: A car's acceleration, braking distance, steering and handling

2. ***Features***

   Features: the "bells and whistles" of a product. A car may have power options, a tape or CD deck, antilock brakes, and reclining seats

3. ***Reliability***

   Reliability: the probability of a product's surviving over a specified period of time under stated conditions of use. A car's ability to start on cold days and frequency of failures are reliability factors

4. ***Conformance***

Conformance: the degree to which physical and performance characteristics of a product match pre-established standards. Car's fit/finish; freedom from noises can reflect this.

5. ***Durability***

Durability: the amount of use one gets from a product before it physically deteriorates or until replacement is preferable.

For car - corrosion resistance & long wear of upholstery fabric

6. ***Serviceability***

- Speed, courtesy, competence of repair work.
- Auto owner -access to spare parts.

7. ***Aesthetics***

- How a product looks, feels, sounds, tastes, or smells.
- Car's color, instrument panel design and "feel of road" –make aesthetically pleasing

8. ***Perceived quality***

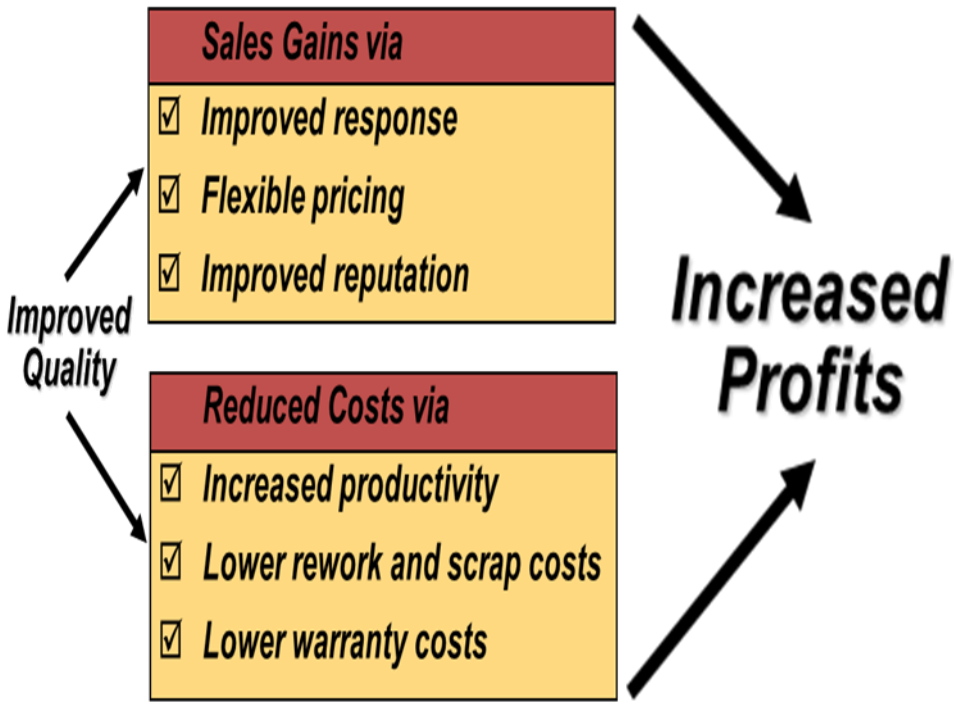
- Subjective assessment of quality resulting from image, advertising, or brand names.
- car, - shaped by magazine reviews-manufacturers' brochures

Quality and Strategy

- Managing quality supports differentiation, low cost, and response strategies
- Quality helps firms increase sales and reduce costs
- Building a quality organization is a demanding task

Two Ways Quality Improves Profitability

Quality helps to boost up the sales through improved response, better pricing and improved reputation. Similarly quality helps to reduce cost due to improved productivity, lower scrap, rework rate and warranty costs. In this way, quality help to increase the profit.



Implications of Quality

1. ***Company reputation***

   Quality helps to improve company reputation through better:

   - Perception of new products
   - Employment practices
   - Supplier relations

2. ***Product liability***

   Quality reduces product liability through lower scrap, warranty cost and thus the reduced risk.

3. ***Global implications***

   In this era of globalization, quality helps for the:

   - Improved ability to compete

Quality Control

Quality Control includes efforts to ensure quality through inspection by acceptance or rejection. It includes reviewing quality of all factors involved in production

Quality Assurance

“Quality assurance includes “all planned & systematic activities implemented within the quality system, & demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality”. It increases the confidence level of Operations Manager that quality products are produced.

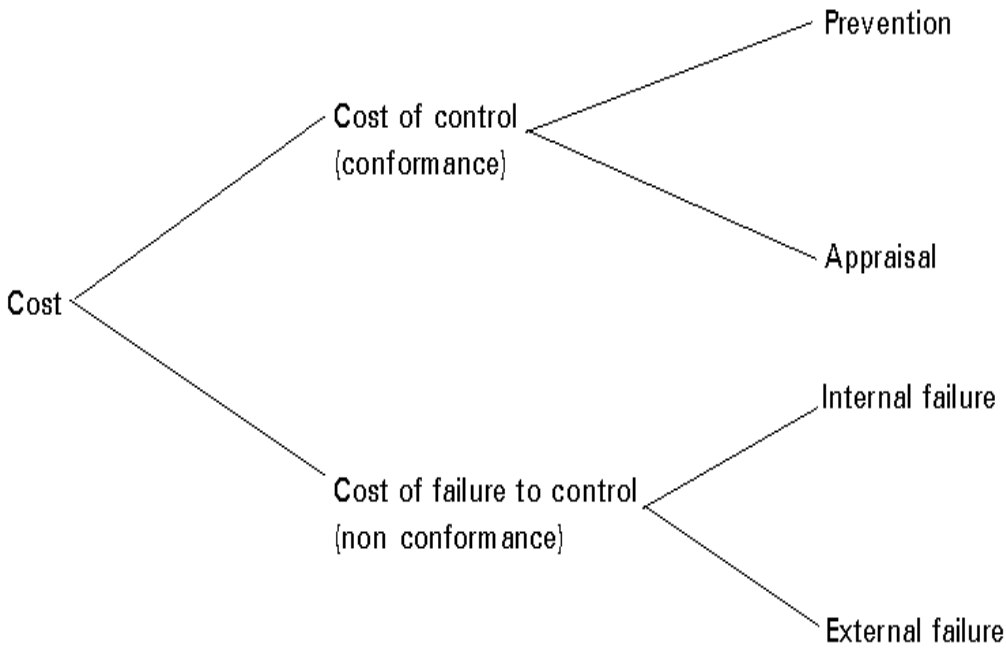
Quality Management

All activities of the overall management function that determine the quality policy, objectives and responsibilities and implement planning, quality control, quality assurance and quality improvement within the quality system” (ISO 840).

What is Cost of Quality??????

“Quality is measured by the cost of quality which is the expense of of non conformance– the cost of doing things wrong.”

These Two Main Areas Can Be Split Further As Shown Below:



Four Segments of Quality Costs:

A. <u>PREVENTION</u>. covers avoiding defects planning, Quality training, Quality circles, training, preventative maintenance & evaluation.

B. <u>APPRAISAL</u>. area covers finding defects by inspection, audit, test & measurement.

C. <u>INTERNAL FAILURE</u>. Cost incurred prior to the shipment of the product or the delivery of the service. These costs are associated with defects that are found prior to customer delivery. covers costs borne by organization itself such as scrap, rework, redesign,.

D. <u>EXTERNAL FAILURE</u>. These are the costs of discovered defects after product shipment or service delivery. covers costs borne by customer such as warranty, administrative cost in dealing with failure & loss of goodwill.

Cost of Quality

Prevention costs

- build it right the first time
- Prevention costs are incurred to prevent defects in products

Appraisal costs

- inspection and testing
- appraisal costs are costs incurred to determine whether products are conforming to specifications

Internal failure costs

- scrap and rework
- Internal failure costs are incurred when nonconforming products are detected prior to shipment.

External failure costs

- warranty claims, recalls, lost business
- External failure costs are incurred because nonconforming products are delivered to customers.
- External failure costs can be more devastating because of warranty costs, lawsuits, damage to the reputation of a company, all of which may greatly exceed the costs of rework or scrap incurred from internal failure costs.

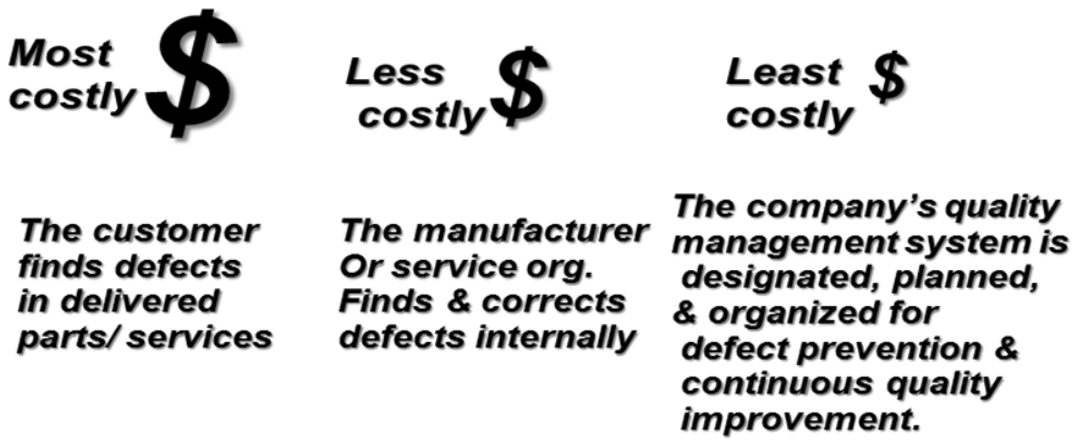
Total Cost of Quality

Total Quality cost, is a combination of prevention, appraisal & failure. Reducing any of these reduces total. key to minimum cost, is striking correct balance b/w three.

Clearly prevention reduces both appraisal and failure costs, -eventually cost of prevention itself starts to increase total cost & so must be controlled & set at an effective level

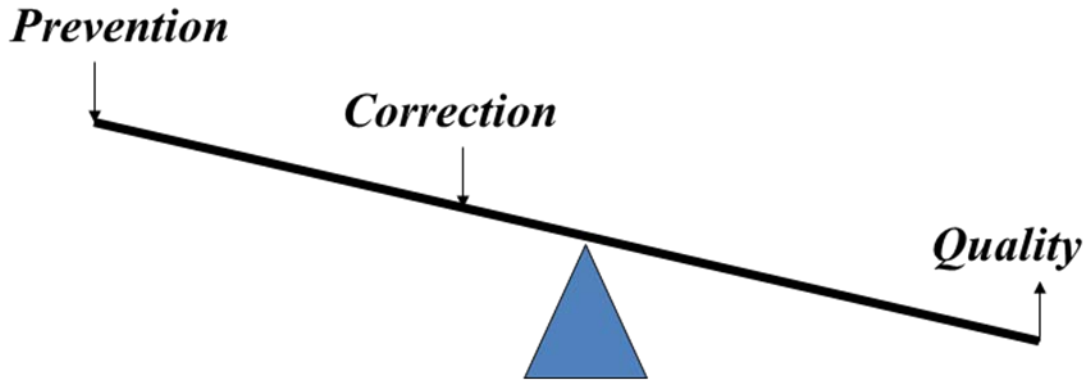
Comparative Cost of Quality

It will be more costly for organizations if customers find defects in products after delivery. In this case organizations will have rework with products and bear warranty charges as well. Planning and managing the quality system to avoid defects will be least costly for the organizations.



A Manager Who Fails To Provide Resources And Time For Prevention Activities Is Practicing False Economy

Concentrate on Prevention, Not Correction



Prevention has more leverage when improving quality.

Leaders in Quality	*Contribution*
W. Edwards Deming	14 Points for Management
Joseph M. Juran	Top management commitment, fitness for use
Armand Feigenbaum	Total Quality Control
Philip B. Crosby	zero defects

W Edwards Deming: placed great importance and responsibility on management, at the individual and company level, believing management to be responsible for 94% of quality problems. His fourteen point plan is a complete philosophy of management that can be applied to small or large organizations in the public, private or service sectors. He believed that adoption of, and action on, the fourteen points was a signal that management intended to stay in business. Deming also encouraged a systematic approach to problem solving and

promoted the widely known ***P**lan, **D**o, **C**heck, **A**ct (PDCA) cycle*. The **PDCA** cycle is also known as the Deming cycle.

The cycle is about learning and ongoing improvement, learning what works and what does not in a systematic way; and the cycle repeats; after one cycle is complete, another is started.

Dr Joseph M Juran: developed the quality trilogy – quality planning, quality control and quality improvement. Good quality management requires quality actions to be planned out, improved and controlled. The process achieves control at one level of quality performance, and then plans are made to improve the performance on a project by project basis, using tools and techniques such as **Pareto** analysis.

Juran believed quality is associated with customer satisfaction and dissatisfaction with the product, and emphasized the necessity for ongoing quality improvement through a succession of small improvement projects carried out throughout the organization.

He concentrated not just on the end customer, but on other external and internal customers.

Armand V Feigenbaum: was the originator of "total quality control", often referred to as total quality. He defined it as:

"An effective system for integrating quality development, quality maintenance and quality improvement efforts of the various groups within an organization, so as to enable production and service at the most economical levels that allow full customer satisfaction**".**

He saw it as a business method and proposed three steps to quality:

1. Quality leadership
2. Modern quality technology

3. Organizational commitment

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- Quality leadership
- Modern quality technology
- Organizational commitment

Philip B Crosby is known for the concepts of "Quality is Free" and "Zero Defects", and his quality improvement process is based on his four absolutes of quality:

Quality is conformance to requirements

- The system of quality is prevention
- The performance standard is zero defects
- The measurement of quality is the price of non-conformance

Ethics and Quality Management

- Operations managers must deliver healthy, safe, quality products and services
- Poor quality risks injuries, lawsuits, recalls, and regulation
- Organizations are judged by how they respond to problems

- All stakeholders must be considered

International Quality Standards

ISO 9000 series

ISO 9000 is a series of five international quality standards. These standards center on the concept of documentation and control of nonconformance and change. ISO 9000 certification can be a requirement of doing business (e.g., in Europe). Also, many companies have found that the process of applying for ISO 9000, while lengthy and expensive, yields important benefits in terms of self-knowledge. U.S. companies are using ISO 9000 certification as a competitive tool, as well.

Common quality standards for products 2000 update places greater emphasis on leadership and customer satisfaction

ISO 14000 series Environmental Standard

This is international standards for environment management

Core Elements:

- Environmental management
- Auditing
- Minimizing how the operations negatively affect the environment

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Lecture 5 Total Quality Management (*TQM*)

Encompasses entire organization, from supplier to customer Stresses a commitment by management to have a continuing, companywide drive toward excellence in all aspects of products and services that are important to the customer

Deming's Fourteen Points

1. **Create consistency of purpose**

TQM is a long-term Process and a way of life. It is a cultural transition which encourages new way of doing things. It is not a program with visible end.

2. **Lead to promote change**

TQM encourages long term and continuous change with incremental improvement. Managers should always lead to promote change on continuous basis

3. **Build quality into the product; stop depending on inspection**

TQM focuses on prevention of defects through a better understanding of customer requirements, use of effective processes, and empowerment of the workforce. It must replace detection of defects through inspection. When errors are detected during inspection, rework is necessary and, consequently, productivity is lowered and costs are increased.

4. **Build long-term relationships based on performance, not price**

Price has no meaning without a measure of quality. Quality emphasis must be first among equal (quality, price, schedule, responsiveness, etc). Low quality ultimately results in high cost even when initial cost is low. Price comparison would be based on "life cycle" or " cost of ownership".

5. **Continuously improve product, quality, and service**

   Improvement is management's responsibility, but to be successful, it must involve the workforce. Best ideas for product improvement come from customers (Von Hippel). Involvement of supplier is essential.

6. **Start training**

   Training is the cornerstone of consistency. Because process improvement will displace workers, there must be cross-training. People, the most valuable resource, should be provided with necessary knowledge and skills.

7. **Emphasize leadership**

   Managers are there to support workers by providing charters, guidance, effective processes, roadblock removal, and resources. Manager should direct his/her efforts horizontally, not vertically. Workers should be considered the customers of their managers; they have a right to expect effective support. Things are managed, people are led. Management reviews focus on processes rather than on people.

8. **Drive out fear**

   Empowerment to workforce let them think & act like owners. Authoritarian management must be replaced by participative mgt. Job security should not be linked to rank or position. If increased productivity threatens job security, worker will resist improvement.

9. **Break down barriers between departments**

   Departmental barriers result in cross-functional competition and sub-operation. The route to success is through development and use of self-directed cross-functional teams. Promotion path in western organizations

is generally vertical in one function. Japanese organizations frequently affect cross-functional transfers to provide general corporate experience and to break down barriers between departments.

10. Stop haranguing workers

Management example is a more effective motivator than slogans, exhortations and targets. Targets without methods are ineffective. Slogans do not help people do the job better. Generally, defects are not caused by the workers; they result from failure to understand what the customer (or manager) require, and they result from ineffective processes, training, tools or environment.

11. Support, help, improve

Management should support and help workers in achieving the predetermined targets and continuous improvement.

12. Remove barriers to pride in work

Strong performers have intrinsic motivation, weak ones get weaker when identified as losers. Note, this may be among the most controversial of Deming's teaching, the Japanese initially dealt with this by awarding annual way increases based on position and seniority alone, but they are increasingly linking annual wage increases to annual performance appraisal (e.g. Toyota). Everyone should be the "captain of his game".

13. Institute a vigorous program of education and self-improvement

Education differs from training but is equally important. Education enhances pride/dignity and potential for professional growth. Managers should encourage openness to change. Company-sponsored education

creates a kind of covenant between the employee and the organization: partnership, mutual growth, reciprocal commitment.

14. Put everybody in the company to work on the transformation

TQM must be implemented from top to down. These must be visible commitment buy senior management, based on demonstrated understanding & practice of TQM principles. Only then will workforce commit itself. TQM infrastructure must be established, but it must not stand outside the organization: it must consist of organization's most credible people, & must be totally integrated (superimposed). Transformation requires change in organizational culture.

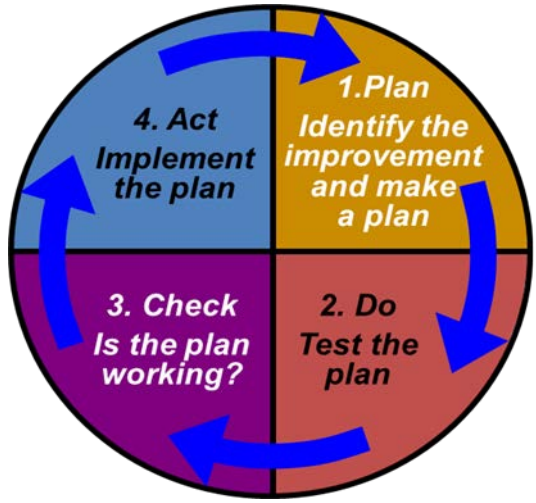
Seven Concepts of TQM

1. Continuous improvement
2. Six Sigma
3. Employee empowerment
4. Benchmarking
5. Just-in-time (JIT)
6. Taguchi concepts
7. Knowledge of TQM tools

Continuous Improvement

- Represents continual improvement of all processes
- Involves all operations and work centers including suppliers and customers
    - People, Equipment, Materials, Procedures

Shewhart's PDCA Model



Zero Defects

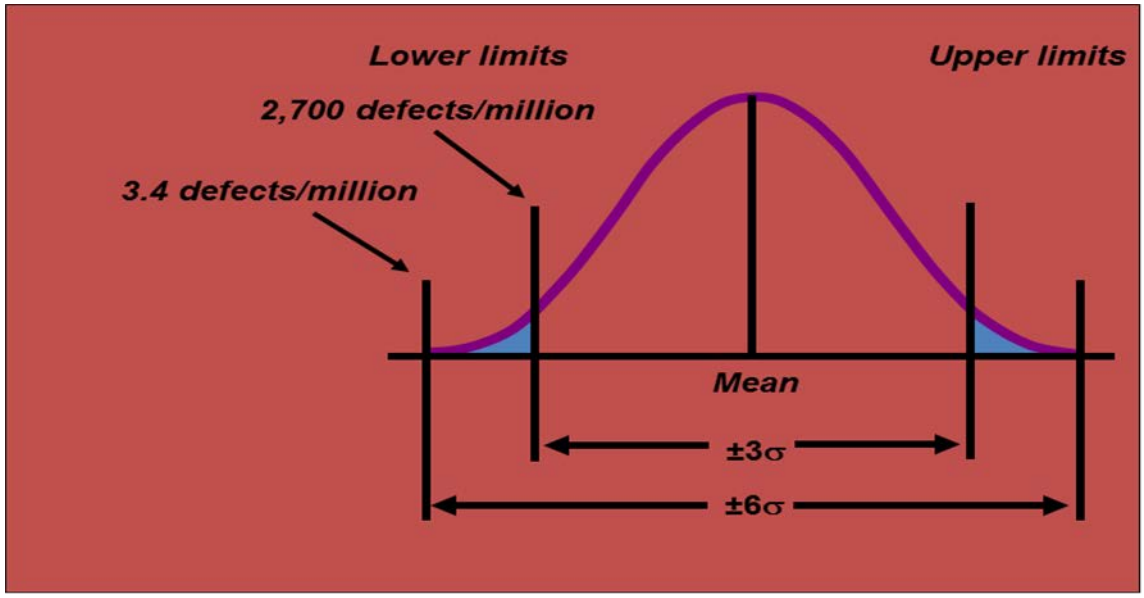
Kaizen

Continuous Improvement

Six Sigma

Two meanings:

1. Statistical definition of a process that is 99.9997% capable, 3.4 defects per million opportunities (DPMO)
2. A program designed to reduce defects, lower costs, and improve customer satisfaction



Six Sigma Program

- Originally developed by Motorola, adopted and enhanced by Honeywell and GE
- Highly structured approach to process improvement
    - A strategy
    - A discipline - DMAIC

1. **D**efine critical outputs and identify gaps for improvement
2. **M**easure the work and collect process data
3. **A**nalyze the data
4. **I**mprove the process
5. **C**ontrol the new process to make sure new performance is maintained

Six Sigma Implementation

- Emphasize defects per million opportunities as a standard metric

- Provide extensive training
- Create qualified process improvement experts (Black Belts, Green Belts, etc.)
- Set stretch objectives

This cannot be accomplished without a major commitment from top level management

- Getting employees involved in product and process improvements
    - 85% of quality problems are due to process and material
- Techniques
    - Build communication networks that include employees
    - Develop open, supportive supervisors
    - Move responsibility to employees
    - Build a high-morale organization
    - Create formal team structures

Quality Circles

- Group of employees who meet regularly to solve problems
- Trained in planning, problem solving, and statistical methods
- Often led by a facilitator
- Very effective when done properly

Benchmarking

Selecting best practices to use as a standard for performance

- Determine what to benchmark
- Form a benchmark team
- Identify benchmarking partners
- Collect and analyze benchmarking information
- Take action to match or exceed the benchmark

Just-in-Time (JIT)

Relationship to quality:

- JIT cuts the cost of quality
- JIT improves quality
- Better quality means less inventory and better, easier-to-employ JIT system
- Pull' system of production scheduling including supply management
    - Production only when signaled
- Allows reduced inventory levels
    - Inventory costs money and hides process and material problems
- Encourages improved process and product quality

Taguchi Concepts

Dr Genichi Taguchi believed it is preferable to design product that is robust or insensitive to variation in the manufacturing process, rather than attempt to control all the many variations during actual manufacture. To put this idea into practice, he took the already established knowledge on experimental design and made it more usable and practical for quality professionals. His message was concerned with the routine optimization of product and process prior to manufacture rather than quality through inspection.

- Engineering and experimental design methods to improve product and process design
- Identify key component and process variables affecting product variation

Taguchi Concepts

1. Quality robustness
2. Quality loss function
3. Target-oriented quality

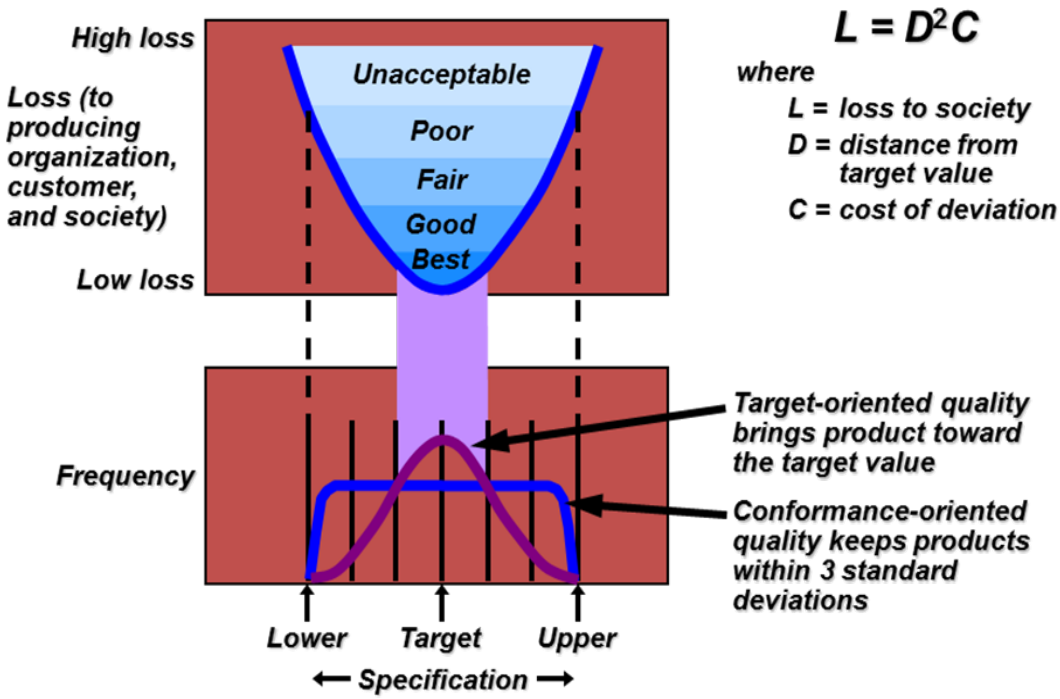
1.Quality Robustness

Ability to produce products uniformly in adverse manufacturing and environmental conditions

- Remove the effects of adverse conditions
- Small variations in materials and process do not destroy product quality

2.Quality Loss Function

- Shows that costs increase as the product moves away from what the customer wants
- Costs include customer dissatisfaction, warranty and service, internal scrap and repair, and costs to society
- Traditional conformance specifications are too simplistic



Tools of TQM

- **Tools for Generating Ideas**

  1. Check sheets
  2. Scatter diagrams
  3. Cause-and-effect diagrams

- **Tools to Organize the Data**

  1. Pareto charts
  2. Flowcharts

- **Tools for Identifying Problems**

  - Histogram
  - Statistical process control chart

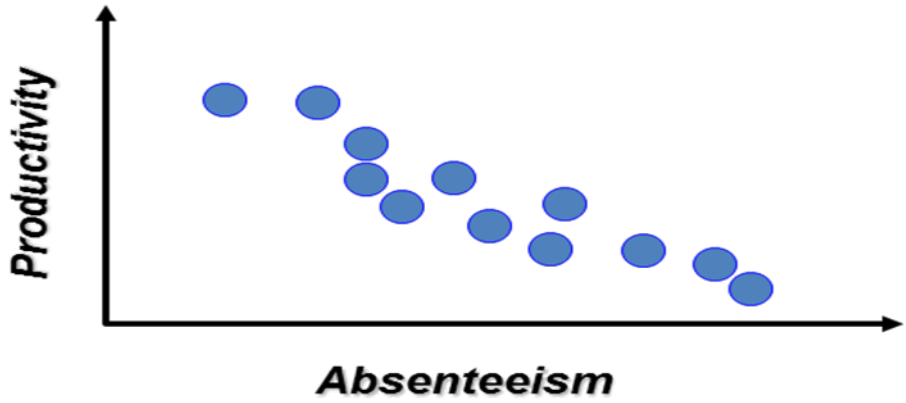
Seven Tools of TQM

(a) Check Sheet: An organized method of recording data

	Hour							
Defect	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	///	/		/	/	/	///	/
B	//	/	/	/			//	///
C	/	//					//	////

b)Scatter Diagram: A graph of the value of one variable vs. another variable

Scatter diagrams are used to study possible relationships between two variables. Although these diagrams cannot prove that one variable causes the other, they do indicate the existence of a relationship, as well as the strength of that relationship. A scatter diagram is composed of horizontal axis containing the measured values of one variable and a vertical axis representing the measurements of the other variable. The purpose of the scatter diagram is to display what happens to one variable when another variable is changed. The diagram is used to test a theory that the two variables are related. The type of relationship that exits is indicated by the slope of the diagram



c)Cause-and-Effect Diagram: A tool that identifies process elements (causes) that might effect an outcome

The fishbone diagram identifies many possible causes for an effect or problem. It can be used to structure a brainstorming session. It immediately sorts ideas into useful categories.

Fishbone Diagram Procedure

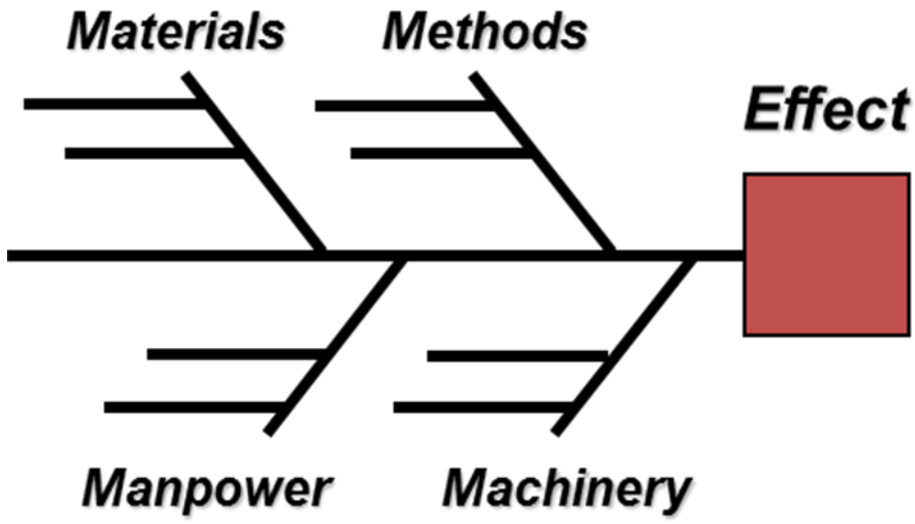
Materials needed: flipchart or whiteboard, marking pens.

1. Agree on a problem statement (effect). Write it at the center right of the flipchart or whiteboard. Draw a box around it and draw a horizontal arrow running to it.
2. Brainstorm the major categories of causes of the problem. If this is difficult use generic headings:

    - Methods
    - Machines (equipment)
    - People (manpower)
    - Materials
    - Measurement

- Environment

3. Write the categories of causes as branches from the main arrow.
4. Brainstorm all the possible causes of the problem. Ask: “Why does this happen?” As each idea is given, the facilitator writes it as a branch from the appropriate category. Causes can be written in several places if they relate to several categories.
5. Again ask “why does this happen?” about each cause. Write sub-causes branching off the causes. Continue to ask “Why?” and generate deeper levels of causes. Layers of branches indicate causal relationships.
6. When the group runs out of ideas, focus attention to places on the chart where ideas are few.



(d) Pareto Chart: A graph to identify and plot problems or defects in descending order of frequency

A bar graph used to arrange information in such a way that priorities for process improvement can be established.

How to Use It

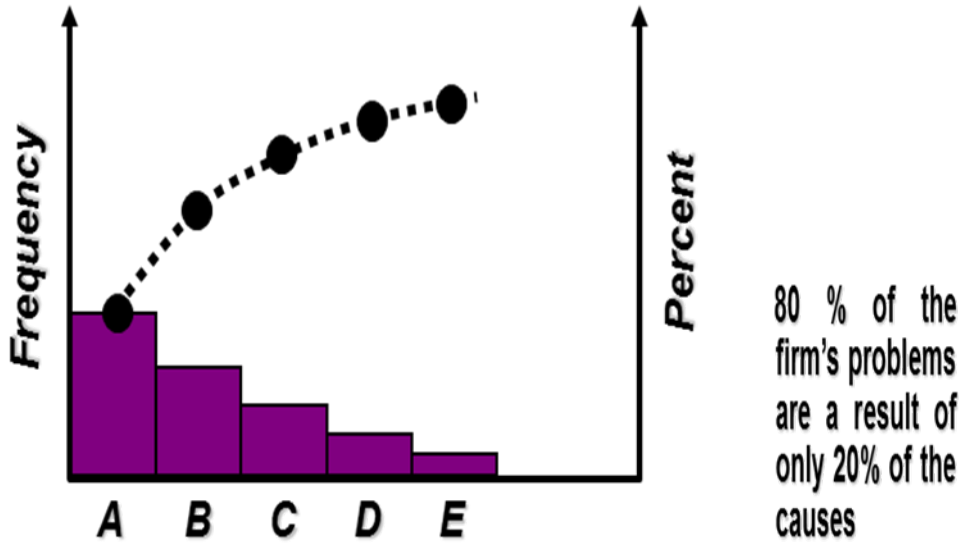
Step 1. Develop a list of problems, items, or causes to be compared.

Step 2. Develop a standard measure for comparing the items.

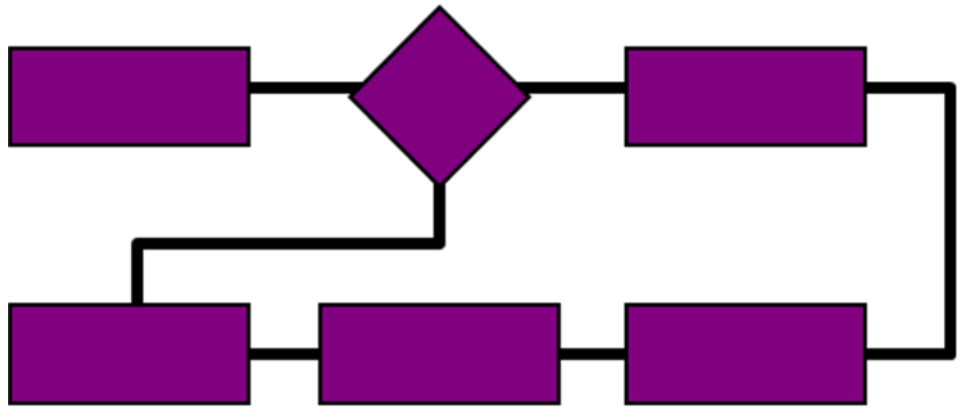
- How often it occurs: frequency (e.g., utilization, complications, errors)
- How long it takes: time
- How many resources it uses: cost

Step 3. Choose a time frame for collecting the data.

Step 4. Tally, for each item, how often it occurred (or cost or total time it took). Then add these amounts to determine the grand total for all items. Find the percent of each item in the grand total by taking the sum of the item, dividing it by the grand total, and multiplying by 100.



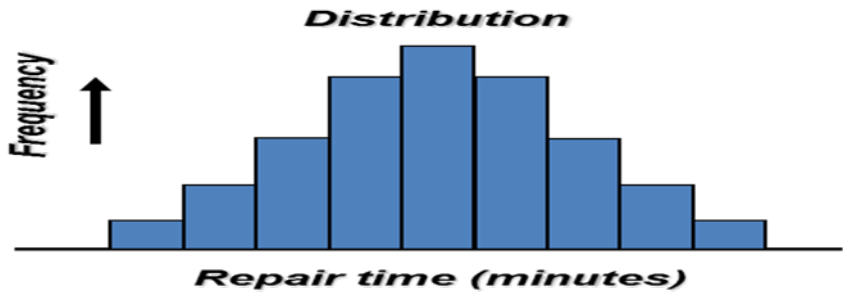
(e) Flowchart (Process Diagram): A chart that describes the steps in a process



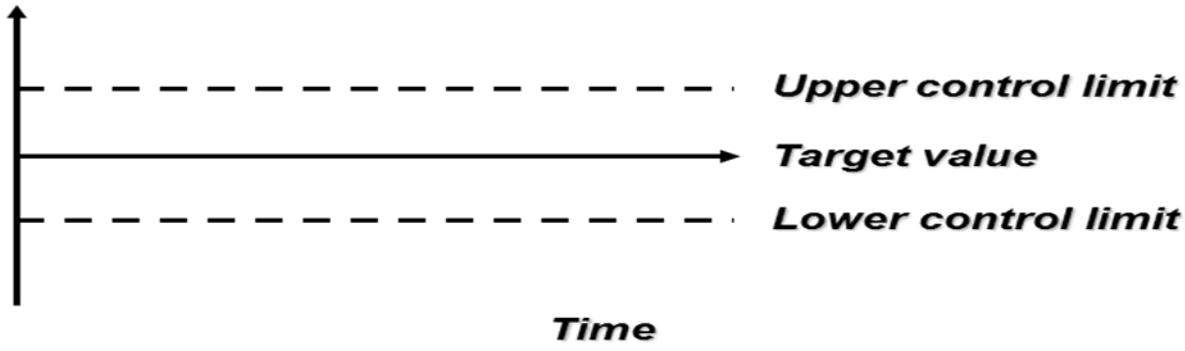
(f) Histogram: A distribution showing the frequency of occurrences of a variable

A histogram is a summary graph showing distribution of data points measured that falls within various class-intervals. A class interval is a division of a range of values into sets of non-overlapping intervals for plotting a histogram. It is drawn with rectangles side by side with the area of each rectangle being

proportional to the frequency of the observations falling into the corresponding class-interval



(g) Statistical Process Control Chart: A chart with time on the horizontal axis to plot values of a statistic



Lecture 6 Managing Quality (*Quality tools implications and Problem solving*)

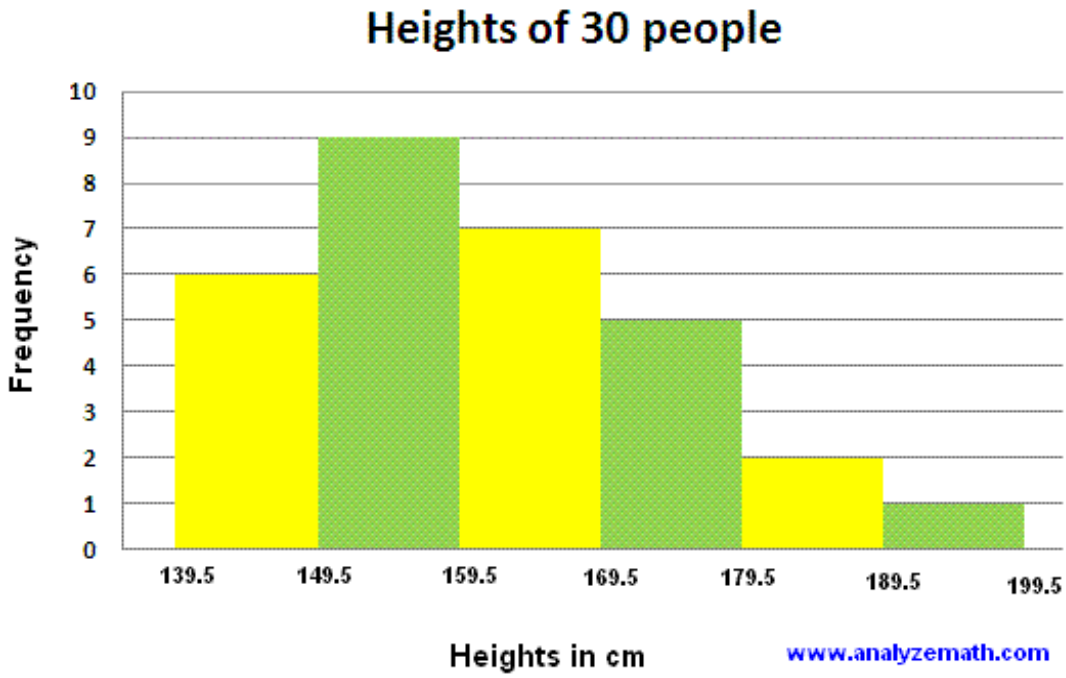
The histogram below shows the heights (in cm) distribution of 30 people.

a) How many people have heights between 159.5 and 169.5 cm?

b) How many people have heights less than 159.5 cm?

c) How many people have heights more than 169.5 cm?

d) What percentage of people have heights between 149.5 and 179.5 cm?



a) 7 people

b) 9 + 6 = 15 people

c) 5 + 2 + 1 = 8 people

d) (9 + 7 + 5)/30 = 0.7 = 70%

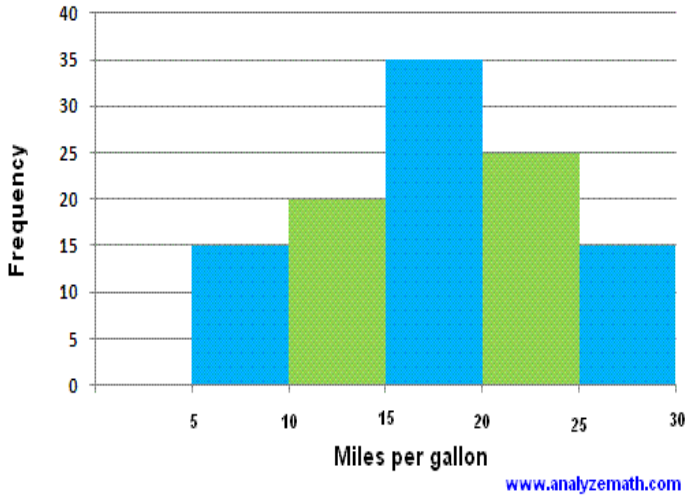
Q2:

The histogram below shows the efficiency level (in miles per gallons) of 110 cars.

a) How many cars have an efficiency between 15 and 20 miles per gallon?

b) How many cars have an efficiency more than 20 miles per gallon?

c) What percentage of cars have an efficiency less than 20 miles per gallon?



a) 35 cars

b) 25 + 15 = 40 cars

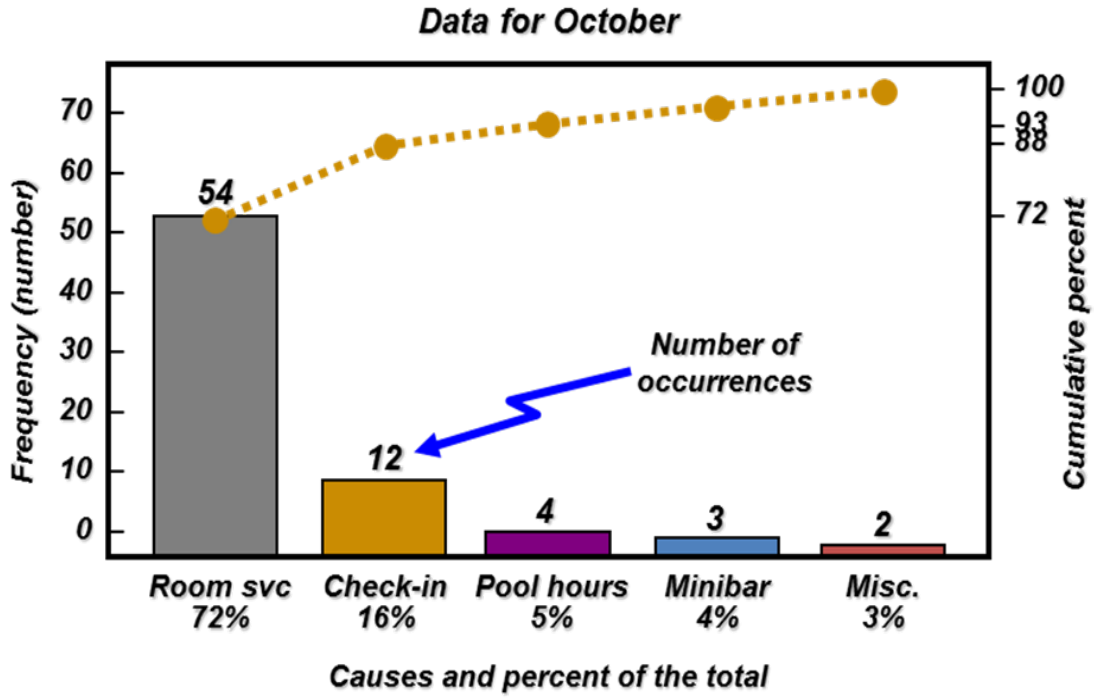
c) (15 + 20 + 35) / 110 = 0.636 = 63.6%

Example (Pareto chart)

The Hard Rock Hotel has just collected the data from 75 complaint calls to the general manager during the month of October. The manager wants to prepare an analysis of the complaints. The data provided are room service, 54; check-in delays, 12; hours the pool is open, 4; minibar prices, 3 and miscellaneous, 2.

Complaint Description	f	f (dec.)	cf	f (%)	cf (%)
Room Service	54	54	54	$\frac{54}{75}$x100=**72**	72
Check-in delays	12	12	66	16	88
Hours the pool is open	4	4	70	5	93
Minibar prices	3	3	73	4	97
Miscellaneous	2	2	75	3	**100**
Total		75			

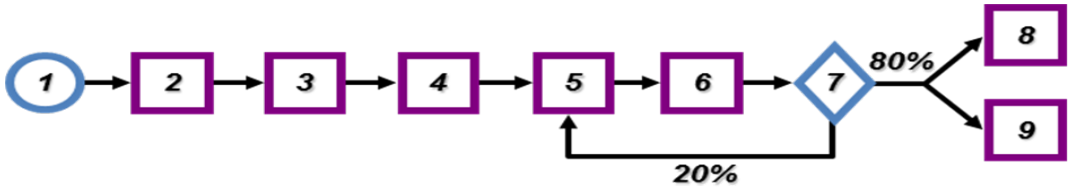
Pareto Charts



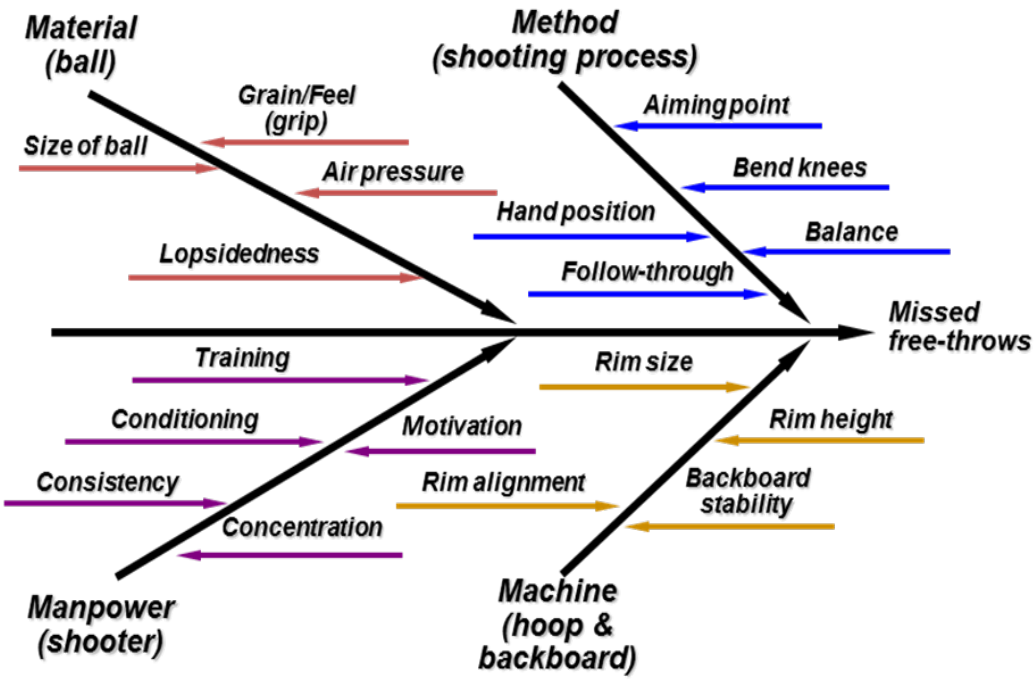
Flow Charts

MRI Flow Chart

1. *Physician schedules MRI*
2. *Patient taken to MRI*
3. *Patient signs in*
4. *Patient is prepped*
5. *Technician carries out MRI*
6. *Technician inspects film*
7. *If unsatisfactory, repeat*
8. *Patient taken back to room*
9. *MRI read by radiologist*
10. *MRI report transferred to physician*
11. *Patient and physician discuss*



Cause-and-Effect Diagrams

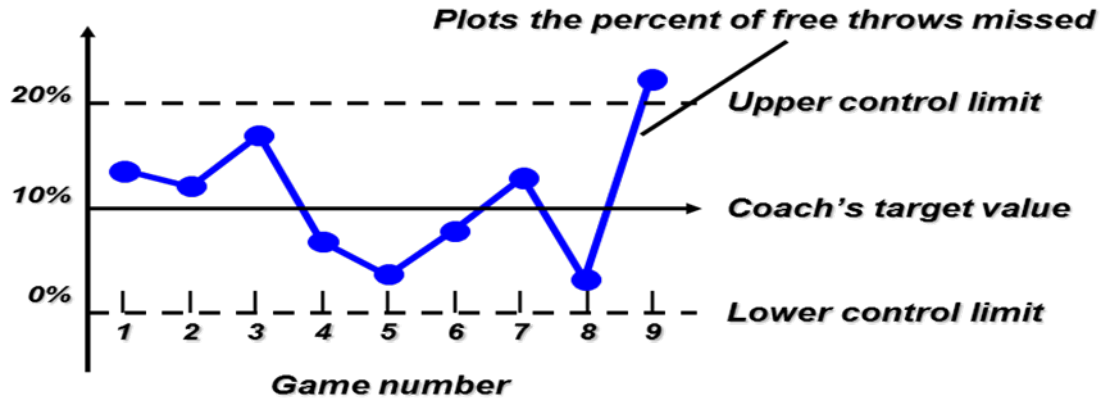


Statistical Process Control (SPC)

- Uses statistics and control charts to tell when to take corrective action
- Drives process improvement
- Four key steps

    1. Measure the process
    2. When a change is indicated, find the assignable cause
    3. Eliminate or incorporate the cause
    4. Restart the revised process

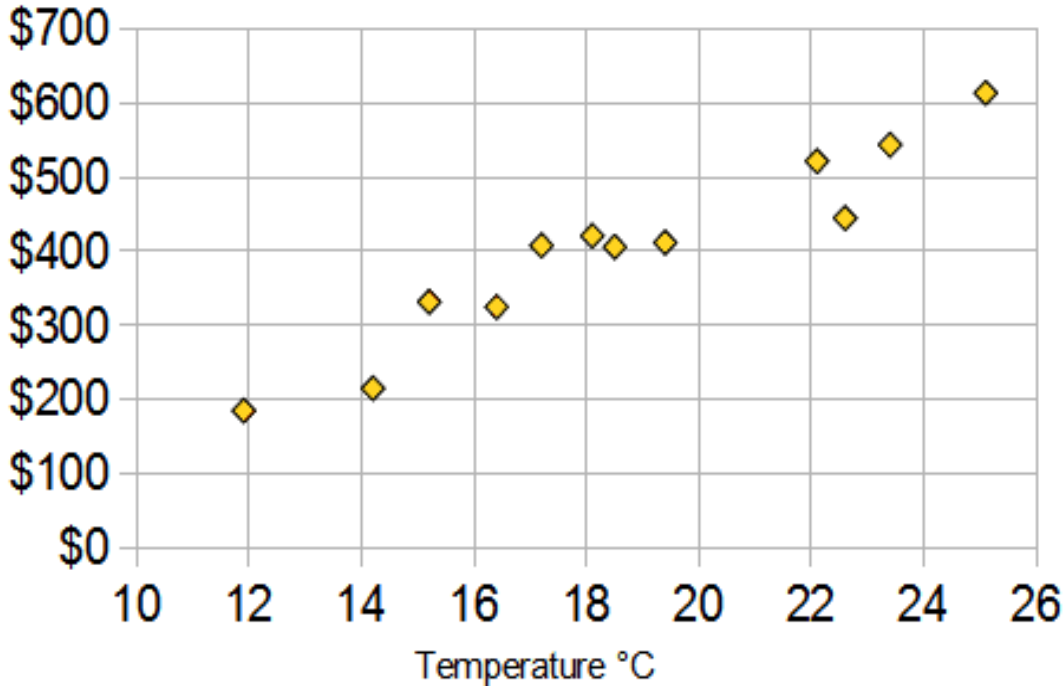
An SPC Chart


Plots the percent of free throws missed
20%
10%
0%
Upper control limit
Coach's target value
Lower control limit
1
2
3
4
5
6
7
8
9
Game number

Example: The local ice cream shop keeps track of how much ice cream they sell versus the temperature on that day. Here are their figures for the last 12 days:

Ice Cream Sales vs Temperature

Temperature °C	Ice Cream Sales
14.2°	$215
16.4°	$325
11.9°	$185
15.2°	$332
18.5°	$406
22.1°	$522
19.4°	$412
25.1°	$614
23.4°	$544
18.1°	$421
22.6°	$445
17.2°	$408



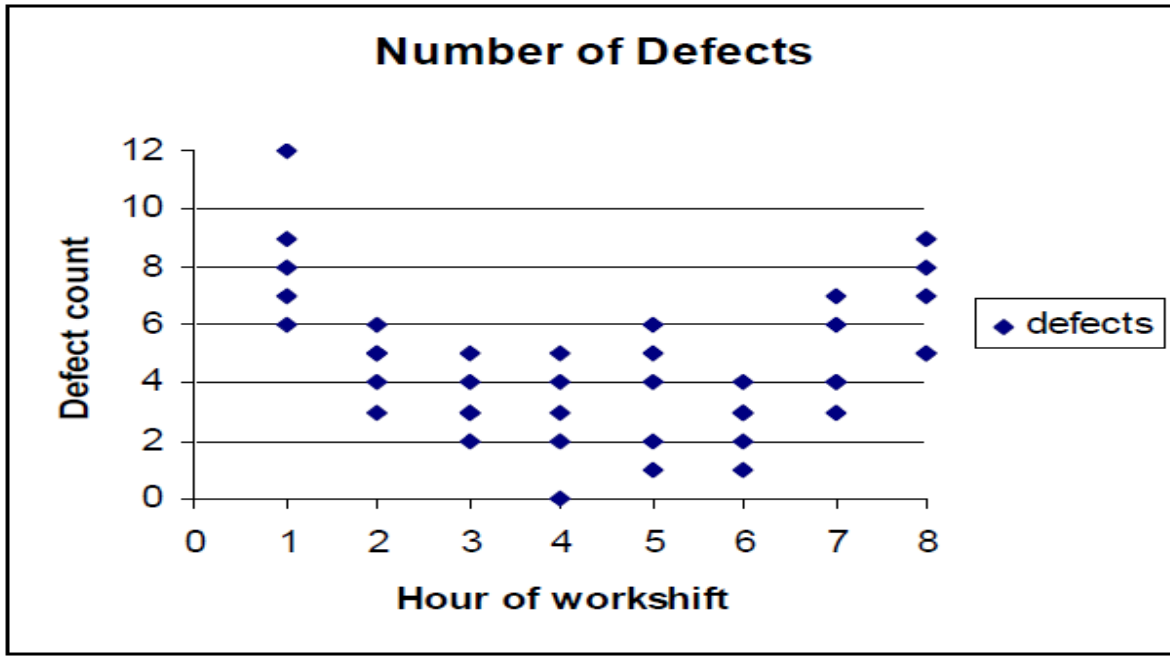
It is now easy to see that warmer weather leads to more sales.

Problem

Management is concerned that workers create more product defects at the very beginning and end of a work shift than at other times of their eight hour workday. Construct a scatter diagram with the following data, collected last week. Is management justified in its belief?

	Number of defects				
	Monday	Tuesday	Wednesday	Thursday	Friday
First hour at work	12	9	6	8	7
Second hour at work	6	5	3	4	5
Third hour at work	5	2	4	3	3
Fourth hour at work	4	0	5	2	3
Fifth hour at work	1	6	2	4	5
Sixth hour at work	4	3	3	2	1
Seventh hour at work	7	4	4	6	3
Eighth hour at work	5	7	8	5	9

Solution



There is fairly convincing evidence that there are more defects in the first and last shift hours than at other times.

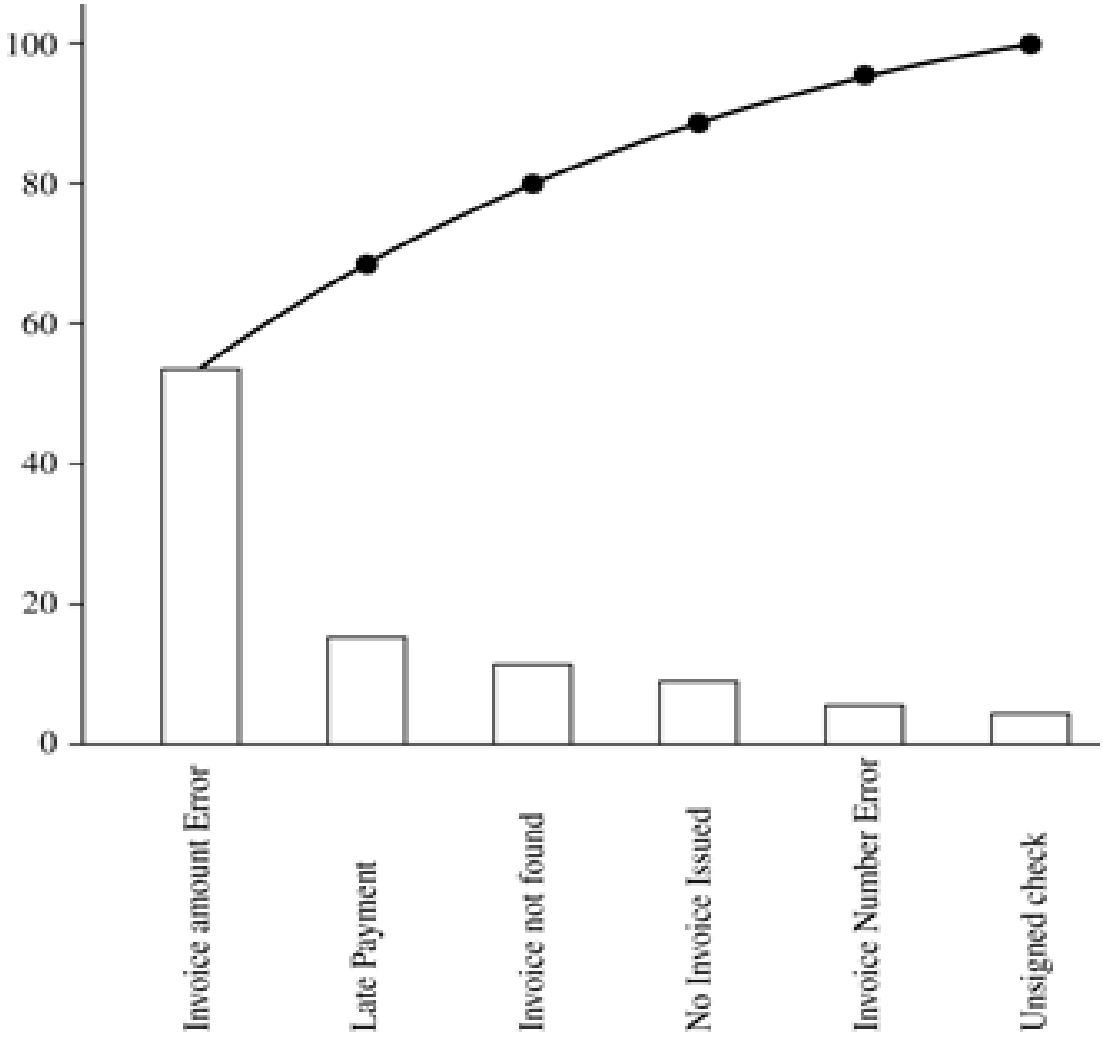
Problem

The accounts receivable department has documented the following defects over a 30-day period: What techniques would you use and what conclusions can you draw about defects in the accounts receivable department?

Category	Frequency
Invoice amount does not agree with the check amount	108
Invoice not on record (not found)	24
No formal invoice issued	18
Check (payment) not received on time	30
Check not signed	8
Invoice number and invoice referenced do not agree	12

Solution

Category	Frequency	Percent	Cumulative %
Invoice amount does not agree with the check amount	108	54	54
Check (payment) not received on time	30	15	69
Invoice not on record (not found)	24	12	81
No formal invoice issued	18	9	90
Invoice number and invoice referenced do not agree	12	6	96
Check not signed	8	4	100
S =	200	100	

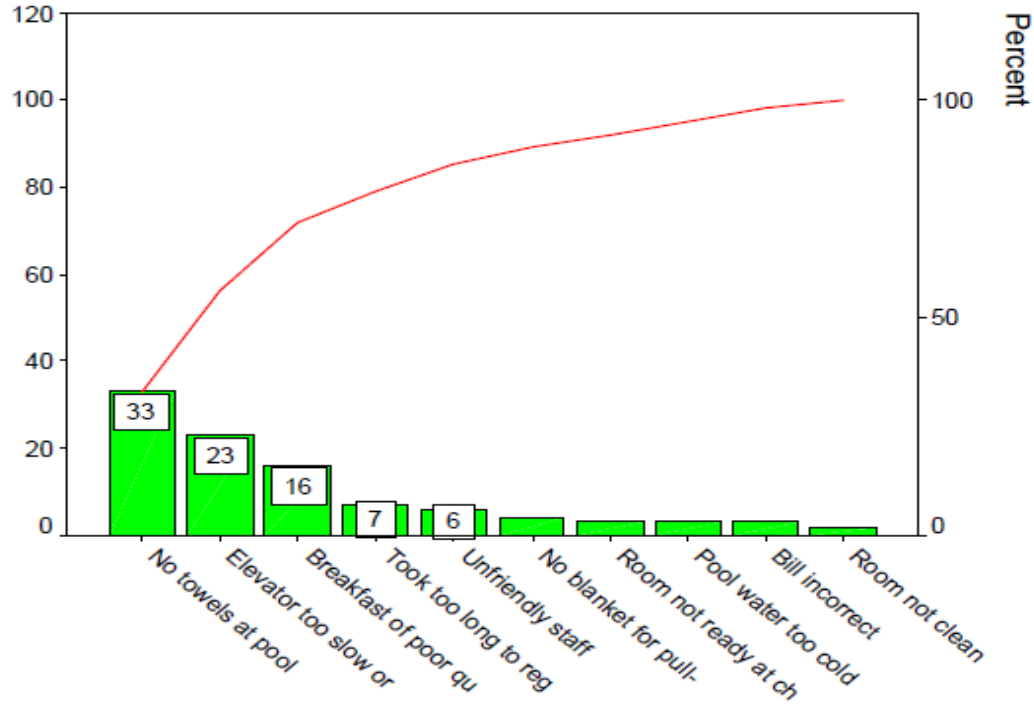

100
80
60
40
20
0
Invoice amount Error
Late Payment
Invoice not found
No Invoice Issued
Invoice Number Error
Unsigned check

Problem

Perform a Pareto analysis on the following information:

Reason for unsatisfying stay at hotel	Frequency
Unfriendly staff	6
Room not clean	2
Room not ready at check-in	3
No towels at pool	33
No blanket for pull-out sofa	4
Pool water too cold	3
Breakfast of poor quality	16
Elevator too slow or not working	23
Took too long to register	7
Bill incorrect	3
Total	100

Solution

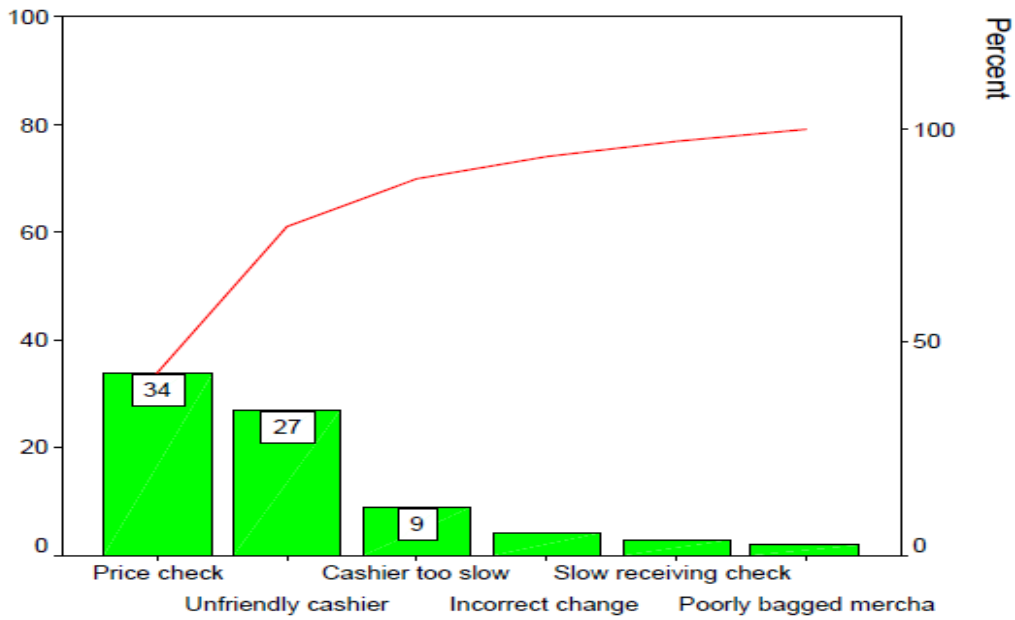

120
100
80
60
40
20
0
Percent
100
50
0
33
23
16
7
6
No towels at pool
Elevator too slow or
Breakfast of poor qu
Took too long to reg
Unfriendly staff
No blanket for pull-
Room not ready at ch
Pool water too cold
Bill incorrect
Room not clean

Problem

Perform a Pareto analysis on the following information:

Reason for unsatisfying check-out at store	Frequency
Unfriendly cashier	27
Incorrect change	4
Cashier too slow	9
Price check	34
Poorly bagged merchandise	2
Slow receiving check approval	3

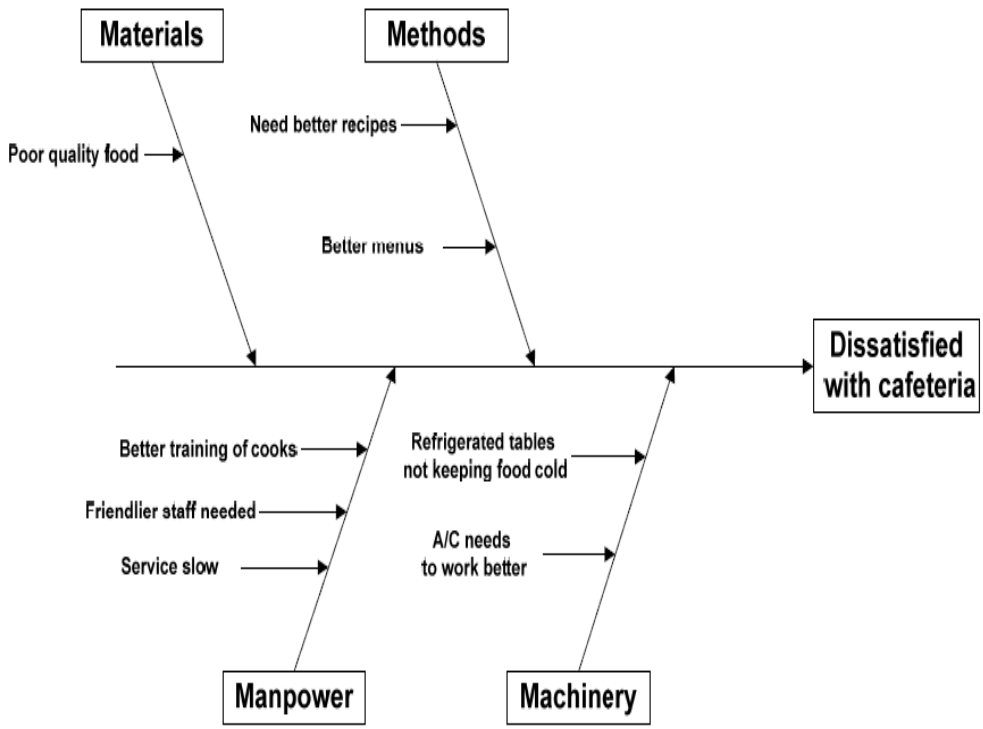
Solution



Problem

Construct a cause-and-effect diagram showing why a student might be dissatisfied with the cafeteria.

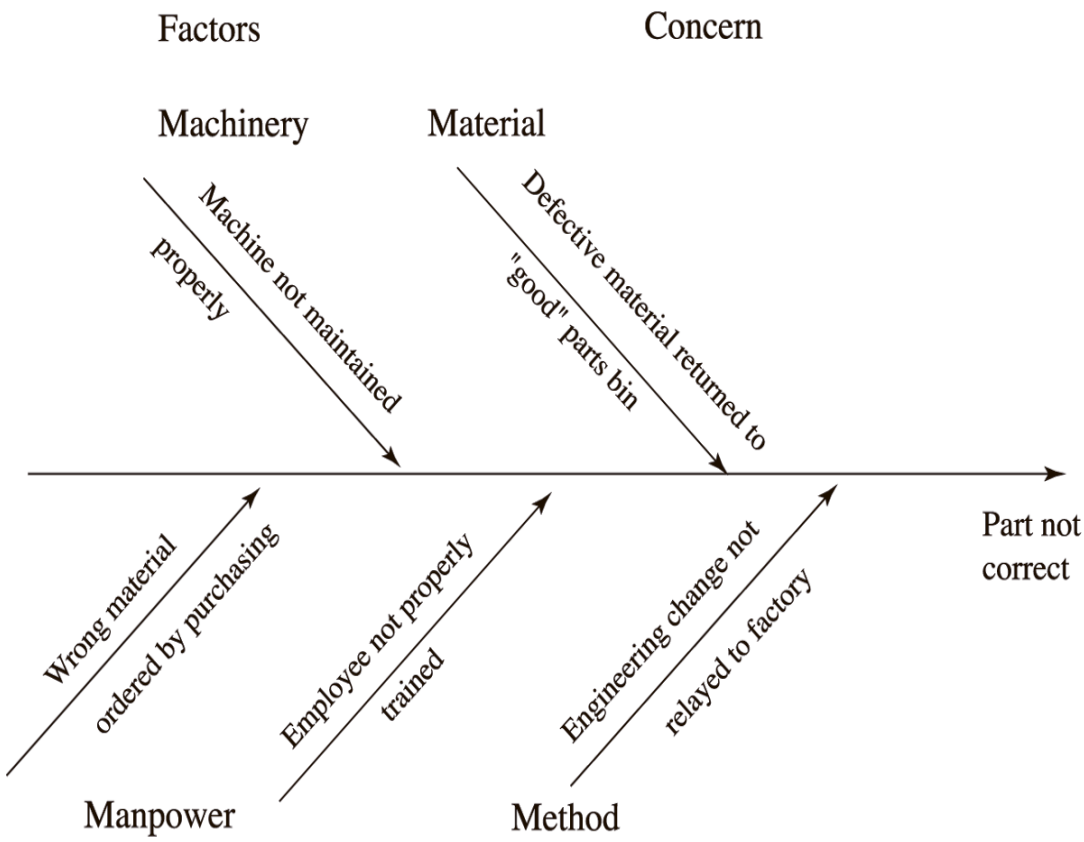
Solution



Problem

Draw a fishbone chart detailing reasons why a part might not be correctly machined.

Solution



Problem

Prepare a flow chart for purchasing a Big Mac at the drive-through window at McDonalds.

Solution

Distance	Symbol	Activity
--		Pull up to speaker
--		Press button
--		Wait for response
--		Verbalize order
--		Get confirmation of order and cost
20		Move car up in line
--		Wait
20		Move car up in line
--		Wait
--		Verify order and cost
--		Pay and receive order
--		Leave
--		Realize they forgot the extra catsup!

Lecture 7: Linear Programming

Linear Programming

- A mathematical technique to allocate limited resources to achieve an objective
- linear programming (LP) is a technique for optimization of a linear objective function, subject to linear equality and linear inequality constraints.

Linear programming determines the way to achieve the best outcome (such as maximum profit or minimum cost) in a given mathematical model and given some list of requirements represented as linear equations.

- It is one of more powerful technique for managerial decisions
- A Linear Programming model seeks to maximize or minimize a linear function, subject to a set of linear constraints.
- The linear model consists of the following components:
  - A set of decision variables.
  - An objective function.
  - A set of constraints
- Will find the minimum or maximum value of the objective
- Guarantees the optimal solution to the model formulated

LP Applications

1. Scheduling school buses to minimize total distance traveled
2. Allocating police patrol units to high crime areas in order to minimize response time

3. Scheduling tellers at banks so that needs are met during each hour of the day while minimizing the total cost of labor

4. Selecting the product mix in a factory to make best use of machine- and labor-hours available while maximizing the firm's profit

5. Picking blends of raw materials in feed mills to produce finished feed combinations at minimum costs

6. Determining the distribution system that will minimize total shipping cost

7. Developing a production schedule that will satisfy future demands for a firm's product and at the same time minimize total production and inventory costs

Requirements of an LP Problem

1. There should be an objective function to maximize or minimize some quantity (usually profit or cost)

2. The restrictions or constraints are present which limit the ability to achieve objective

3. There must be alternative courses of action from which to choose

4. The objective and constraints in linear programming problems must be expressible in terms of linear equations or inequalities

Mathematical formulation of Linear Programming model

Step 1

- Study the given situation
- Find the key decision to be made
    - Identify the decision variables of the problem

Step 2

- Formulate the objective function to be optimized

Step 3

- Formulate the constraints of the problem

Step 4

- Add non-negativity restrictions or constraints

The objective function , the set of constraints and the non-negativity restrictions together form an LP model.

Formulating LP Problems

The product-mix problem at Shader Electronics

☑ Two products

1. Shader X-pod, a portable music player
2. Shader BlueBerry, an internet-connected color telephone

☑ Determine the mix of products that will produce the maximum profit

	Hours Required to Produce 1 Unit		
Department	X-pods (X_1)	BlueBerrys (X_2)	Available Hours This Week
Electronic	4	3	240
Assembly	2	1	100
Profit per unit	$7	$5	

Decision Variables:

X_1 = number of X-pods to be produced

X_2 = number of BlueBerrys to be produced

Objective Function:

Maximize Profit = $\$7X_1 + \$5X_2$

There are three types of constraints

1. Upper limits where the amount used is ≤ the amount of a resource
2. Lower limits where the amount used is ≥ the amount of the resource
3. Equalities where the amount used is = the amount of the resource

First Constraint:

Electronic time used is ≤ Electronic time available

$4X_1 + 3X_2 \leq 240$ (hours of electronic time)

Second Constraint:

Assembly time used is ≤ Assembly time available

$2X_1 + 1X_2 \leq 100$ (hours of assembly time)

Graphical Solution

☑ Can be used when there are two decision variables

1. Plot the constraint equations at their limits by converting each equation to an equality

2. Identify the feasible solution space
3. Create an iso-profit line based on the objective function
4. Move this line outwards until the optimal point is identified

$4X_1 + 3X_2 = 240$-------(I) . **2X1 + 1X2 = 100-----(II)**

If $X_2 = 0$, $X_1 = 60$then : Point (60, 0) , If $X_2 = 0$, $X_1 = 50$ then: Point (50, 0)

If $X_1 = 0$, $X_2 = 80$then : Point (0, 80) , If $X_1 = 0$, $X_2 = 100$ then :Point (0, 100)

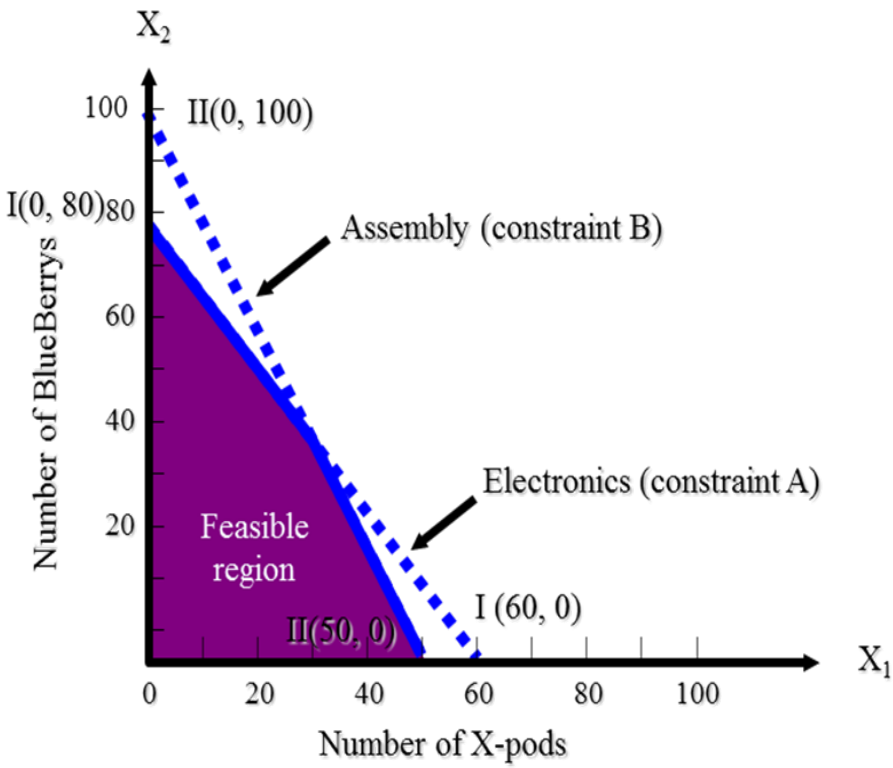


Figure B.3

Iso-Profit Line Solution Method

Choose a possible value for the objective function

$210 = 7$X_1$ + 5X_2

Solve for the axis intercepts of the function and plot the line

X_2 = 42 X_1 = 30

Graphical Solution

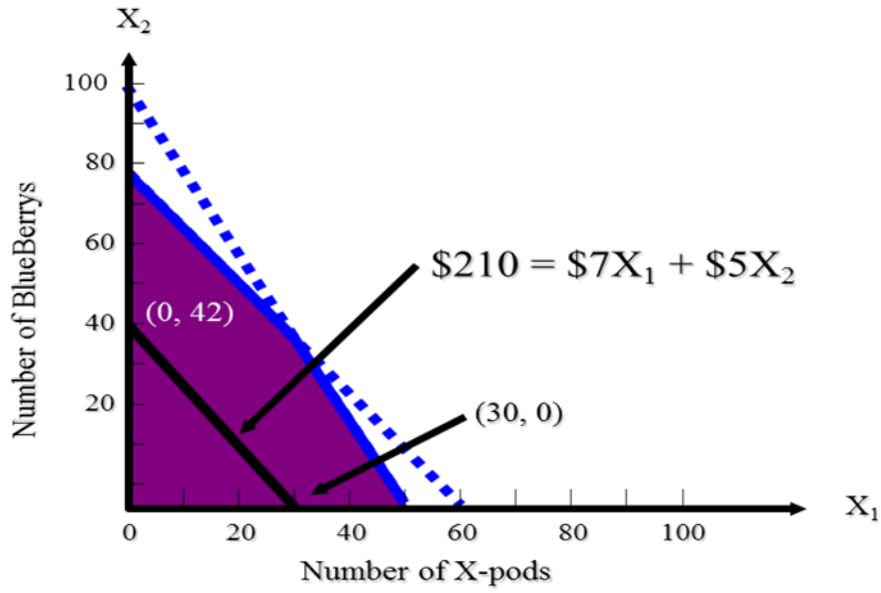


Figure B.4

Graphical Solution

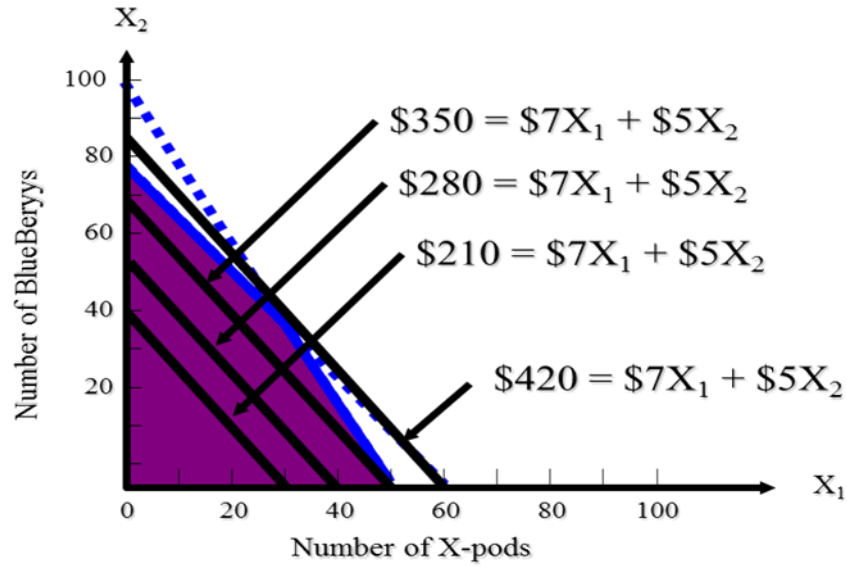


Figure B.5

Graphical Solution

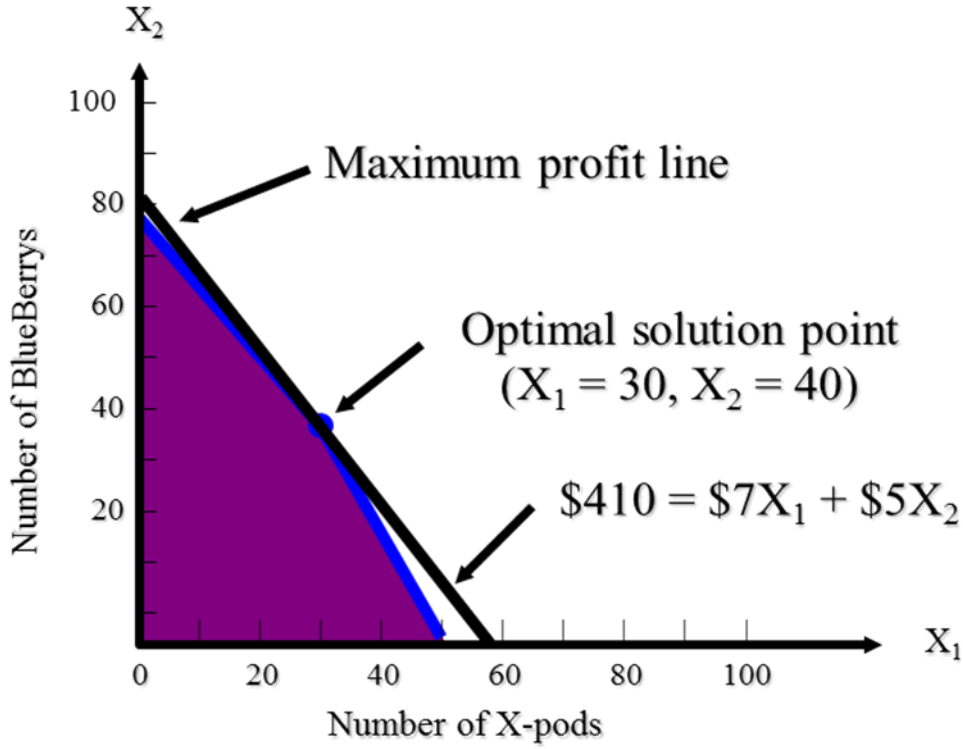


Figure B.6

Corner-Point Method

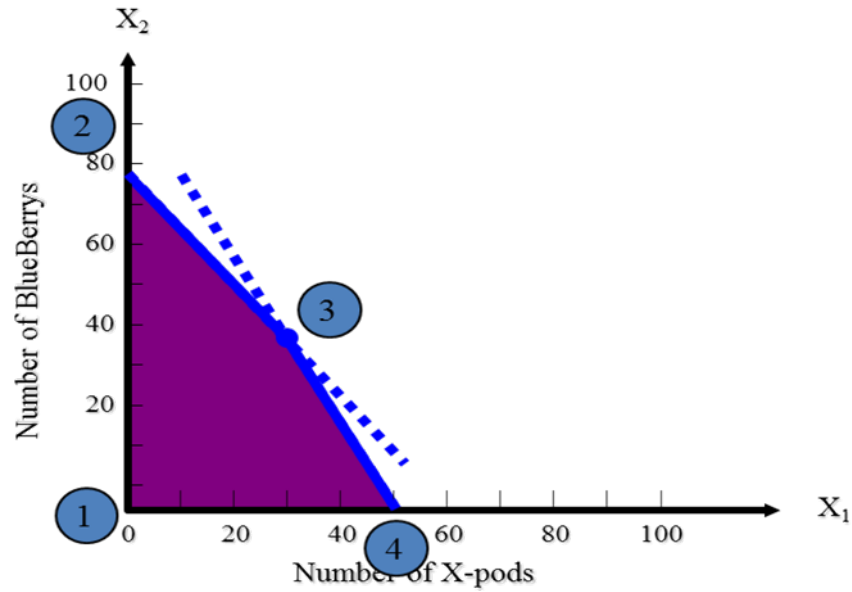


Figure B.7

The optimal value will always be at a corner point

Find the objective function value at each corner point and choose the one with the highest profit

Point 1 1 : $(X_1 = 0, X_2 = 0)$ **Profit \$7(0) + \$5(0) = \$0**

Point 2 : $(X_1 = 0, X_2 = 80)$ **Profit \$7(0) + \$5(80) = \$400**

Point 4 : $(X_1 = 50, X_2 = 0)$ **Profit \$7(50) + \$5(0) = \$350**

Solve for the intersection of two constraints

$4X_1 + 3X_2 \leq 240$ **(electronics time)**

$2X_1 + 1X_2 \leq 100$ **(assembly time)**

$4X_1 + 3X_2 = 240$

$-4X_1 - 2X_2 = -200$

$+ 1X_2 = 40$

$4X_1 + 3(40) = 240$

$4X_1 + 120 = 240$

$X_1 = 30$

Maximize $Z = 5x_1 + 6x_2$

Subject to $3x_1 + 2x_2 \leq 120$ ..... (i)

$4x_1 + 6x_2 \leq 260$ ..... (ii)

$x_1 \geq 0$

$x_2 \geq 0$

Solution:

For Line (i)

y_1 intercept Put $x_1 = 0$ in eq (i)

$2x_2 = 120$

$x_2 = 60$

$(0, 60)$

x_1 intercept Put $x_2 = 0$ in eq (i)

$3x_1 = 120$

$x_1 = 40$

$(40, 0)$

For Line (ii)

y_2 intercept Put $x_1 = 0$ in eq (ii)

$$6x_2 = 260$$

$$x_2 = 43\frac{1}{3}$$

$$x_2 = 43.3$$

$$(0, 43.3)$$

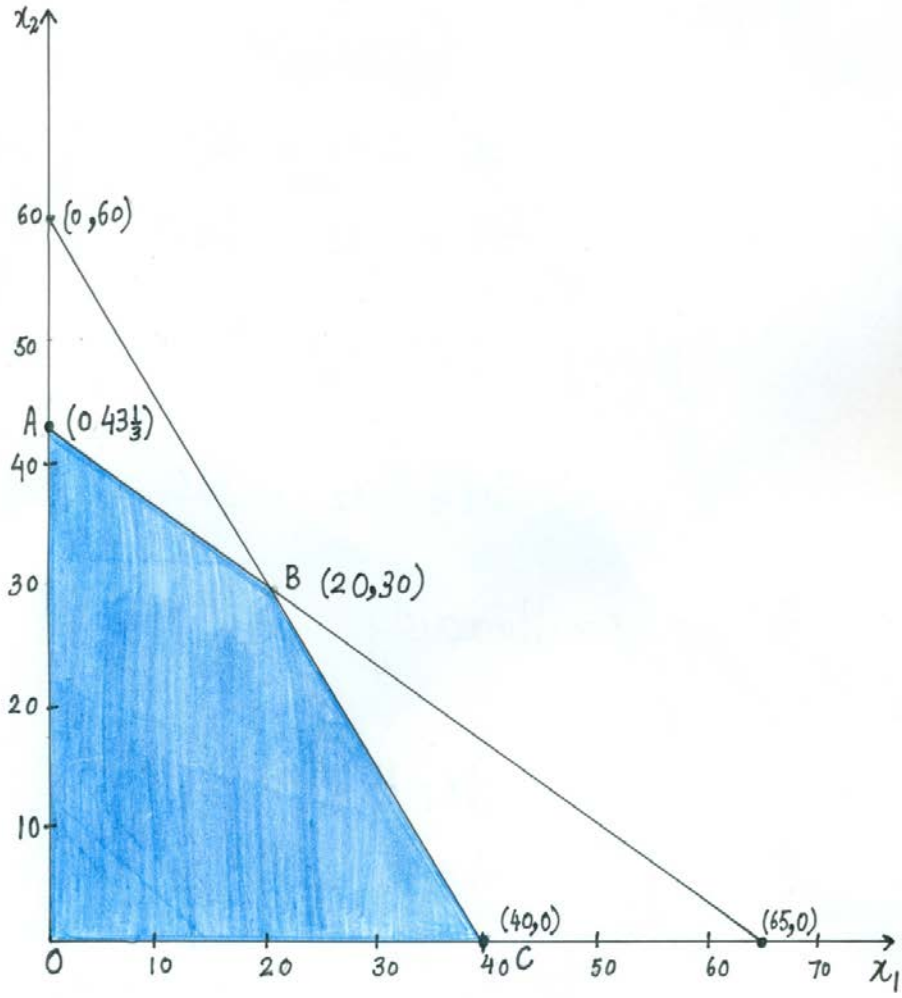
x_2 intercept Put $x_2 = 0$ in eq (ii)

$$4x_1 = 260$$

$$x_1 = 65$$

$$(65, 0)$$

GRAPH:-



Feasible region is OABC

Solve the two equation simultaneously for coordinate B

$$3x_1 + 2x_2 = 120 \quad \ldots\ldots (i)$$
$$4x_1 + 6x_2 = 260 \quad \ldots\ldots (ii)$$

Multiplying eq (i) by 3

$$9x_1 + 6x_2 = 360 \quad \ldots\ldots (iii)$$

Solving simultaneously eq (ii) and (iii)

$$\begin{array}{rrr} 9x_1 & + 6x_2 & = 360 \\ -4x_1 & +\ 6x_2 & = \underline{260} \\ \hline 5x_1 & & = 100 \end{array}$$

$$x_1 = 20$$

Put $x_1 = 20$ in eq (i)

$$3(20) + 2x_2 = 120$$
$$60 + 2x_2 = 120$$
$$2x_2 = 60$$
$$x_2 = 30$$

Coordinates of B (20, 30)

Corner Point	(x_1, x_2)	$Z = 5x_1 + 6x_2$
O	(0, 0)	$5(0) + 6(0) = 0$
A	$(0, 43\frac{1}{3})$	$5(0) + 6(43\frac{1}{3}) = 260$
B	(20, 30)	$5(20) + 6(30) = 280$ *
C	(40, 0)	$5(40) + 7(0) = 200$

A manufacturing department produces two products A & B. Both products are produced on the same automatic machines, the time taken on each machine varies as:

	Product A	**Product B**
	Machine minutes per Unit	**Machine minutes per unit**
Machine W	**2**	**6**
Machine X	**8**	**4**

Total machine minutes available are as under:

Machine W = 66

Machine X = 120

The expected profit on product A and B is Rs. 16 and Rs. 12 respectively. Calculate the number of units of product A and B, the department should produce to maximize profit.

Maximize $z = 16x + 12y$

$2x + 6y \leq 66$ I

$8x + 4y \leq 120$ II

Solution:-

For Line I

$2x + 6y = 66$

y intercept Put $x = 0$

$6y = 66$

$y = 11$

$(0, 11)$

x intercept Put $y = 0$

$2x = 66$

$x = 33$

$(33, 0)$

For Line II

$$8x + 4y = 120$$

y intercept

Put $x = 0$

$$4y = 120$$

$$y = 30$$

$(0, 30)$

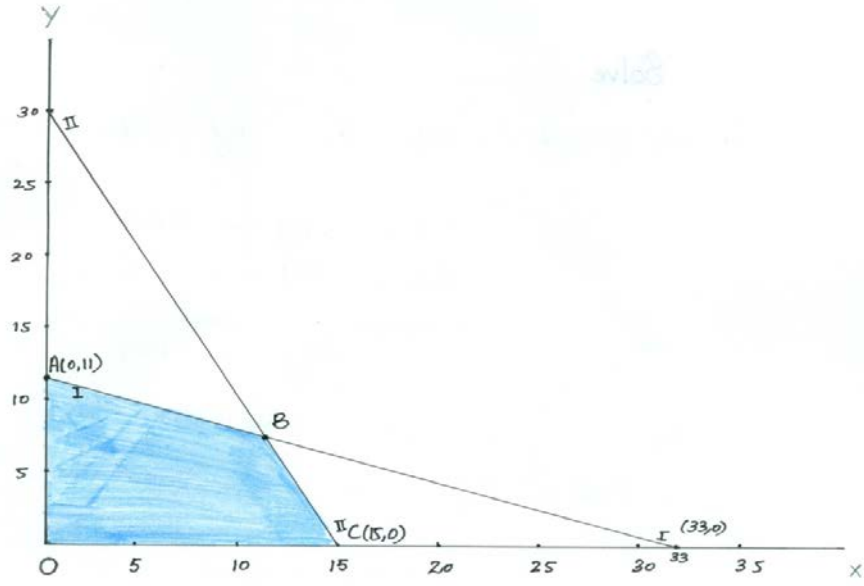
x intercept

Put $y = 0$

$$8x = 120$$

$$x = 15$$

$(15, 0)$



Feasible region is OABC

For B coordinates solve eq I and II

$$2x + 6y = 66 \quad \text{—— I}$$
$$8x + 4y = 120 \quad \text{—— II}$$

Multiplying eq (I) by 4 and Solve

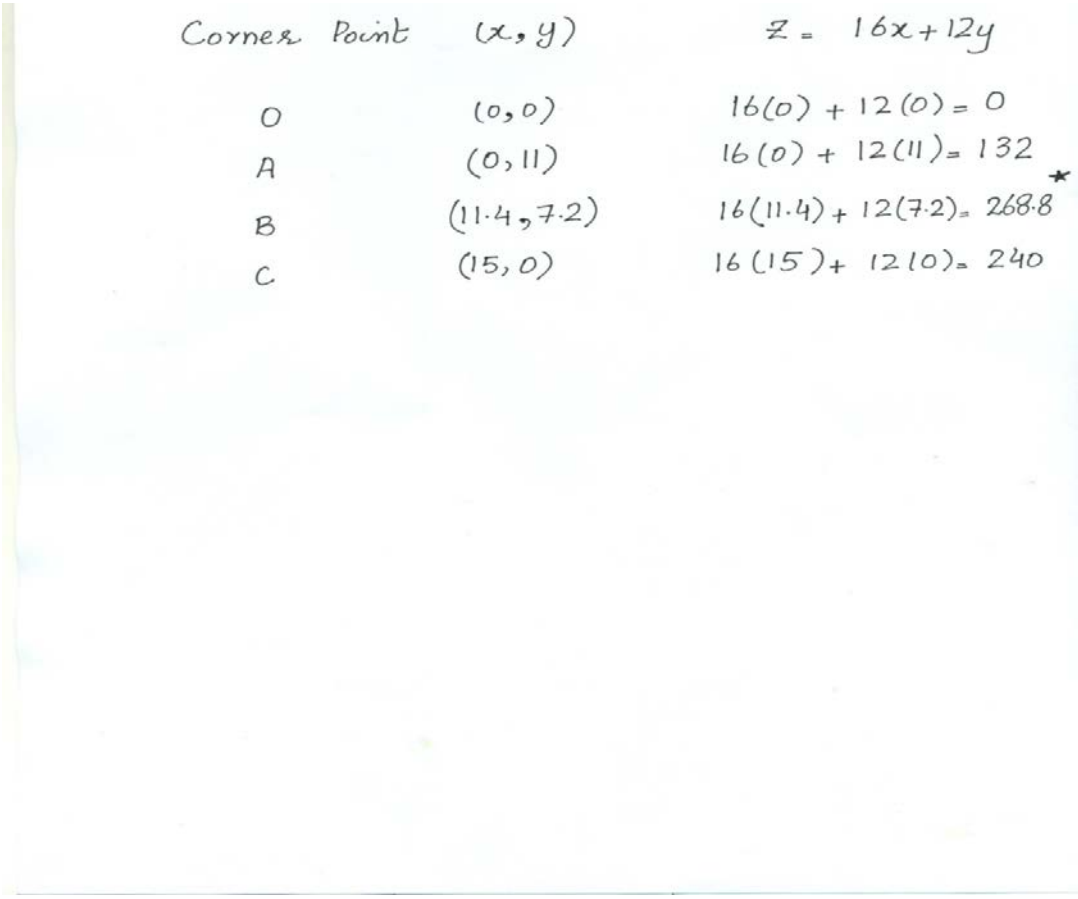
$$\begin{array}{rrl} 8x + 24y & = & 264 \\ 8x + 4y & = & 120 \\ - \quad - & & - \\ \hline 20y & = & 144 \end{array}$$

$$y = 7.2$$

Put 7.2 in eq I

$$2x + 6(7.2) = 66$$
$$2x + 43.2 = 66$$
$$2x = 22.8$$
$$x = 11.4$$

B (11.4, 7.2)



A manufacturing department produces two products A & B. Both products are produced on the same automatic machines, the time taken on each machine varies as:

	Product A	Product B
	Machine minutes per Unit	Machine minutes per unit
Machine W	2	6
Machine X	8	4
Machine Y	4	8

Total machine minutes available are as under:

Machine W = 66

Machine X = 120

Machine Y = 96

The expected profit on product A and B is Rs. 16 and Rs. 12 respectively. Calculate the number of units of product A and B, the department should produce to maximize profit.

Maximize $Z = 16x + 12y$

Subject to $2x + 6y \leq 66$ I

$8x + 4y \leq 120$ II

$4x + 8y \leq 96$ III

Solution:-

For Line I $2x + 6y = 66$

y intercept Put $x = 0$

$6y = 66$

$y = 66/6$

$y = 11$ $(0, 11)$

x intercept Put $y = 0$

$2x = 66$

$x = 33$ $(33, 0)$

For Line II

$$8x + 4y = 120$$

y intercept — Put $x = 0$

$$4y = 120$$

$$y = 30$$

$$(0, 30)$$

x intercept — Put $y = 0$

$$8x = 120$$

$$x = 15$$

$$(15, 0)$$

For Line III

$$4x + 8y = 96$$

y intercept — put $x = 0$

$$8y = 96$$

$$y = 12$$

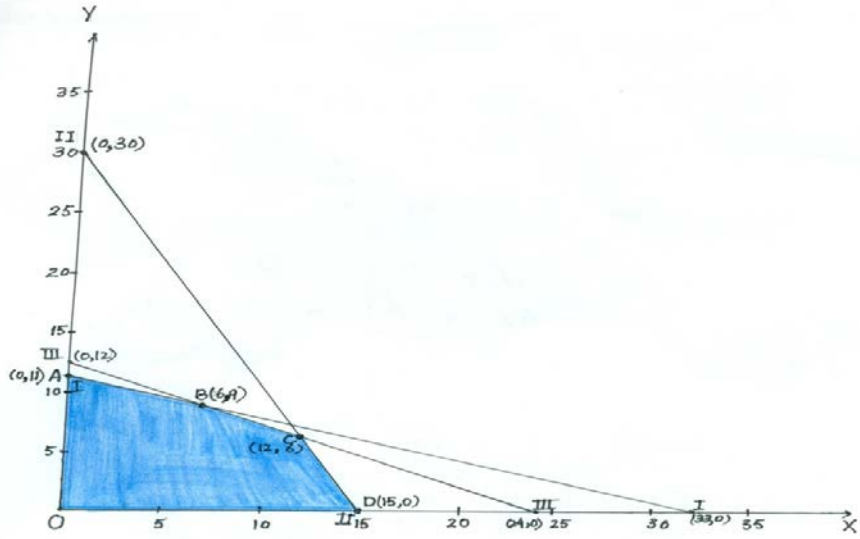
$$(0, 12)$$

x intercept — put $y = 0$

$$4x = 96$$

$$x = 24$$

$$(24, 0)$$



Feasible region is OABCD

For B coordinates

Solve eq I and III simultaneously

$$2x + 6y = 66 \quad \ldots\ldots \text{eq I}$$
$$4x + 8y = 96 \quad \ldots\ldots \text{eq III}$$

Multiplying eq I by 2

$$4x + 12y = 132$$
$$\underline{-}\,4x + \underline{-}\,8y = \underline{-}\,96$$
$$4y = 36$$
$$y = 9$$

Put $y = 9$ in eq I

$$2x + 6(9) = 66$$
$$2x + 54 = 66$$
$$2x = 12$$
$$x = 6$$

B (6, 9)

For C coordinates

Solve eq II and eq III

$$8x + 4y = 120 \quad \ldots\ldots \text{II}$$
$$4x + 8y = 96 \quad \ldots\ldots \text{III}$$

Multiplying eq II by 2 and solve

$$\begin{array}{rcl} 16x + 8y & = & 240 \\ 4x + 8y & = & 96 \\ - \quad - & & - \\ \hline 12x & = & 144 \end{array}$$

$$x = 144/12$$
$$x = 12$$

Put $x = 12$ in eq II

$$8(12) + 4y = 120$$
$$96 + 4y = 120$$
$$4y = 24$$
$$y = 6$$

C (12, 6)

Corner Point	(x, y)	$Z = 16x + 12y$
O	$(0, 0)$	$16(0) + 12(0) = 0$
A	$(0, 11)$	$16(0) + 12(11) = 132$
B	$(6, 9)$	$16(6) + 12(9) = 204$
C	$(12, 6)$	$16(12) + 12(6) = 264$*
D	$(15, 0)$	$16(15) + 12(0) = 240$

Flair Furniture Company Data - Table 7.1

Hours Required to Produce One Unit

Flair Furniture Company Data - Table 7.1

Hours Required to Produce One Unit

Department	*T* Tables	*C* Chairs	Available Hours This Week
Carpentry	4	3	240
Painting &Varnishing	2	1	100
Profit Amount	$7	$5	

Constraints: $4T + 3C \leq 240$ (Carpentry)

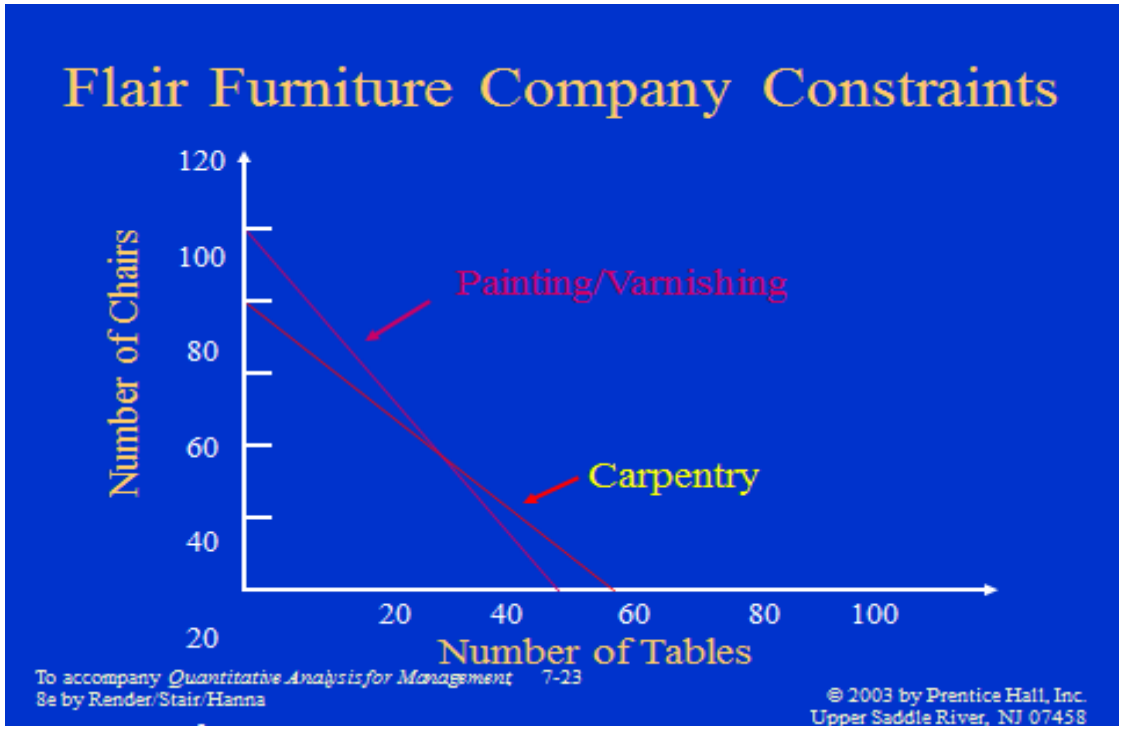
$2T + 1C \leq 100$ (Paint & Varnishing)

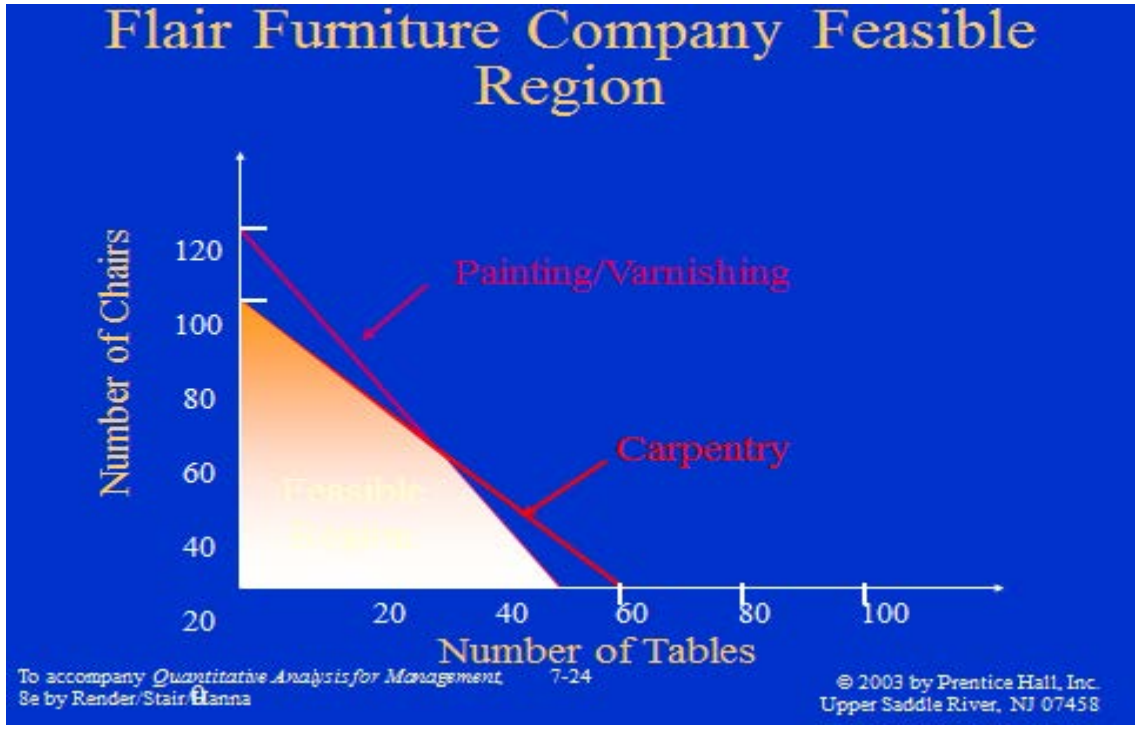
Objective: Max: $7T + 5C$

To accompany *Quantitative Analysis for Management*, 8e by Render/Stair/Hanna

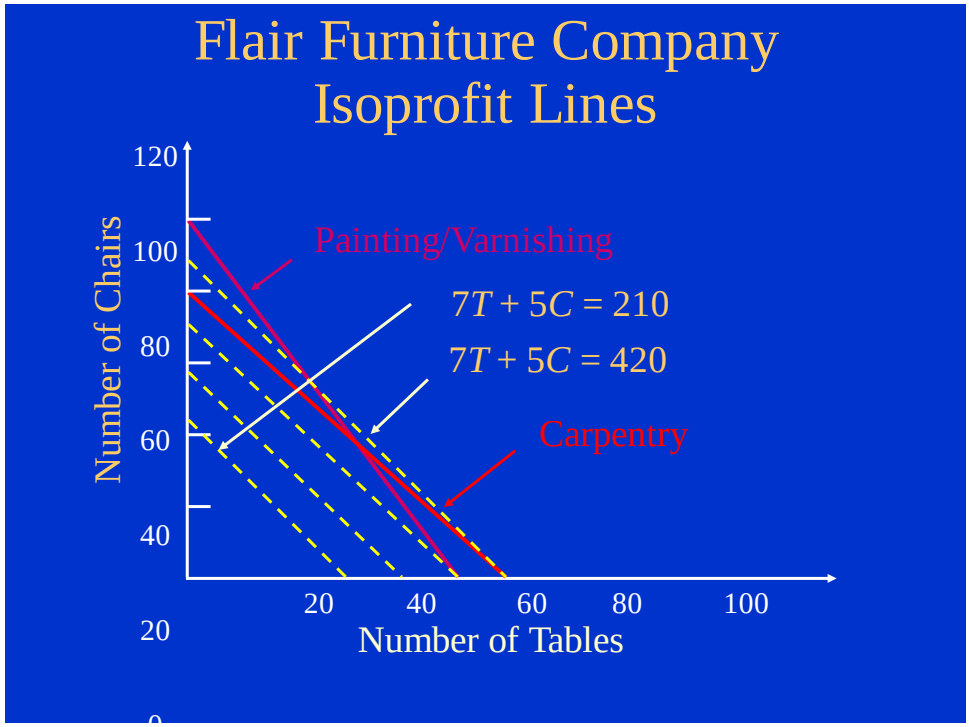
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Flair Furniture Company Constraints

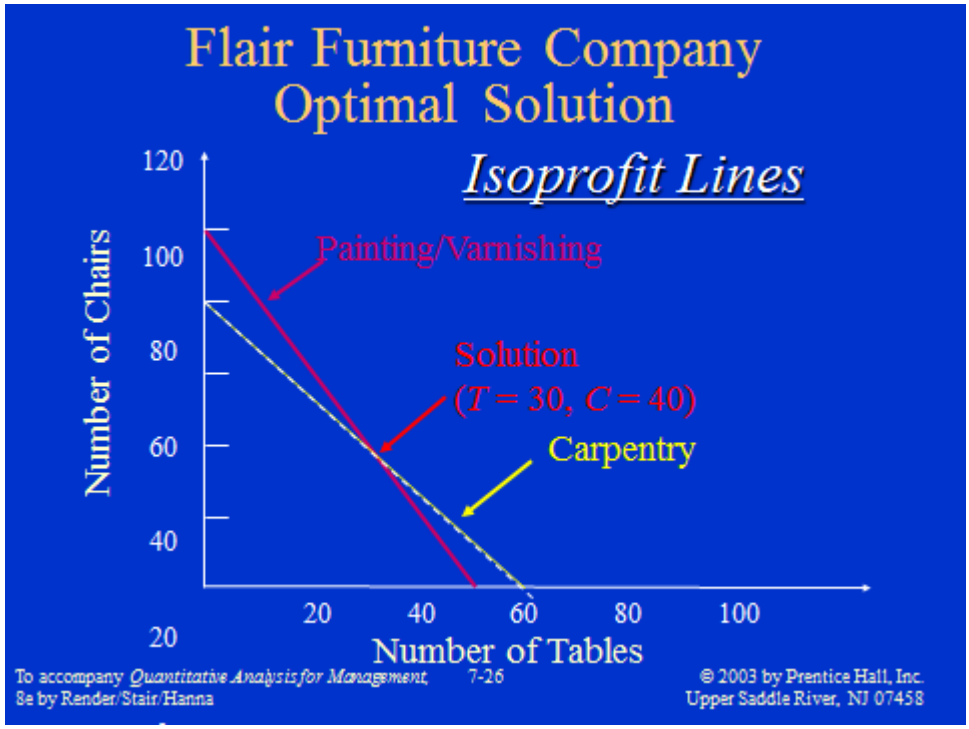


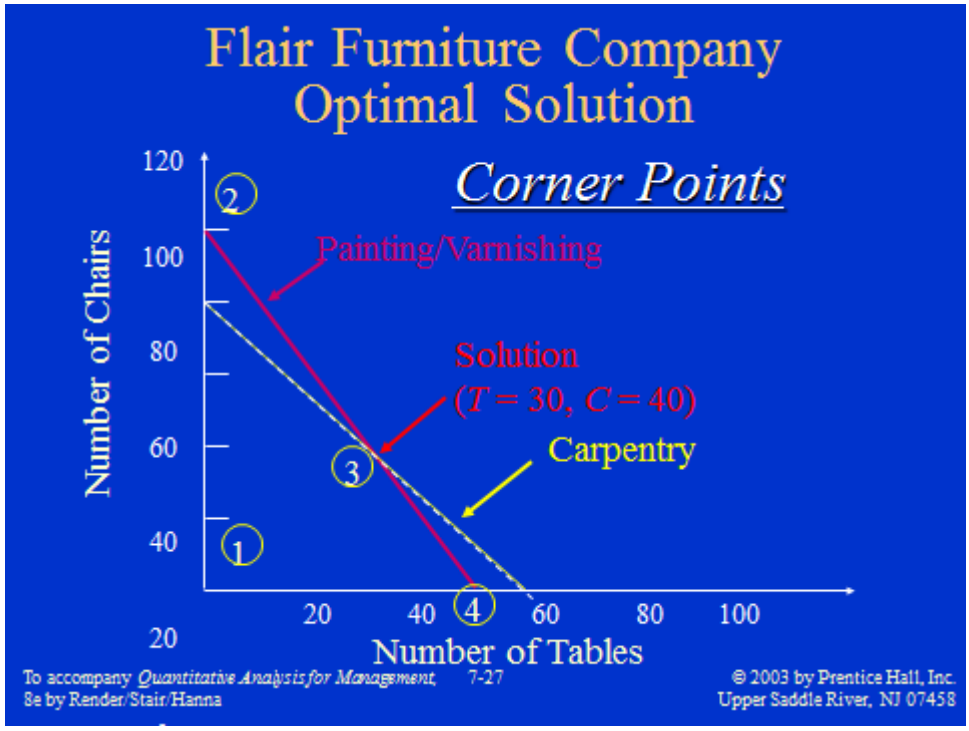


Flair Furniture Company Isoprofit Lines



Flair Furniture Company Optimal Solution




Flair Furniture Company
Optimal Solution
Corner Points
Painting/Varnishing
Solution
(T = 30, C = 40)
Carpentry
Number of Chairs
Number of Tables
120
100
80
60
40
20
20
40
60
80
100
1
2
3
4
To accompany Quantitative Analysis for Management, 8e by Render/Stair/Hanna
7-27
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Lecture 9: LINEAR PROGRAMMING (LP) Minimization

Illustration/Example

Solving Minimization Problems

X_1 = number of tons of black-and-white picture chemical produced

X_2 = number of tons of color picture chemical produced

Minimize total cost = $2{,}500X_1 + 3{,}000X_2$

Subject to:

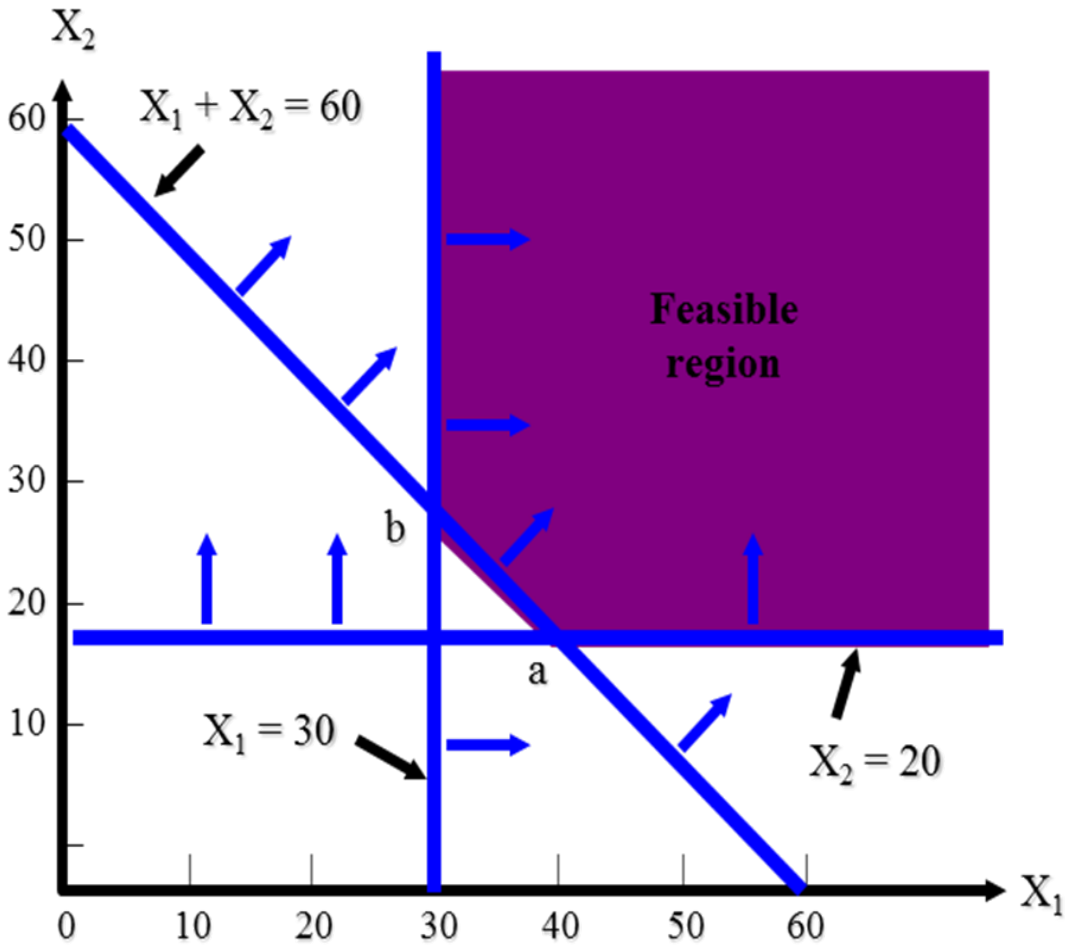
$X_1 \geq 30$ tons of black-and-white chemical

$X_2 \geq 20$ tons of color chemical

$X_1 + X_2 \geq 60$ tons total

$X_1, X_2 \geq \$0$ non-negativity requirements

Minimization Example



Minimization Example

Total cost at a = $2{,}500X_1 + 3{,}000X_2$

= 2,500 (40) + 3,000(20)

= $160,000

Total cost at b = $2{,}500X_1 + 3{,}000X_2$

= 2,500 (30) + 3,000(30)

= $165,000

Lowest total cost is at point a

3C - 1

Minimize $C = 40x + 50y$

$3x + 5y \geq 150$ I

$5x + 5y \geq 200$ II

$3x + y \geq 60$ III

$x, y \geq 0$

Solution:-

For Line I

$3x + 5y \geq 150$

y intercept Put $x = 0$

$5y = 150$

$y = 30$

$(0, 30)$

x intercept Put $y = 0$

$3x = 150$

$x = 50$

$(50, 0)$

For Line II

$$5x + 5y = 200$$

y intercept — Put $x = 0$

$$5y = 200$$

$$y = 40$$

$(0, 40)$

x intercept — Put $y = 0$

$$5x = 200$$

$$x = 40$$

$(40, 0)$

For Line III

$$3x + y = 60$$

y intercept — Put $x = 0$

$$y = 60$$

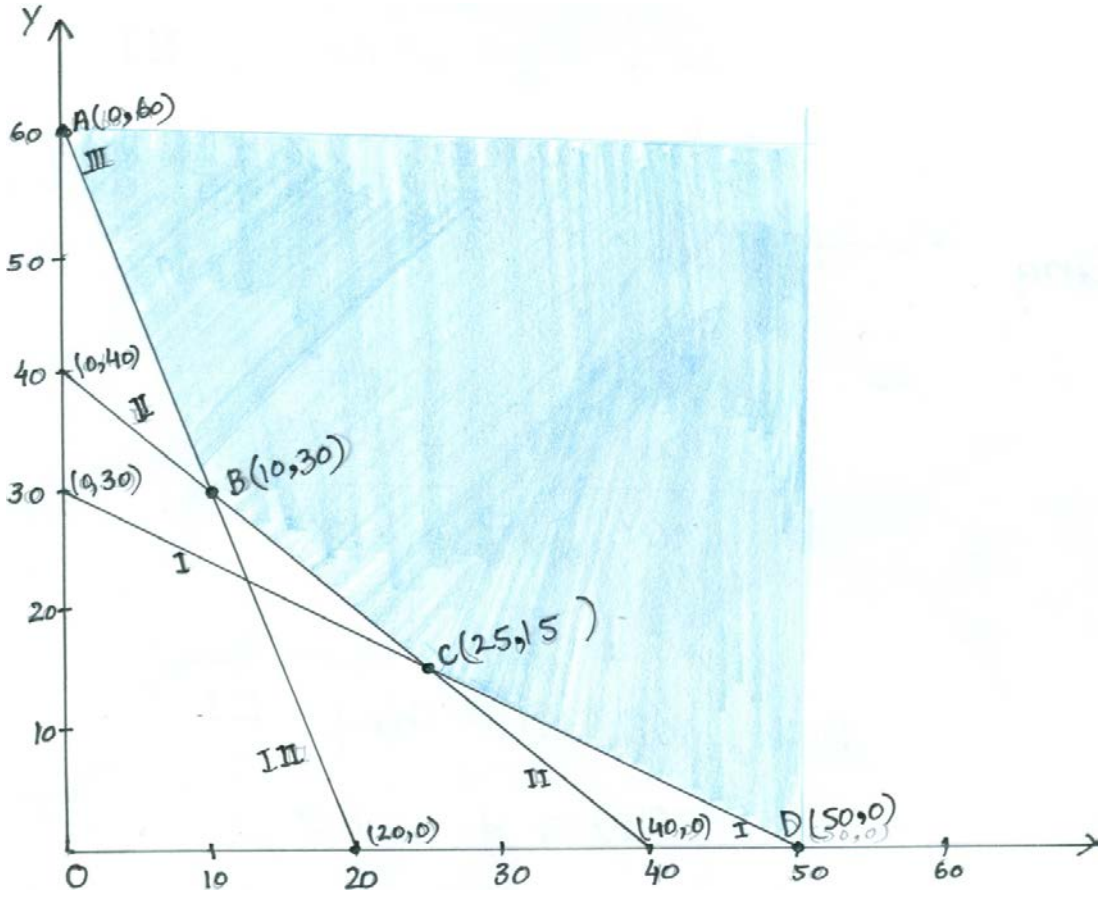
$(0, 60)$

x intercept — Put $y = 0$

$$3x = 60$$

$$x = 20$$

$(20, 0)$


Y
A(0,60)
60
III
50
(0,40)
40
II
B(10,30)
(0,30)
30
I
20
C(25,15)
10
III
II
(20,0)
(40,0)
I
D(50,0)
0
10
20
30
40
50
60

For B coordinate solve eq II and III

$$5x + 5y = 200 \quad \text{II}$$
$$3x + y = 60 \quad \text{III}$$

Multiplying eq III by 5 and solve

$$\begin{array}{r} 5x + 5y = 200 \\ \underline{15x + 5y = 300} \\ \hline -10x = -100 \end{array}$$

$$x = 10$$

Put $x = 10$ in eq III

$$3(10) + y = 60$$
$$30 + y = 60$$
$$y = 30$$

B (10, 30)

For C coordinate solve eq I and II

$$\begin{array}{rcl} 3x + 5y & = & 150 \\ 5x + 5y & = & 200 \\ \hline -2x & = & -50 \end{array}$$

$$x = 25$$

Put $x = 25$ in eq I

$$3(25) + 5y = 150$$

$$75 + 5y = 150$$

$$5y = 75$$

$$y = 15$$

$$C(25, 15)$$

Corner Point	(x, y)	$C = 40x + 50y$
A	$(0, 60)$	$40(0) + 50(60) = 3000$
B	$(10, 30)$	$40(10) + 50(30) = 1900$
C	$(25, 15)$	$40(25) + 50(15) = 1750$ *
D	$(50, 0)$	$40(50) + 50(0) = 2000$

Problem

The Queen City Nursery manufactures bags of potting soil from compost and topsoil. Each cubic foot of compost costs 12 cents and contains 4 pounds of sand, 3 pounds of clay, and 5 pounds of humus. Each cubic foot of topsoil costs 20 cents and contains 3 pounds of sand, 6 pounds of clay, and 12 pounds of humus. Each bag of potting soil must contain at least 12 pounds of sand, at least 12 pounds of clay, and at least 10 pounds of humus. Plot the constraints and identify the feasible region. Graphically or with corner points find the best combination of compost and topsoil that meets the stated conditions at the lowest cost per bag. Identify the lowest cost possible.

Queen City Nursery

	Compost	Topsoil		RHS
Minimize	0.12	0.2		
Sand	4	3	$\geq$	12
Clay	3	6	$\geq$	12
Humus	5	12	$\geq$	10

Let compost $= x$

Topsoil $= y$

Minimize $C = 0.12x + 0.2y$

$4x + 3y \geq 12$ I

$3x + 6y \geq 12$ II

$5x + 12y \geq 10$ III

For Line I

$$4x + 3y = 12$$

y intercept Put $x = 0$

$$3y = 12$$

$$y = 4$$

$(0, 4)$

x intercept Put $y = 0$

$$4x = 12$$

$$x = 3$$

$(3, 0)$

For Line II

$$3x + 6y = 12$$

y intercept Put $x = 0$

$$6y = 12$$

$$y = 2$$

$(0, 2)$

x intercept Put $y = 0$

$$3x = 12$$

$$x = 4$$

$(4, 0)$

For Line III

$$5x + 12y = 10$$

y intercept Put $x = 0$

$$12y = 10$$

$$y = 0.833$$

$$(0, 0.833)$$

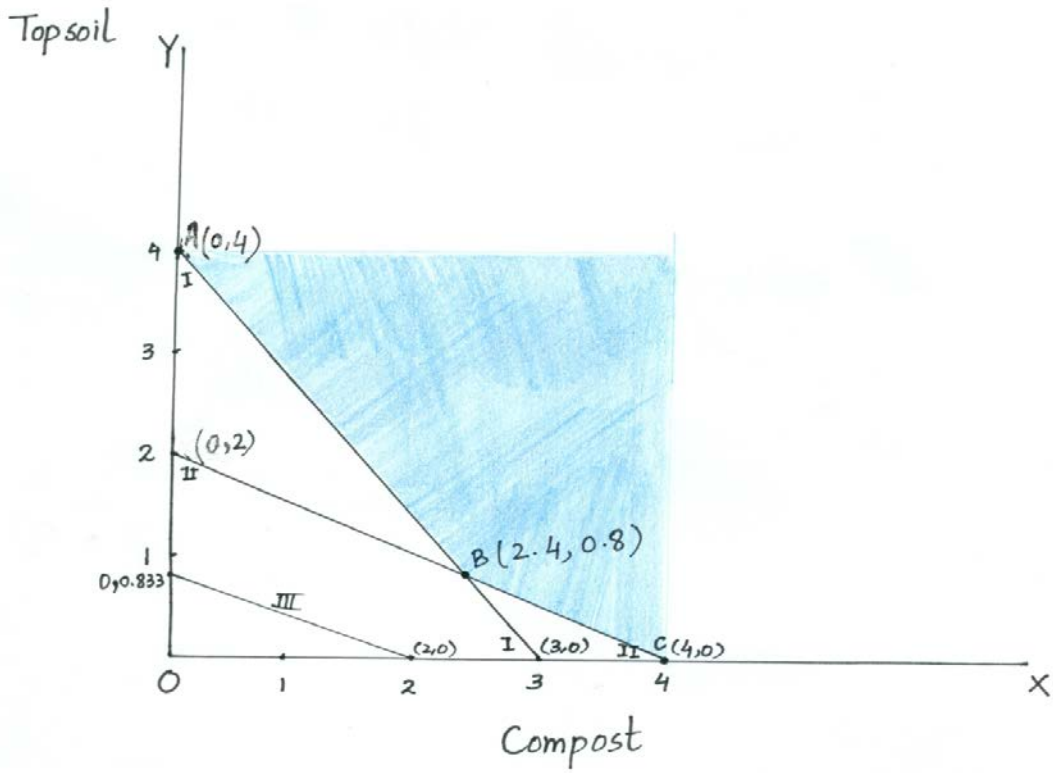
x intercept Put $y = 0$

$$5x = 10$$

$$x = 2$$

$$(2, 0)$$

Queen City Nursery



For coordinates of B

Solve eq I and II

$$4x + 3y = 12 \quad \ldots\ldots \text{I}$$
$$3x + 6y = 12 \quad \ldots\ldots \text{II}$$

Multiplying eq I by 2 and solve

$$\begin{array}{rcrcr} 8x & + & 6y & = & 24 \\ 3x & + & 6y & = & 12 \\ - & & - & & - \end{array}$$

$$5x = 12$$

$$x = 2.4$$

Put $x = 2.4$ in eq I

$$4(2.4) + 3y = 12$$
$$9.6 + 3y = 12$$
$$3y = 2.4$$
$$y = 0.8$$

B(2.4 , 0.8)

Corner Point	x (Compost)	y (Topsoil)	$C = 0.12x + 0.2y$
A	0	4	$0.12(0) + 0.2(4) = 0.8$
B	2.4	0.8	$0.12(2.4) + 0.2(0.8) = 0.448$ *
C	4	0	$0.12(4) + 0.2(0) = 0.48$

Problem

Rienzi Farms grows sugar cane and soybeans on its 500 acres of land. An acre of soybeans brings a $1000 contribution to overhead and profit; an acre of sugar cane has a contribution of $2000. Because of a government program no more than 200 acres may be planted in soybeans. During the planting season 1200 hours of planting time will be available. Each acre of soybeans requires 2 hours, while each acre of sugar cane requires 5 hours. The company seeks maximum contribution (profit) from its planting decision.

a. Algebraically state the decision variables, objective and constraints.

b. Plot the constraints

c. Solve graphically, using the corner point method.

(5-1)

Rienzi Farms Solution

	x_1	x_2		RHS
Maximize	1000	2000		
Acres	1	1	$\leq$	500
Soybean restriction	1	0	$\leq$	200
Planting labor	2	5	$\leq$	1,200

$Z = 1000x_1 + 2000x_2$

$x_1 + x_2 \leq 500$ I

$x_1 \leq 200$ II

$2x_1 + 5x_2 \leq 1200$ III

For Line I

y intercept Put $x_1 = 0$

$x_2 = 500$

(0, 500)

x intercept Put $x_2 = 0$

$x_1 = 500$

(500, 0)

For line III

y intercept Put $x_1 = 0$

$$2x_1 + 5x_2 = 1200$$

$$5x_2 = 1200$$

$$x_2 = 240$$

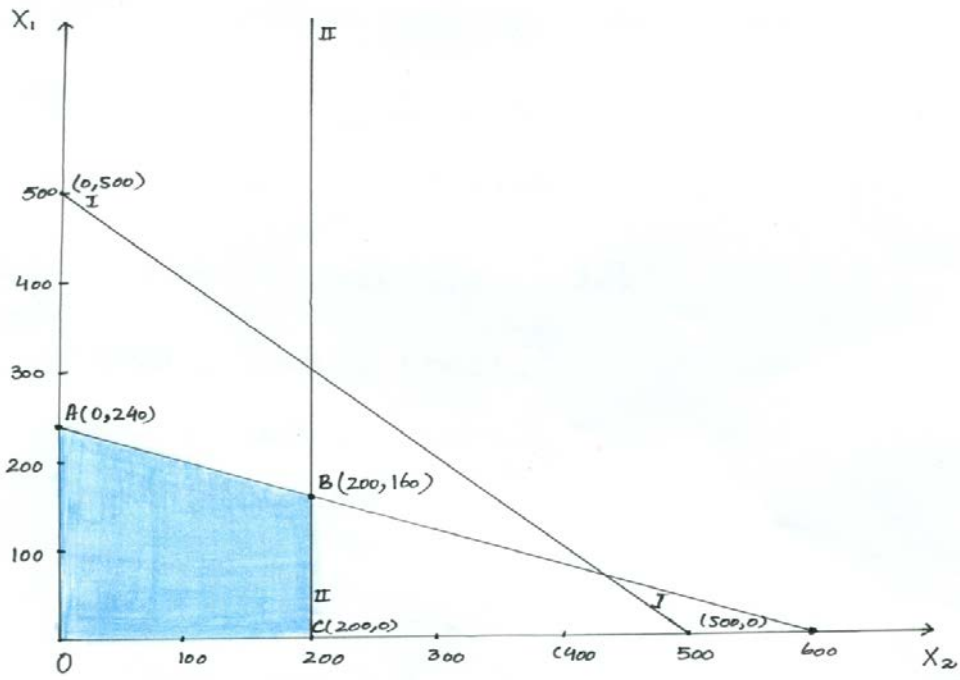
$$(0, 240)$$

x intercept Put $x_2 = 0$

$$2x_1 = 1200$$

$$x_1 = 600$$

$$(600, 0)$$



Feasible Region is OABC

For coordinate B

Solve eq II and III

$$x_1 = 200 \quad \ldots\ldots \quad II$$

$$2x_1 + 5x_2 = 1200 \quad \ldots\ldots \quad III$$

Put $x_1 = 200$ in eq III

$$2(200) + 5x_2 = 1200$$

$$400 + 5x_2 = 1200$$

$$5x_2 = 800$$

$$x_2 = 160$$

B (200, 160)

Corner Point	(x_1, x_2)	$Z = 1000x_1 + 2000x_2$
O	0,0	$1000(0) + 2000(0) = 0$
A	(0, 240)	$1000(0) + 2000(240) = 480,000$
B	(200, 160)	$1000(200) + 2000(160) = 520,000$ *
C	(200, 0)	$1000(200) + 2000(0) = 200,000$

Lecture 10 TWO-VARIABLE LP MODEL

EXAMPLE: "THE GALAXY INDUSTRY PRODUCTION"

- Galaxy manufactures two toy models:
  - Space Ray.
  - Zapper.
- Resources are limited to
  - 1200 pounds of special plastic.
  - 40 hours of production time per week.

- Marketing requirement
  - Total production cannot exceed 800 dozens.
  - Number of dozens of Space Rays cannot exceed number of dozens of Zappers by more than 450.
- Technological input
  - Space Rays requires 2 pounds of plastic and

3 minutes of labor per dozen.

  - Zappers requires 1 pound of plastic and

4 minutes of labor per dozen.

- Current production plan calls for:
  - Producing as much as possible of the more profitable product, Space Ray ($8 profit per dozen).
  - Use resources left over to produce Zappers ($5 profit per dozen).
- The current production plan consists of:

Space Rays = 550 dozens

Zapper = 100 dozens

Profit = 4900 dollars per week

A Linear Programming Model can provide an intelligent solution to this problem

SOLUTION:

- Decisions variables:
  - X1 = Production level of Space Rays (in dozens per week).
  - X2 = Production level of Zappers (in dozens per week).
- Objective Function:
  - Weekly profit, to be maximized

The Linear Programming Model

Max 8X1 + 5X2 (Weekly profit)

subject to

2X1 + 1X2 < = 1200 (Plastic)

3X1 + 4X2 < = 2400 (Production Time)

X1 + X2 < = 800 (Total production)

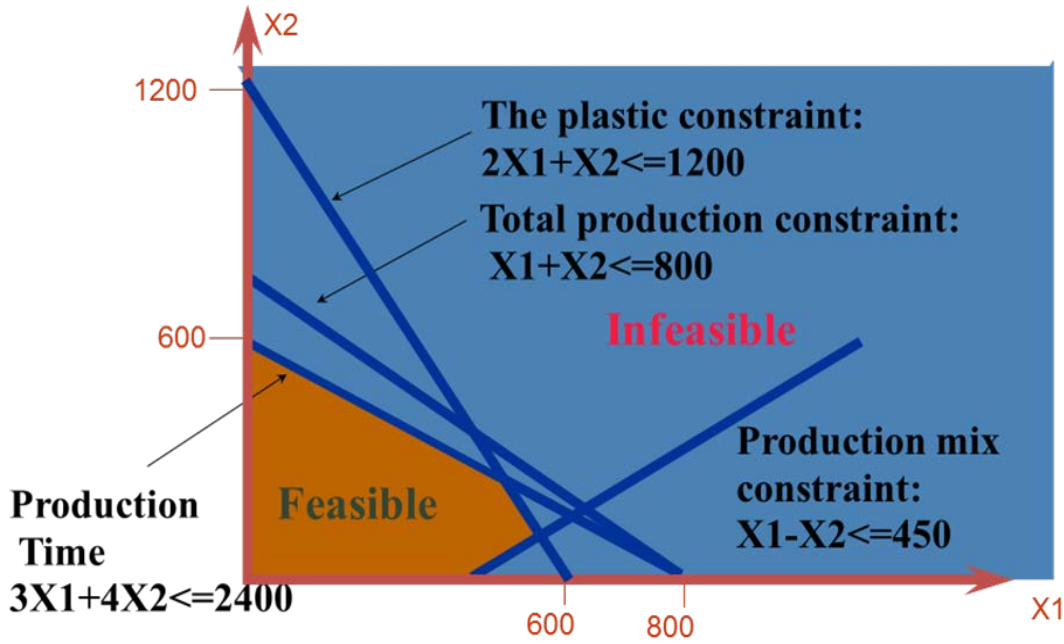
X1 - X2 < = 450 (Mix)

X_j> = 0, j = 1,2 (Nonnegativity

Feasible Solutions for Linear Programs

The set of all points that satisfy all the constraints of the model is called feasible region.

Using a graphical presentation we can represent all the constraints, the objective function, and the three types of feasible points



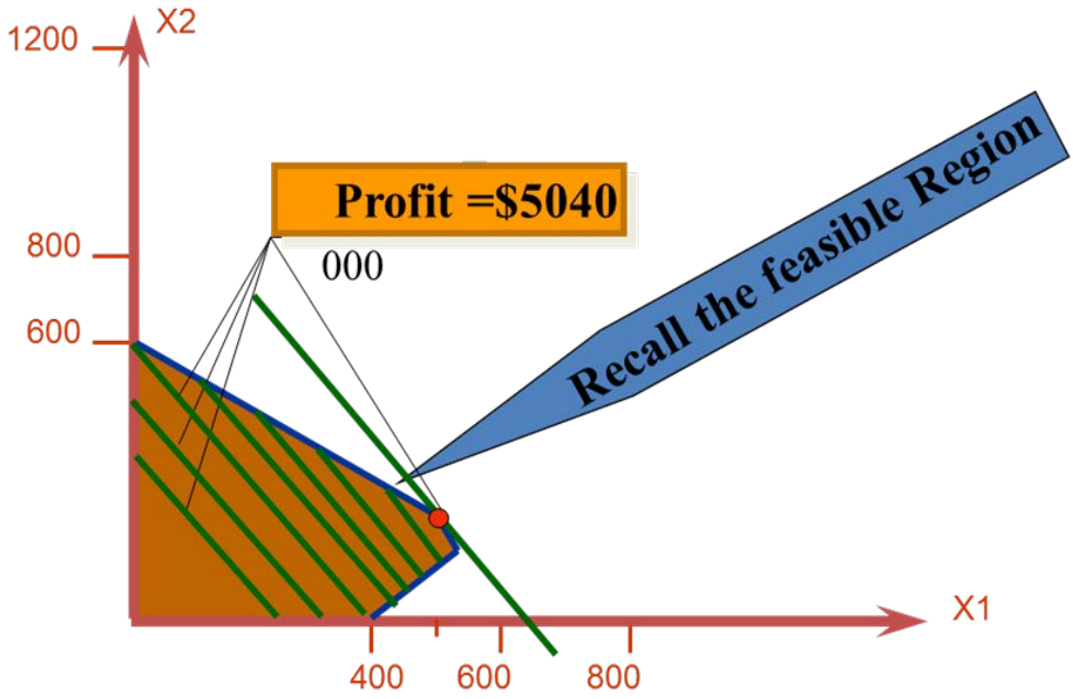
Solving Graphically for an Optimal Solution.

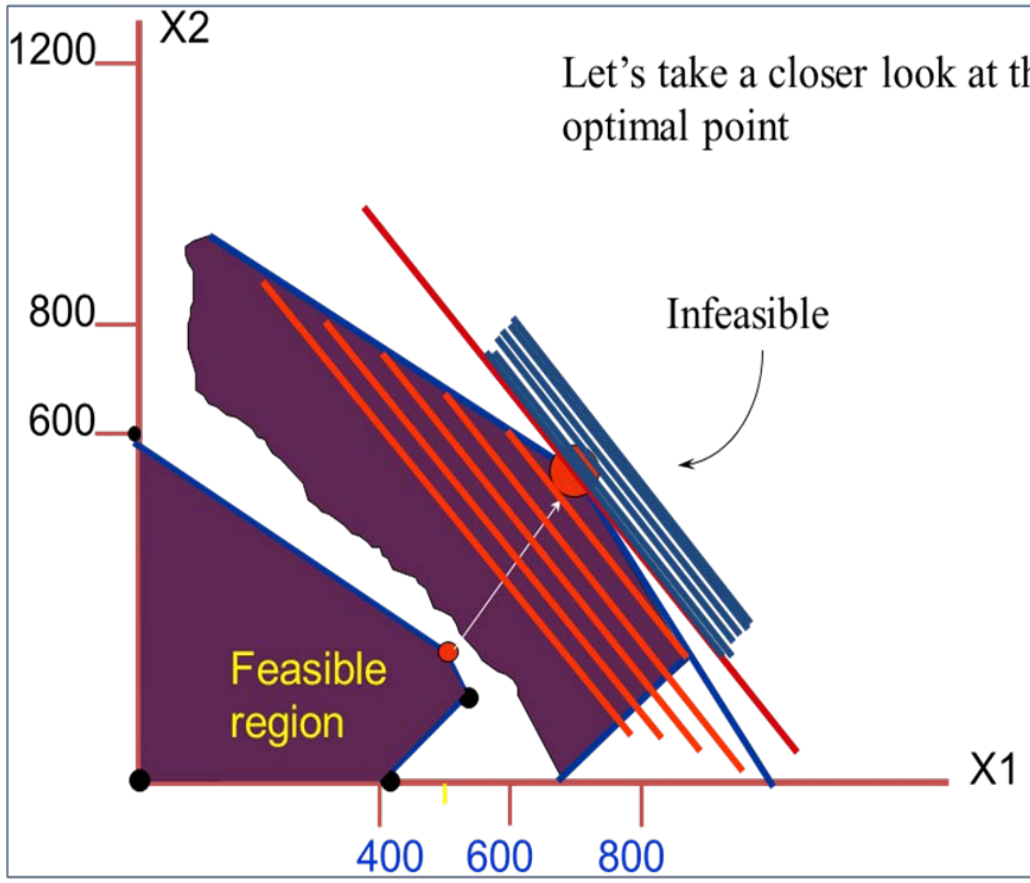
We now demonstrate the search for an optimal solution

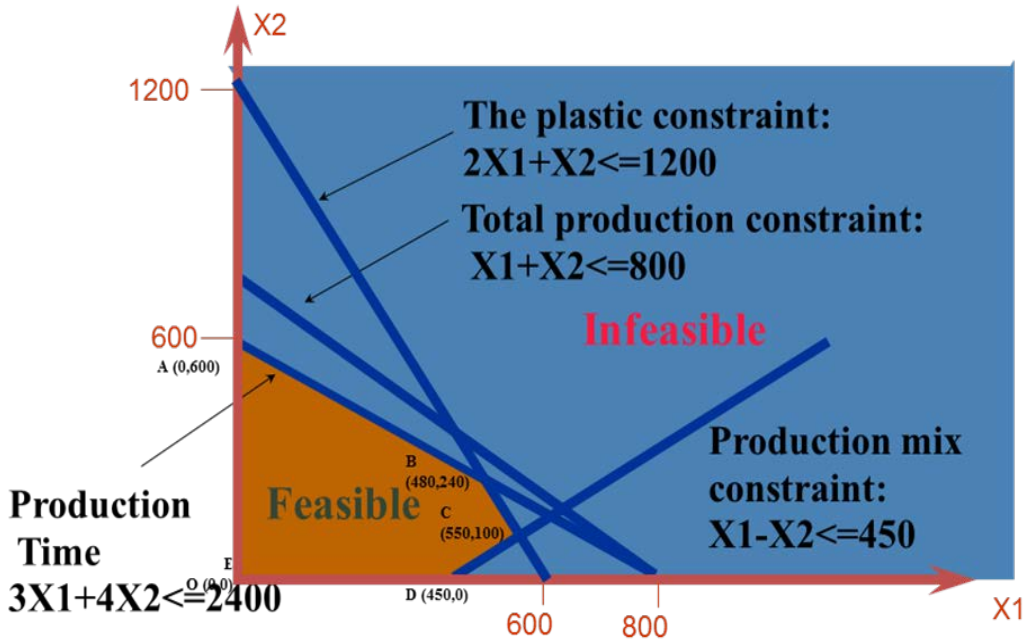
Start at some arbitrary profit, say profit = $2,000...

Then increase the profit, if possible...

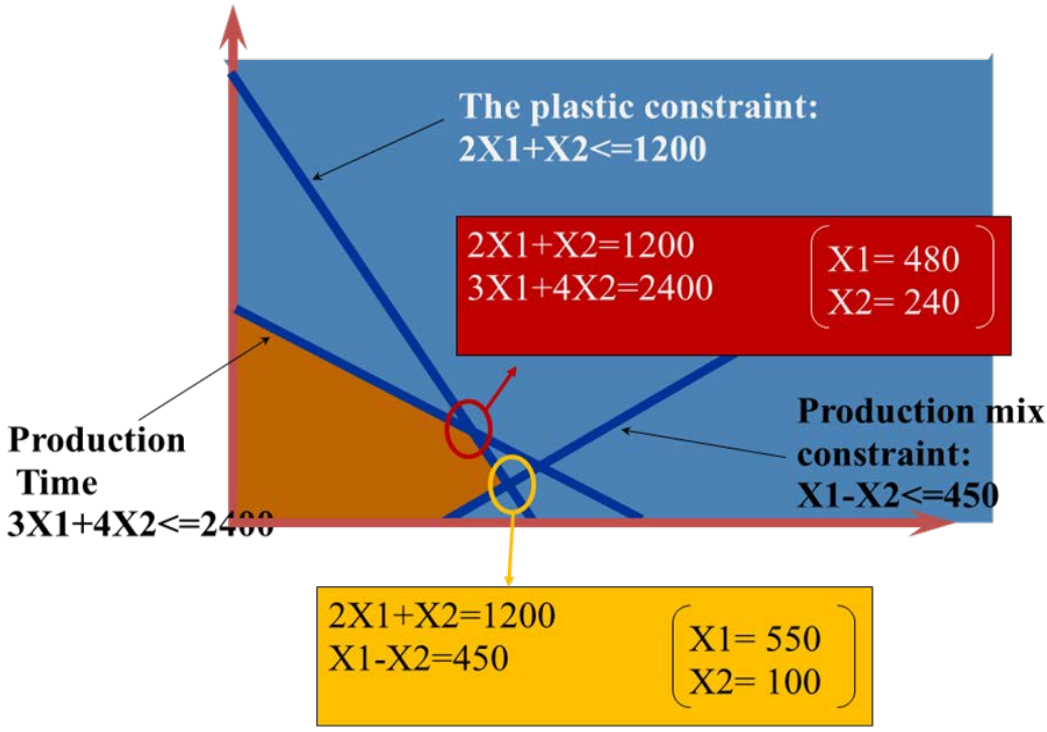
...and continue until it becomes infeasible


X2
1200
800
600
Profit =$5040
000
Recall the feasible Region
X1
400
600
800


X2
1200
800
600
Let's take a closer look at the optimal point
Infeasible
Feasible region
X1
400
600
800



- To determine the value for X1 and X2 at the optimal point, the two equations of the binding constraint must be solved.



By Compensation on :

Max 8X1 + 5X2

(X1, X2)	Objective fn
(0,0)	0
(450,0)	3600
(480,240)	5040
(550,100)	4900
(0,600)	3000

The maximum profit (5040) will be by producing:

Space Rays = 480 dozens, Zappers = 240 dozens

Illustration

A manager must decide on the mix of products to produce for the coming week. Product A requires three minutes per unit for molding, two minutes per unit for painting, and one minute for packing. Product B requires two minutes per unit for molding, four minutes for painting, and three minutes per unit for packing. There will be 600 minutes available for molding, 600 minutes for painting, and 420 minutes for packing. Both products have contributions of $1.50 per unit.

Requirements:

1. Algebraically state the objective and constraints of this problem.
2. Plot the constraints on the grid and identify the feasible region.
3. Maximize objective function

Let

X1 = Product A

X2 = Product B

	A (X1)	**B (X2)**	Maximum Availability
Molding	3	2	600
Painting	2	4	600
Packing	1	3	420
Profit	1.50	1.50	

Graphical Method

1. Algebraically state the objective and constraints of this problem.

Maximize Z = 1.50**X1+**1.50**X2**

Subject to

$3X1 + 2X2 \leq 600$ (Molding constraint)……(I)

$2X1 + 4X2 \leq 600$ (Painting constraint)……(II)

$X1 + 3X2 \leq 420$ (Packing constraint)……(III)

$X1, X2 \geq 0$ (Non-negative constraint)

2 **Plot the constraints on the coordinate Axis and identify the feasible region.**

Solution

Find the coordinates (X1, X2) for each constraint as well as for objective function and draw them on the same coordinate axis.

3X1 + 2X2 = 600 **Put X1=0** **3(0)+2(X2)=600** **X2= 300** **(0,300)**	**3X1 + 2X2 = 600** **Put X2=0** **3 (X1) + 2(0)=600** **X1 = 200** **(200, 0)**

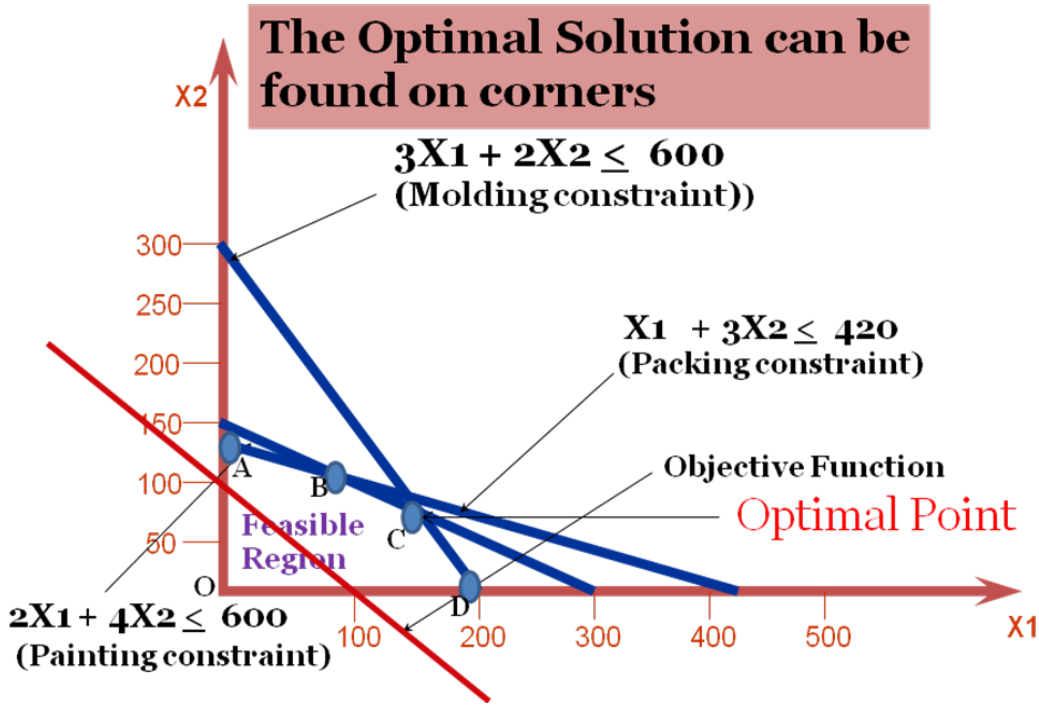
2X1 + 4X2 = 600 Put X1=0 **2(0)+4(X2)=600** **X2= 150** **(0,150)**	**2X1 + 4X2 = 600 Put X2=0** **2 (X1) + 4(0)=600** **X1 = 300** **(300, 0)**
X1 + 3X2 =420 Put X1=0 **(0)+3(X2)=420** **X2= 140** **(0,140)**	**X1 + 3X2 = 420 Put X2=0** **(X1) + 3(0)=240** **X1 = 420** **(420, 0)**

X1 + 3X2 =420 Put X1=0 **(0)+3(X2)=420** **X2= 140** **(0,140)**	**X1 + 3X2 = 420 Put X2=0** **(X1) + 3(0)=240** **X1 = 420** **(420, 0)**

Z =1.50X1+1.50X2 **Let Z=150** **1.50X1+1.50X2 =150** **Put X1=0** **1.50 (0)+1.50X2 =150** **X2= 100** **(0,100)**	**Z =1.50X1+1.50X2** **Let Z=150** **1.50X1+1.50X2 =150** **Put X2=0** **1.50X1+1.50 (0)=150** **X1 = 100** **(100, 0)**

Objective Function

Graphical Method (cont.)



- One of the corner point (B) is the intersection of following two lines

$$2X1 + 4X2 \leq 600 \qquad (1)$$

$$X1 + 3X2 \leq 420 \qquad (2)$$

We can find their solution by following methods;

1. Substitution
2. Addition
3. Subtraction

Here we use the subtraction method

step 1: multiply equation 2 with 2 and rewrite

$$2X1 + 4X2 = 600 \quad (1)$$

$$-2X1 \pm 6X2 = -840 \quad (2)$$

$$-2X2 = -240$$

$$X2 = 120$$

By putting $X2 = 120$ in equation 1 we will get

$$2(X1) + 4(120) = 600$$

$$X1 = 60$$

$$B\ (60, 120)$$

- Other of the corner point (C) is the intersection of following two lines

$$3X1 + 2X2 \leq 600 \quad (I)$$

$$2X1 + 4X2 \leq 600 \quad (II)$$

step 1: multiply equation I with 2, rewrite and subtract

$$6X1 + 4X2 = 1200$$
$$\pm 2X1 \pm 4X2 = \pm 600$$

$$4X1 = \mathbf{600}$$

$$X1 = 150$$

By putting $X1 = 150$ in equation 1 we will get

$$3(150) + 2X2 = 600$$

$$X2 = 75$$

$$C\ (150,\ 75)$$

Corner Points	**(X1, X2)**	**Objective function: Z=1.5X1+1.5X2**
O	(0,0)	0
A	(0, 140)	1.5(0) + 1.5(140)= 210
B	(60, 120)	1.5(60) + 1.5(120)= 270
C	(150, 75)	1.5(150) + 1.5(75)= **337.5**
D	(200, 0)	1.5(200) + 1.5(0)= 300

Formulation of Linear Programming

A company wants to purchase at most 1800 units of a product. There are two types of the product M1 and M2 available. M1 occupies $2ft^{3,}$ costs Rs. 4 and the company makes the profit of Rs. 3. M2 occupies $3ft^3$, costs Rs. 5, and the company makes the profit of Rs. 4. If the budget is Rs. 5500/= and warehouse has 3000 $ft^3$for the products.

Requirement

Formulate the problem as linear programming problem.

Solutions

Let

X1 = Product M1

X2 = Product M2

	M1 (x1)	**M2 (x2)**	**Maximum Availability**
Area	2	3	3000
Cost	4	5	5500
Profit	3	4	
Additional Condition	Company wants to purchase at most 1800 units of a product.		

<u>Step 1</u>

- **Key decision to be made**

- Maximization of Profit

- **Identify the decision variables of the problem**

Let

X1 = Product M1

X2 = Product M2

Step 2

Formulate the objective function to be optimized

- For maximization the objective function is based on profit
    - Profit from M1 = 3X1
    - Profit from M2 = 4X2

so our objective function will be like this

Maximize Z = 3X1+4X2

Step 3

Formulate the constraints of the problem

- For area the maximum availability is 3000 ft^3, and area required for M1 (X1) is 2 ft^3 where for product M2 (X2) is 3 ft^3. so the constraint become as under

  2X1 + 3X2 $\leq$ 3000

- For cost the maximum availability is Rs. 5500, Product M (X1) required Rs. 4 per unit and product M2 (X2) required Rs. 5 per unit so the constraint become as under

$4X1 + 5\,X2 \leq 5500$

Third condition:

Company wants to purchase at most 1800 units of a product

This is the production constraints that the company must produce at most 1800 of the product and the product is composed of X1 and X2, so the mixture of these two

$X1 + X2 \leq 1800$

Step 4

- Add non-negativity restrictions or constraints

The decision variables should be non negative, which can be expressed in mathematical form as under;

$X1, x2 \geq 0$

The whole Linear Programming model is as under;

Maximize $Z = 3X1+4X2$ (Objective Function)

Subject to

$2X1 + 3X2 \leq 3000$ (Area Constraint)

$4X1 + 5\,X2 \leq 5500$ (Cost Constraint)

$X1 + X2 \leq 1800$ (Product Constraint)

$X1, X2 \geq 0$ (Non-Negative Constraint)

Lecture11 **Simplex Method**

Objective. $f = 5x_1 + 4x_2$ Maximization

Subject to: $5x_1 + 3x_2 \leq 21$, $x_1 + 2x_2 \leq 7$ } Constraints

$x_1, x_2 \geq 0$

Simplex Method

Slack variable, Surplus var., Artificial

$3x_1 + 2x_2 \leq 3 \Rightarrow$ slack variable

$3x_1 + 2x_2 + S_1 = 3$ are always added

$5x_1 + 3x_2 \geq 3$

$5x_1 + 3x_2 - S_1 = 3$

Surplus variables are always subtracted

$5x_1 + 3x_2 = 3$

$5x_1 + 3x_2 + A_1 = 3$

Artificial variables are always added

$$f = 5x_1 + 4x_2$$

$$5x_1 + 3x_2 \leq 21$$

$$x_1 + 2x_2 \leq 7$$

Let s_1 and s_2 be two slack variables for first and 2nd constraint respectively

$$5x_1 + 3x_2 + s_1 = 21 \quad \text{---} (1)$$

$$x_1 + 2x_1 + s_2 = 7 \quad \text{---} (2)$$

$$x_1, x_2, s_1, s_2 \geq 0$$

Initial sol:

Let $x_1 = 0$, $x_2 = 0$

$s_1 = 21$ $\quad 4-2=2$

$s_2 = 7$

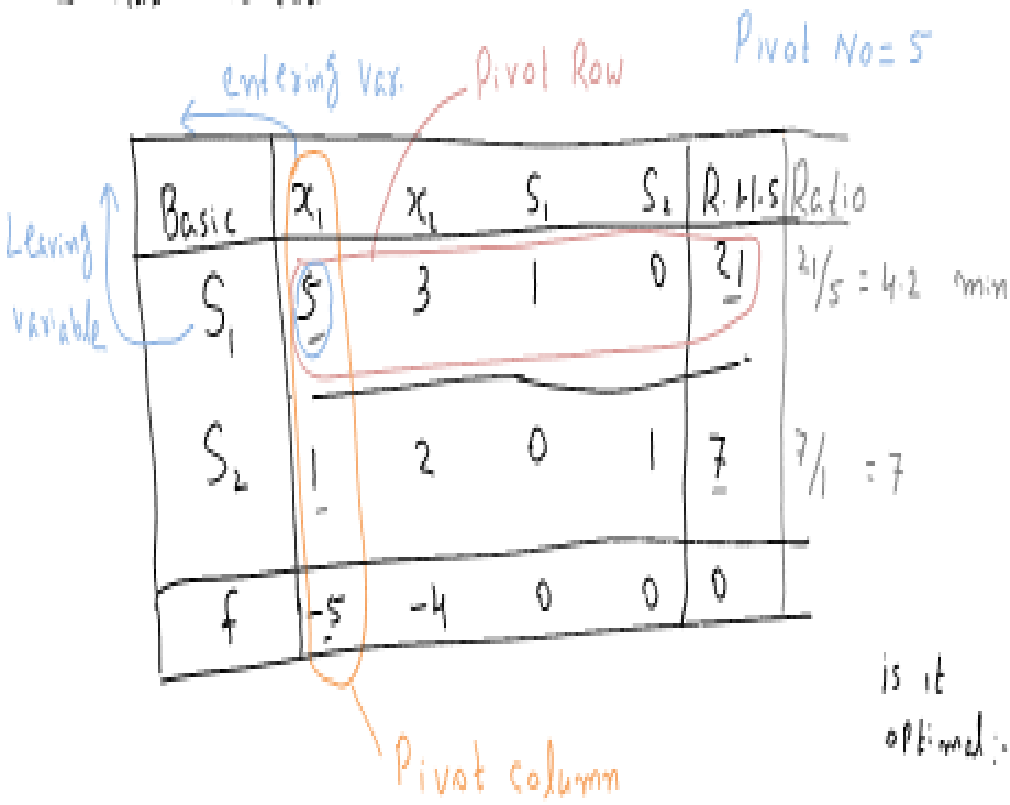
$f: 5x_1 + 4x_2$

$$5x_1 + 3x_2 + s_1 = 21$$

$$x_1 + 2x_2 + s_2 = 7$$

$$f - 5x_1 - 4x_2 = 0$$

Initial Tableau



is it optimal?

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \left[\text{old Pivot Row}\right]$$

$$= \frac{1}{5}\begin{bmatrix} 5 & 3 & 1 & 0 & 21 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & \frac{3}{5} & \frac{1}{5} & 0 & \frac{21}{5} \end{bmatrix}$$

New Row = old Row − Pivot column coefficient × [New Pivot Row]

=

$7 - \frac{21}{5} : \frac{35-21}{5} : \frac{14}{5}$

$2 - \frac{3}{5} : \frac{10-3}{5} : \frac{7}{5}$

$$\text{New } S_1 \text{ Row} = \begin{bmatrix} 1 & 2 & 0 & 1 & 7 \end{bmatrix}$$

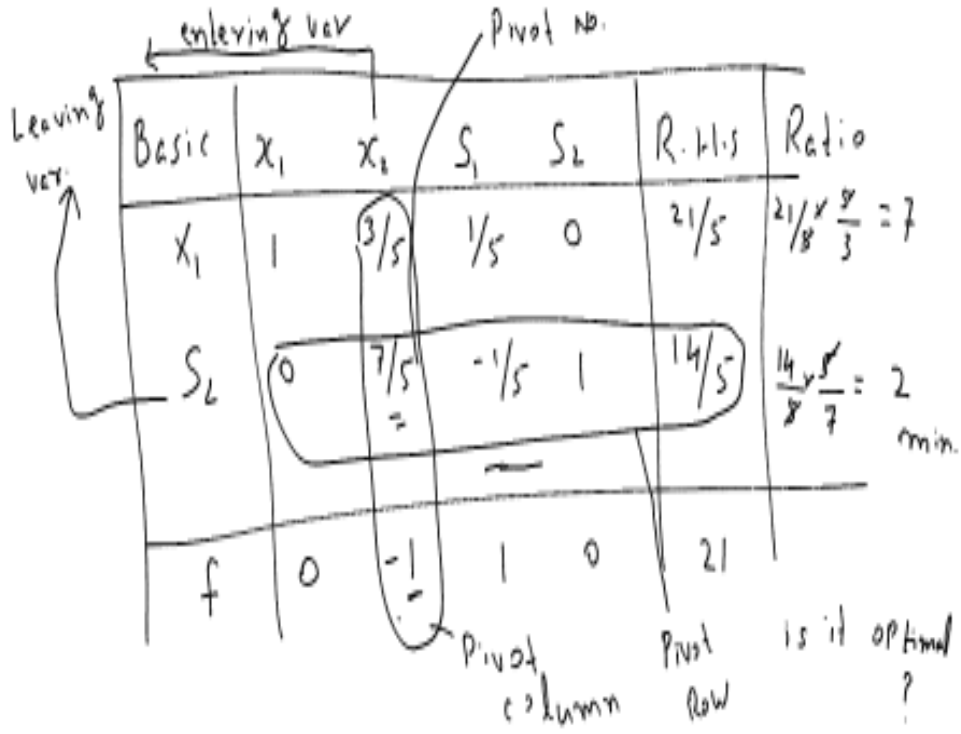
$$-(1)\begin{bmatrix} 1 & 3/5 & 1/5 & 0 & \frac{21}{5} \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 7/5 & -1/5 & 1 & \frac{14}{5} \end{bmatrix}$$

New f Row = $[-5 \quad -4 \quad 0 \quad 0 \quad 0]$

$-(-5)\left[1 \quad \frac{3}{5} \quad \frac{1}{5} \quad 0 \quad \frac{21}{5}\right]$

$= [0 \quad -1 \quad 1 \quad 0 \quad 21]$



New Pivot Row: $\frac{1}{7/5}\begin{bmatrix} 0 & \frac{7}{5} & \frac{-1}{5} & 1 & \frac{14}{5} \end{bmatrix}$

$= \frac{5}{7}\begin{bmatrix} 0 & \frac{7}{5} & \frac{-1}{5} & 1 & \frac{14}{5} \end{bmatrix}$

$= \begin{bmatrix} 0 & 1 & \frac{-1}{7} & \frac{5}{7} & 2 \end{bmatrix}$

New x_1 Row: $= \begin{bmatrix} 1 & \frac{3}{5} & \frac{1}{5} & 0 & \frac{21}{5} \end{bmatrix}$

$-\frac{3}{5}\begin{bmatrix} 0 & 1 & \frac{-1}{7} & \frac{5}{7} & 2 \end{bmatrix}$

$= \begin{bmatrix} 1 & 0 & \frac{2}{7} & \frac{-3}{7} & 3 \end{bmatrix}$

$\frac{1}{5} + \frac{3}{35}$

$\frac{7+3}{35} = \frac{10}{35} = \frac{2}{7}$

$\frac{21}{5} - \frac{6}{5} = \frac{15}{5}$

New I Row: $= \begin{bmatrix} 0 & -1 & 1 & 0 & 21 \end{bmatrix}$

$-(-1)\begin{bmatrix} 0 & 1 & \frac{-1}{7} & \frac{5}{7} & 2 \end{bmatrix}$

$= \begin{bmatrix} 0 & 0 & \frac{6}{7} & \frac{5}{7} & 23 \end{bmatrix}$

Basic	x_1	x_2	s_1	s_2	R.H.S	Ratio
x_1	1	0	$2/7$	$-3/7$	3	
x_2	0	1	$-1/7$	$5/7$	2	
f	0	0	$6/7$	$5/7$	23	

is it optimal ?

$x_1 = 3$

$x_2 = 2$

$f = 5x_1 + 4x_2$

$= 5(3) + 4(2)$

$= 15 + 8$

$= \boxed{23}$ → max value of f

Lecture 12 Simplex Method

Maximization

Steps of Simplex Method

1. Express the problem in equation form
2. Write the inequalities in form of equalities
3. Determine an initial feasible solution
4. Write initial tableau / iteration
5. Determine the criteria for optimality
6. Select an entering variable using the optimality condition
7. Select a leaving variable using the feasibility condition
8. Write the optimal solution

There are following steps related to solving a Maximization problem by simplex method

1. **Express the problem in equation form**
    - In the case the given problem is in the form of statements we need to translate it in equations
2. **Write the inequalities in form of equalities**

In this step we encounter normally three kinds of problems:

Type	**Less than equal to form (≤)**
Example	4X1 + 3X2 ≤ 240
Solution	❑ Introduce slack variable to solve this kind of problem ❑ Slack variables are always added
New Equation	4X1 + 3X2 + S1= 240
Type	**Equal to form (=)**
Example	4X1 + 3X2 = 240
Solution	❑ Introduce artificial variable to solve this kind of problem ❑ Artificial variables are always added
New Equation	4X1 + 3X2 + A1= 240
Type	**Greater than Equal to form (≥)**
Example	4X1 + 3X2 ≥ 240
Solution	❑ Introduce surplus variable and these are always subtracted ❑ Introduce artificial variable to solve this kind of problem and these are always added
New Equation	4X1 + 3X2 - S1+ A1= 240

Determine an initial feasible solution

To determine an initial feasible solution see how much equations and variables are their. This will help in deciding how much variables would be given arbitrary values

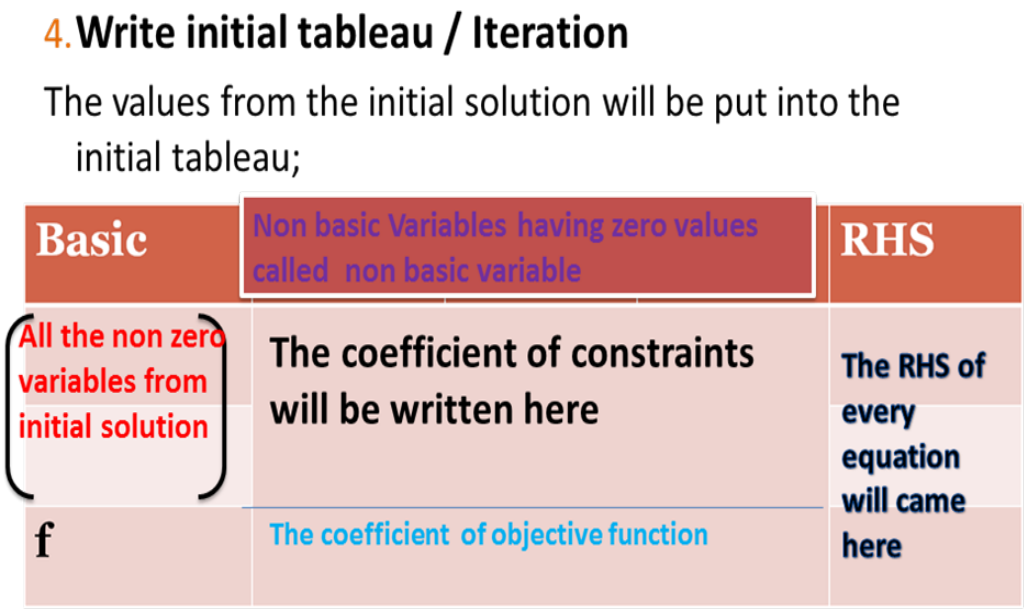
Arbitrary values = # of Variables -- # of Equations

Suppose we have 6 variables and 4 equations;

Arbitrary values = 6 – 4 = 2

So the two variables will be given arbitrary values equal to zero

All the variables and the RHSs of equations should be non negative



5. Determine the criteria for optimality

Solution of current tableau is said to be optimal if all the objective function co-efficient becomes **Non Negative / Positive**

6. Select an entering variable using the optimality condition

The entering variable in a maximization probe is non basic variable with most negative co efficient in the f- row. The optimum is reached at the iteration where all the f- row coefficients are non negative

7. Select a leaving variable using the feasibility condition

In case of maximization the leaving variable is the basic variable associated with the smallest non negative ratio with the strictly positive denominator. There is no need to take ratios for negative and zero because they can not be entered into basic variable column.

8.Write the optimal solution

When the solution criteria is satisfied, the values of the decision variables will be taken from tableau from corresponding RHS.

Put these values in the original maximization function to calculate optimal point.

Illustration No 1

Maximize: $\mathbf{f=5x_1+ 4x_2}$ (Objective Function)

Subject to: (Constraints)

$6x_1+ 4x_2 \leq 24$ (1)

$x_1+ 2x_2 \leq 6$ (2)

$-x_1+ x_2 \leq 1$ (3)

$x_2 \leq 2$ (4)

(Non-Negative Constraints)

$$x_{1,}\, x_2 \geq 0$$

Rewriting Constraints equations in homogeneous order

Step 1. Rewriting Constraints equations in homogeneous order

$$6x_1 + 4x_2 \leq 24 \qquad (1)$$

$$x_1 + 2x_2 \leq 6 \qquad (2)$$

$$-x_1 + x_2 \leq 1 \qquad (3)$$

$$0x_1 + x_2 \leq 2 \qquad (4)$$

$$x_{1,}\, x_2 \geq 0$$

Inequalities Constraints in Equation Form

Write inequalities constraints in equation form by adding slack variable "S".

e.g. $6x_1 + 4x_2 + S = 24$ (S is slack variable)

Let S_1, S_2, S_3 and S_4 be the slack variables for first, second, third and fourth constraints respectively.

$$6x_1 + 4x_2 + S1 = 24 \qquad \ldots\ldots\ldots\ldots \qquad (5)$$

$$x_1 + 2x_2 + S_2 = 6 \qquad \ldots\ldots\ldots\ldots \qquad (6)$$

$$-x_1 + x_2 + S_3 = 1 \qquad \ldots\ldots\ldots\ldots \qquad (7)$$

$$0x_1 + x_2 + S_4 = 2 \qquad \ldots\ldots\ldots\ldots \qquad (8)$$

$x_1, x_2, S_1, S_2, S_3, S_4 \geq 0$ $\quad f - 5X_1 - 4X_2 = 0$

Initial feasible solution

How many variable will be given Arbitrary values = # of Variables -- # of Equations

6 - 4 = 2

Let x1= 0, x2 = 0

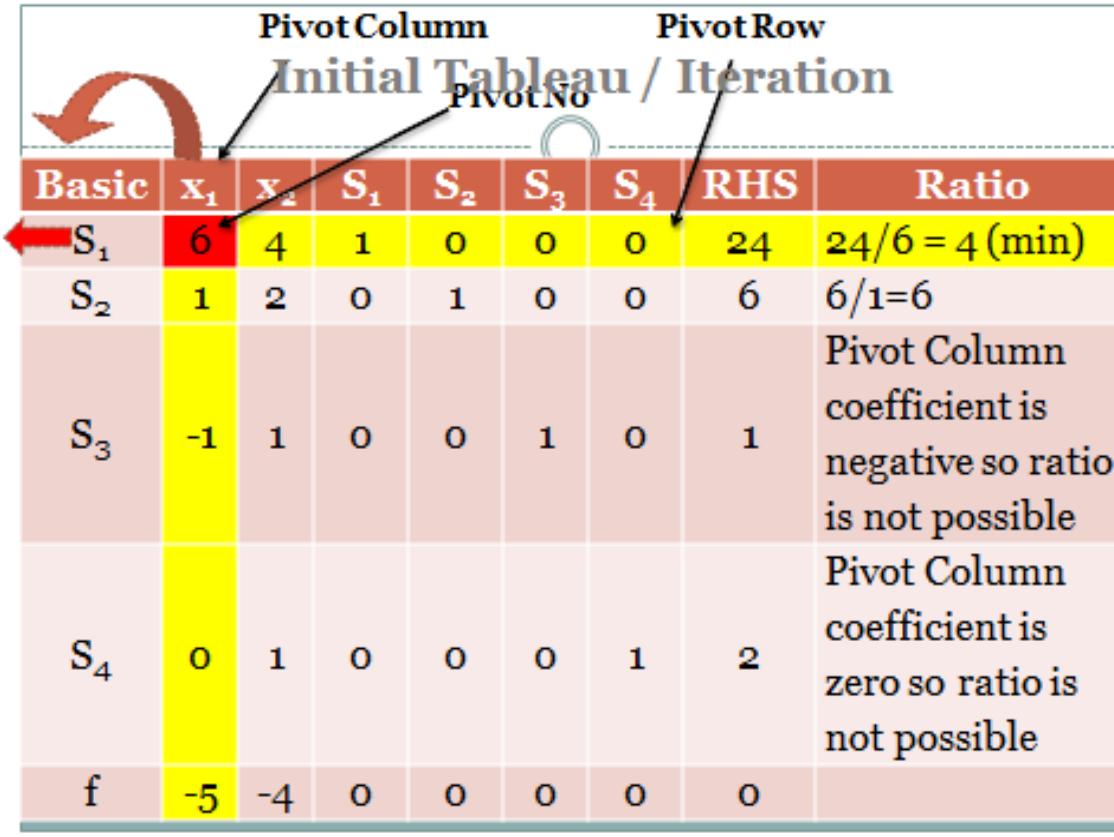
Putting above values in objective function (f=5x1+ 4x2) and equation 5-8,

f = 0

S1 = 24, S2 = 6

S3 = 1, S4 = 2

$x_1, x_2, S_1, S_2, S_3, S_4 \geq 0$



Basic	x_1	x_2	S_1	S_2	S_3	S_4	RHS	Ratio
S_1	6	4	1	0	0	0	24	24/6 = 4 (min)
S_2	1	2	0	1	0	0	6	6/1=6
S_3	-1	1	0	0	1	0	1	Pivot Column coefficient is negative so ratio is not possible
S_4	0	1	0	0	0	1	2	Pivot Column coefficient is zero so ratio is not possible
f	-5	-4	0	0	0	0	0	

Some cross checking measures

The basic variables are equal to 1 under their respective columns and all the other values in columns will be zero, so if you don't have zero or one on these position it means you have done some thing wrong.

Basic	x_1	x_2	S_1	S_2	S_3	S_4	RHS
S_1	6	4	1	0	0	0	24
S_2	1	2	0	1	0	0	6
S_3	-1	1	0	0	1	0	1
S_4	0	1	0	0	0	1	2
f	-5	-4	0	0	0	0	0

Calculation for next Iteration

$$\textbf{New Pivot Row} = \frac{\textbf{1}}{\textbf{Pivot No.}} \textbf{ X } \textbf{Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{\textbf{1}}{6} \textbf{ X } [6 \quad 4 \quad 1 \quad 0 \quad 0 \quad 0 \quad 24]$$

$$= [1 \quad 2/3 \quad 1/6 \quad 0 \quad 0 \quad 0 \quad 4]$$

New Row = Old Row – [Pivot Column Coefficient x New Pivot Row]

New S2 Row = [1 2 0 1 0 0 6]

- (1)[1 2/3 1/6 0 0 0 4]

= [0 4/3 -1/6 1 0 0 2]

Calculation

New S3 Row =[-1 1 0 0 1 0 1]

-(-1) [1 2/3 1/6 0 0 0 4]

= [0 5/3 1/6 0 1 0 5]

New S4 Row = [0 1 0 0 0 1 2]

- (0) [1 2/3 1/6 0 0 0 4]

= [0 1 0 0 0 1 2]

New f Row = [-5 -4 0 0 0 0 0]

-(-5) [1 2/3 1/6 0 0 0 4]

= [0 -2/3 5/6 0 0 0 20]

Still the solution is not optimal as there is -2/3 as negative coefficient of objective function so we again repeat the whole process

Basic	**x_1**	**x_2**	**S_1**	**S_2**	**S_3**	**S_4**	**RHS**	**Ratio**
x_1	**1**	**2/3**	**1/6**	**0**	**0**	**0**	**4**	**4/(2/3)=6**
S_2	**0**	**4/3**	**-1/6**	**1**	**0**	**0**	**2**	**2/(4/3) = 1.5 (min)**
S_3	**0**	**5/3**	**1/6**	**0**	**1**	**0**	**5**	**5/(5/3) = 3**
S_4	**0**	**1**	**0**	**0**	**0**	**1**	**2**	**2/1=2**
f	**0**	**-2/3**	**5/6**	**0**	**0**	**0**	**20**	

Calculation

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \text{ X Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{\mathbf{1}}{4/3} \mathbf{X} \quad [0 \quad 4/3 \quad -1/6 \quad 1 \quad 0 \quad 0 \quad 2]$$

New Pivot Row= 3/4[0 4/3 -1/6 1 0 0 2]

[0 1 -1/8 3/4 0 0 3/2]

Calculation

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New x_1 Row = [1 2/3 1/6 0 0 0 4]

- (2/3)[0 1 -1/8 3/4 0 0 3/2]

= [1 0 1/4 -1/2 0 0 3]

New S3 Row = [0 5/3 1/6 0 1 0 5]

- 5/3[0 1 -1/8 3/4 0 0 3/2]

= [0 0 3/8 -5/4 1 0 5/2]

New S_4 Row = [0 1 0 0 0 1 2]

- (1) [0 1 -1/8 3/4 0 0 3/2]

= [0 0 1/8 -3/4 0 1 1/2]

New f Row = [0 -2/3 5/6 0 0 0 20]

- (-2/3) [0 1 -1/8 3/4 0 0 3/2]

= [0 0 3/4 1/2 0 0 21]

Criteria for optimality

Solution of current tableau is said to be optimal if all the objective function co-efficient becomes Non Negative / Positive

Criteria for optimality satisfied

Basics	x_1	x_2	S_1	S_2	S_3	S_4	**RHS**
x_1	**1**	**0**	**1/4**	**-1/2**	**0**	**0**	**3**
x_2	**0**	**1**	**-1/8**	**3/4**	**0**	**0**	**3/2**
S_3	**0**	**0**	**3/8**	**-5/4**	**1**	**0**	**5/2**
S_4	**0**	**0**	**1/8**	**-3/4**	**0**	**1**	½
f	**0**	**0**	**3/4**	**1/2**	**0**	**0**	**21**

Criteria for Optimum Solution because all coefficients (of objective function) are non-negative or zero

Optimal Solution

X1 = 3

X2 = 3/2

f = 21

Cross checking of maximization point

put values of X1 and X2 from above solution into original objective function

$$f=5x_1+4x_2$$

$$=5\,(3)+4(3/2)$$

$$=21$$

Lecture 13 Simplex Method (Minimization)

Penalty Method Big M Method

Illustration

Minimize $f=4x_1+ x_2$ (Objective Function)

Subject to: (Constraints)

$3x_1+ x_2 = 3$

$4x_1+ 3x_2 \geq 6$

$x_1+ 2x_2 \leq 4$

$x_1, x_2 \geq 0$ (Non-Negativity Constraints)

Inequalities Constraints in Equation Form

Let S_1 and S_2 be the surplus and slack variables for second and third constraints, respectively.

Minimize $f =4x_1+ x_2$ (Objective Function)

Subject to: (Constraints)

$3x_1+ x_2 = 3$ ……. (1)

$4x_1+ 3x_2 – S_1 = 6$ ……. (2)

$x_1+ 2x_2 + S_2 = 4$ ……. (3)

$x_1, x_2, S_1 , S_2 \geq 0$

Initial solution

Arbitrary values = # of Variables -- # of Equations

4 - 2 = 2

Let x1= 0, x2 = 0

Putting above values in objective function

($f = 5x_1 + 4x_2$) and equation 1-3,

$f = 0$

$0 = 3$ (Contradiction) **This is against the basic rules of Mathematics as the 0 cannot be equal to 3**.

$S_1 = -6$ (Violation) **This is against the non negativity constraint that X must be non zero.**

$S_2 = 4$

This situation cannot be called as initial feasible solution because it is not satisfying the conditions so to make it feasible we need to add Artificial variables in equations having contradictions and violation

This is against the non negativity constraint that X must be non zero.

Artificial Variables

Let A_1 and A_2 be the artificial variables for first and second equation respectively.

Minimize: $f = 4x_1 + x_2$ (Objective Function)

Subject to: (Constraints)

$3x_1 + x_2 + A_1 = 3$ ……. (4)

$4x_1 + 3x_2 - S_1 + A_2 = 6$ ……. (5)

$x_1 + 2x_2 + S_2 = 4$ ……. (6)

$x_1, x_2, S_1, S_2, A_1 + A_2 \geq 0$

Solution of Artificial Variable

Questions in which we introduce artificial variables can not solve straight away. We have to use following two methods to solve it

1. Penalty Method or M-Method (Big M Method)
2. Two Phase Method

In this lecture we will solve this problem by Penalty Method

Solution by Penalty Method (Big M Method)

Let $M > > 0$ (M is very very large positive No.)

$f = 4x1 + x2 + MA1 + MA2$ ……. <7>

we put penalty to artificial variables

- **A1**

Use Equation no 4 to find the value of A1

$3x1+ x2 + A1= 3$

$A1 = 3 - 3x1- x2$

- **A2**

Use Equation no 5 to find the value of A2

$4x_1+ 3x_2 – S_1 + A_2= 6$

$A_2= 6 - 4x_1- 3x_2 + S_1$

Putting these values of A_1 and A_2 in eq. <7> we get

$f = 4x1+ x2 + M(3 - 3x1- x2)+ M(6 - 4x1- 3x2 + S1)$

$=4x1+ x2 + 3M– 3Mx1- Mx2)+ 6M– 4Mx1- 3Mx2 + MS1$

$=(4 – 7M)x1+ (1 – 4M)X2 + MS1 + 9M$

$= 9M +(– 7M + 4)x1+ (– 4M+1)X2 + MS1$

Problem set

$f = (– 7M + 4)x1+ (– 4M+1)X2 + MS1+ 9M$

Subject to:

$3x1+ x2+ A1 = 3$ …… (4)

$4x1+ 3x2 – S1 + A2= 6$ …… (5)

$x1+ 2x2+ S24$ …… (6)

$x_1, x_2, S_1 , S_2 , A_1 + A_2 \geq 0$

Initial Feasible Solution

Arbitrary values =# of Variables -- # of Equation

6 - 3 = 3

Let x1= 0, x2 = 0, S1 = 0

Putting above values in objective functions and equation 4-6,

f = 9M

A1 = 3

A2 = 6

S2 = 4

This solution is called initial feasible solution because it satisfies the Non negativity constraint and also do not have any contradiction or violation

Initial Tableau

Initial Tableau

Basis	x_1	x_2	S_1	S_2	A_1	A_2	RHS	Ratio
A_1	3	1	0	0	1	0	3	3/3 = 1(min)
A_2	4	3	-1	0	0	1	6	6/4 = 1.5
S_2	1	2	0	1	0	0	4	4/1 = 4
f	7M - 4	4M - 1	-M	0	0	0	9M	

This tableau is not satisfied because our criteria for minimization is non positivity of all the coefficients of objective function so we will iterate it further

We select the entering and leaving variable, the entering variable will be with the highest positive objective function coefficient and leaving variable will be with minimum ratio

Calculation

$$\textbf{New Pivot Row} = \frac{1}{\textbf{Pivot No.}} \textbf{ X Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{1}{3} \textbf{ X } [3 \quad 1 \quad 0 \quad 0 \quad 1 \quad 0 \quad 3]$$

$$\textbf{[1 1/3 0 0 1/3 0 1]}$$

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New A2 Row = [4 3 -1 0 0 1 6]

- (4)[1 1/3 0 0 1/3 0 1]

= [0 5/3 -1 0 -4/3 1 2]

New S2 Row =[1 2 0 1 0 0 4]

- (1) [1 1/3 0 0 1/3 0 1]

= [0 5/3 0 1 -1/3 0 3]

New f Row =

[7M-4 4M-1 -M 0 0 0 9M]

- (7M-4) [1 1/3 0 0 1/3 0 1]

[0 5M+1/3 -M 0 -7M+4/3 0 2M+4]

Tableau 1

Basis	X1	X2	S1	S2	A1	A2	RHS	Ratio
X1	1	1/3	0	0	1/3	0	1	1÷1/3=3
A2	0	5/3	-1	0	-4/3	1	2	2÷5/3= 1.2(min)
S2	0	5/3	0	1	-1/3	0	3	3÷5/3= 1.8
f	0	5M+1/3	-M	0	-7M+4/3	0	2M+4	

This tableau does not fulfill condition of optimality because our criteria for minimization is non positivity of all the coefficients of objective function so we will iterate it further

Calculation

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \text{ X Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{1}{5/3} \times [0 \quad 5/3 \quad -1 \quad 0 \quad -4/3 \quad 1 \quad 2]$$

$$= \frac{3}{5} \times [0 \quad 5/3 \quad -1 \quad 0 \quad -4/3 \quad 1 \quad 2]$$

$$[0 \quad 1 \quad -3/5 \quad 0 \quad -4/5 \quad 3/5 \quad 6/5]$$

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New X1 Row = [1 1/3 0 0 1/3 0 1]

- (1/3) [0 1 -3/5 0 -4/5 3/5 6/5]

= **[1 0 1/5 0 3/5 -1/5 3/5]**

New S2 Row =[0 5/3 0 1 -1/3 0 3]

-(5/3) [0 1 -3/5 0 -4/5 3/5 6/5]

= **[0 0 1 1 1 -1 1]**

New f Row =

[0 5M+1/3 -M 0 -7M+4/30 2M+4]

-(5M+1/3) [0 1 -3/5 0 -4/5 3/5 6/5]

$$0 \quad 0 \quad \frac{1}{5} \quad 0 \quad \frac{-15M+19}{15} \quad \frac{-5M-1}{5} \quad \frac{18}{5}$$

Tableau 2

Basis	X1	X2	S1	S2	A1	A2	RHS	Ratio
X1	1	0	1/5	0	3/5	-1/5	3/5	3/5÷1/5 =3
X2	0	1	-3/5	0	-4/5	3/5	6/5	
S2	0	0	1	1	1	-1	1	1/1=1 (min)
f	0	0	1/5	0	-15M+24 /15	-5M-1/5	18/5	

This tableau is not satisfied because our criteria for minimization is non positivity of all the coefficients of objective function so we will iterate it further

New Pivot Row = $\frac{1}{\text{Pivot No.}}$ **X Old Pivot Row**

New Pivot Row = $\frac{1}{1}$ X [0 0 1 1 1 -1 1]

= [0 0 1 1 1 -1 1]

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New X1 Row = [1 0 1/5 0 3/5 -1/5 3/5]

-(1/5) [0 0 1 1 1 -1 1]

= **[1 0 0 -1/5 2/5 0 2/5]**

New X2 Row =[0 1 -3/5 0 -4/5 3/5 6/5]

-(3/5) [0 0 1 1 1 -1 1]

= **[0 1 0 3/5 -1/5 0 9/5]**

New f Row = $[0 \quad 0 \quad \frac{1}{5} \quad 0 \quad \frac{-15M+24}{15} \quad \frac{-5M-1}{5} \quad \frac{18}{5}]$

-(1/5) [0 0 1 1 1 -1 1]

[0 0 0 -1/5 -15M+21/15 -M 17/5]

Tableau 3

Basis	X1	X2	S1	S2	A1	A2	RHS	Ratio
X1	1	0	0	-1/5	2/5	0	2/5	
X2	0	1	0	3/5	-1/5	0	9/5	
S1	0	0	1	1	1	-1	1	
f	0	0	0	-1/5	-15M+21 /15	-M	17/5	

This tableau is SATISFIED because our criteria for minimization is non positivity of all the coefficients of objective function which is attained

Optimal Solution

X1 = 2/5

X2 = 9/5

f = 17/5

Cross checking of maximization point

put values of X1 and X2 from above solution into original objective function

$f=4x_1+ x_2$

=4 (2/5) + (9/5)

=17/5

Lecture 14 : Simplex Method Minimization Two Phase method

Illustration

Minimize $f=4x_1+ x_2$ (Objective Function)

Subject to: (Constraints)

$3x_1+ x_2 = 3$

$4x_1+ 3x_2 \geq 6$

$x_1+ 2x_2 \leq 4$

$x_1, x_2 \geq 0$ (Non-Negativity Constraints)

Inequalities Constraints in Equation Form

Let S_1 and S_2 be the surplus and slack variables for second and third constraints, respectively.

Minimize $f =4x_1+ x_2$ (Objective Function)

Subject to: (Constraints)

$3x_1+ x_2 = 3$ ……. (1)

$4x_1+ 3x_2 – S_1 = 6$ ……. (2)

$x_1+ 2x_2 + S_2 = 4$ ……. (3)

$x_1, x_2, S_1 , S_2 \geq 0$

Arbitrary values =# of Variables -- # of Equations

4 - 2 = 2

Let x1= 0, x2 = 0

Putting above values in objective function

(f =$5x_1$+ $4x_2$) and equation 1-3,

f = 0

0 = 3 (Contradiction) **This is against the basic rules of Mathematics as the 0 cannot be equal to 3.**

S_1 = -6 (Violation) **This is against the non negativity constraint that X must be non zero.**

S_2 = 4

This situation cannot be called as initial feasible solution because it is not satisfying the condition. In order to make it feasible we need to add Artificial variables In equations having contradictions and violation

Artificial Variables

Let A_1 and A_2 be the artificial variables for first and second equation respectively.

Minimize: f =$4x_1$+ x_2 (Objective Function)

Subject to: (Constraints)

$3x_1$+ x_2 + A_1= 3 …… (4)

$4x_1$+ $3x_2$ – S_1 + A_2= 6 …… (5)

x_1+ $2x_2$ + S_2 = 4 …… (6)

$x_1, x_2, S_1, S_2, A_1 + A_2 \geq 0$

Solution of Artificial Variable

Questions which involve artificial variables can not solve straight away. We have to use following two methods to solve it

1. **Penalty Method or M-Method (Big M Method)**
2. **Two Phase Method**

In this lecture we will solve this problem by Two Phase Method

Solution by Two Phase Method

Phase I:

In Phase I we introduce artificial objective function Capital "F" as the sum of artificial variables introduced in the constraints. We substitute the values of artificial variables from the constraints and get artificial objective function.

We have Two artificial variables so the artificial objective function would be as under;

F = A1 + A2

Artificial Objective Function

- **A1**

Use Equation no 4 to find the value of A1

$$3x1+ x2 + A1= 3$$

$A1 = 3 - 3x1 - x2$

- **A2**

Use Equation no 5 to find the value of A2

$$4x_1 + 3x_2 - S_1 + A_2 = 6$$

$$A_2 = 6 - 4x_1 - 3x_2 + S_1$$

$F = A_1 + A_2$

Putting the values of A1 and A2

$$F = (3 - 3X1 - X2) + (6 - 4X1 - 3X2 + S1)$$

$$= 9 - 7x_1 - 4x_2 + S_1$$

Minimize $f = 4x1 + x2$

$$F = 9 - 7x_1 - 4x_2 + S_1$$

Subject to:

$3x1 + x2 + A1 = 3$ ……. (4)

$4x1 + 3x2 - S1 + A2 = 6$ ……. (5)

$x1 + 2x2 + S2 = 4$ ……. (6)

$x_1, x_2, S_1, S_2, A_1 + A_2 \geq 0$

Arbitrary values =# of Variables -- # of Equation

6 - 3 = 3

Let x1= 0, x2 = 0, S1 = 0

Putting above values in objective functions

and equation 4-6,

F = 9

f = 0

A1 = 3

A2 = 6

S2 = 4

This solution is called initial feasible solution because it satisfies the all Non negativity constraint and also do not have any contradiction or violation

Initial Tableau

Basics	X_1	X_2	S_1	S_2	A1	A2	RHS	Ratio
A1	3	1	0	0	1	0	3	3/3=1(Min)
A2	4	3	-1	0	0	1	6	6/4=1.5
S2	1	2	0	1	0	0	4	4/1=4
f	-4	-1	0	0	0	0	0	
F	7	4	-1	0	0	0	9	

For leaving variable the rule is same as maximization, the variable with minimum ratio;A1

In artificial function of minimization we select the maximum positive as the entering variable which is X1

Optimal solution for Artificial objective Function

The solution of artificial objective function is said to be optimal when artificial objective functions coefficients become non-positive or zero

Calculation

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \text{ X Old Pivot Row}$$

New Pivot Row = $\frac{1}{3}$ **X** [3 1 0 0 1 0 3]

= [1 1/3 0 0 1/3 0 1]

Calculation

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New A2 Row = [4 3 -1 0 0 1 6]

- (4)[1 1/3 0 0 1/3 0 1]

= [0 5/3 -1 0 -4/3 1 2]

New S2 Row = [1 2 0 1 0 0 4]

- (1) [1 1/3 0 0 1/3 0 1]

= [0 5/3 0 1 -1/3 0 3]

New f Row = [-4 -1 0 0 0 0 0]

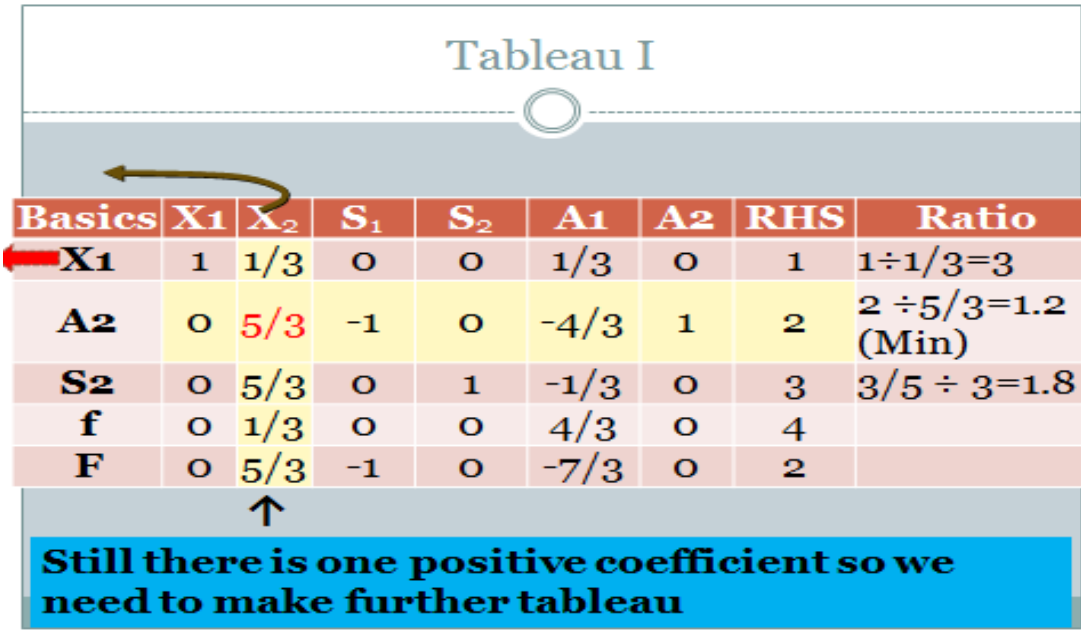
- (-4) [1 1/3 0 0 1/3 0 1]

= [0 1/3 0 0 4/3 0 4]

New F Row = [7 4 -1 0 0 0 9]

- (7) [1 1/3 0 0 1/3 0 1]

= [0 5/3 -1 0 -7/3 0 2]



Still there is ne positive coefficient so we need to make further tableau

Calculation

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \text{ X Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{1}{5/3} \mathbf{X} \; [0 \quad 5/3 \quad -1 \quad 0 \quad -4/3 \quad 1 \quad 2]$$

[0 1 -3/5 0 -4/5 3/5 6/5]

Calculation

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New X1 **Row** =

[1 1/3 0 0 1/3 0 1]

-(1/3)[0 1 -3/5 0 -4/5 3/5 6/5]

= **[1 0 1/5 0 3/5 -1/5 3/5]**

New S2 **Row** =

[0 5/3 0 1 -1/3 0 3]

-(5/3)[0 1 -3/5 0 -4/5 3/5 6/5]

= **[0 0 1 1 1 -1 1]**

New f Row =

[0 1/3 0 0 4/3 0 4]

-(1/3)[0 1 -3/5 0 -4/5 3/5 6/5]

= **[0 0 1/5 0 8/5 -1/5 18/5]**

New F Row

[0 5/3 -1 0 -7/3 0 2]

-(5/3)[0 1 -3/5 0 -4/5 3/5 6/5]

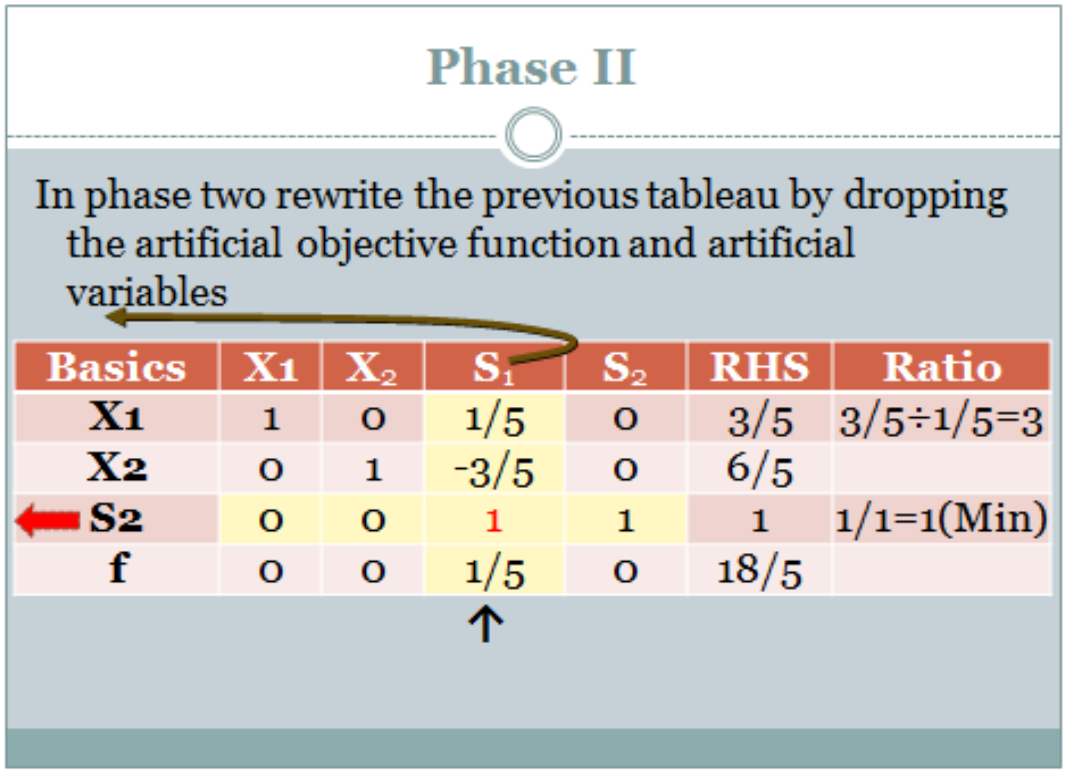
= [0 0 0 0 -1 -1 0]

Tableau II

Basics	**X1**	**X_2**	**S_1**	**S_2**	**A1**	**A2**	**RHS**
X1	1	0	1/5	0	3/5	-1/5	3/5
X2	0	1	-3/5	0	-4/5	3/5	6/5
S2	0	0	1	1	1	-1	1
f	0	0	1/5	0	8/5	-1/5	18/5
F	0	0	0	0	-1	-1	0

Now there is no positive value in the artificial function so this is the end of Phase I

Phase II



Calculation

$$\text{New Pivot Row} = \frac{1}{\text{Pivot No.}} \text{ X Old Pivot Row}$$

$$\text{New Pivot Row} = \frac{1}{1} \mathbf{X} [0 \quad 0 \quad 1 \quad 1 \quad 1]$$

[0 0 1 1 1]

Calculation

New Row = Old Row – Pivot Column Coefficient x New Pivot Row

New X1 Row =

[1 0 1/5 0 3/5]

-(1/5) [0 0 1 1 1]

= **[1 0 0 -1/5 2/5]**

New X2 Row =

[0 1 -3/5 0 6/5]

-(-3/5)[0 0 1 1 1]

= **[0 1 0 3/5 9/5]**

New f Row =

[0 0 1/5 0 18/5]

-(1/5) [0 0 1 1 1]

= **[0 0 0 -1/5 17/5]**

Tableau

Basics	**X1**	**X_2**	**S1**	**S_2**	**RHS**
X1	1	0	0	-1/5	2/5
X2	0	0	0	3/5	9/5
S1	0	0	1	1	1
f	0	0	0	-1/5	17/5

Now there is no positive value in the objective function so this is the optimal point

Optimal Solution

X1 = 2/5

X2 = 9/5

f = 17/5

Cross checking of maximization point

put values of X1 and X2 from above solution into original objective function

$$\mathbf{f=4x_1+ x_2}$$

=4 (2/5) + (9/5)

=17/5

Lecture 15 Simplex Method Four Special cases in Simplex

Simplex Algorithm – Special cases

There are four special cases arise in the use of the simplex method.

1. Degeneracy
2. Alternative optimal
3. Unbounded solution
4. infeasible solution

Degeneracy (no improvement in objective)

- Degeneracy: It is situation when the solution of the problem degenerates.
- Degenerate Solution: A Solution of the problem is said to be degenerate solution if value or values of basic variable(s) become zero
- It occurs due to redundant constraints.
- This is in itself not a problem, but making simplex iterations form a degenerate solution, give rise to cycling, meaning that after a certain number of iterations without improvement in objective value the method may turn back to the point where it started.

Example:

Max $f = 3x_1 + 9x_2$

Subject to:

$x_1 + 4x_2 \leq 8$

$X_1 + 2x_2 \leq 4$

$X_1, x_2 \geq 0$

The solution:

Step 1. write inequalities in equation form

Let S1 and S2 be the slack variables

$X_1 + 4X_2 + s_1 = 8$

$X_1 + 2X_2 + s_2 = 4$

$X_1, X_2, s_1, s_2 \geq 0$

Let X1=0, X2=0

f=0, S1=8, S2=4

The solution:

Step 1. write inequalities in equation form

Let S1 and S2 be the slack variables

$X_1 + 4X_2 + s_1 = 8$

$X_1 + 2X_2 + s_2 = 4$

$X_1, X_2, s_1, s_2 \geq 0$

Let X1=0, X2=0

f=0, S1=8, S2=4

- Initial Tableau

X_2 will enter the basis because of having minimum objective function coefficient.

Entering Variable

Leaving Variable

Basis	X_1	X_2	S_1	S_2	RHS	Ratio
S_1	1	4	1	0	8	8/4=2
S_2	1	2	0	1	4	4/2=2
f	-3	-9	0	0	0	

S_1 and S_2 tie for leaving variable(with same minimum ratio 2) so we can take any one of them arbitrary.

- Tableau 1

Basis	X_1	X_2	S_1	S_2	RHS	Ratio
X_2	1/4	1	1/4	0	2	8
S_2	½	0	-1/2	1	0	0 min
f	-3/4	0	9/4	0	18	

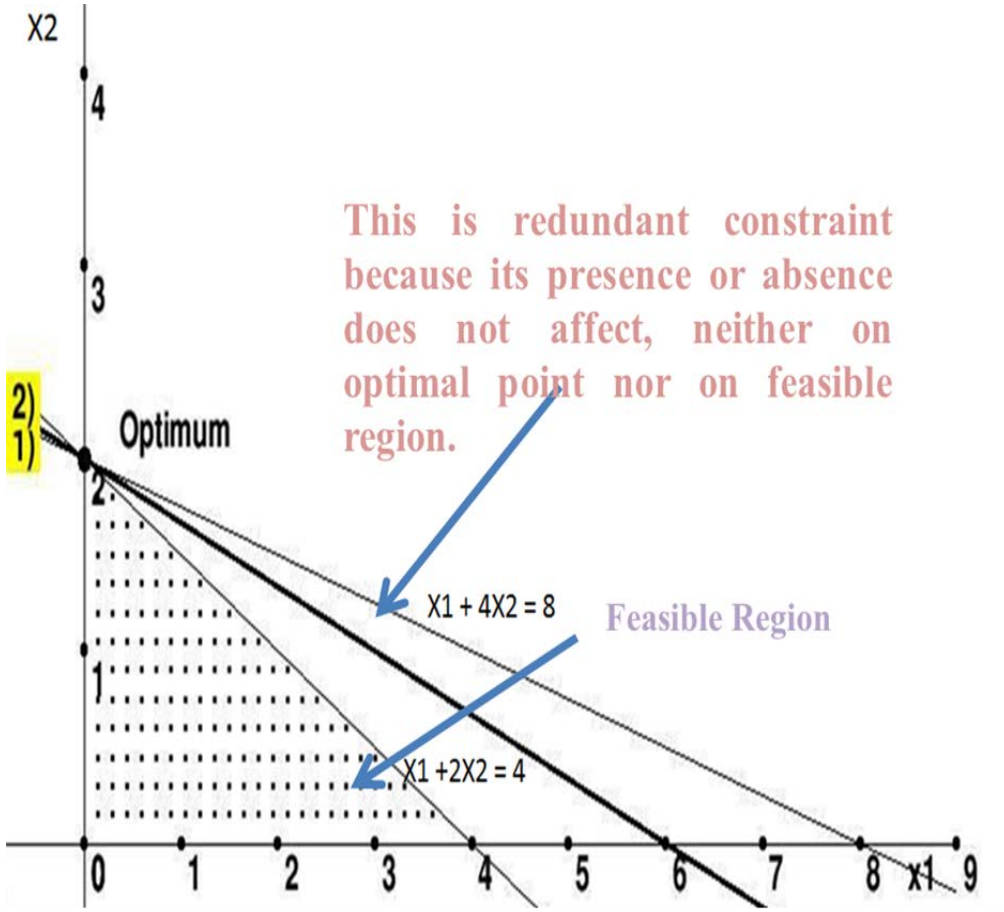
Here basic variable S_2 is 0 resulting in a degenerate basic solution.

Tableau 2

Basis	X_1	X_2	S_1	S_2	RHS
X_2	0	1	1/2	-1/2	2
X_1	1	0	-1	2	0
f	0	0	3/2	3/2	18

Same objective

- Same objective function no change and improvement (cycle)



Alternative optimal

- If the f-row value for one or more non basic variables is 0 in the optimal tableau, alternate optimal solution exists.
- When the objective function is parallel to a binding constraint, objective function will assume same optimal value. So this is a situation when the value of optimal objective function remains the same.

We have infinite number of such points

Example:

Max $2x_1 + 4x_2$

ST

$x_1 + 2x_2 \leq 5$

$x_1 + x_2 \leq 4$

$x_1, x_2 \geq 0$

The solution

Max $2x_1 + 4x_2$

Let S1and S2 be the slack variables

$x_1 + 2x_2 + s_1 = 5$

$x_1 + x_2 + s_2 = 4$

$x_1, x_2, s_1, s_2 \geq 0$

Initial solution

Let $x_1 = 0$, $x_2 = 0$,

$f=0$, $s_1= 5$, $s_2 = 4$

Initial Tableau

Entering Variable

Leaving Variable

Basis	X1	X2	S1	S2	RHS	Ratio
S_1	1	2	1	0	5	5/2=2.5
S_2	1	1	0	1	4	4/1=4
f	-2	-4	0	0	0	

- Optimal solution is 10 when x2=5/2, x1=0.

Basis	X1	X2	S1	S2	RHS	Ratio
X_2	1/2	1	1/2	0	5/2	5
S_2	1/2	0	-1/2	1	3/2	3 min
f	0	0	2	0	10	

- How do we know that alternative optimal exist ?

Entering Variable

- By looking at f-row coefficient of the nonbasic variable.

Leaving Variable

Basis	X1	X2	S1	S2	RHS	Ratio
X_2	1/2	1	1/2	0	5/2	5
S_2	1/2	0	-1/2	1	3/2	3
f	0	0	2	0	10	

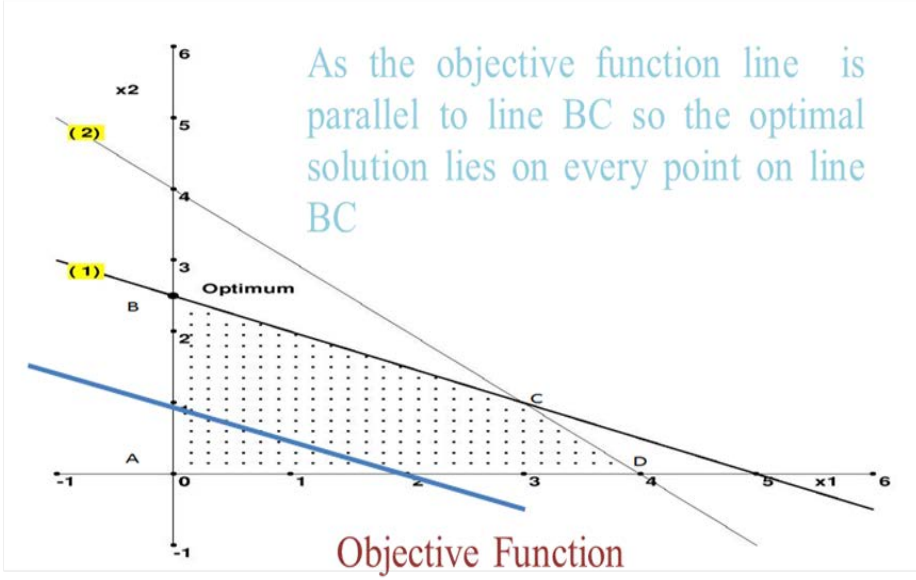
- that x1 can enter the basic solution without changing the value of f. Optimal sol. f=10 x1=0, x2=5/2

- The second alternative optima is:

Basis	X1	X2	S1	S2	RHS
X2	0	1	1	-1	1
X1	1	0	-1	2	3
F	0	0	2	0	10

- The new optimal solution is 10 when x1=3, x2=1

Any point on BC represents an alternate optimum with f=10



- In practice alternate optimals are useful as they allow us to choose from many solutions experiencing deterioration in the objective value.

Unbounded Solution

When determining the leaving variable of any tableau, if there is no positive ratio (all the entries in the pivot column are negative and zeros), then the solution is unbounded.

Example

Max $2x_1 + x_2$

Subject to

$x_1 - x_2 \leq 10$

$2x_1 \leq 40$

$x_1, x_2 \geq 0$

Solution

Max $2x_1 + x_2$

Let S1and S2 be the slack variables

$x_1 - x_2 + s_1 = 10$

$2x_1 + 0x_2 + s_2 = 40$

$x_1, x_2, s_1, s_2 \geq 0$

Initial Solution: $x_1 = 0$, $x_2 = 0$,

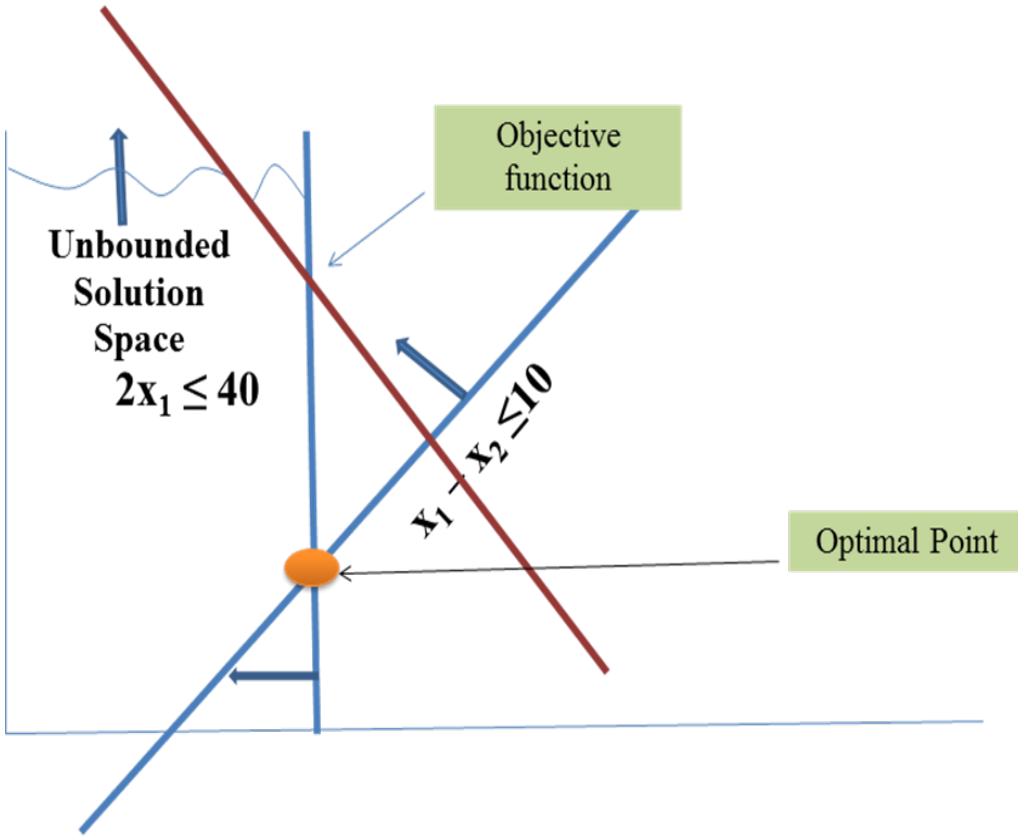
$f=0$, $s_1 = 10$, $s_2 = 40$

Basis	X1	X2	S1	S2	RHS	Ratio
S1	1	-1	1	0	10	10 min
S2	2	0	0	1	40	20
f	-2	-1	0	0	0	

Basis	X1	X2	S1	S2	RHS	Ratio
X1	1	-1	1	0	10	-
S2	0	2	-2	1	20	10
F	0	-3	2	0	20	

Basis	X1	X2	S1	S2	RHS	Ratio
X_1	1	0	0	½	20	-
X_2	0	1	-1	1/2	10	-
f	0	0	-3	3/2	50	

- The values of non basic variable are either zero or negative.
- So, solution space is unbounded



Infeasible Solution

A problem is said to have infeasible solution if there is no feasible optimal solution is available

Example:

Max $f=3x_1+2x_2$

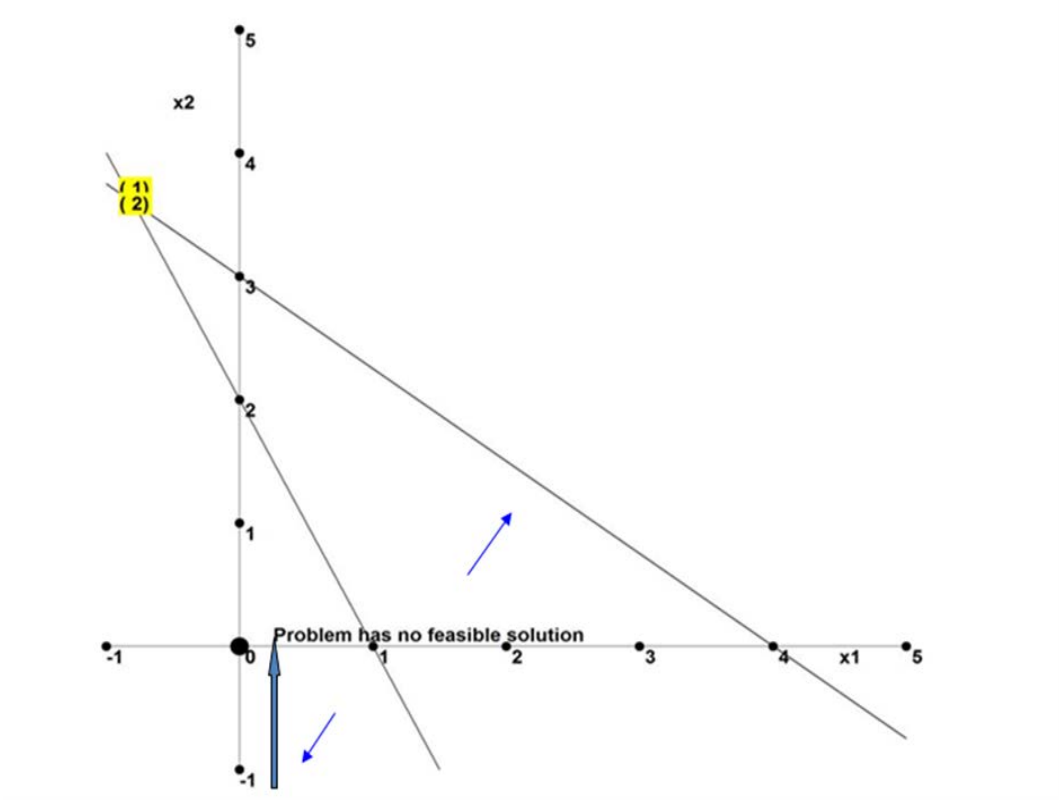
S.T.

$2x_1+x_2 \leq 2$

$3x_1+4x_2 \geq 12$

$x_1, x_2=0$

Solution (Graphical):



It is clear from above graph that there is no feasible solution available which can satisfy both of the constraints.

Lecture 16 Transportation Model

What is transportation model?

The transportation problem is one of the subclasses of linear programming problem where the objective is to transport various quantities of a single homogeneous product that are initially stored at various origins, to different destinations in such a way that the total transportation is minimum.

Transportation models

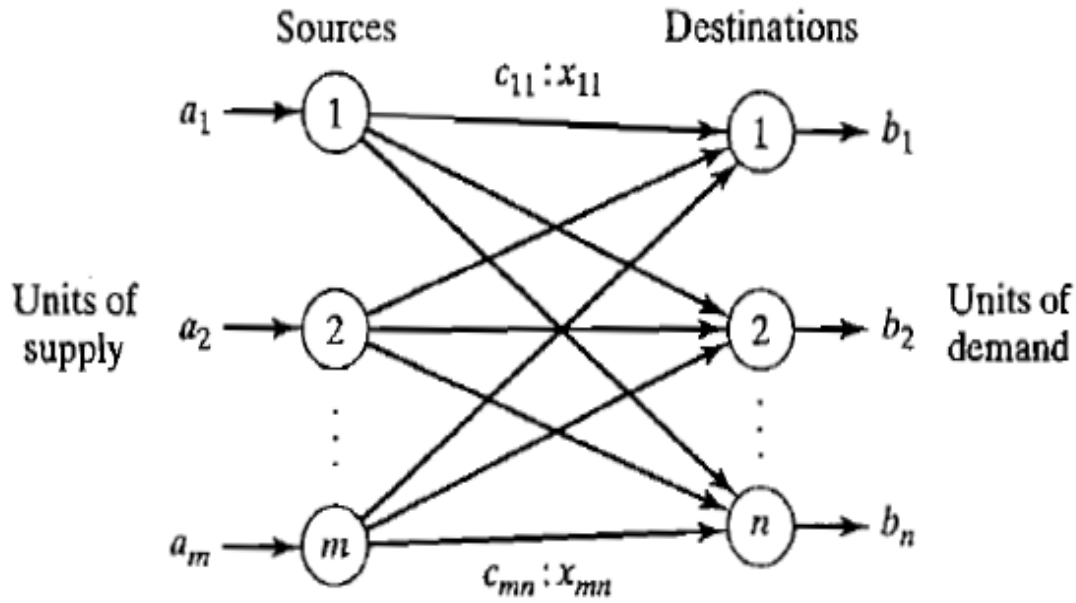
- Find lowest cost shipping arrangement
- Used primarily for existing distribution systems

Purpose of Transportation models

- Transportation models or problems are primarily concerned with the optimal (best possible) way in which a product produced at different factories or plants (called supply origins) can be transported to a number of warehouses (called demand destinations).
- The objective in a transportation problem is to fully satisfy the destination requirements within the operating production capacity constraints at the minimum possible cost

Real Life Application

Suppose there are different sources 1,2,……., m with different units of supply a_1, a_2, …….a_m. Similarly there are different destination 1, 2, …….n with different units of demand a_1, a_2, …….a_m. C_{11} is the cost for supplying X_{11} units from source a_1 to destination b_1. Similarly C_{mn} is the cost of supplying X_{mn} units from source m to destination n. This is exhibited in following figure:



We will have to plan a transportation model from different sources to destinations so that cost may be minimized.

Explanation of Transportation model

Sources	**Destination**			**Supply**
	D1	D2	D3	
S1	Cij Xij	Cij Xij	Cij Xij	C1
S2	Cij Xij	Cij Xij	Cij Xij	C2
S3	Cij Xij	Cij Xij	Cij Xij	C3
Demand	d1	d2	d3	C1+C2+C3= d1+d2+d3

- Let Xij are the units to be transported from source i (i=1, 2, 3….) to destination j (j=1, 2, 3….) and
- Cij is the cost to transport goods from source i (i=1, 2, 3….) to destination j (j=1, 2, 3….)

- After substituting ij with respective numbers the previous table will become like this;

Sources	Destination			Supply
	D1	D2	D3	
S1	C_{11} X_{11}	C_{12} X_{12}	C_{13} X_{13}	C1
S2	C_{21} X_{21}	C_{22} X_{22}	C_{23} X_{23}	C2
S3	C_{31} X_{31}	C_{32} X_{32}	C_{33} X_{33}	C3
Demand	d1	d2	d3	C1+C2+C3= d1+d2+d3

From above table it is clear that there are three sources of supply i.e. S1, S2 and S3 and there are three destinations or sources of demand D1, D2 and D3. Total supply of sources S3, S2 and S3 is C1, C2 and C3 respectively. Total demand for three D1, D2 and D3 is d1, d2 and d3 respectively. Total supply of three sources (C1+C2+C3) is equal to the total demand of three destinations (d1+d2+d3). C_{11} is the cost of transportation of X_{11} number of goods from source S1 to destination D1. Similarly C_{32} is the cost of transportation of X_{32} number of units from source S3 to destination D2 and so on.

Transportation Problem

- How much should be shipped from several sources to several destinations
    - Sources: Factories, warehouses, etc.
    - Destinations: Warehouses, stores, etc.

Transportation Problem Solution Steps

- **Define problem**
- **Set up transportation table (matrix)**
    - Summarizes all data
    - Keeps track of computations
- **Develop *initial* solution**
    - Northwest corner rule
- **Find *optimal* solution**

  Stepping stone method

Formulating a transportation problem

Lets take an example to describe the procedure of formulation of problem;

Example 1:

Powerco has three electric power plants that supply the electric needs of four cities.

- The associated supply of each plant and demand of each city is given in the table 1.

Table 1. Shipping costs, Supply, and Demand for Powerco Example

Transportation Tableau

Sources	***Destination***				
	City 1	***City 2***	***City 3***	***City 4***	***Supply (Million kwh)***
Plant 1	$8	$6	$10	$9	35
Plant 2	$9	$12	$13	$7	50
Plant 3	$14	$9	$16	$5	40
Demand (Million kwh)	45	20	30	30	125

A transportation problem is specified by the supply, the demand, and the shipping costs. So the relevant data can be summarized in a transportation

tableau. The transportation tableau implicitly expresses the supply and demand constraints and the shipping cost between each demand and supply point.

Solution

Decision Variable:

Since we have to determine how much electricity is sent from each plant to each city;

X_{ij} = Amount of electricity produced at plant i and sent to city j

X_{14} = Amount of electricity produced at plant 1 and sent to city 4

Objective function

Since we want to minimize the total cost of shipping from plants to cities;

Minimize $Z = \sum Cij\ Xij$

Minimize $Z = 8X_{11}+6X_{12}+10X_{13}+9X_{14}$

$+9X_{21}+12X_{22}+13X_{23}+7X_{24}$

$+14X_{31}+9X_{32}+16X_{33}+5X_{34}$

Supply Constraints

Since each supply point has a limited production capacity;

$X_{11}+X_{12}+X_{13}+X_{14} <= 35$

$X_{21}+X_{22}+X_{23}+X_{24} <= 50$

$X_{31}+X_{32}+X_{33}+X_{34} <= 40$

Demand Constraints

The company is required to meet the demand of different destinations represented in the form of inequalities as;

$X_{11}+X_{21}+X_{31} >= 45$

$X_{12}+X_{22}+X_{32} >= 20$

$X_{13}+X_{23}+X_{33} >= 30$

$X_{14}+X_{24}+X_{34} >= 30$

Sign Constraints

Since a negative amount of electricity can not be shipped all Xij's must be non negative;

$Xij >= 0$ (i= 1,2,3; j= 1,2,3,4)

LP Formulation of Powerco's Problem

Min Z = $8X_{11}+6X_{12}+10X_{13}+9X_{14}+9X_{21}+12X_{22}+13X_{23}+7X_{24}$

$+14X_{31}+9X_{32}+16X_{33}+5X_{34}$

S.T.: $X_{11}+X_{12}+X_{13}+X_{14} <= 35$ (Supply Constraints)

$X_{21}+X_{22}+X_{23}+X_{24} <= 50$

$X_{31}+X_{32}+X_{33}+X_{34} <= 40$

$X_{11}+X_{21}+X_{31} >= 45$ (Demand Constraints)

$X_{12}+X_{22}+X_{32} >= 20$

$X_{13}+X_{23}+X_{33} >= 30$

$X_{14}+X_{24}+X_{34} >= 30$

Xij >= 0 (i= 1,2,3; j= 1,2,3,4) (Sign Constraint)

General Description of a Transportation Problem

1. A set of *m* supply points from which a good is shipped. Supply point *i* can supply at most s_i units.

2. A set of n demand points to which the good is shipped. Demand point j must receive at least d_j units of the shipped good.

3. Each unit produced at supply point i and shipped to demand point j incurs a variable cost of c_{ij}.

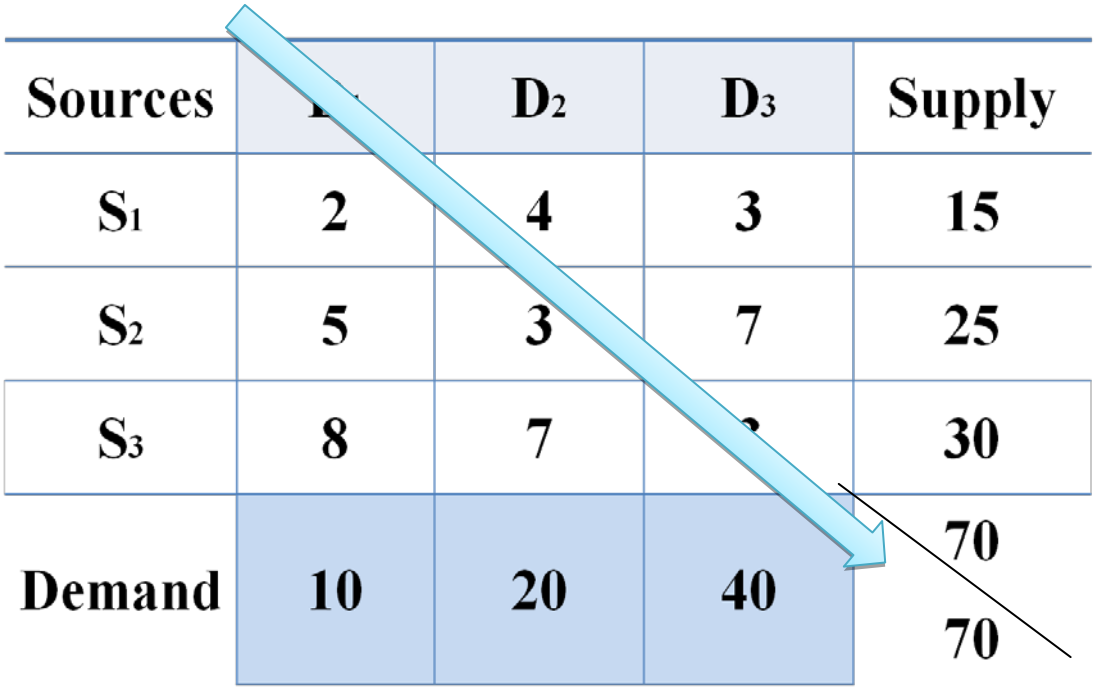
Types of Transportation Problem

1. Balanced Transportation Problem
2. Unbalanced Transportation Problem
   - Less Supply as Compared to Demand
   - Less Demand as Compared to Supply

Balanced Transportation Problem

If Total supply equals to total demand, the problem is said to be a balanced transportation problem:

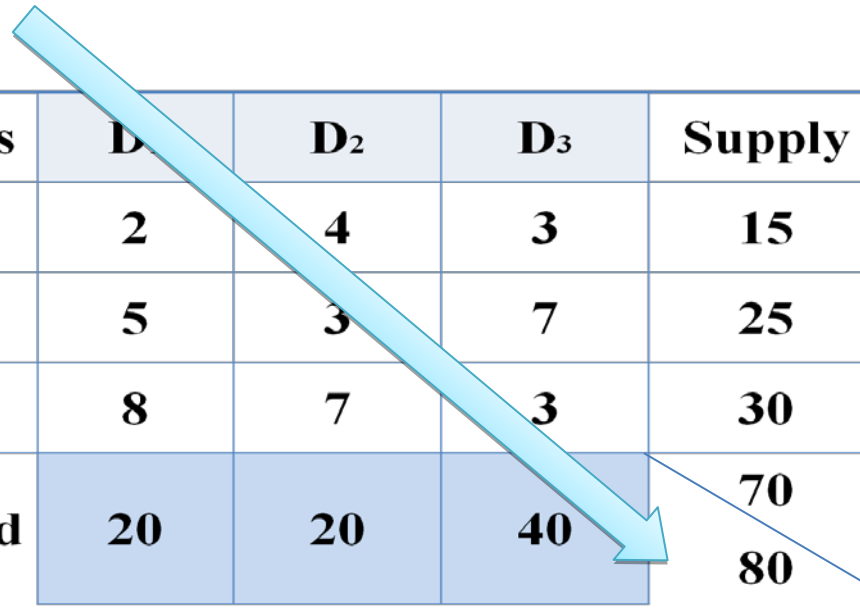
$$\sum_{i=1}^{i=m} s_i = \sum_{j=1}^{j=n} d_j$$



Sources	[illegible]	D_2	D_3	Supply
S_1	2	4	3	15
S_2	5	3	7	25
S_3	8	7	[illegible]	30
Demand	10	20	40	70 / 70

Supply is Less than Total Demand

If a transportation problem has a total supply that is strictly less than total demand the problem has no feasible solution. There is no doubt that in such a case one or more of the demand will be left unmet. Generally in such situations a penalty cost is often associated with unmet demand and as one can guess this time the total penalty cost is desired to be minimum. To solve such problem we need to introduce fictitious sources to provide the required supply at zero cost or cost provided in the problem.



Sources	D	D_2	D_3	Supply
S_1	2	4	3	15
S_2	5	3	7	25
S_3	8	7	3	30
Demand	20	20	40	70 80

Sources	D1	D2	D3	Supply
S1	2	4	3	15
S2	5	3	7	25
S3	8	7	3	30
Sf	0	0	0	10
Demand	20	20	40	80 80

A Fictitious Source Sf with supply of 10 is introduced which equalized the demand and supply.

Supply Exceeds Total Demand

If total supply exceeds total demand, we can balance the problem by adding dummy demand point. Since shipments to the dummy demand point are not real, they are assigned a cost of zero.

Sources	D_1	D_2	D_3	Supply
S_1	2	4	3	25
S_2	5	3	7	25
S_3	8	7	3	30
Demand	10	20	40	80 70

Supply exceeds the total demand so Fictitious destinations would be introduced to balance the problem .

Sources	D_1	D_2	D_3	D_f	Supply
S_1	2	4	3	0	25
S_2	5	3	7	0	25
S_3	8	7	3	0	30
Demand	10	20	40	10	80 80

Finding the initial feasible solution

Unlike other Linear Programming problems, a *balanced* TP with m supply points and n demand points is easier to solve, although it has m + n equality constraints. The reason for that is, if a set of decision variables (x_{ij}'s) satisfy all but one constraint, the values for x_{ij}'s will satisfy that remaining constraint automatically.

Methods to find Initial Feasible Solution

There are two basic methods:

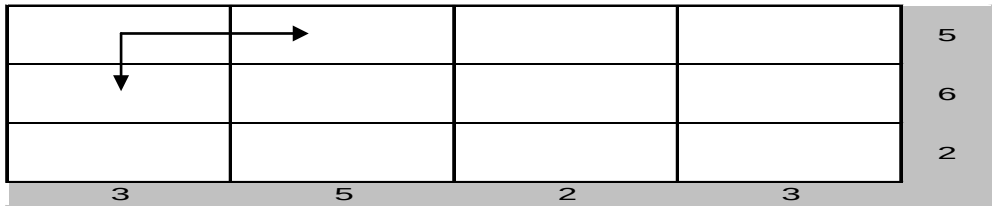
1. Northwest Corner Method
2. Least - Cost Method

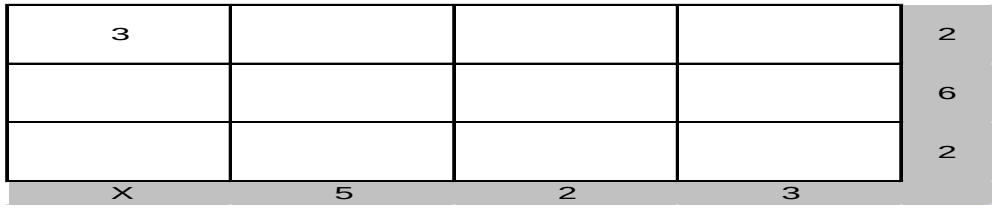
Northwest Corner Method

To find the Initial Feasible Solution by the NWC method:

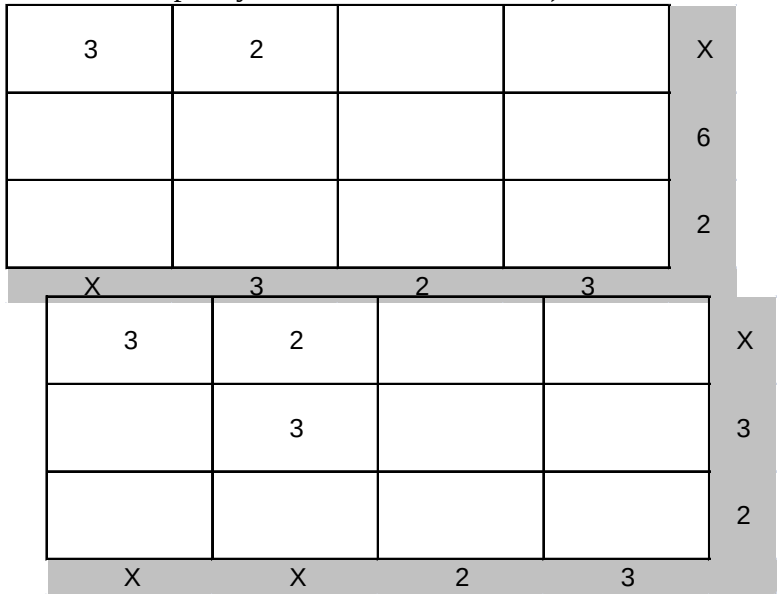
Begin in the upper left (northwest) corner of the transportation tableau and set x_{11} as large as possible (here the limitations for setting x_{11} to a larger number, will be the demand of demand point 1 and the supply of supply point 1. Your x_{11} value can not be greater than minimum of this 2 values).

According to the explanations in the previous slide we can set $x_{11}=3$ (meaning demand of demand point 1 is satisfied by supply point 1).





After we check the east and south cells, we saw that we can go east (meaning supply point 1 still has capacity to fulfill some demand).



After applying the same procedure, we saw that we can go south this time (meaning demand point 2 needs more supply by supply point 2).

3	2			X
	3	2		1
				2
X	X	X	3	

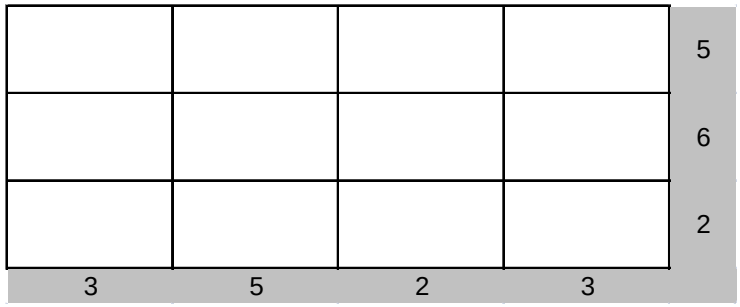
3	2			X
	3	2	1	X
				2
X	X	X	2	

Finally, we will have the following bfs, which is:

$$x_{11}=3,\ x_{12}=2,\ x_{22}=3,\ x_{23}=2,\ x_{24}=1,\ x_{34}=2$$

3	2			X
	3	2	1	X
			2	X
X	X	X	X	

North West Corner Method



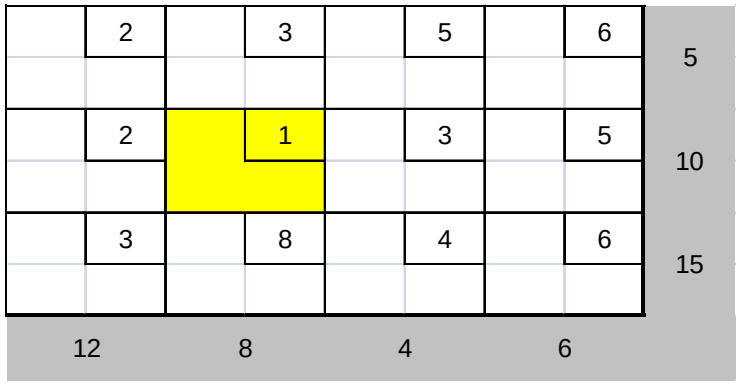
Least Cost Method

The Northwest Corner Method does not utilize shipping costs. It can yield an initial feasible solution easily but the total shipping cost may be very high. The minimum cost method uses shipping costs in order to come up with an initial feasible solution that has a lower cost. To begin the minimum cost method, first we find the decision variable with the smallest shipping cost (X_{ij}). Then assign X_{ij} its largest possible value, which is the minimum of s_i and d_j

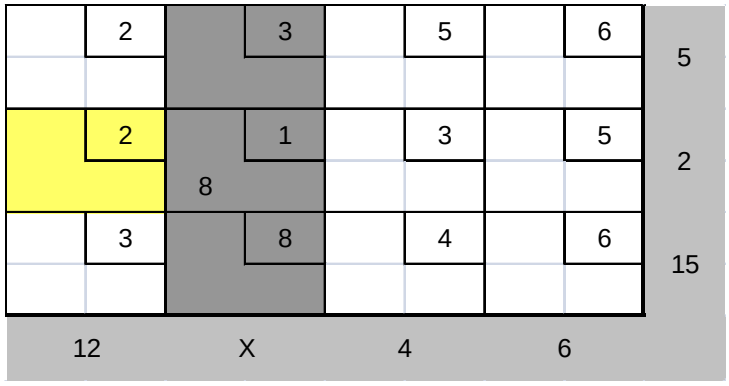
After that, as in the Northwest Corner Method we should cross out row i and column j and reduce the supply or demand of the noncrossed-out row or column by the value of Xij. Then we will choose the cell with the minimum cost of shipping from the cells that do not lie in a crossed-out row or column and we will repeat the procedure.

An example for Minimum Cost Method

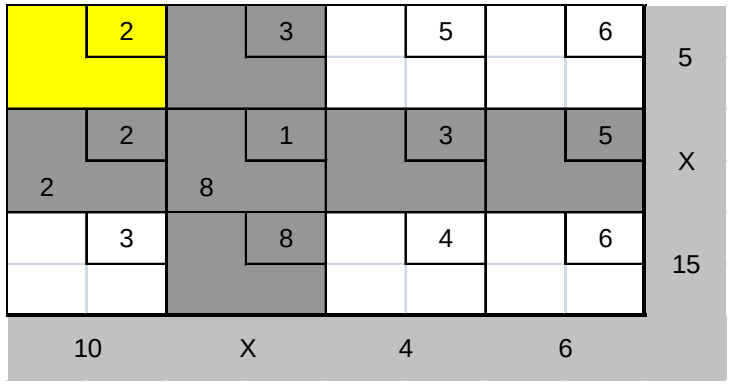
Step 1: Select the cell with minimum cost.



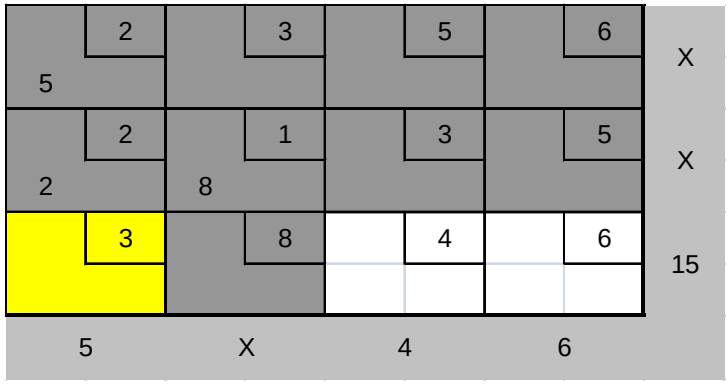
Step 2: Cross-out column 2



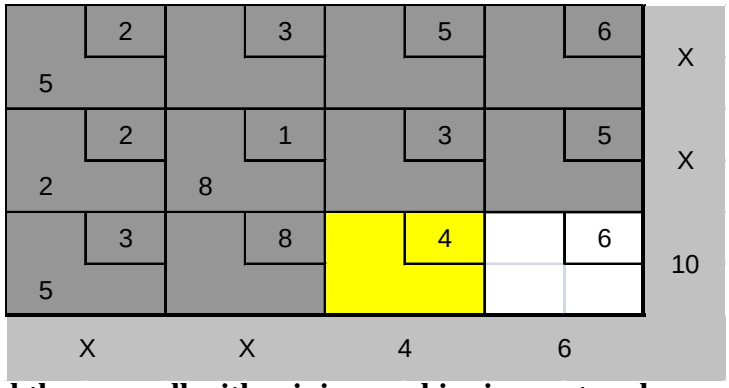
Step 3: Find the new cell with minimum shipping cost and cross-out row 2



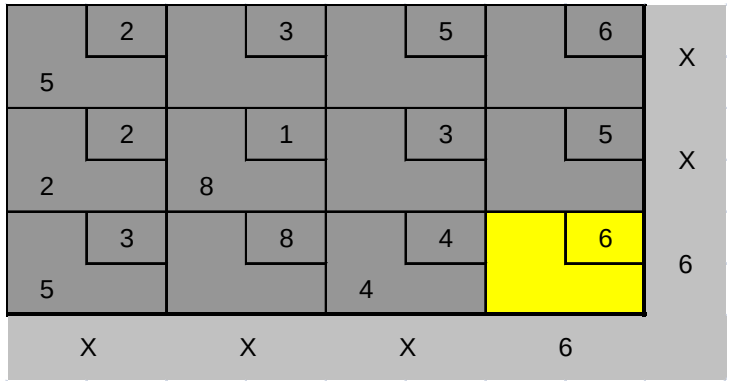
Step 4: Find the new cell with minimum shipping cost and cross-out row 1



Step 5: Find the new cell with minimum shipping cost and cross-out column 1

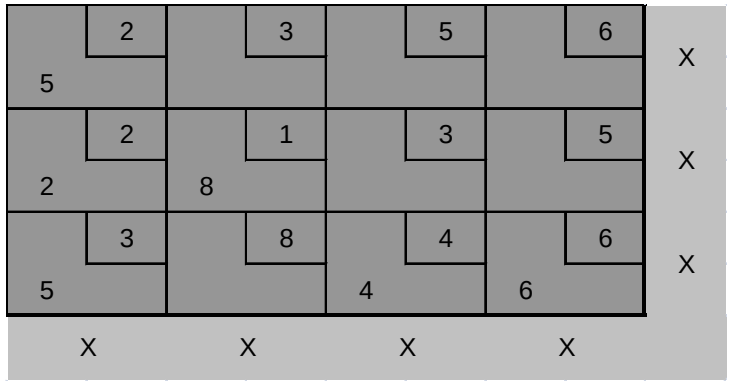


Step 6: Find the new cell with minimum shipping cost and cross-out column 3



Step 7: Finally assign 6 to last cell. The Initial feasible solution is found as:

X_{11}=5, X_{21}=2, X_{22}=8, X_{31}=5, X_{33}=4 and X_{34}=6



Least Cost Method

In this way we will fill out table using least cost method.

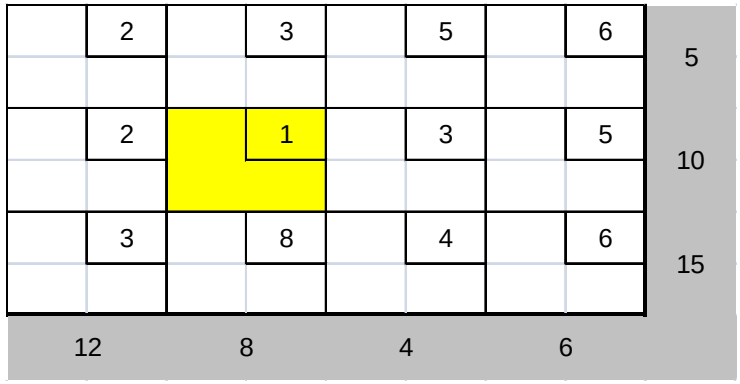


ILLUSTRATION-TRANSPORTATION METHOD

A company has two factories ‘A’ and ‘B’ at two different locations which produce batteries. Total supply capacity of factories ‘A’ and ‘B’ is 600 and 1200 batteries respectively. The company wants to supply their batteries to 3 destination towns ‘1’, ‘2’ and ‘3’ at different locations. The total demand of batteries in the three destination towns is 400, 800 and 600 respectively. Per unit cost of shipment from Factory ‘A’ to the three destination towns is $0.5, $3.5 and $2 respectively. Per unit cost of shipment from Factory ‘B’ to the three destination towns is $0.5, $2 and $1 respectively. Formulate optimum transportation plan for the company so that total cost of transportation is minimized.

		Destination			
		1	**2**	**3**	**Output Capacity (SS)**
Factory	**A**	0.5	3.5	2	600
	B	0.5	2	1	1200
Requirements (DD)		400	800	600	1800 1800

Initial Solution

We can fill the table and find the initial cost solution by using any of the following method:

- North West Corner Method
- Least Cost Method

North West Corner Method

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 **400**	3.5	2	600
	B	0.5	2	1	1200
Requirements (DD)		400	800	600	1800 1800

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 **400**	3.5 200	2	600
	B	0.5	2	1	1200
Requirements (DD)		400	800	600	1800 / 1800

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 **400**	3.5 **200**	2	600
	B	0.5	2 **600**	1	1200
Requirements (DD)		400	800	600	1800 / 1800

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 400	3.5 200	2	600
	B	0.5	2 600	1 600	1200
Requirements (DD)		400	800	600	1800 1800

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 **400**	3.5 **200**	2	600
	B	0.5	2 **600**	1 **600**	1200
Requirements (DD)		400	800	600	1800 / 1800

Above table shows that initially we can supply 400 units from factory A to destination 1, 200 units from factory A to destination 2, 0 units from factory A to destination 3, 0 units from factory B to destination 1, 600 units from factory B to destination 2 and 600 units from factory B to destination 3. So multiplying relevant number of units with respective unit cost we can compute initial cost of this transportation plan as:

Initial Cost = 400 x 0.5 + 200 x 3.5 + 600 x 2 + 600 x 1 =2700 Is it optimal?

Balanced Problem:

SS=DD

In a minimum type of transportation problem, a solution is optimal if all the optimal indices is either 0 or +ve

In a maximum type of transportation problem, a solution is optimal if all the improvement indices is either 0 or -ve

Improvement Indices

Improvement indices are computed for unoccupied cells or empty cells. There are two unoccupied cells i.e. A→3 and B→1. We will find out closed loops for

these cells.

A→3= 2- 3.5 +2 – 1= -0.5

B→1= 0.5 - 2 +3.5 – 0.5= 1.5

θ = ?

Determine minimum

200 - θ = 0, θ = 200

600 - θ = 0, θ = 600

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	1 400	4	3 200	600
	B	1	2 800	1 400	1200
Requirements (DD)		400	800	600	1800 / 1800

Cost = 400 x 0.5 + 200 x 2 + 800 x 2 + 400 x 1 =2600 Is it optimal?

Improvement Indicies

A→2= 3.5 – 2 + 1 – 2 = 0.5

B→1= 0.5 - 1 + 2 – 0.5 = 1

Optimum condition is satisfied therefore

Minimum Cost = 2600

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5	3.5	2	600
	B	0.5	2	1	1200
Requirements (DD)		400	800	600	1800 1800

Initial Solution

We can fill the table and find the initial cost solution by using any of the following method:

- North West Corner Method
- Least Cost Method

North West Corner Method

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	0.5 **400**	3.5 **200**	2	600
	B	0.5	2 **600**	1 **600**	1200
Requirements (DD)		400	800	600	1800 / 1800

For Occupied Cells $C_{ij} = U_i + V_j$

$C_{11} = U_1 + V_1 = 0.5$

$C_{12} = U_1 + V_2 = 3.5$

$C_{22} = U_2 + V_2 = 2$

$C_{23} = U_2 + V_3 = 1$

Unknown variables= U_1, U_2, V_1, V_2, V_3

Let $U_1 = 0$

$V_1 = 0.5$

$U_2 = -1.5$

$V_2 = 3.5$

$V_3 = 2.5$

For Un Occupied Cells $C_{ij} – (U_i + V_j)$

$A \rightarrow 3 = C_{13} – (U_1 + V_3) = 2 – (0 + 2.5) = -0.5$

$B \rightarrow 1 = C_{21} - (U_2 + V_1) = 0.5 - (-1.5 + 0.5) = 1.5$

$\theta = ?$

Determine minimum

$200 - \theta = 0, \qquad \theta = 200$

$600 - \theta = 0, \qquad \theta = 600$

		Destination			
		1	2	3	Output Capacity (SS)
Factory	A	1 **400**	4	3 **200**	600
	B	1	2 **800**	1 **400**	1200
Requirements (DD)		400	800	600	1800 / 1800

For Occupied Cells $C_{ij} = U_i + V_j$

$C_{11} = U_1 + V_1 = 0.5$

$C_{13} = U_1 + V_3 = 2$

$C_{22} = U_2 + V_2 = 2$

$C_{23} = U_2 + V_3 = 1$

Unknown variables= U_1, U_2, V_1, V_2, V_3

Let $U_1 = 0$

$V_1 = 0.5$

$U_2 = -1$

$V_2 = 3$

$V_3 = 2$

For Un Occupied Cells $C_{ij} – (U_i + V_j)$

$A \rightarrow 2 = C_{12} – (U_1 + V_2) = 3.5 – (0 + 3) = 0.5$

$B \rightarrow 1 = C_{21} – (U_2 + V_1) = 0.5 - (-1 + 0.5) = 1$

Optimal condition is satisfied therefore

Minimum cost = 2600For Un Occupied Cells $C_{ij} – (U_i + V_j)$

$A \rightarrow 2 = C_{12} – (U_1 + V_2) = 3.5 – (0 + 3) = 0.5$

$B \rightarrow 1 = C_{21} – (U_2 + V_1) = 0.5 - (-1 + 0.5) = 1$

Optimal condition is satisfied therefore

Minimum cost = 2600

Lecture 18 Transportation Method

Illustration 1

Sources	D_1	D_2	D_3	Capacity
S_1	2	4	3	15
S_2	5	3	7	25
S_3	8	7	3	30
Demand	10	20	40	70 70

Initial Solution by North West Corner Rule

Initial Solution by North West Corner Rule

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 Xij	4 Xij	3 Xij	15
S2	5 Xij	3 Xij	7 Xij	25
S3	8 Xij	7 Xij	3 Xij	30
Demand	10	20	40	70

S1D1 box is the most north column so we fill this first. See its column total which is 10 and row total which is 15. we place the less no in the box so is 10. Now the column total has been exhausted/completely filled and we mark zero to below box and the row total decrease to 5.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 Xij	3 Xij	5
S2	5 0	3 Xij	7 Xij	25
S3	8 0	7 Xij	3 Xij	30
Demand	0	20	40	70

S1D2 box is the most adjacent west column so we fill this first now. See its column total which is 20 and row total which is 5. we place the less no in the box so is 5. Now the row total has been completely filled and we give zero to respective row total and the column total decreases to 15.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 5	3 0	0
S2	5 0	3 Xij	7 Xij	25
S3	8 0	7 Xij	3 Xij	30
Demand	0	15	40	70

S2D2 box is the most adjacent north column to the previous cell just filled. So we fill this first. See its column total which is 15 and row total which is 25. We place the less no in the box so is 15. Now the column total has been exhausted and we assign zero to relevant column total and the row total decreases to 10.

Sources	Destination			Capacityy
	D1	D2	D3	
S1	2 10	4 5	3 0	0
S2	5 0	3 15	7 Xij	10
S3	8 0	7 0	3 Xij	30
Demand	0	0	40	70

S2D3 box is the most adjacent west column so we fill this first. See its column total which is 40 and row total which is 10. we place the less no in the box so is 10. Now the row total has been totally filled and the column total decrease to 30.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 5	3 0	0
S2	5 0	3 15	7 10	0
S3	8 0	7 0	3 Xij	30
Demand	0	0	30	70

S3D3 box is the last column so we fill this first. See its column and row total which is 30 . So we place 30 in the box and both column and row balance will be utilized fully.

Every time while finding the initial solution the column and row total of last box will be equal as in the given case 30.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 5	3 0	0
S2	5 0	3 15	7 10	0
S3	8 0	7 0	3 30	0
Demand	0	0	0	70

Sources	**Destination**			**Capacity**
	D1	D2	D3	
S1	2 10	4 5	3 0	15
S2	5 0	3 15	7 10	25
S3	8 0	7 0	3 30	30
Demand	10	20	40	70

No of Basic Variables= m+n-1

=3+3-1=5

m= No of sources

n= No of destinations

This calculation shows that at least 5 cells should be occupied to find the solution.

Sources	**Destination**			**Capacity**
	D1	D2	D3	
S1	2 10	4 5	3 0	15
S2	5 0	3 15	7 10	25
S3	8 0	7 0	3 30	30
Demand	10	20	40	70

Basic variables

Non basic variables

Total cost

Total cost = Xij * Cij

Total is calculated on the basis of all the basic variables because non basic variables are zero and their cost will also becomes zero when multiplied with zero units.

= 10 x 2 +5 x 4 +15 x 3 + 10 x 7+30 x 3 =245

Criteria for Optimality

All the shadow cost, which must be non negative

Shadow cost, for basic variables is always zero so there is no need to find their shadow cost

Shadow cost:

Vij = (Ui + Vj) –Cij

So we need to find the U and V.

Shadow cost

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 5	3 0	15 U1
S2	5 0	3 15	7 10	25 U2
S3	8 0	7 0	3 30	30 U3
Demand	10 V1	20 V2	40 V3	70

If we find the values of U1,U2,U3, and V1,V2 and V3 than we can easily find the shadow cost

Write the equations for the basic variables

U1+V1=2

U1+V2=4

U2+V2=3

U2+V3=7

U3+V3=3

There are 6 basic variables and 5 equations so we will give one variable arbitrary value which is equal to zero

Let U2=0

By putting this U2 zero we can easily find the value of all other variables which will be as follows

U1=1 V1=1

U2=0 V2=3

U3=-4 V3=7

Sources	Destination			Capacity
	D1	D2	D3	
S1	0 2 10	4 5	5 3 0	15 U1=1
S2	5 0	3 15	7 10	25 U2=0
S3	8 0	7 0	3 30	30 U3=-4
Demand	10 V1=1	20 V2=3	40 V3=7	70

Shadow cost of Shadow cost of S1D1

Vij = (Ui + Vj) –Cij

V11 = (U1 + V1) –C11

=(1+1) -2

=0

So save time and do not calculate the shadow cost for basic variables. Write the shadow cost on opposite side of cost in the S1D3

Vij = (Ui + Vj) –Cij

V13 = (U1 + V3) –C13

=(1+7) -3

=5

Shadow cost of Shadow cost of S1D1

Vij = (Ui + Vj) –Cij

V11 = (U1 + V1) –C11

=(1+1) -2

=0

So save time and do not calculate the shadow cost for basic variables. Write the shadow cost on opposite side of cost in the S1D3

Vij = (Ui + Vj) –Cij

V13 = (U1 + V3) –C13

=(1+7) -3

=5

Sources	Destination			Capacity
	D1	D2	D3	
S1	0 2 10	4 5	5 3 0	15 U1=1
S2	-4 5 0	3 15	7 10	25 U2=0
S3	-11 8 0	-8 7 0	3 30	30 U3=-4
Demand	10 V1=1	20 V2=3	40 V3=7	70

Our criteria of optimality is non positivity of shadow cost which is not satisfied as we have S1D3 box with positive shadow cost so we use **θ**

Sources	Destination			Capacity
	D1	D2	D3	
S1	0 2 10	4 5-θ	5 3 0+θ	15 U1=1
S2	-4 5 0	3 15+θ	7 10-θ	25 U2=0
S3	-11 8 0	-8 7 0	3 30	30 U3=-4
Demand	10 V1=1	20 V2=3	40 V3=7	70

Add **θ** in cell having largest positive shadow cost this will disturb the row and column balances for which you need to add and subtract **θ** from some other cells

Max θ = Min of (10,5) =5

The boxes from which the θ has been subtracted Replace the **θ** with 5 and make new tableau.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	4 0	3 5	15 U1
S2	5 0	3 20	7 5	25 U2
S3	8 0	7 0	3 30	30 U3
Demand	10 V1	20 V2	40 V3	70

Again find the shadow cost by finding the same rules as discussed above .

Total Cost:

=10*2+5*3+20*3+5*7+30*3

=220 (cost decreased as compared to previous tableau)

Equations:

U1+V1=2

U1+V3=3

U2+V2=3

U2+V3=7

U3+V3=3

- Let U2=0

By putting this U2 zero we can easily find the value of all other variables which will be as follows

- U1=-4 V1=6
- U2=0 V2=3
- U3=-4 V3=7

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10	-5 4 0	3 5	15 U1= - 4
S2	1 5 0	3 20	7 5	25 U2=0
S3	-6 8 0	-8 7 0	3 30	30 U3= - 4
Demand	10 V1= 6	20 V2=3	40 V3=7	70

Our criteria of optimality is non positivity of shadow cost which is not satisfied as we have S2D1 box with positive shadow cost so we use **θ**

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 10-θ	-5 4 0	3 5+θ	15 U1= - 4
S2	1 5 0+θ	3 20	7 5-θ	25 U2=0
S3	-6 8 0	-8 7 0	3 30	30 U3= - 4
Demand	10 V1= 6	20 V2=3	40 V3=7	70

We can no add θ in S3D2 because its above and below boxes have zero units and we can not balance in zero .

- **Max θ = Min of (10,5)**

  =5

The boxes from which the θ has been subtracted

Replace the **θ** with 5 and make new tableau.

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 5	4 0	3 10	15 U1=
S2	5 5	3 20	7 0	25 U2=
S3	8 0	7 0	3 30	30 U3=
Demand	10 V1=	20 V2=	40 V3=	70

Total Cost:

=5*2+10*3+5*5+20*3+30*3

=215 (The cost further reduced)

Shadow cost Equations:

U1+V1=2

U1+V3=3

U2+V1=5

U2+V2=3

U3+V3=3

- Let U2=0

By putting this U2 zero we can easily find the value of all other variables which will be as follows

- U1=-3 V1=5
- U2=0 V2=3
- U3=3 V3=6

Sources	Destination			Capacity
	D1	D2	D3	
S1	2 5	-4 4 0	3 10	15 U1= -3
S2	5 5	3 20	-1 7 0	25 U2=0
S3	-6 8 0	-7 7 0	3 30	30 U3= 3
Demand	10 V1=5	20 V2=3	40 V3=6	70

All the shadow costs are non positive (negative) which is the indication of optimal solution**.**

Optimal Distribution

- S1 ———> D1 = 5
- S1 ———> D3 = 10
- S2 ———> D1 = 5
- S2 ———> D2 = 20
- S3 ———> D3 = 30

Total = 70

Lecture 19 Transportation Problem

Total Capacity (Supply) exceeds Total Demand

Illustration 1

Minimize the transportation cost

Sources	D_1	D_2	D_3	Capacity
S_1	10	15	22	15
S_2	9	8	3	25
S_3	12	8	20	45
Demand	20	20	30	85 70

Solution

In this case we will introduce the fictitious destinations with demand equal to the difference of total capacity and total demands at zero cost of transportation from sources to fictitious destinations or at the cost stated in problem. We then use transportation algorithm to find the optimal solution**.**

Sources	D_1	D_2	D_3	D_f	Capacity
S_1	10	15	22	0	15
S_2	9	8	3	0	25
S_3	12	8	20	0	45
Demand	20	20	30	15	85 / 85

Initial Solution by Least Cost First Rule

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 Xij	15 Xij	22 Xij	0 Xij	15
S2	9 Xij	8 Xij	3 Xij	0 Xij	25
S3	12 Xij	8 Xij	20 Xij	0 Xij	45
Demand	20	20	30	15	85

In Df column all the cells have 0 cost which is least one, we can select any one of them to be filled first. We selected S1Df cell, see its column total which is 15 and row total which is also 15. We place the less no in the box so is 15. Now the column total has been exhausted/filled and we give zero to column total in cell below. Row total also decreases to zero.

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	0
S2	9 Xij	8 Xij	3 Xij	0 0	25
S3	12 Xij	8 Xij	20 Xij	0 0	45
Demand	20	20	30	0	85

S2D3 cell has the lowest cost equal to 3 , See its column total which is 30 and row total which is 25. We place the less no in the cell so is 25. Row total has been exhausted/filled and we give zero to remaining cells while column total has been decreased to only 5

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	0
S2	9 0	8 0	3 25	0 0	0
S3	12 Xij	8 Xij	20 Xij	0 0	45
Demand	20	20	5	0	85

Now S3D2 cell has the lowest cost equal to 8 , See its column total which is 20 and row total which is 45. We place the less no in the cell so is 20. Column total has been exhausted/filled while row total has been decreased to only 25

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	0
S2	9 0	8 0	3 25	0 0	0
S3	12 Xij	8 20	20 Xij	0 0	25
Demand	20	0	5	0	85

Now S3D1 cell has the lowest cost equal to 12 , See its column total which is 20 and row total which is 25. we place the less no in the cell so is 20. Column total has been exhausted/filled while row total has been decreased to only 5

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	0
S2	9 0	8 0	3 25	0 0	0
S3	12 20	8 20	20 Xij	0 0	5
Demand	0	0	5	0	85

Last remaining cell is S3D3 which has its column total and row total equal to 5. The total is same for both sides so we place 5 in the cell.

Initial Solution by Least Cost First Rule

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	0
S2	9 0	8 0	3 25	0 0	0
S3	12 20	8 20	20 5	0 0	0
Demand	0	0	0	0	85

This is the initial feasible solution. Rewrite the tableau with its capacity and demand

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	15
S2	9 0	8 0	3 25	0 0	25
S3	12 20	8 20	20 5	0 0	45
Demand	20	20	30	15	85

No of Basic Variables= m+n-1

=3+4-1 =6

m= No of sources

n= No of destinations

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0	15 0	22 0	0 15	15 U1
S2	9 0	8 0	3 25	0 0	25 U2
S3	12 20	8 20	20 5	0 0	45 U3
Demand	20 V1	20 V2	30 V3	15 V4	85

There are only five basic variables so we need another variable as a basic variables.

U1+V4=0 let U2=0

U2+V3=3 U1= V1=-5

U3+V1=12 U2=O V2=-9

U3+V2=8 U3=17 V3=3

U3+V3=20 V4=???

By using these equations when we calculate values we are unable to find the values of U1 and V4. it is due to less no of basic variables .

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0+ ε	15 0	22 0	0 15	15
S2	9 0	8 0	3 25	0 0	25
S3	12 20	8 20	20 5	0 0	45
Demand	20	20	30	15	85

We add epsilon which is slightly greater than 0 , this addition makes the non basic variable as basic variable this is slightly higher than zero so it does not affect the balance. We can add epsilon in any cell of column of V4 or in row of U1.

Equations

Now we have another basic variable we write its equation. Addition of this new equation help us to find the values for U1 and V4

U1+V4=0 let U2=0

U2+V3=3 U1=15 V1=-5

U3+V1=12 U2=O V2=-9

U3+V2=8 U3=17 V3=3

U3+V3=20 V4=-15

U1+V1=10

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 0+ ε	15 0	22 0	0 15	15 U1=15
S2	9 0	8 0	3 25	0 0	25 U2=0
S3	12 20	8 20	20 5	0 0	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-15	85

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	0 10 0+ ε	15 0	-4 22 0	0 15	15 U1=15
S2	9 0	8 0	3 25	0 0	25 U2=0
S3	12 20	8 20	20 5	0 0	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-15	85

Shadow cost of S1D1

Vij = (Ui + Vj) –Cij

V11 = (U1 + V1) –C11

=(15-5) -10

=0

- **ZERO shadow cost indicates that it is a basic variable Shadow cost of S1D3**

Vij = (Ui + Vj) –Cij

V13 = (U1 + V3) –C13

=(15+3) -22

=-4

In this way we calculate the shadow cost of all the cells.

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	0 10 0+ ε	-9 15 0	-4 22 0	0 15	15 U1=15
S2	-14 9 0	-17 8 0	3 25	-15 0 0	25 U2=0
S3	12 20	8 20	20 5	2 0 0	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-15	85

One shadow cost is positive so we use the addition and subtraction of θ .

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	0 10 0+ ε+θ	-9 15 0	-4 22 0	0 15-θ	15 U1=15
S2	-14 9 0	-17 8 0	3 25	-15 0 0	25 U2=0
S3	12 20-θ	8 20	20 5	2 0 0+θ	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-15	85

Total cost

Total cost = Xij * Cij

Total is calculated on the basis of all the basic variables because non basic variables are zero and their cost will also becomes zero when multiplied with zero units.

= 25*3 + 20*12 + 20*8 + 5*20

=575

Max θ= Min (15,20)

= 15

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 15	15 0	22 0	0 0	15 U1=
S2	9 0	8 0	3 25	0 0	25 U2=
S3	12 5	8 20	20 5	0 15	45 U3=
Demand	20 V1=	20 V2=	30 V3=	15 V4=	85

Equations

U1+V1=10 let U2=0

U2+V3=3 U1=15 V1=-5

U3+V1=12 U2=O V2=-9

U3+V2=8 U3=17 V3=3

U3+V3=20 V4=-17

U3+V4=0

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 15	15 0	22 0	0 0	15 U1=15
S2	9 0	8 0	3 25	0 0	25 U2=0
S3	12 5	8 20	20 5	0 15	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-17	85

Sources	Destination				Capacity
	D1	D2	D3	Df	
S1	10 15	-9 15 0	-4 22 0	-2 0 0	15 U1=15
S2	-14 9 0	-17 8 0	3 25	-17 0 0	25 U2=0
S3	12 5	8 20	20 5	0 15	45 U3=17
Demand	20 V1=-5	20 V2=-9	30 V3=3	15 V4=-17	85

All the shadow costs are non positive so the conditions for optimality has been satisfied.

If the conditions does not satisfy than we will use the previous process of addition of θ and further tabulation till the conditions satisfied, presence or absence of epsilon does not affect the solution so its up to you, whether to retain it or just drop it.

Total Cost

Total cost= 15*10 + 25*3 + 5*12 + 20*8 + 5*20

= 150 + 75 + 60 + 160 +100

= 545

Optimal Distribution

- S1 ——— > D1 = 15
- S2 ——— > D3 = 25
- S3 ——— > D1 = 5
- S3 ——— > D2 = 20
- S3 ——— > D3 = 5
- S3 ——— > Df = 15

Total = 85

Total cost=

15*10 + 25*3 + 5*12 + 20*8 + 5*20

=545

Maximization Total Demand exceeds Total Capacity (Supply)

Maximization

Maximization problem may be solved by the use of following method

- Multiply the given pay off matrix of profits or gain by -1. Then use the transportation technique for minimization to obtain optimal solution.
- To calculate the total profit or gain multiply the total cost by -1

Illustration

Sources	D_1	D_2	D_3	Capacity
S_1	10	15	12	15
S_2	9	8	3	25
S_3	12	8	20	25
Demand	30	20	30	65 / 80

- Maximize the profit for this problem

Introduce the fictitious supply to balance at zero profit

Sources	D1	D2	D3	Capacity
S1	10	15	12	15
S2	9	8	3	25
S3	12	8	20	25
Sf	0	0	0	15
Demand	30	20	30	80

Sources	Destination			Capacity
	D1	D2	D3	
S1	10 Xij	15 Xij	12 Xij	15
S2	9 Xij	8 Xij	3 Xij	25
S3	12 Xij	8 Xij	20 Xij	25
S_f	0 Xij	0 Xij	0 Xij	**15**
Demand	30	20	30	80

Initial Solution by North West Corner Rule

Sources	Destination			Capacity
	D1	D2	D3	
S1	10 15	15 0	12 0	15
S2	9 15	8 10	3 0	25
S3	12 0	8 10	20 15	25
Sf	0 0	0 0	0 15	15
Demand	30	20	30	80

For maximization we multiply all the profits or gains by -1.

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	-15 0	-12 0	15
S2	-9 15	-8 10	-3 0	25
S3	-12 0	-8 10	-20 15	25
Sf	0 0	0 0	0 15	15
Demand	30	20	30	80

Total Profit

Total Cost =15*-10 + 15*-9 + 10*-8 + 10*-8 + 15* -20 = -745

Total Profit=-1*- 745= 745

No of Basic Variables= m+n-1

=4+3-1=6

m= No of sources

n= No of destinations

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	-15 0	-12 0	15 U1=
S2	-9 15	-8 10	-3 0	25 U2=
S3	-12 0	-8 10	-20 15	25 U3=
Sf	0 0	0 0	0 15	15 U4=
Demand	30 V1=	20 V2=	30 V3=	80

For calculating shadow cost we need to find the values of U and V variables

Equations

U1+V1=-10 let U2=0

U2+V1=-9 U1=-1 V1=-9

U2+V2=-8 U2=O V2=-8

U3+V2=-8 U3=0 V3=-20

U3+V3=-20 U4=20

U4+V3=0

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	-15 0	-9 -12 0	15 U1=-1
S2	-9 15	-8 10	-3 0	25 U2=0
S3	-12 0	-8 10	-20 15	25 U3=0
Sf	0 0	0 0	0 15	15 U4=20
Demand	30 V1=-9	20 V2=-8	30 V3=-20	80

Shadow cost of S1, D3

Vij = (Ui + Vj) –Cij

V11 = (U1 + V3) –C13

=(-1-20) -12 =-9

We can calculate all the shadow cost in the same way for others .

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	6 -15 0	-9 -12 0	15 U1=-1
S2	-9 15	-8 10	-17 -3 0	25 U2=0
S3	3 -12 0	-8 10	-20 15	25 U3=0
Sf	11 0 0	12 0 0	0 15	15 U4=20
Demand	30 V1=-9	20 V2=-8	30 V3=-20	80

We add θ in maximum positive shadow cost to proceed further because our optimal condition is not yet satisfied.

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	6 -15 0	-9 -12 0	15 U1=-1
S2	-9 15	-8 10	-17 -3 0	25 U2=0
S3	3 -12 0	-8 10-θ	-20 15+θ	25 U3=0
S_f	11 0 0	12 0 0+θ	0 15-θ	15 U4=20
Demand	30 V1=-9	20 V2=-8	30 V3=-20	80

Maximum θ = Min (10,15) = 10

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	-15 0	-12 0	15 U1=
S2	-9 15	-8 10	-3 0	25 U2=
S3	-12 0	-8 0	-20 25	25 U3=
Sf	0 0	0 10	0 5	15 U4=
Demand	30 V1=	20 V2=	30 V3=	80

Total Cost= 15*-10 +15*-9 + 10*-8 + 25*-20 = **-865**

Total Profit/Gain = -1 * -865 = **865**

Equations

U1+V1=-10

let U2=0

U2+V1=-9 U1=-1 V1=-9

U2+V2=-8 U2= 0V2=-8

U3+V3=-20 U3=-12 V3=-8

U4+V2=0 U4=8

U4+V3=0

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	-15 0	-12 0	15 U1=-1
S2	-9 15	-8 10	-3 0	25 U2=0
S3	-12 0	-8 0	-20 25	25 U3=-12
Sf	0 0	0 10	0 5	15 U4=8
Demand	30 V1=-9	20 V2=-8	30 V3=-8	80

Now we can calculate the shadow costs for all cells

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15	6 -15 0	3 -12 0	15 U1=-1
S2	-9 15	-8 10	-5 -3 0	25 U2=0
S3	-9 -12 0	-12 -8 0	-20 25	25 U3=-12
Sf	-1 0 0	0 10	0 5	15 U4=8
Demand	30 V1=-9	20 V2=-8	30 V3=-8	80

shadow costs are still positive so we use θ to proceed further

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 15-θ	6 15 0+θ	3- -12 0	15 U1=-1
S2	-9 15+θ	-8 10-θ	-5 -3 0	25 U2=0
S3	-9 -12 0	-12 -8 0	-20 25	25 U3=-12
S_f	-1 0 0	0 10	0 5	15 U4=8
Demand	30 V1=-9	20 V2=-8	30 V3=-8	80

Maximum θ = Min (10, 15) = 10

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 5	-15 10	-12 0	15 U1=
S2	-9 25	-8 0	-3 0	25 U2=
S3	-12 0	-8 0	-20 25	25 U3=
Sf	0 0	0 10	0 5	15 U4=
Demand	30 V1=	20 V2=	30 V3=	80

Total Cost = 5*-10 + 10*-15 + 25*-9 + 25*-20 = **- 925**

Total Gain/Profit= -1 * -925 = **925**

Equations

U1+V1=-10

let U2=0

U1+V2=-15 U1=-1 V1=-9

U2+V1=-9 U2= 0 V2=-14

U3+V3=-20 U3=-6 V3=-14

U4+V2=0 U4=14

U4+V3=0

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 5	-15 10	-12 0	15 U1=-1
S2	-9 25	-8 0	-3 0	25 U2=0
S3	-12 0	-8 0	-20 25	25 U3=-6
Sf	0 0	0 10	0 5	15 U4=14
Demand	30 V1=-9	20 V2=-14	30 V3=-14	80

Now the shadow cost for each cell can be calculated easily.

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 5	-15 10	-3 -12 0	15 U1=-1
S2	-9 25	-6 -8 0	-11 -3 0	25 U2=0
S3	-3 -12 0	-12 -8 0	-20 25	25 U3=-6
Sf	5 0 0	0 10	0 5	15 U4=14
Demand	30 V1=-9	20 V2=-14	30 V3=-14	80

Criteria for optimality is not satisfied so we will proceed further with use of θ .

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 5-θ	-15 10+θ	-3 -12 0	15 U1=-1
S2	-9 25	-6 -8 0	-11 -3 0	25 U2=0
S3	-3 -12 0	-12 -8 0	-20 25	25 U3=-6
S_f	5 0 0+θ	0 10-θ	0 5	15 U4=14
Demand	30 V1=-9	20 V2=-14	30 V3=-14	80

Maximum θ = Min (5, 10) = 5

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 0	-15 15	-12 0	15 U1=
S2	-9 25	-8 0	-3 0	25 U2=
S3	-12 0	-8 0	-20 25	25 U3=
Sf	0 5	0 5	0 5	15 U4=
Demand	30 V1=	20 V2=	30 V3=	80

Total Cost =15*-15 + 25*-9 + 25*-20 = **-950**

Total Profit/Gain= -1 * - 950 **= 950**

Equations

U1+V2=-15 let U2=0

U2+V1=-9 U1=-6 V1=-9

U3+V3=-20 U2= 0 V2=-9

U4+V1=0 U3=-11 V3=-9

U4+V2=0 U4=9

U4+V3=0

Sources	Destination			Capacity
	D1	D2	D3	
S1	-10 0	-15 15	-12 0	15 U1=-6
S2	-9 25	-8 0	-3 0	25 U2=0
S3	-12 0	-8 0	-20 25	25 U3=-11
Sf	0 5	0 5	0 5	15 U4=9
Demand	30 V1=-9	20 V2=-9	30 V3=-9	80

Now calculate the shadow costs for non basic cells

Sources	Destination			Capacity
	D1	D2	D3	
S1	-5 - 10 0	15 15	-3 -12 0	15 U1=-6
S2	-9 25	-1 -8 0	-6 -3 0	25 U2=0
S3	-8 -12 0	-12 -8 0	-20 25	25 U3=-11
Sf	0 5	0 5	0 5	15 U4=9
Demand	30 V1=-9	20 V2=-9	30 V3=-9	80

Criteria for optimality has been satisfied as all the shadow costs are non-positive

Optimal Distribution

S1 ————> D2 = 15

S2 ————> D1 = 25

S3 ————> D3 = 25

Sf ————> D1 = 5

Sf ————> D2 = 5

Sf ————> D3 = 5

Total = 80

Total Gain = 950

Lecture 21: Assignment Model

Assignment Model

Assignment models are meant for making one-to-one assignments. These assignments may be from people to tasks, classes to classrooms or machines to jobs etc.

Example

A shop has 3 workers and 3 repair projects

Decision: Which worker to assign to which project?

Objective: Minimize cost in wages to get all 3 projects done

Assignment problem is solved by **Hungarian Method.**

Following are the steps if we are interested in minimization for assignment model:

Step 1:

Identify the minimum of each row and subtract identified minimum number from each entry of corresponding row

Step 2:

Identified the minimum of each column and subtract the identified minimum number from each entry of the column.

(Note that step 1 and 2 are interchangeable)

Step 3:

Start from first row. If there is single zero in any row, assign it (by squaring) and cross all other zeros in the corresponding column. If initially there are two zeros

in any row, leave it and move to next row. Similarly start column wise now. If there is single zero in any column, assign it (by squaring) and cross zeros in the corresponding rows. If initially there are two zeros in any column, leave it and move to next column. This step should be continued till all the zeros are either assigned or crossed. If this step doesn't give the feasible solution (all jobs are not assigned) go to step 4.

Step 4:

In this step, do following steps sequence wise:

i. Tick an un-assigned row.

ii. If a ticked row has a zero then tick the corresponding column.

iii. If a ticked column has assignments then tick the corresponding row.

iv. Repeat step 2 and 3 till no more ticking is possible.

Draw lines through un-ticked rows and ticked columns. The number of lines represents the maximum number of assignments possible.

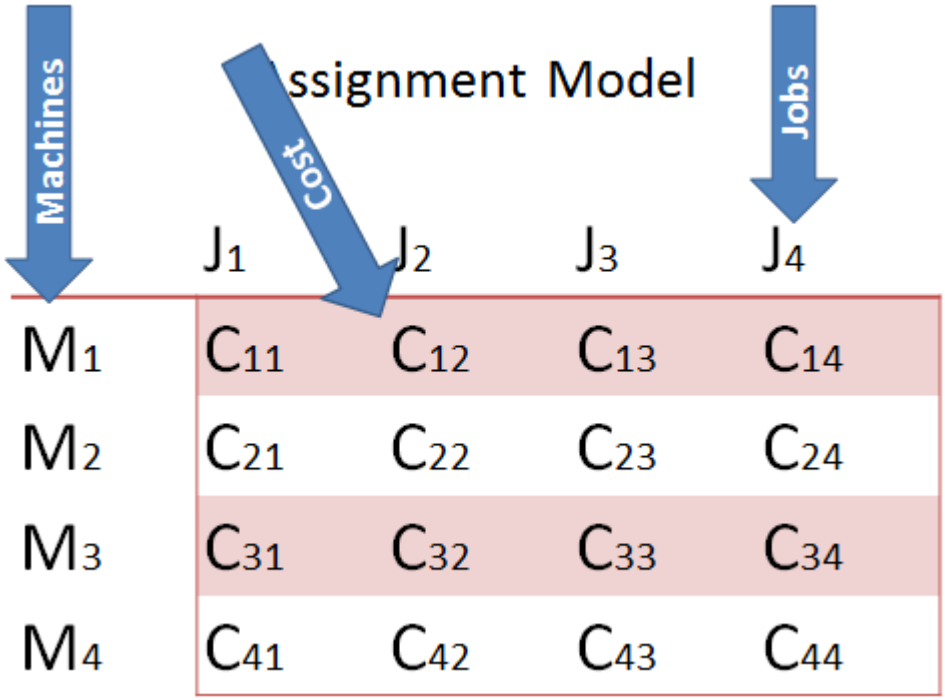
Step 5:

Find the smallest number through which line is not passed. Add this smallest number to the number at the intersection of lined rows and columns. Subtract this number from those numbers through which line is not passing. Rest numbers will remain same (through which only one line is passed i.e. other than intersection points).

Step 6:

Repeat step 3. Now the optimal assignment can be made by putting square on the zero entry of the assigned job which will have no alternatives. If optimal assignment is still not possible, repeat this process (step 3-6) in similar way until

all the jobs are assigned. To calculate the total cost, refer these finally assigned zeros to the original pay off matrix.



Problem

	J_1	J_2	J_3	J_4
M_1	15$	13$	14$	17$
M_2	11$	12$	15$	13$
M_3	13$	12$	10$	11$
M_4	15$	17$	14$	16$

Requirement:

Which job is to be assigned to any one machine to get the minimum cost.

	J_1	J_2	J_3	J_4	
M_1	15	13	14	17	13
M_2	11	12	15	13	11
M_3	13	12	10	11	10
M_4	15	17	14	16	14

Row operation

	J_1	J_2	J_3	J_4
M_1	2	0	1	4
M_2	0	1	4	2
M_3	3	2	0	1
M_4	1	3	0	2
	0	0	0	1

Column operation

	J_1	J_2	J_3	J_4
M_1	2	[0]	1	3
M_2	[0]	1	4	1
M_3	3	2	~~0~~	[0]
M_4	1	3	[0]	1

$M_1 \rightarrow J_2$ 13 $

$M_2 \rightarrow J_1$ 11 $

$M_3 \rightarrow J_4$ 11 $

$M_4 \rightarrow J_3$ 14 $

49 $ (min. cost)

As there are four assignments so this table will give us the solution and there is no need to move to the next step. Comparing the assignments with the original model, Job 2 should be assigned to Machine 1 and it bears cost of 13$. Job 1 should be assigned to Machine 2 and it bears the cost of 11$. Job 4 should be assigned to Machine 3 and it bears cost of 11$ and Job 3 should be assigned to Machine 4 and it bears the cost of 14$. So the total minimum cost of this assignment model is 49$.

Problem

		Projects		
		P1	P2	P3
Persons	A	11$	14$	6$
	B	8$	10$	11$
	C	9$	12$	7$

Requirement:

Which project is to be assigned to which person to get the minimum cost

	P_1	P_2	P_3	
A	11	14	6	6
B	8	10	11	8
C	9	12	7	7

Row operation

	P_1	P_2	P_3
A	5	8	0
B	0	2	3
C	2	5	0
	0	2	0

Column operation

	P_1	P_2	P_3
A	5	6	[0] ✓
B	[0]	✗	3
C	2	3	✗ ✓
			✓

min: 2

	P_1	P_2	P_3
A	3	4	[10]
B	✗	[0]	5
C	[0]	1	✗

$A_1 \rightarrow P_3$ 6 $

$B \rightarrow P_2$ 10 $

$C \rightarrow P_1$ 9 $

25 $

Lecture 22: Assignment Model cond..

Problem

	J_1	J_2	J_3	J_4
M_1	2	3	5	4
M_2	3	8	12	15
M_3	4	15	17	18
M_4	5	17	18	20

Requirement:

Which job is to assign to which machine to get the minimum cost

	J_1	J_2	J_3	J_4	
M_1	2	3	5	4	2
M_2	3	8	12	15	3
M_3	4	15	17	18	4
M_4	5	17	18	20	5

Row operation

	J_1	J_2	J_3	J_4
M_1	0	1	3	2
M_2	0	5	9	12
M_3	0	11	13	14
M_4	0	12	13	15
	0	1	3	2

Column operation.

	J_1	J_2	J_3	J_4
M_1	~~4~~	[0]	~~6~~	~~10~~
M_2	[0]	4	6	10 ✓
M_3	~~4~~	10	10	12 ✓
M_4	~~4~~	11	10	13 ✓

✓

min = 4

	J_1	J_2	J_3	J_4
M_1	4	~~0~~	[0]	~~0~~
M_2	~~0~~	[0]	2	6
M_3	[0]	6	6	8 ✓
M_4	~~0~~	7	6	9 ✓

✓

min = 6

	J_1	J_2	J_3	J_4
M_1	10	~~0~~	~~0~~	[0]
M_2	6	[0]	2	6
M_3	[0]	~~0~~	~~0~~	2
M_4	~~0~~	1	[0]	3

$M_1 \rightarrow J_4$ 4 $

$M_2 \rightarrow J_2$ 8 $

$M_3 \rightarrow J_1$ 4 $

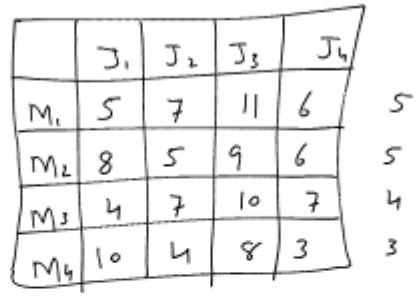
$M_4 \rightarrow J_3$ 18 $

34 $ (minimum cost)

Jobs

	J_1	J_2	J_3	J_4
M_1	5	7	11	6
M_2	8	5	9	6
M_3	4	7	10	7
M_4	10	4	8	3

Requirement:
Which job is to be assigned to which machine to get the minimum cost.?



Row operation



min = 1

	J_1	J_2	J_3	J_4
M_1	0	2	2	1
M_2	3	0	~~0~~	1
M_3	~~0~~	3	2	3
M_4	7	1	1	0

min = 1

	J_1	J_2	J_3	J_4
M_1	~~0~~	1	1	~~0~~
M_2	4	0	~~0~~	1
M_3	0	2	1	2
M_4	8	1	1	0

	J_1	J_2	J_3	J_4
M_1	0	~~0~~	~~0~~	~~0~~
M_2	5	0	~~0~~	2
M_3	~~2~~	1	0	2
M_4	8	~~0~~	~~0~~	0

$J_1 \rightarrow M_1$ 5

$J_2 \rightarrow M_2$ 5

$J_3 \rightarrow M_3$ 10

$J_4 \rightarrow M_4$ 3

23 (minimum cost)

Lecture 23: Assignment Model: Maximization

Maximization

For maximization objective in assignment model, following two methods can be used?

Method 1:

Multiply the given pay off matrix of profits or gains by -1. Then use the usual assignment technique to obtain the optimal solution . To calculate the total profit or gain referred back to the original pay off matrix.

Method 2:

Subtract each and every entry of pay off matrix of profits and gain from maximum of all entries of pay off matrix. To obtain the optimal solution, use the assignment technique for minimization. To calculate the total gain of matrix refer back to original pay off matrix

Illustration

	Jobs			
	J_1	J_2	J_3	J_4
M_1	2	4	3	5
M_2	3	8	9	12
M_3	4	12	11	10
M_4	3	18	15	12

Requirement:
Which job is to be assigned to which machine to get the maximum profit?

Method I

	J_1	J_2	J_3	J_4
M_1	2	4	3	5
M_2	3	8	9	12
M_3	4	12	11	10
M_4	3	18	15	12

× by −1

	J_1	J_2	J_3	J_4	
M_1	−2	−4	−3	−5	−5
M_2	−3	−8	−9	−12	−12
M_3	−4	−12	−11	−10	−12
M_4	−3	−18	−15	−12	−18

$-2-(-5)$
$-2+5=3$

Row operation

	J_1	J_2	J_3	J_4
M_1	3	1	2	0
M_2	9	4	3	0
M_3	8	0	1	2
M_4	15	0	3	6
	3	0	1	0

Column operation

	J_1	J_2	J_3	J_4
M_1	[0]	1	1	~~0~~
M_2	6	4	2	[0]
M_3	5	~~0~~	[0]	2
M_4	12	[0]	2	6

$J_1 \rightarrow M_1$ 2 $

$J_4 \rightarrow M_2$ 12 $

$J_3 \rightarrow M_3$ 11 $

$J_2 \rightarrow M_4$ 18 $

43 $

	Jobs			
	J_1	J_2	J_3	J_4
M_1	2	4	3	5
M_2	3	8	9	12
M_3	4	12	11	10
M_4	3	18	15	12

Requirement:
Which job is to be assigned to which machine to get the maximum profit?

Method II

	J_1	J_2	J_3	J_4
M_1	2	4	3	5
M_2	3	8	9	12
M_3	4	12	11	10
M_4	3	18	15	12

18

	J_1	J_2	J_3	J_4	
M_1	16	14	15	13	13
M_2	15	10	9	6	6
M_3	14	6	7	8	6
M_4	15	0	3	6	0

Row operation

	J_1	J_2	J_3	J_4
M_1	3	1	2	0
M_2	9	4	3	0
M_3	8	0	1	2
M_4	15	0	3	6
	3	0	1	0

Column operation

	J_1	J_2	J_3	J_4
M_1	[0]	1	1	~~0~~
M_2	6	4	2	[0]
M_3	5	~~0~~	[0]	2
M_4	12	[0]	2	6

Job 1 → M_1 $2

Job 4 → M_2 $12

Job 3 → M_3 $11

Job 2 → M_4 $18

43 $ (Max. Profit)

Problem

	J_1	J_2	J_3	J_4
M_1	2	5	6	4
M_2	3	10	9	12
M_3	4	16	17	15
M_4	3	18	22	19

	J_1	J_2	J_3	J_4	
M_1	20	17	16	18	16
M_2	19	12	13	10	10
M_3	18	6	5	7	5
M_4	19	4	0	3	0

Row operation

	J_1	J_2	J_3	J_4
M_1	4	1	0	2
M_2	9	2	3	0
M_3	13	1	0	2
M_4	19	4	0	3
	4	1	0	0

Column operation

	J_1	J_2	J_3	J_4
M_1	[0]	~~0~~	~~0~~	2
M_2	5	1	3	[0]
M_3	9	[0]	~~0~~	2
M_4	15	3	[0]	3

$J_1 \rightarrow M_1$ 2 $

$J_4 \rightarrow M_2$ 12 $

$J_2 \rightarrow M_3$ 16 $

$J_3 \rightarrow M_4$ 22 $

52 $ (Max. Profit)

Lecture 24: Unbalanced Assignment Model

Unbalanced Assignment Model

In unbalanced assignment model, the number of jobs may not be equal to the number of machines.

There can be two cases for unbalanced assignment model:

Case 1

This is the case when the total number of machines exceeds total number of jobs. In this case, introduce required number of fictitious or dummy jobs at '0' cost or at the cost stated in the problem to get the balanced assignment problem. Then use the assignment technique to obtain the optimal assignment. The fictitious or dummy jobs assigned to the machines mean that the corresponding machine will not be assigned any job.

Case 2

This is the case when the total number of jobs exceeds total number of machines. In this case, introduce required number of fictitious or dummy machines at '0' cost or at the cost stated in the problem to get the balanced assignment problem. Then use the assignment technique to obtain the optimal assignment. The jobs which are assigned fictitious or dummy machines will be left over.

Illustration: **Machine exceeds the Jobs**

Problem

	J_1	J_2	J_3	J_4
M_1	2	4	3	5
M_2	3	8	9	12
M_3	4	12	11	10
M_4	3	18	15	12
M_5	2	22	20	18
M_6	3	25	15	20

Requirement: Which job is to assign which machine to get the minimum cost

In this given problem, there are only four jobs while six machines. In an ideal condition there should be equal no of jobs so we need to make them equal. For this purpose we will introduce two fictitious jobs at zero cost.

Balanced Problem

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3	5	0	0
M_2	3	8	9	12	0	0
M_3	4	12	11	10	0	0
M_4	3	18	15	12	0	0
M_5	2	22	20	18	0	0
M_6	3	25	15	20	0	0

Step 1. Identify minimum of each row

	J_1	J_2	J_3	J_4	J_5	J_6	Min. Row
M_1	2	4	3	5	0	0	0
M_2	3	8	9	12	0	0	0
M_3	4	12	11	10	0	0	0
M_4	3	18	15	12	0	0	0
M_5	2	22	20	18	0	0	0
M_6	3	25	15	20	0	0	0

Subtract identified no from each and every entry of corresponding row

	J_1	J_2	J_3	J_4	J_5	J_6	Min. Row
M_1	2	4	3	5	0	0	0
M_2	3	8	9	12	0	0	0
M_3	4	12	11	10	0	0	0
M_4	3	18	15	12	0	0	0
M_5	2	22	20	18	0	0	0
M_6	3	25	15	20	0	0	0

Step 2. identify minimum of column

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3	5	0	0
M_2	3	8	9	12	0	0
M_3	4	12	11	10	0	0
M_4	3	18	15	12	0	0
M_5	2	22	20	18	0	0
M_6	3	25	15	20	0	0
Min. column	2	4	3	5	0	0

Subtract identified no from each and every entry of corresponding column

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	0	0	0	0	0	0
M_2	1	4	6	7	0	0
M_3	2	8	8	5	0	0
M_4	1	14	12	7	0	0
M_5	0	18	17	13	0	0
M_6	1	21	12	15	0	0
Min. column	2	4	3	5	0	0

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	0	0	0	0	0	0
M_2	1	4	6	7	0	0
M_3	2	8	8	5	0	0
M_4	1	14	12	7	0	0
M_5	0	18	17	13	0	0
M_6	1	21	12	15	0	0
					✓	✓

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	~~0~~	[0]	~~0~~	~~0~~	1	1
M_2	~~0~~	3	5	6	[0]	~~0~~ ✓
M_3	1	7	7	4	~~0~~	[0] ✓
M_4	~~6~~	13	11	6	~~0~~	~~0~~ ✓
M_5	[0]	18	17	13	1	1 ✓
M_6	~~0~~	20	11	14	~~0~~	~~0~~ ✓
	✓				✓	✓

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	3	~~0~~	[0]	~~0~~	4	4
M_2	~~0~~	[0]	2	3	~~0~~	~~0~~
M_3	1	4	4	1	[0]	~~0~~ ✓
M_4	~~0~~	10	8	3	~~0~~	[0] ✓
M_5	[0]	15	14	10	1	1 ✓
M_6	~~0~~	17	8	11	~~0~~	~~0~~ ✓
	✓				✓	✓

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	4	~~4~~	[0]	~~4~~	5	5
M_2	1	[0]	2	3	1	1
M_3	1	3	3	[0]	~~4~~	~~4~~
M_4	~~4~~	9	7	2	[0]	~~4~~
M_5	[0]	14	13	9	1	1
M_6	~~4~~	16	7	10	~~10~~	[0]

Original Tableau

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3*	5	0	0
M_2	3	8*	9	12	0	0
M_3	4	12	11	10*	0	0
M_4	3	18	15	12	0*	0
M_5	2*	22	20	18	0	0
M_6	3	25	15	20	0	0*

Optimal Distribution

- M1 -------→ J3=3
- M2 -------→ J2=8
- M3 -------→ J4=10
- M4 -------→ J5=0
- M5 -------→ J1=2
- M6 -------→ J6=0

TOTAL =23

Illustration: Jobs exceeds Machines

Problem

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3	5	2	3
M_2	3	8	9	12	15	12
M_3	4	12	11	10	18	16
M_4	3	18	15	12	20	15

Requirement:
Which job is to assign which machine to get the minimum cost

In this given problem, there are only four machines but six jobs. In an ideal condition there should be equal no of jobs so we need to make them equal. For this purpose we will introduce two fictitious Machines at zero cost.

Balanced Problem

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3	5	2	3
M_2	3	8	9	12	15	12
M_3	4	12	11	10	18	16
M_4	3	18	15	12	20	15
M_5	0	0	0	0	0	0
M_6	0	0	0	0	0	0

Step 1. Identify minimum of each row

	J_1	J_2	J_3	J_4	J_5	J_6	Min. Row
M_1	2	4	3	5	2	3	2
M_2	3	8	9	12	15	12	3
M_3	4	12	11	10	18	16	4
M_4	3	18	15	12	20	15	3
M_5	0	0	0	0	0	0	0
M_6	0	0	0	0	0	0	0

Subtract identified no from each and every entry of corresponding row

	J_1	J_2	J_3	J_4	J_5	J_6	Min. Row
M_1	0	2	1	3	0	1	2
M_2	0	5	6	9	12	9	3
M_3	0	8	7	6	14	12	4
M_4	0	15	12	9	17	12	3
M_5	0	0	0	0	0	0	0
M_6	0	0	0	0	0	0	0

Step 2. identify minimum of column

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	0	2	1	3	0	1
M_2	0	5	6	9	12	9
M_3	0	8	7	6	14	12
M_4	0	15	12	9	17	12
M_5	0	0	0	0	0	0
M_6	0	0	0	0	0	0
Min. Column	0	0	0	0	0	0

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	0	2	1	3	0	1
M_2	0	5	6	9	12	9
M_3	0	8	7	6	14	12
M_4	0	15	12	9	17	12
M_5	0	0	0	0	0	0
M_6	0	0	0	0	0	0

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	5	2	1	3	0	1
M_2	0	0	1	4	7	4
M_3	0	3	2	1	9	7
M_4	0	10	7	4	12	7
M_5	5	0	0	0	0	0
M_6	5	0	0	0	0	0

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	6	2	1	3	0	1
M_2	1	0	1	4	7	4
M_3	~~8~~	2	1	0	8	6
M_4	0	9	6	3	11	6
M_5	6	~~8~~	0	~~8~~	~~8~~	~~8~~
M_6	6	~~8~~	~~8~~	~~8~~	~~8~~	0

Original Tableau

	J_1	J_2	J_3	J_4	J_5	J_6
M_1	2	4	3	5	2*	3
M_2	3	8*	9	12	15	12
M_3	4	12	11	10*	18	16
M_4	3*	18	15	12	20	15
M_5	0	0	0*	0	0	0
M_6	0	0	0	0	0	0*

Optimal Distribution

- M1 -------→ J5=2
- M2 -------→ J2=8
- M3 -------→ J4=10
- M4 -------→ J1=3
- M5 -------→ J3=0
- M6 -------→ J6=0

TOTAL =23

Lecture 25: Forecasting

What Is Forecasting?

Forecasting is an art and science of predicting future events. Every day, managers must make decisions about service delivery without knowing what will happen in the future. Forecasts enable them to anticipate the future and plan accordingly. Good forecasts are the basis for short-, medium-, and long-term planning, and are essential input to all types of service production systems. Forecasts have two primary uses: to help managers plan the system, and also to help them plan the use of the system. Planning the system itself is long-range planning: about the kinds of services supplied and the number of each to offer, what facilities and equipment to have, which location optimizes service delivery to the particular patient population, and so on. Planning the use of the system is short-range and medium-range planning for supplies and workforce levels, purchasing and production, budgeting, and scheduling.

All of the above plans rely on forecasts. Forecasting is not an exact science, however; its results are rarely perfect, and the actual results usually differ. For the best possible forecasts, a manager must blend experience and good judgment with technical expertise.

All forecasts have certain common elements regardless of the technique used. The underlying assumption is that past events will continue. It also is a given that errors will occur because of the presence of randomness, and that actual results are more than likely to be different from those predicted. Forecasts of a group of items (aggregate forecasts) tend to be more accurate than those for individual items. For example, forecasts made for a whole hospital would tend to be more accurate than a departmental forecast, because forecasting errors among a group tend to cancel each other. Finally, it is generally accepted that forecast accuracy decreases as the time horizon (the period covered) increases. Short-

range forecasts face fewer uncertainties than longer-range forecasts do, so they tend to be more accurate. A flexible organization, which responds quickly to changes in demand, makes use of a shorter, more accurate forecasting horizon than do less flexible competitors, who must use longer forecast horizons.

Forecasting Time Horizons

- Short-range forecast
  - **Up to 1 year**
  - **Purchasing, job scheduling, workforce levels, job assignments, production levels**
- **Medium-range forecast**
  - **1 to 3 years**
  - **Sales and production planning, budgeting**
- **Long-range forecast**
  - **3^+ years**
  - **New product planning, facility location, research and development**

Steps in Forecasting

Many forecasting methods are available to managers for planning, to estimate future demand or any other issues at hand. However, for any type of fore-cast to bring about later success, it must follow a step-by-step process comprising following major steps;

1. **Define purpose of forecast**

This indicates the urgency with which the forecast is needed and identifies the amount of resources that can be justified and the level of accuracy necessary.

2. **Define the time horizon of the forecast**

Decide on the period to be covered by the forecast, keeping in mind that accuracy decreases as the time horizon increases.

3. Select the appropriate forecasting technique

The selection of a forecasting model will depend on the computer and financial resources available in an organization, as well as on the complexity of the problem under investigation.

4. Gather the data

Gather the appropriate data required for the forecasting. It depends on your forecasting technique whether to collect quantitative or qualitative data.

5. Analyze the data

Use the appropriate data, and make appropriate assumptions with the best possible forecasting model. Managers often have to make assumptions based on experience with a given situation, and sometimes by trial and error. In forecasting, analyzing appropriate data refers to a) the availability of relevant historical data; and b) recognizing the variability in a given data set.

6. Make the forecast

The outcome of analyzing the data is the forecasting mechanism which can be used to forecast the required thing.

7. Validate, implement and monitor results

The last step is the implementation and monitoring the forecast to determine whether it is performing in a satisfactory manner. If it is not, reexamine the method, assumption, validity of data and so on; modify as needed; and prepare a revised forecast.

Forecasting Approaches

There are two general approaches to forecasting: qualitative and quantitative. Qualitative methods mainly consist of subjective input, which often defy precise numerical description. Quantitative methods involve either the projection of historical data or the development of associative models that attempt to utilize casual variables to make a forecast.

Qualitative techniques permit inclusion of soft information in the forecasting process. Those factors are often omitted or downplayed when quantitative techniques are used because they are difficult or impossible to quantify. Quantitative techniques consist mainly of analyzing objective or hard data. They usually avoid personal biases that sometimes contaminate qualitative methods. In practice either or both approaches might be used to develop a forecast.

Qualitative Forecasting Methods

Expert Opinion

- This technique is often used by committee or panel of experts seeking to develop new ideas or solve complex problems.
- They often involve "brainstorming sessions".
- It is important in such sessions that any ideas or opinions be permitted to be presented without regard to its relevancy and without fear of criticism.

Delphi Approach

- A panel of experts, each of whom is physically separated from the others and is anonymous, is asked to respond to a sequential series of questionnaires.
- After each questionnaire, the responses are tabulated and the information and opinions of the entire group are made known to each of the other panel members so that they may revise their previous forecast response.
- The process continues until some degree of consensus is achieved.

Other Quantitative Methods

- **Jury of executive opinion** consists of combining top executives' views concerning future sales.
- **Sales force composite** combines the individual forecasts of salespeople.
- **Customer expectations** (customer surveys) use customers' expectations as the basis for the forecast. The data are typically gathered by a customer survey by the sales force.

Quantitative Forecasting Methods

There are numerous methods which are categorized under this section some of them are as under;

- **Time series forecasting** is a set of observations measured at successive points in time or over successive periods of time
- **Regression Analysis** statically relates sales to one or more explanatory (independent) variables. Explanatory variables may be marketing decisions (price changes, for instance), competitive information, economic data, or any other variable related to sales.
- **Exponential smoothing** makes an exponentially smoothed weighted average of past sales, trends, and seasonality to derive a forecast.
- **Moving average** takes an average of a specified number of past observations to make a forecast. As new observations become available, they are used in the forecast and the oldest observations are dropped.
- **Box-Jenkins** uses the auto correlative structure of sales data to develop an autoregressive moving average forecast from past sales and forecast errors.
- **Trend line analysis** fits a line to the sales data by minimizing the squared error between the line and actual past sales values. This line is then projected into the future as the forecast.
- **Decomposition** breaks the sales data into seasonal, cyclical, trend and noise components and projects each into the future.
- **Straight-line projection** is a visual extrapolation of the past data, which is projected into the future as the forecast.
- **Life-cycle analysis** bases the forecast upon whether the product is judged to be in the introduction, growth, maturity, or decline stage of the life cycle.
- **Simulation** uses the computer to model the forces, which affect sales: customers, marketing plans, competitors, flow of goods, etc. The simulation model is a mathematical replication of the actual corporation.
- **Expert systems** use the knowledge of one or more forecasting experts to develop decision rules to arrive at a forecast.

- **Neural networks** look for patterns in previous history of sales and explanatory data to uncover relationships. These relationships are used to produce the forecast.

Now we will discuss some of important quantitative techniques in detail.

Time-Series Approach

A time series is a sequence of evenly spaced observations taken at regular intervals over a period of time (such as daily, hourly, weekly, monthly, or yearly). An example of a time series is the monthly admissions to a multisystem hospital. Forecasts from time-series data assume that future values of the series can be predicted from past values. Analysis of a time series can identify the behavior of the series in terms of trend, seasonality, cycles, irregular variations, or random variations. A trend is a, long-term, upward or downward movement in data. Seasonality refers to short-term, relatively frequent variations generally related to factors such as weather, holidays, and vacations; facilities often experience weekly and even daily “seasonal” variations.

Cycles are patterns in the data that occur every several years, often in relation to current economic conditions. Such cycles often exhibit wavelike characteristics that mimic the business cycle. Irregular variations are “spikes” in the data caused by chance or unusual circumstances; they do not reflect typical behavior and should be identified and removed from the data whenever possible. Random variations are residual variations that remain after all other behaviors have been accounted for.

Naive Approach

The simplest forecasting technique is termed the naive method. A naive forecast for any period simply projects the previous period’s actual value. For example, if demand for a particular service was 100 units last week, the naive forecast for the upcoming week is 100 units. If demand in the upcoming week turns out to be 75 units, then the forecast for the following week would be 75 units. The naive

forecast can also be applied to a data set that exhibits sea-sodality or a trend. For example, if the seasonal demand in October is 100 units, then the naive forecast for next October would equal the actual demand for October of this year.

Although this technique may seem too simplistic, its advantages are low cost and ease of preparation and comprehension. Its major weakness, of course, is its inability to make highly accurate forecasts. Another weakness is that it simply replicates the actual data, with a lag of one period; it does not smooth the data. However, the decision to use naive forecasts certainly has merit if the results experienced are relatively close to the forecast (if the resulting accuracy is deemed acceptable). The accuracy of a naive forecast can serve as a standard against which to judge the cost and accuracy of other techniques; the manager can decide whether or not the increase in accuracy of another method is worth its additional cost.

Techniques for Averaging

Historical data usually contain a certain amount of noise (random variation) that tends to obscure patterns in the data. Randomness arises from a multitude of relatively unimportant factors that cannot possibly be predicted with any certainty.

The optimal situation would be to completely remove randomness from the data and leave only “real” variations (for example, changes in the level of patient demand). Unfortunately, it is usually impossible to distinguish between these two kinds of variations. The best one can hope for is that the small variations are random and the large variations actually mean something. Averaging techniques smooth out some of the fluctuations in a data set; individual highs and lows are “averaged” out. A forecast based on an average shows less variability than the original data set do. The result of using averaging techniques is that minor variations are treated as random variations and essentially “smoothed” out of the data set. Although the larger variations, those deemed likely to reflect “real”

changes, are also smoothed, it is to a lesser degree. Three techniques for averaging are described in this section: naive forecasts, moving averages, and exponential smoothing.

Moving Averages

Moving average method is the average of a series of past actual values of data. It provides overall impression of data over time. While a naive forecast uses data from the previous period, a moving average forecast uses a number of the most recent actual data values. The moving average forecast is found using the following equation:

$$F_t = \mathrm{MA}_n = \frac{\sum A_i}{n}$$

Where

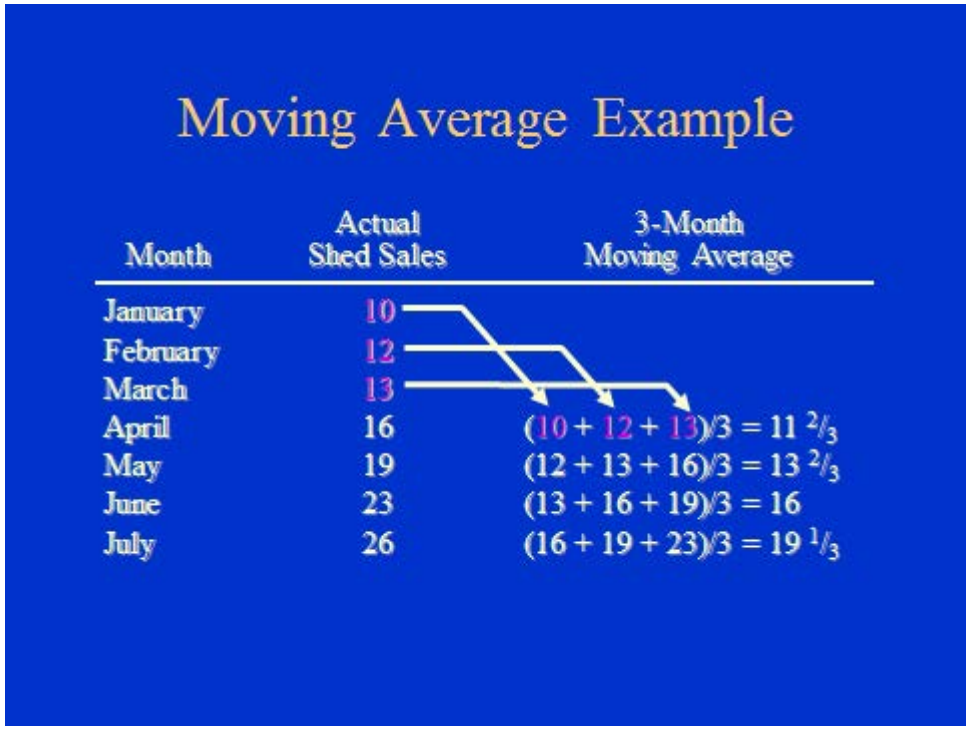
F*t* = Forecast for time period t

Ma*n* = Moving average with n periods

A*i* = Actual value with age i

i =“Age” of the data (i 5 1, 2, 3 . . .)

n = Number of periods in moving average



In above table, actual shed sales for different months are provided. First 3 year moving average can be calculated by taking average of sales for months of January, February and March. Similarly 2nd 3-month moving average can be calculated by taking average of February, March and April sales values and so on.

Example 1

A clinic has the following yearly patient visits, and would like to predict the volume of business for the next year for budgeting purposes.

Period (t)	Age (n)	Visits
1	5	15,908
2	4	15,504
3	3	14,272
4	2	13,174
5	1	10,022

Solution: Using formula the three-period moving average (MA3) for period 6 is

$$F_6 = \mathrm{MA}_3 = (14{,}272 + 13{,}174 + 10{,}022) \div 3 = 12{,}489.$$

With the available data a health care manager can back forecast earlier periods; this is a useful tool for assessing accuracy of a forecast, as will be explained later.

Computation of 3-period moving averages for the OB/GYN visits then would look like this:

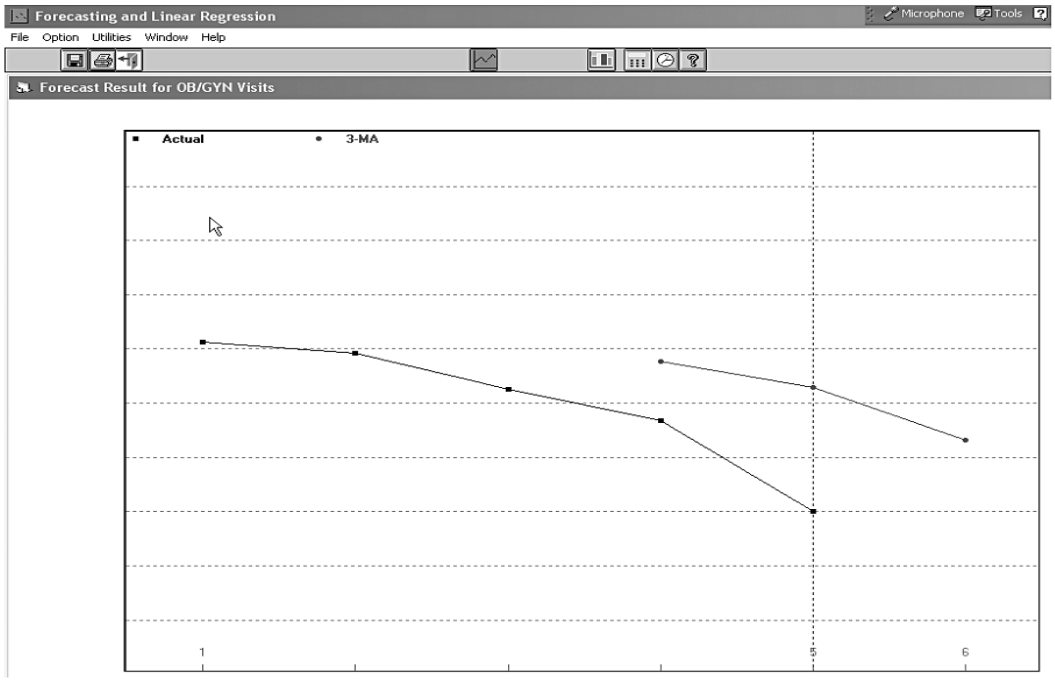
Period (t)	Age (n)	Visits	Forecast
1	5	15,908	
2	4	15,504	
3	3	14,272	
4	2	13,174	15,228
5	1	10,022	14,317
6			12,489

This technique derives its name from the fact that as each new actual value becomes available, the forecast is updated by adding the newest value and dropping the oldest and then recalculating the average. Thus the forecast "moves" by reflecting only the most recent values. For instance, to calculate the forecasted value of 15,228 for period 4 (F4), the visits from periods 1 through 3 were averaged; to calculate F5, visits from period 1 were dropped, but visits from period 4 were added to the average. n

A health care manager can incorporate as many data points as desired in the moving average. The number of data points used determines the sensitivity of the forecasted average to the new values being added. The fewer the data points in an average, the more responsive the average tends to be. If a manager seeks responsiveness from the forecast, only a few data points should be used. It is important to point out, however, that a highly sensitive forecast will also be more responsive to random variations (less smooth). On the other hand, moving averages based on many data points will be smoother, but less responsive to "real" changes. The decision maker must consider the cost of responding more

slowly to changes in the data against the cost of responding to what may be simply random variations.

WINQSB GRAPHICAL SOLUTION: MOVING AVERAGE (MA3)



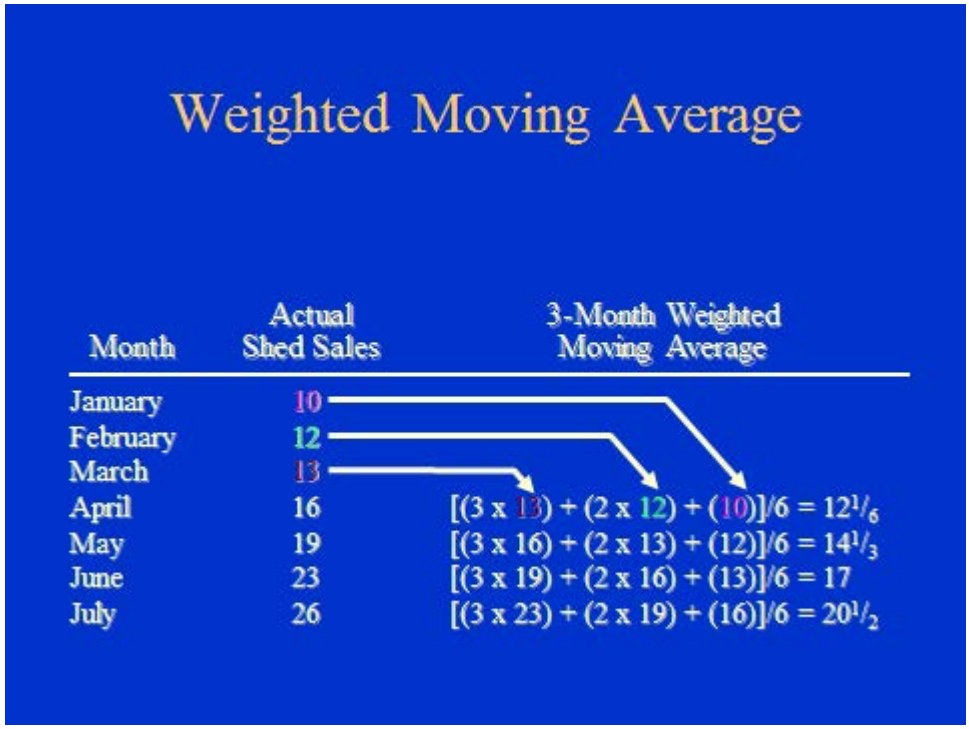
Source: Screen shots reprinted by permission from Microsoft Corporation and Yih-Long Chang (author of WinQSB).

Weighted Moving Average (WMA)

Moving average forecasts are easy to compute and understand; however, all the values are weighted equally. For example, in an eight-year moving average, each value is given a weight of one-eighth. Should data that are ten years old have equal weight (importance) with data collected last year? It certainly depends on the situation that a health care manager faces, but he or she could choose to compute a weighted average to assign more weight to recent values. A weighted

average is similar to a moving average, except that it assigns more weight to the most recent values in a time series. For example, the most recent data might be given a weight of .50, the next most recent value a weight of .30, and .20 for the next. These values are totally subjective (based on the manager's previous experiences with the data in question), with the only requirements being that the weights sum to 1.00, and that the heaviest weights are assigned to the most recent values. Trial and error is used to find an acceptable weighting pattern. The advantage of a weighted average over a simple moving average is that the weighted average is more reflective of the most recent actual results. Formally, weighted moving average is expressed as:

$$F_t = \mathrm{MA}_n = \sum w_i A_i.$$



Weights Applied	Period
3	Last month
2	Two months ago
1	Three months ago
6	Sum of weights

Example No 2

Continuing with Example 1; since there is a downward trend in visits and in period 5 there is a sharp decline, a weight of .5 or even higher is justified by the health care manager to calculate a weighted average for period 6.

Solution:

In this analysis, a weighted average, using formula for the clinic for period 6 would be:

$$F_6 = 14{,}272 * .2 + 13{,}174 * .3 + 10{,}022 * .5 = 11{,}818.$$

Period (t)	Age (n)	Visits	Weights	Forecast
1	5	15,908		
2	4	15,504		
3	3	14,272	.2	
4	2	13,174	.3	
5	1	10,022	.5	
6				11,818

Exponential Smoothing

In a single exponential smoothing forecast, each new forecast is based on the previous forecast plus a percentage of the difference between that forecast and the actual value of the series at that point, expressed as:

Where α is the smoothing constant, expressed as a percentage. Formally, the exponential smoothing equation can be written as:

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

Where

Ft = Forecast for period t

Ft-1 = Forecast for period t - 1

A = Smoothing constant

At-1 = Actual value (i.e., patient visits) in period t - 1.

The smoothing constant (α) represents a percentage of the forecast error. Each new forecast is equal to the previous forecast plus a percentage of the previous error.

Example No 3

Using the data from Example 1, build forecasts with smoothing constant α = 0.3.

Solution: Following the previous example and formula given above, we can build forecasts for periods as data become available. After period 1 the health care manager would have the number of actual visits, which are recorded as 15,908, and with this information the best one can do for the second period is a naive forecast.

Hence 15,908 becomes the forecast for period 2. When period 2 data become available, it will be recorded as actual in this case, 15,504. Now to forecast period 3, with a 5 .3, the new forecast would be computed as follows:

$$F3 = 15{,}908 + .30(15{,}504 - 15{,}908) = 15{,}786.8$$

Then, for period 3, if the actual visits turn out to be 14,272, the next forecast would be:

$$F4 = 15{,}786.8 + .30(14{,}272 - 15{,}786.8) = 15{,}332.4$$

Similarly, F5 and F6 can be calculated as:

$$F5 = 15{,}332.4 + .30(13{,}174 - 15{,}332.4) = 14{,}684.9$$

$$F6 = 14{,}684.9 + .30(10{,}022 - 14{,}684.9) = 13{,}286.0$$

Smoothing constant $\alpha = 0.3$			Error
Period (t)	Actual (Visits)	Forecast	(Actual − Forecast)
1	15,908	—	
2	15,504	15,908	−404.0
3	14,272	15,786.8	−1,514.8
4	13,174	15,332.4	−2,158.4
5	10,022	14,684.9	−4,662.9

The closer the smoothing constant (α) is to one, the faster the forecast is to adjust using forecast errors (the greater the smoothing). Commonly used values for a range from 0.10 to 0.60 and are usually selected by judgment or trial and error.

Correlation

Correlation tells about following things about data;

- How strong is the linear relationship between the variables?

- Correlation does not necessarily imply causality!
- Coefficient of correlation, r, measures degree of association
- Values range from -1 to +1

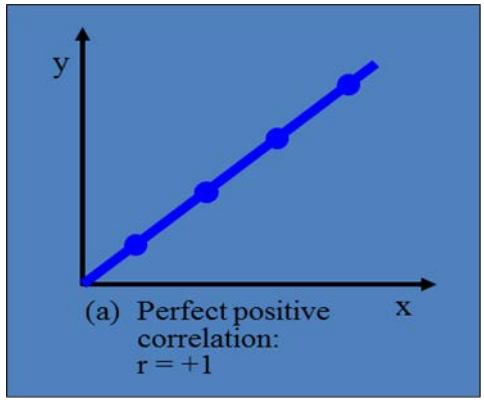
Correlation is calculated by the following formula.

$$r = \frac{n\Sigma xy - \Sigma x\Sigma y}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

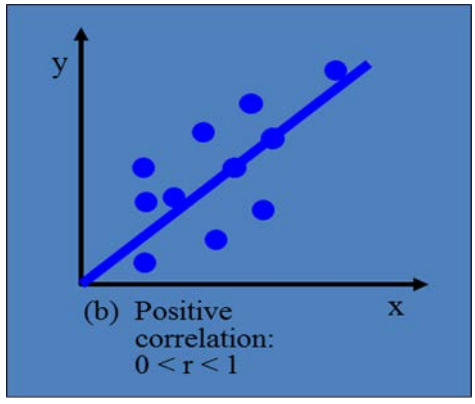
Types of correlation

Correlation is of following four types;

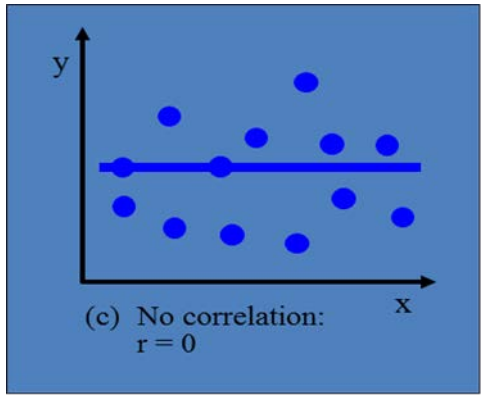
- Perfect positive correlation
- Perfect negative correlation
- Positive correlation
- No correlation

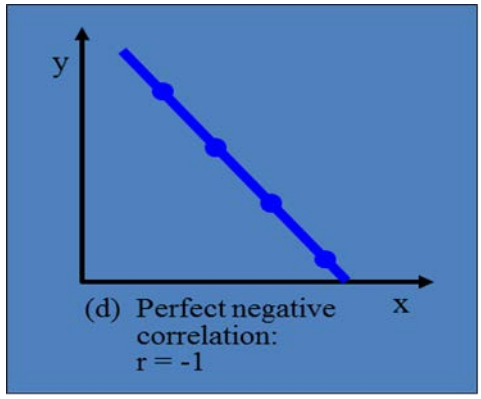


(a) Perfect positive correlation: $r = +1$



(b) Positive correlation: $0 < r < 1$





Coefficient of Determination, r^2, measures the percent of change in y predicted by the change in x. its Values range from 0 to 1 and easy to interpret.

Techniques for Trend Projection

A trend is a gradual, long-term movement caused by changes in population, income, or culture. Assuming that there is a trend present in a data set, it can be analyzed by finding an equation that correlates to the trend in question. The trend may or may not be linear in its behavior. Plotting the data can give a manager insight into whether a trend is linear or nonlinear.

Forecasting Techniques Based on Linear Regression

By minimizing the sum of the squared errors, which is called the least squares method, regression analysis can be used to create a representative line that has the form:

$$y = a + b * x$$

Where

y = the predicted (dependent) variable

x = the predictor (independent) variable

b = the slope (rise/run) of the data line

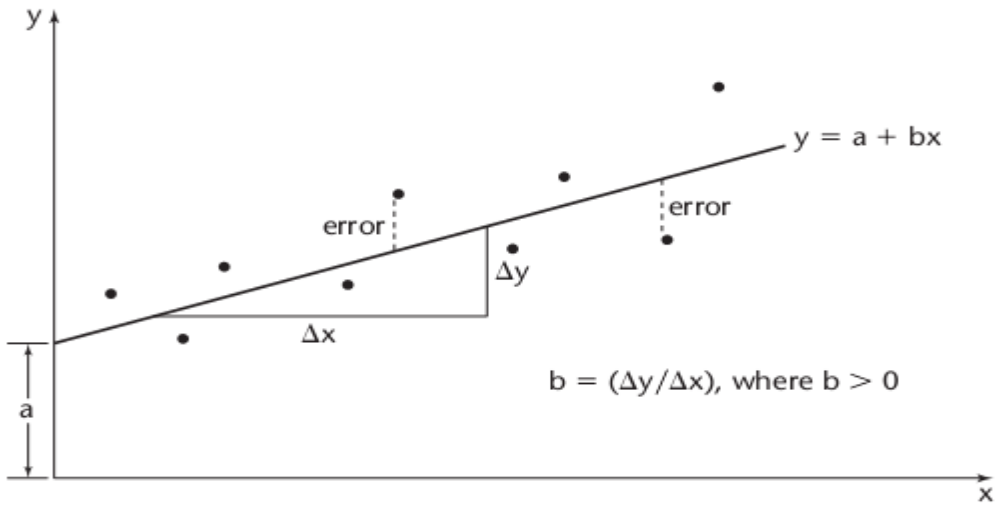
a = the value of y when x is equal to zero.

Consider the regression equation example y = 20 + 5x. The value of y when x = 0 is 20, and the slope of the line is 5. Therefore, the value of y will increase by five units for each one unit increase in x. If x = 15, the forecast (y) will be 20 + 5(15), or 95 units. This equation could be plotted on a graph by finding two points on the line. One of those points can be found in the way just mentioned; putting in a value for x. The other point on the graph would be a (i.e. Yx at x = 0). The coefficients of the line, α and *b*, can be found (using historical data) with the following equations:

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2}$$

$$a = \frac{\sum y - b\sum x}{n}.$$

Linear regression graphical representation



The graph illustrates the regression line concept, showing the errors that are minimized by the least square method by positioning the regression line using the appropriate slope (*b*) and y intercept (α).

Linear Regression as a Trend Line

Linear regression often is used to describe trends in data. The only difference in this application is that the independent variable x, takes a value in time and is shown as t, and the equation is represented as:

$$y = a + b * t$$

Where

y = the predicted (dependent) variable

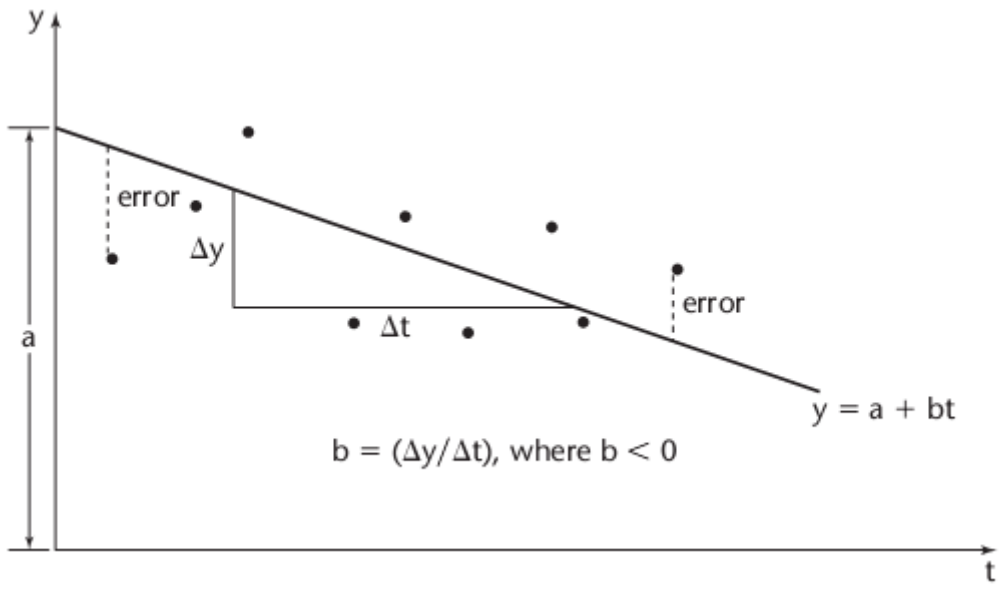
t = the predictor time variable

b = the slope of the data line

α = value of y when t is equal to zero.

Graphic illustration of a negative trend line (when b<0) is shown in Figure below.

If the trend were positive (b > 0), it would have looked like that in linear regression.

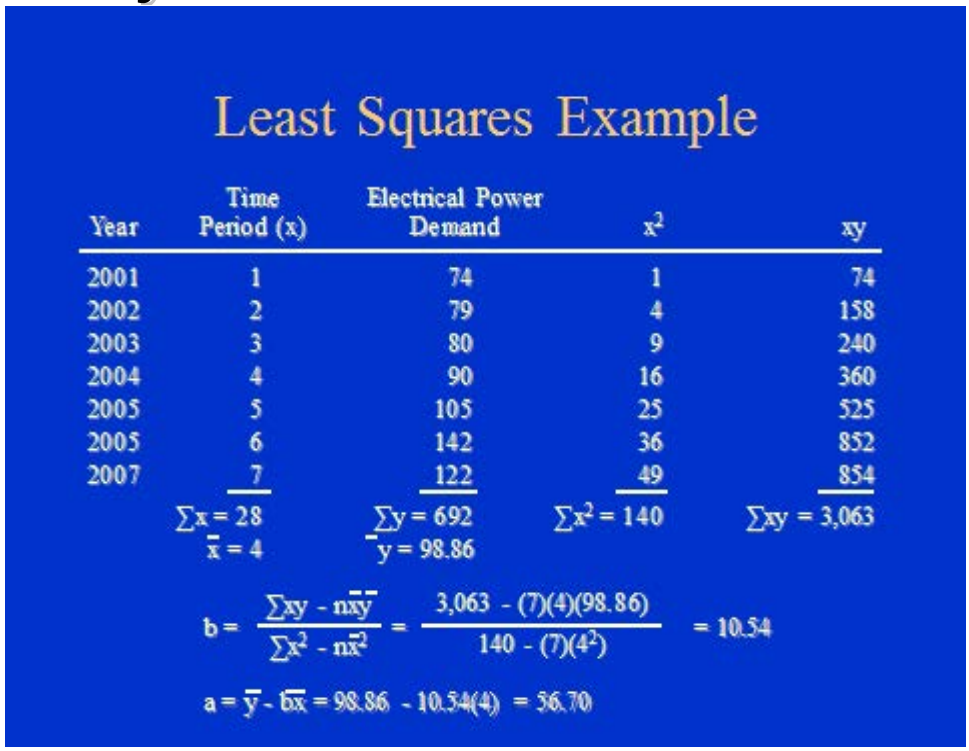


Equations to calculate the regression variables

$$y = a + bx$$

$$b = \frac{\Sigma xy - n\bar{x}\bar{y}}{\Sigma x^2 - n\bar{x}^2}$$

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



The trend line is

$$\hat{y} = 56.70 + 10.54x$$

Multiple Regression Analysis

If more than one independent variable is to be used in the model, linear regression can be extended to multiple regression to accommodate several independent variables.

$$y = a + b_1x_1 + b_2x_2 \ldots$$

Lecture 26: Project Management

What is a Project?

The fundamental nature of a project is that it is a “temporary endeavor undertaken to create a unique product, service, or result”. Projects are distinguished from operations and from programs.

Temporary Endeavor

To be temporary signifies that there is a discrete and definable commencement and conclusion; the management of a project requires tailored activities to support this characteristic, as such, a key indicator of project success is how it performs against its schedule—that is, does is start and end on time.

Unique Deliverable

The uniqueness of the deliverable, whether it is a product, service, or result, requires a special approach in that there may not be a pre-existing blueprint for the project’s execution and there may not be a need to repeat the project once it is completed. Uniqueness does not mean that there are not similarities to other projects, but that the scope for a particular project has deliverables that must be produced within constraints, through risks, with specific resources, at a specific place, and within a certain period; therefore, the process to produce the deliverable as well as the deliverable itself is unique.

Progressive Elaboration

This unique process and deliverable produces the third characteristic of a project: progressive elaboration. Project management is a group of interrelated processes, implemented in a progressively elaborative manner, in which to produce the deliverable. Progressive elaboration is the revealing and focusing of details through time. For example, in the engineering design process, a general and broad concept may be a starting point for the design team; but through the design process, the concept is narrowed to a specific scope and is further elaborated to achieve the completed design; moreover, it may continue to be elaborated and not be finalized until the product, service, or result is delivered.

Complex Activities

Not simple, repetitive acts, such as mowing the lawn, running the weekly payroll, washing the car, or loading the delivery truck.

One Goal

Projects must have a single goal as compared to a program

Specified Time

Projects have a specified completion date

Within Budget

Projects also have resource limits (people, money, machines)

According to Specification

The customer or recipient of the deliverables from the project expects a certain level of functionality and quality from the project. These may be self-imposed or customer-specified, and are fixed as far as the project manager is concerned

Other "Projects"

A clarification should be made with respect to Reclamation language. In Reclamation, a project is typically a congressionally authorized or directed activity that allows Reclamation to do something specific. Traditionally, projects are groups of infrastructure, such as the Central Arizona Project, the Lower Colorado Dams Project, or the Central Valley Project. The Reclamation "project" activities would range from the traditional planning, designing, and building of structures, to negotiating and signing delivery contracts, developing operations plans, and completing environmental compliance documents.

In historic Reclamation vernacular, the operation and maintenance of the completed project is also often considered as part of the "project." Additionally at times in Reclamation, the people managing projects are often referred to as something other than project managers—they may be called team leaders, coordinators, activity managers or program managers; people managing "projects" may be called area managers or facility managers. Because of these connotations, care should be taken to distinguish between Reclamation "projects" and projects as defined above.

A Project versus an Operation

The operations of an organization are continuing and repetitive activities that are executed to achieve its mission and sustain the business, but without a definable end to their performance and without a unique output—that is, it is not produced or provided only once.

A Project versus a Program

A project differs from a program in that "a program is a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements or related work outside the scope of discrete projects in the program." Furthermore, programs often involve a series of repetitive or cyclical undertakings. In Reclamation, a program is typically a group of projects administered by Reclamation. Reclamation programs do not have to be specifically authorized, and a program's schedule may continue past any individual project. Examples of Reclamation programs are the Safety of Dams Program and the RAX Program.

Project Parameters

A standard must be established by which to define and measure project success.

Fundamentally, project success is the delivery of the required product, service, or result on time and within budget. To meet these objectives is to deliver a quality project concept of the triple constraint project scope, time and cost is very important. Project quality is affected by balancing these three interrelated factors. "The relationship among these factors is such that if any one of the three factors change, at least one other factor is likely to be affected."

Figure illustrates this constrained relationship, sometimes called the "iron triangle."



Cost and time are intuitive, but the role played by scope warrants further discussion. To understand the significance of scope, one must appreciate the relationship between scope and the project objectives. For the scope to contribute to project quality, it must be managed to meet the demands of the project objective by reliably providing the required functions, nothing more or nothing less. It is not simply a matter of keeping the scope from creeping, or a matter of completing the cheapest and fastest project; it is establishing the appropriate scope and delivering the commensurate product, service, or result.

Classification of Project Types

Projects are undertaken at all levels of the organization. They may involve a single person or many thousands. Their duration ranges from a few weeks to a few years. Projects may involve a single unit of one organization or may cross-organizational boundaries. As projects are often implemented as a means of achieving an organization's strategic plan they are critical for the organizations growth. Examples of projects could include:

- Developing a new product or service
- Effecting a change in structure, staffing, or style of an organization
- Developing a new or modified information system
- Implementing a new business procedure or process

Projects can be classified as social sector and infrastructure. Some examples are:

- Transportation — Highways, mass transit, airports
- Utilities — Electric power, gas, telephones
- Education — Schools, colleges, dormitories
- Public Safety — Police, fire, National guard
- Recreation — Parks, playgrounds, historic sites
- Development — Harbors, dams, irrigation,
- Research — Health, space, agriculture
- Defense — Military equipment and systems
- Conservation — Forests, shorelines, pollution

Project Management

Project management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements. Project management is accomplished through the use of the following 5 processes:

- Initiation
- Planning
- Execution
- Controlling and
- Closure

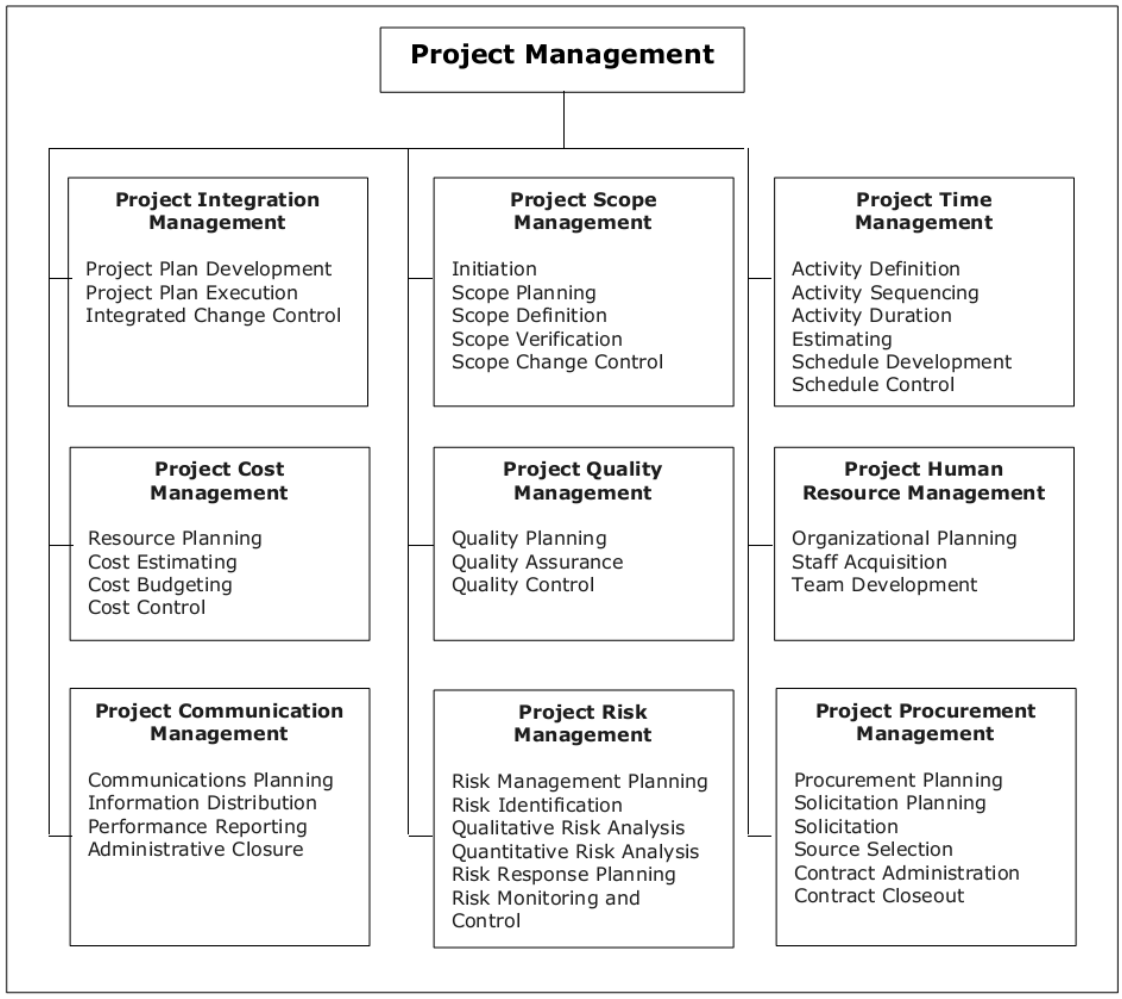
The project team manages the various activities of the project, and the activities typically involve:

- Competing demands for: scope, time, cost, risk, and quality.
- Managing expectations of stakeholders.
- Identifying requirements.

It is important to note that many of the processes within project management are iterative in nature. This is partly due to the existence of and the necessity for progressive elaboration in a project throughout the project life cycle; i.e., the more you know about your project, the better you are able to manage it. The term “project management “is sometimes used to describe an organizational approach to the management of ongoing operations. This approach treats many aspects of ongoing operations as projects to apply project management techniques to them. A detailed discussion of the approach itself is outside the scope of this document.

Project Management Knowledge Areas

The Project Management Knowledge Areas describes project management knowledge and practice in terms of the various component processes. These processes have been organized into nine knowledge areas, as described below and as illustrated in figure below.



Project Integration Management describes the processes required to ensure that the various elements of the project are properly coordinated. It consists of project plan development, project plan execution, and integrated change control.

Project Scope Management describes the processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully. It consists of initiation, scope planning, scope definition, scope verification, and scope change control.

Project Time Management describes the processes required to ensure timely completion of the project. It consists of activity definition, activity sequencing, activity duration estimating, schedule development, and schedule control.

Project Cost Management describes the processes required to ensure that the project is completed within the approved budget. It consists of resource planning, cost estimating, cost budgeting, and cost control.

Project Quality Management describes the processes required to ensure that the project will satisfy the needs for which it was undertaken. It consists of quality planning, quality assurance, and quality control.

Project Human Resource Management describes the processes required to make the most effective use of the people involved with the project. It consists of organizational planning, staff acquisition, and team development.

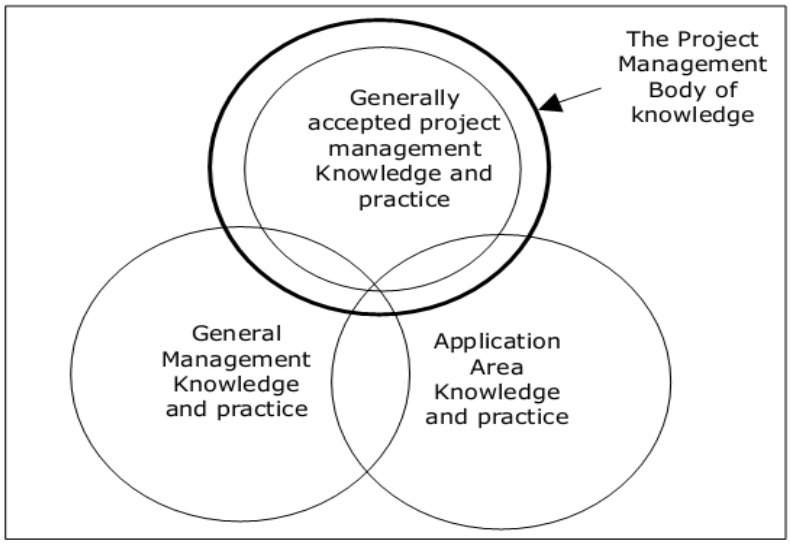
Project Communications Management describes the processes required to ensure timely and appropriate generation, collection, dissemination, storage, and ultimate disposition of project information. It consists of communications planning, information distribution, performance reporting, and administrative closure.

Project Risk Management describes the processes concerned with identifying, analyzing, and responding to project risk. It consists of risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, and risk monitoring and control.

Project Procurement Management describes the processes required to acquire goods and services from outside the performing organization. It consists of procurement planning, solicitation planning, solicitation, source selection, contract administration, and contract closeout.

Relationship to Other Management Disciplines

General management encompasses planning, organizing, staffing, executing, and controlling the operations of an ongoing enterprise. General management also includes supporting disciplines such as law, strategic planning, logistics, and human resources management. The current discussion of project management (Figure given below) overlaps and in certain cases even modifies the general management principles in many areas such as organizational behavior, financial forecasting, and planning techniques, to name just a few.



Application areas are categories of projects that have common elements significant in such projects, but are not needed or present in all projects. Application areas are usually defined in terms of:

- Functional departments and supporting disciplines, such as legal, production and inventory management, marketing, logistics and personnel.
- Technical elements, such as software development, pharmaceuticals, water and sanitation engineering, or construction engineering.
- Management specializations, such as government contracting, community development, or new product development.
- Industry groups, such as automotive, chemicals, agriculture, or financial services.

Project Management Processes

To help understanding the integrative nature of project management, and to emphasize the importance of integration, project management has been defined in terms of the various component processes and their interactions. This section provides an introduction to the concept of project management as a number of interlinked processes.

Project Processes: Projects are composed of processes. A process is “a series of actions bringing about a result”. Project processes are performed by people and generally fall into one of two major categories:

- Project management processes describe, organize, and complete the work of the project.
- Product-oriented processes specify and create the project's product. Product-oriented processes are typically defined by the project life and vary by application area.

Project management processes and product-oriented processes overlap and interact throughout the project. For example, the scope of the project cannot be defined in the absence of some basic understanding of how to create the product.

Process Groups: Project management processes can be organized into five groups of one or more processes each:

- Initiating processes — authorizing the project or phase.
- Planning processes — defining and refining objectives and selecting the best of the alternative courses of action to attain the objectives that the project was undertaken to address.
- Executing processes— coordinating people and other resources to carry out the plan.
- Controlling processes— ensuring that monitoring and measuring progress regularly to identify variances from plan so that corrective action can be taken when necessary meet project objectives.
- Closing processes— formalizing acceptance of the project or phase and bringing it to an orderly end.

Process Interactions: Within each process group, the individual processes are linked by their inputs and outputs. By focusing on these links, we can describe each process in terms of it's:

- Inputs - documents or documentable items that will be acted upon.
- Tools and techniques - mechanisms applied to the inputs to create the outputs.
- Outputs - documents or documentable items that are a result of the process.

The project management processes common to most projects in most application areas are described here. The process interactions illustrated here are also typical of most projects in most application areas.

- **Initiating Processes:** Authorizing the project or phase is part of project scope management.

- **Planning Processes:** Planning is of major importance to a project because the project involves doing something that has not been done before. As a result, there are relatively more processes in this section. However, the number of processes does not mean that project management is primarily planning—the amount of planning performed should be commensurate with the scope of the project and the usefulness of the information developed. Planning is an ongoing effort throughout the life of the project.

Core processes: Some planning processes have clear dependencies that require them to be performed in essentially the same order on most projects. For example, activities must be defined before they can be scheduled or coasted. These core-planning processes may be iterated several times during any one phase of a project. They include:

- Scope Planning - developing a written scope statement as the basis for future project decisions.
- Scope Definition - subdividing the major project deliverables into smaller, more manageable components.
- Activity Definition - identifying the specific activities that must be performed to produce the various project deliverables.
- Activity Sequencing - identifying and documenting interactivity dependencies.
- Activity Duration Estimating - estimating the number of work periods that will be needed to complete individual activities.
- Schedule Development - analyzing activity sequences, activity durations, and resource requirements to create the project schedule.
- Risk Management Planning - deciding how to approach and plan for risk management in a project.
- Resource Planning - determining what resources (people, equipment, materials) and what quantities of each should be used to perform project activities.
- Cost Estimating - developing an approximation (estimate) of the costs of the resources required to complete project activities.
- Cost Budgeting - allocating the overall cost estimate to individual work activities.
- Project Plan Development - taking the results of other planning processes and putting them into a consistent, coherent document.

Facilitating processes: Interactions among the other planning processes are more dependent on the nature of the project. For example, on some projects, there may be little or no identifiable risk until after most of the planning has been done and the team recognizes that the cost and schedule targets are extremely aggressive and thus involve considerable risk. Although these facilitating processes are performed intermittently and as needed during project planning, they are not optional. They include:

- Quality Planning - identifying which quality standards are relevant to the project and determining how to satisfy them.
- Organizational Planning - identifying, documenting, and assigning project roles, responsibilities, and reporting relationships.
- Staff Acquisition - getting the human resources needed assigned to and working on the project.
- Communications Planning - determining the information and communications needs of the stakeholders: who needs what information, when will they need it, and how will it be given to them.
- Risk Identification - determining which risks might affect the project and documenting their characteristics.
- Qualitative Risk Analysis – performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.
- Quantitative Risk Analysis - measuring the probability and impact of risks and estimating their implications for project objectives.
- Risk Response Planning - developing procedures and techniques to enhance opportunities and to reduce threats to the project's objectives from risk.
- Procurement Planning - determining what to procure, how much to procure, and when.
- Solicitation Planning - documenting product requirements and identifying potential sources.
- Executing Processes: The executing processes include core processes and facilitating processes.
- Project Plan Execution - carrying out the project plan by performing the activities included therein.
- Quality Assurance - evaluating overall project performance on a regular basis to provide confidence that the project will satisfy the relevant quality standards.
- Team Development - developing individual and group competencies to enhance project performance.

- Information Distribution - making needed information available to project stakeholders in a timely manner.
- Solicitation - obtaining quotations, bids, offers, or proposals as appropriate.
- Source Selection - choosing from among potential sellers.
- Contract Administration - managing the relationship with the seller.

Controlling Processes: Project performance must be monitored and measured regularly to identify variances from the plan. Variances are fed into the control processes in the various knowledge areas. Adjustments are made to the plan to the extent of the variances observed (i.e., those that jeopardize the project objectives). For example, a missed activity finish date may require adjustments to the current staffing plan, reliance on overtime, or tradeoffs between budget and schedule objectives. Controlling also includes taking preventive action in anticipation of possible problems. The controlling process group contains core processes and facilitating processes. They various interactions between core and facilitating processes are:

- Integrated Change Control – coordinating changes across the entire project.
- Scope Verification - formalizing acceptance of the project scope.
- Scope Change Control - controlling changes to project scope.
- Schedule Control - controlling changes to the project schedule.
- Cost Control - controlling changes to the project budget.
- Quality Control - monitoring specific project results to determine if they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance.
- Performance Reporting - collecting and disseminating performance information. This includes status reporting, progress measurement, and forecasting.
- Risk Monitoring and Control - keeping track of identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans, and evaluating their effectiveness in reducing risk.

Closing Processes: The following components make the closing process.

- Contract Closeout - completion and settlement of the contract, including resolution of any open items.

- ❖ Administrative Closure - generating, gathering, and disseminating information to formalize phase or project completion, including evaluating the project and compiling lessons learned for use in planning future projects or phases.

The Project Life Cycle

Dividing a project into phases makes it possible to lead it in the best possible direction. Through this organization into phases, the total work load of a project is divided into smaller components, thus making it easier to monitor. The following paragraphs describe a phasing model that has been useful in practice. It includes six phases:

1. Conception/selection
2. Planning
3. Implementation
4. Control
5. Evaluation
6. Termination

Conception/selection

The conception phase is the beginning of the project. In this phase, the idea for the project is explored and elaborated. The goal of this phase is to examine the feasibility of the project. In addition, decisions are made concerning who is to carry out the project, which party (or parties) will be involved and whether the project has an adequate base of support among those who are involved.

In this phase, the current or prospective project leader writes a proposal, which contains a description of the above-mentioned matters. Examples of this type of project proposal include business plans and grant applications. The prospective sponsors of the project evaluate the proposal and, upon approval, provide the necessary financing. The project officially begins at the time of approval. Questions to be answered in the Conception/selection phase include the following:

- ❖ Why this project?
- ❖ Is it feasible?
- ❖ Who are possible partners in this project?
- ❖ What should the results be?

- What are the boundaries of this project (what is outside the scope of the project)?

The ability to say ‘no’ is an important quality in a project leader. Projects tend to expand once people have become excited about them. The underlying thought is, ’While we’re at it, we might as well …’ Projects to which people keep adding objectives and projects that keep expanding are nearly certain to go off schedule, and they are unlikely to achieve their original goals.

In this phase, the project partners enter a (temporary) relationship with each other. To prevent the development of false expectations concerning the results of the project, it makes sense to explicitly agree on the type of project that is being started:

- A research and development project;
- A project that will deliver a prototype or ‘proof of concept’;
- A project that will deliver a working product.

The choice for a particular type of project largely determines its results. For example, a research and development project delivers a report that examines the technological feasibility of an application. A project in which a prototype is developed delivers all of the functionalities of an application, but they need not be suitable for use in a particular context (e.g. by hundreds of users). A project that delivers a working product must also consider matters of maintenance, instructions and the operational management of the application.

Many misunderstandings and conflicts arise because the parties that are involved in a project are not clear on these matters. Customers may expect a working product, while the members of the project team think they are developing a prototype. A sponsor may think that the project will produce a working piece of software, while the members of the project team must first examine whether the idea itself is technically feasible.

Planning

The level of effort increases, and plans are developed to determine what the project will entail, when it will be scheduled, whom it will benefit, what quality level should be maintained, and what the budget will be.

Implementation

The project takes shape during the implementation phase. This phase involves the construction of the actual project result. Programmers are occupied with encoding, designers are involved in developing graphic material, contractors are building, and the actual reorganization takes place. It is during this phase that the project becomes visible to outsiders, to whom it may appear that the project has just begun. The implementation phase is the ‘doing’ phase, and it is important to maintain the momentum.

In one project, it had escaped the project team’s attention that one of the most important team members was expecting to become a father at any moment and would thereafter be completely unavailable for about a month. When the time came, an external specialist was brought in to take over his work, in order to keep the team from grinding to a halt. Although the team was able to proceed, the external expertise put a considerable dent in the budget.

At the end of the implementation phase, the result is evaluated according to the list of requirements that was created in the definition phase. It is also evaluated according to the designs. For example, tests may be conducted to determine whether the web application does indeed support Explorer 5 and Firefox 1.0 and higher. It may be determined whether the trim on the building has been made according to the agreement, or whether the materials that were used were indeed those that had been specified in the definition phase. This phase is complete when all of the requirements have been met and when the result corresponds to the design. Those who are involved in a project should keep in mind that it is hardly ever possible to achieve a project result that precisely meets all of the requirements that were originally specified in the definition phase. Unexpected events or advancing insight sometimes require a project team to deviate from the original list of requirements or other design documents during the implementation of the project. This is a potential source of conflict, particularly if an external customer has ordered the project result. In such cases, the customer can appeal to the agreements that were made during the definition phase.

As a rule, the requirements cannot be changed after the end of the definition phase. This also applies to designs: the design may not be changed after the design phase has been completed. Should this nonetheless be necessary (which does sometimes occur), the project leader should ensure that the changes are discussed with those involved (particularly the decision-makers or customers) as soon as possible. It is also important that the changes that have been chosen are well documented, in order to prevent later misunderstandings.

Control

Control involves ensuring that monitoring and measuring of progress is being carried regularly to identify variances from plan so that corrective action can be taken when necessary to meet project objectives.

Evaluation

Evaluation of the project is planned for right from the onset, and is ongoing as the different milestones are tackled. The type of evaluation that goes on during the project has been referred to as formative evaluation. It is said to be formative because the project is in the process of being formed. This distinguishes it from the evaluation conducted at the end of the project, commonly referred to as summative evaluation. It is said to be summative because the project is being summed up or closed.

To evaluate a project is to attempt to determine whether the overall status of the work is acceptable in terms of intended value to the target customer once the job is finished. Project evaluation provides the basis for management decisions on how to proceed with the project, and appraises the progress and performance of a job compared to what was originally planned. It is through the project process review that evaluation is enabled. This is usually conducted at major milestones throughout the life of the project. During the process review, lessons are learned about the project.

There are numerous reasons for conducting project evaluation periodically, and these are some of them.

- Ensuring informed management of the project;
- Improving the performance of individual team members;
- Revealing problems early so that corrective measures can be taken in good time;
- Identifying areas where future distance education projects should be managed differently;
- Keeping customers informed of the status of the project at a given point in time; and
- Reaffirming the project targets for the benefit of stakeholders.

You may want to add your own reasons from personal experience. Distance education practitioners who engage in project management has often asked how best to conduct project evaluation. For a fact, there are a number of ways to do

that and one of them is to use a form that can readily be used to capture vital information.

Termination

After the successful completion of project the team dispersed and the project terminate with lesson learned for future.

What is Project Planning?

One of the tasks of the project manager in any organization is to achieve the organization's objectives through the effective management of resources, both human and hardware. This means using such resources to:

- Make the correct interventions;
- Do the right things;
- Do the things at the right time; and
- With the right quality.

The need for the project manager to make sure that certain stages are properly planned cannot be overemphasized.

Project Planning and organization

Of all the aspects of project management referred to above, planning is probably the most crucial. Without planning, it is difficult to imagine how, for example, the project manager can determine targets, to say nothing of how he/she can convince stakeholders to buy into the project. Both well-managed and badly managed projects go through stages or phases. Think of a badly managed project in your workplace. What phases did it go through?

There are three basic considerations that a successful project manager takes into account. These are:

1. **Defining the problem**

Defining the problem involves identifying the problem, and then decides what the difference will be after solving it.

2. **Developing solution options**

In this case, the manager and his/her team determine how many different ways are available about solving the problem. They should brainstorm solution alternatives.

3. Planning the project

Chaotic Misunderstandings Accusations Increased conflicts punishing the Innocent Disillusionment Project Planning involves answering the questions – What must be done? Who must do what? What is the cost? How is it to be done? When should it be done? Project planning is summed up in following steps;

1) Defining the problem
2) Brainstorm alternatives
3) Plan the project
4) Implement the plan
5) Monitor the project
6) Close the project

It is worth noting that the emphasis and timing spent on a particular stage will depend on the magnitude of the task, the amount of thinking and input needed for the job.

The good manager will ensure that the team members are clear what the problem is, why it is said to be a problem, why it has to be solved, and agree what alternative solutions are at the disposal of the team. Most certainly, if there is no agreement at the beginning, the project is likely to lead to some of the most difficult conflicts. There are several barriers to good planning, namely:

- Prevailing paradigms among the members. A paradigm is what each individual member perceives about a problem. People have different beliefs about a given situation.
- The nature of human beings. It is natural for members to be skeptical about colleagues or the project itself. This is usually because of workplace politics or personality clashes.
- Competing responsibilities. Members often belong to different sections of an organization, and their being assigned to membership of the project may be against their will. Some will most likely consider the project to be interfering with what they consider their core responsibilities in the organization.

- Negative attitudes. These arise for various reasons, one of them having to do with taking orders from a manager who is not the member's supervisor.

You may have other barriers from personal experience. Add them to the few already given above. When you have done that, let's turn to planning before the project begins, during the course of the project, and when we have finished the project. We shall base our discussion on a given project, which is:

Developing a communication course for immigration officers

The problem

Immigration officers in the country face challenges communicating with visitors coming from all over the world. Currently there is no training programmed to help them cope with the situation.

P = the team has to work together to develop the course.

C = The Ministry of Home Affairs has allocated a budget for the project.

T = Development of the course has to take place within the current financial year.

S = the course should help officers deal with speakers of different languages, not speakers of English only.

Before Starting the Project

The planning should include three steps.

Step One: Setting objectives

The following should be agreed. Add any two of your own in the space below.

- Define and agree what is to be accomplished.
- Ensure objectives are specific (clear to everybody), measurable, achievable (can be attained), realistic (not too far-fetched), and time-based (attainable within agreed time).
- Agree who will play what role.
- Establish a shared project vision.
- Agree about time lines (scheduling).

- ❖ As a team, specify how you will know when you are succeeding or failing stage by stage.

Step Two: Plan and organize for action

The following should be agreed. Add any two of your own in the space below.

- ❖ Determine the strategy the team is going to follow in order to tackle the job.
- ❖ Analyze the tasks and activities that need to be done.
- ❖ Agree on the resources required (people, time, materials, equipment, authority)
- ❖ Establish alternative methods in case things do not go according to plan.
- ❖ A leader whose authority is defined should be appointed. The head of the organization should ensure the leader's role is explained to all.

Step Three: Establish controls

The following should be agreed. Add any two of your own in the space below.

- ❖ The standards of performance expected should be clear to every member.
- ❖ Measures to ensure compliance with agreed standards should be put in place by the team.
- ❖ Controls, milestones and exit points that will be used to keep in touch with progress should be agreed (time checks, formal reporting, informal reporting, observation, systems, etc.)
- ❖ Threats and risks should be raised at regular meetings.
- ❖ Failure should be recognized by all and confronted in a constructive manner.
- ❖ Ensure that ever team member understands the plan, its time scale and where the individual's contribution fits.

Regarding risks, it is helpful to assess risks of failure relative to the schedule, the budget, project quality, and customer satisfaction. The simplest way to conduct a risk analysis is to ask:

- ❖ What could go wrong?
- ❖ What could keep us from achieving the project objectives?

It is beneficial to list the possible risks first, and then think about contingencies for dealing with them.

During the Project

Planning during the project involves re-planning when plans formulated before project inception need re-visiting. We shall refer to that step as the implementation stage.

Step 4: Implementation

There are four implementation components that the project manager should account for, namely, direction, duration, dynamics, and discussion.

Direction

To establish a sense of direction, these questions should be constantly asked, and answers provided:

- Are the team members complying with the objectives?
- Are we succeeding or failing?
- Is the project moving in the right direction?
- Are the controls being met?
- Is the product, at various stages, of good quality?

Duration

Duration refers to the time taken to accomplish the project on the basis of time taken for different tasks on the action plan. Three questions should guide operations.

- Are we sticking to the time scale?
- Are the milestones being met?
- Is the deadline still achievable?

Dynamics

Dynamics is concerned with the way members operate in order to achieve a common purpose. It is the project manager's prerogative to constantly check on the dynamics by asking and answering these questions.

- What is the level of productivity?
- Is everyone actively involved? If not, then why not?

- Is the group atmosphere positive or negative?
- Apart from words spoken, are there certain actions that indicate the prevailing team spirit?

Dialogue

Interaction is crucial during operations. For one thing, project members do not belong to the same department, hence the need to keep one another informed. It pays to repeat the same information, for among members are some who are slow to grasp, or others who may deliberately pretend that they have not heard. The project manager should keep the following questions in mind.

Are members still aware of key issues: their individual roles, the purpose of the project, the time-lines, etc.?

- How is information being shared?
- Does everyone know what is going on?
- Do members who have replaced old ones know enough about the project?
- Are regular meetings held?
- During any given meeting is there a clear agenda?
- During meetings, are all members encouraged to contribute to the dialogue?
- Are members who fail to attend meetings informed about latest developments?
- Are stakeholders who do not attend meetings given regular update on the project progress?

After Completing the Project

When the last milestone is reached, we say that the project has been completed. What then remains is to reflect and assess the processes from the beginning up to the end. The team should meet and answer some questions. This will be Step 5.

Step 5: Project Evaluation

The following questions will guide decision-making and the way forward.

- When was the project completed?
- Were the milestones and exit points completed within the target time scale?
- What were the main causes of delay, if any?

- What went well?
- What went badly?
- Who worked well or badly, and why?
- How well and efficiently were resources used?
- Why did the project succeed or fail?
- Was the product of good quality?
- What changes could be made in the future for the better management of a comparable project?
- What lessons can be learned from the project?
- What can be done to improve teamwork?
- Did the project receive full institutional support?

On the basis of what has been discussed above, contribute your own views by working on this activity, which is based on the project topic already mentioned earlier, namely, *Developing a*

communication course for immigration officers.

Project Manager

In a small sense project managers perform the same functions as other managers. That is, they plan, schedule, motivate, and control. However, what makes them unique is that they manage temporary, non repetitive activities, to complete a fixed life project. Unlike functional managers, who take over existing operations, project managers create a project team and organization where none existed before. They must decide what and how things should be done instead of simply managing set processes. They must meet the challenges of each phase of the project life cycle, and even oversee the dissolution of their operation when the project is completed.

Project managers must work with a diverse troupe of characters to complete projects. They are typically the direct link to the customer and must manage the tension between customer expectations and what is feasible and reasonable. Project managers provide direction, coordination, and integration to the project team, which is often made up of part-time participants loyal to their functional departments. They often must work with a cadre of outsiders—vendors, suppliers, subcontractors—who do not necessarily share their project allegiance.

Project managers are ultimately responsible for performance (frequently with too little authority). They must ensure that appropriate trade-offs are made between the time, cost, and performance requirements of the project. At the same time, unlike their functional counterparts, project managers generally possess only rudimentary technical knowledge to make such decisions. Instead, they must orchestrate the completion of the project by inducing the right people, at the right time, to address the right issues and make the right decisions.

While project management is not for the timid, working on projects can be an extremely rewarding experience. Life on projects is rarely boring; each day is different from the last. Since most projects are directed at solving some tangible problem or pursuing some useful opportunity, project managers find their work personally meaningful and satisfying. They enjoy the act of creating something new and innovative. Project managers and team members can feel immense pride in their accomplishment, whether it is a new bridge, a new product, or needed service. Project managers are often stars in their organization and well compensated.

Good project managers are always in demand. Every industry is looking for effective people who can get the right things done on time. Clearly, project management is a challenging and exciting profession. This text is intended to provide the necessary knowledge, perspective, and tools to enable students to accept the challenge.

Responsibilities of Project Manager

- To complete the project within time, within budget and according to specifications
- To act as an intermediary between top management and project team
- To obtain feedback for learning lessons
- To train and educate the project staff

Selecting the Project Manager

A person should have following qualities to be selected as a project manager

- Mature, Calm and aggressive
- Good terms with senior management
- Generalist
- Credibility- Technical and Administrative
- Sensitivity

- Leadership Style
- Ethical Responsibilities

Project Manager Vs Functional Manager

Functional Manager

- Functional manager is in charge of one of a firm's functional departments such as marketing, engineering, or finance.
- Such department heads are usually specialists in the areas they manage.
- They are analytically oriented and they know something of the details of each operation for which they are responsible.
- They know how to analyze and attack a problem.
- Functional manager uses the analytical approach
- Functional manager must be more skilled at analysis

Project Manager

- A PM, by contrast, is usually a generalist with a wide background of experience and knowledge. A PM must oversee many functional areas
- PM has an ability to put many pieces of a task together to form a coherent whole
- Project manager must be more skilled at synthesis
- PM uses the systems approach

Project Organization

Purpose

The purpose of Project Origination is to evaluate projects pro-posed for the next planning cycle and to reach a consensus on the projects to be selected. During this phase, the strength of a project's Business Case is tested, and the viability of the Proposed Solution is explored. A determination is made as to whether the project is consistent with the agency's strategic plan and affordable within budget guidelines. The Project Proposal process may actually be part of the budget cycle, serving as the justification for budget requests. In this case, Project Proposals may need to be created a full budget cycle prior to the project's anticipated initiation.

Other factors that impact Project Origination include statutory requirements, regulations, legislative restrictions, and civil service rules.

Each organization has its own approach to green-lighting desired projects. The approach outlined below is only one of many possible variations of the evaluation and selection process. There are some general principles, however, that apply to any effective evaluation and selection process:

- The deciding body must have enough information about the merits of the project's Business Case and the viability of its Proposed Solution to make a meaningful evaluation;
- The competing projects' merits must be evaluated and compared using a consistently applied methodology;
- The selection process must take into consideration the project's fit with the organizational mission and strategic plan.

Types of Project Organization

Project organization is of the following types;

- Functional organization
- Pure project organization
- The Matrix organization

Functional organization

Project is made a part of one of the functional divisions of the firm.

Major Advantages

- Maximum flexibility in the use of staff
- Individual experts can be utilized by many different projects
- Specialists in the division can be grouped to share knowledge and experience.
- The functional division also serves as a base of technological continuity when individuals choose to leave the project and even the parent firm.
- Functional division contains the normal path of advancement for individuals whose expertise is in the functional area

Disadvantages

- Client is not the focus of activity and concern
- Functional division tends to be oriented toward the activities particular to its function

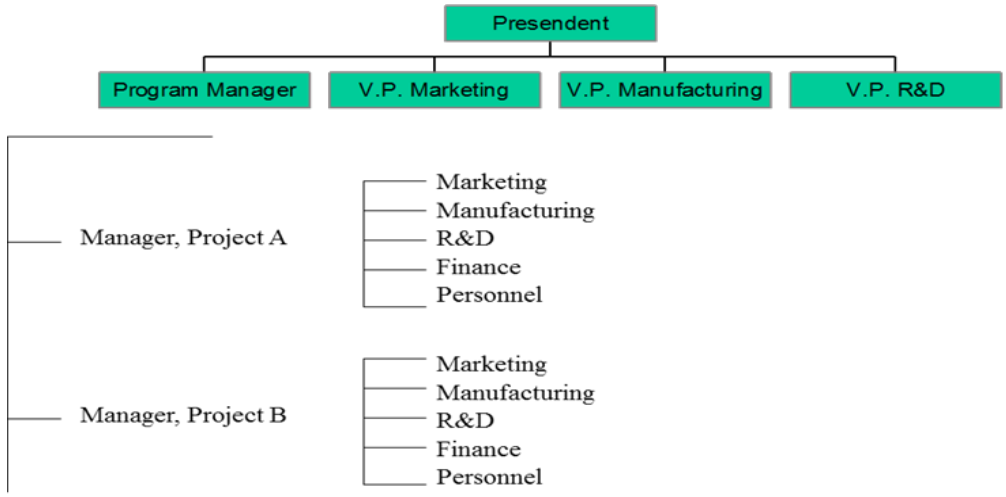
- Occasionally in functionally organized projects, no individual is given full responsibility for the project.
- Response to client needs is slow and arduous
- Project issues that are directly within the interest area of the functional home may be dealt with carefully, but those outside normal interest areas may be given short shrift, if not totally ignored
- Motivation of people assigned to the project tends to be weak.
- Such an organization arrangement does not facilitate a holistic approach to the project.

Pure project organization

The project is separated from the rest of the parent system. It becomes a self-contained unit with its own technical staff, its own administration, tied to the parent firm by the tenuous strands of periodic progress reports and oversight

Advantages

- The project manager has full line authority over the project. All members of the project work force are directly responsible to the PM
- The lines of communication are shortened and PM communicates directly with senior corporate management.
- The project team that has a strong and separate identity of its own tends to develop a high level of commitment from its members.
- Because authority is centralized, the ability to make swift decisions is greatly enhanced.
- Unity of command exists.
- Pure project organizations are structurally simple and flexible which makes them relatively easy to understand and to implement.

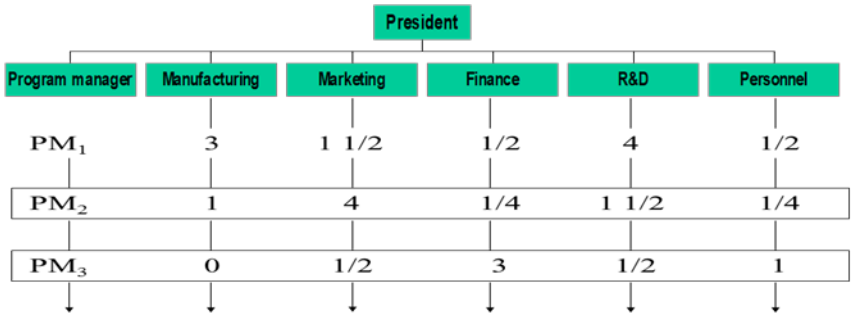


Disadvantages

- When the parent organization takes on several projects, it is common for each one to be fully staffed. This can lead to considerable duplication of effort.
- PM may stockpile equipment and technical assistance in order to be certain that it will be available when needed
- Pure project groups seem to foster inconsistency in the way in which policies and procedures are carried out.
- In pure project organizations, the project takes on a life of its own. Team members form strong attachments to the project and to each other.
- Worry about "life after the project ends"

The Matrix organization

I*t couples some of the advantages of the pure project organization with some of the desirable features of the functional organization, and to avoid some of the disadvantages of each, the matrix organization was developed. In fact, the functional and the pure project organizations represent extremes.*



Advantages

- The project is the point of emphasis. PM takes responsibility for managing the project, for bringing it in time, within cost, and to specifications
- There is less anxiety about what happens when the project is completed
- Response to client needs is as rapid as in the pure project case
- Consistency with the policies, practices, and procedures of the parent firm tends to be preserved
- Where there are several projects simultaneously under way, matrix organization allows a better companywide balance of resources to achieve the several different time/cost/performance targets of the individual projects.

Disadvantages

- The movement of resources from project to project in order to satisfy the several schedules may foster political infighting among the several PMs.
- For strong matrices, problems associated with shutting down a project are almost as severe as those in pure project organizations.
- Division of authority and responsibility inherent in matrix management is complex.
- Matrix management violates the management principle of unity of command. Project workers have at least two bosses.

Benefits of Project Management

- To make the investment activity economically viable, technically sound, financially profitable, managerially efficient, socially acceptable and institutionally desirable
- Aims at achieving specific goals and objectives
- Aims to complete investment activity within triple constraints

- Project management is essential for complex project needs coordination of multiple people, multiple resources, multiple tasks and multiple decision points Project management allows us to accomplish more work in less time and with less people.
- Project management provides a means for solving problems.
- Project management increases quality.
- Project management allows people to make good company decisions.
- It ensures better return on investment.
- Project management will provide better control of scope changes.
- Project management makes the organization more efficient and effective through better organizational behavior principles.

Causes of Project Failure

Projects that have failed generally display several of the following characteristics:

- The customer's conditions of satisfaction have not been negotiated.
- The project no longer has a high priority.
- No one seems to be in charge.
- The schedule is too optimistic
- The project plan is not used to manage the project.
- Sufficient resources have not been committed.
- Project status is not monitored against the plan.
- No formal communications plan is in place.
- The project has lost sight of its original goals.
- There is no change management process in place.

Project Management Software

The project management and software development communities have definitely responded to the need to provide more software to assist in managing projects. The Project Management Center, a Web site for people involved in project management, provides an alphabetical directory of more than 300 project management software solutions (www.infogoal.com/pmc). This site and others demonstrate the growth in available project management software products, especially Web-based tools. Deciding which project management software to use has become a project in itself.

Many people still use basic productivity software such as Microsoft Word and Excel to perform many project management functions, including determining project scope, time, and cost, assigning resources, preparing project documentation, and other tasks. People often use productivity software instead of specialized project management software because they already have it and know how to use it. However, there are hundreds of project management software tools that provide specific functionality for managing projects. These project management software tools can be divided into three general categories based on functionality and price:

- Low-end tools: These tools provide basic project management features and generally cost less than $200 per user. They are often recommended for small projects and single users. Most of these tools allow users to create Gantt charts, which cannot be done easily using current productivity software. Some of these tools are available online while others are stand-along desktop applications

- Midrange tools: A step up from low-end tools, midrange tools is designed to handle larger projects, multiple users, and multiple projects. All of these tools can produce Gantt charts and network diagrams, and can assist in critical path analysis, resource allocation, project tracking, status reporting, and other tasks. Prices range from about $200 to $600 per user, and several tools require additional server software for using workgroup features. Microsoft Project is still the most widely used project management software today in this category and in general. Figure 1-9 provides a screen shot from Project 2007 showing a Gantt chart for a project that you can create by following the steps in Appendix A. There is also an enterprise version of Microsoft Project, as described briefly below.

- High-end tools: Another category of project management software is high-end tools, sometimes referred to as enterprise project management software. These tools provide robust capabilities to handle very large projects, dispersed workgroups, and enterprise and portfolio management functions that summarize and combine individual project information to provide an enterprise view of all projects. These products are generally licensed on a per-user basis, integrate with enterprise database management software, and are accessible via the Internet. In mid-2002, Microsoft introduced the first version of their Enterprise Project Management software, and in 2003, they introduced the Microsoft

Enterprise Project Management solution, which was updated in 2007 to include Microsoft Office Project Server 2007 and Microsoft Office Project Portfolio Server 2007. In 2008, Oracle acquired Primavera Software, Inc., another popular tool for project-intensive industries.

Benefits of project management (PM) software

- **Project scheduling.** Project software can help automatically produce critical path diagrams or Gantt charts. The software can also instantly update these time plans when new information is entered and produce automatic exception reports to monitor and control the project e.g. actual v budgeted time.
- **Budgeting and controlling cost.** Project software will help plan and control project expenditure more effectively and improve communication of financial reporting. After budgeted data has been input, actual costs and estimated costs to complete the project can be tracked, any material exceptions instantly reported. E.g. actual v budget expenditure.
- **Communication and coordination.** Project software can provide automatic report templates with good graphical features, these help to provide effective information and communicate to various stakeholders of a project. Real-time calendars, diaries and reminders can also help coordinate meetings more effectively.
- **Work breakdown structure.** Project software can help assist with planning and coordination of project staff by breaking tasks or activities down in to more manageable and smaller units of work or activities to be completed. Automatic schedules of work can be printed off and used to delegate tasks to different staff within the project team.
- **Risk management.** Project software will help manage the sheer complexity of managing funds, equipment, staff and other stakeholders to achieve project objectives. Good for What if analysis, the project manager can change different variables e.g. the duration of activities or cost allowances, in order to understand any fundamental impact this would have on the project.
- **Greater accuracy and ease of updating and reprinting reports**. Improves the efficiency of how data is gathered, summarized and communicated.

Project Selection

Firms are literally bombarded with opportunities, but of course, no organization enjoys infinite resources to be able to pursue every opportunity that presents itself. Choices must be made, and to best ensure that they select the most viable projects, many managers develop priority systems—guidelines for balancing the opportunities and costs entailed by each alternative. The goal is to balance the competing demands of time and advantage. The pressures of time and money affect most major decisions, and decisions are usually more successful when they are made in a timely and efficient manner. For example, if your firm's sales department recognizes a commercial opportunity it can exploit, you need to generate alternative projects quickly to capitalize on the prospect. Time wasted is generally opportunity lost. On the other hand, you need to be careful: You want to be sure that, at least as far as possible, you are making the best choice among your options. Thus organizational decision makers develop guidelines—selection models that permit them to save time and money while maximizing the likelihood of success.

A number of decision models are available to managers responsible for evaluating and selecting potential projects. As you will see, they run the gamut from qualitative and simple to quantitative and complex. All firms, however, try to develop a screening model (or set of models) that will allow them to make the best choices among alternatives within the usual constraints of time and money.

Suppose you were interested in developing a model that allowed you to effectively screen project alter-natives. How might you ensure that the model was capable of picking potential "winners" from the large set of possible project choices? After much consideration, you decide to narrow the focus for your screening model and create one that will allow you to select only projects that have high potential payoffs. All other issues are ignored in favor of the sole criterion of commercial profitability. The question is: Would such a screening model be useful? Souder identifies five important issues that managers should consider when evaluating screening models:

- **Realism:** An effective model must reflect organizational objectives, including a firm's strategic goals and mission. Criteria must also be reasonable in light of such constraints on resources as money and personnel. Finally, the model must take into account both commercial risks and technical risks, including performance, cost, and time. That is: Will the project work as intended? Can we keep to the original budget or

is there a high potential for escalating costs? Is there a strong risk of significant schedule slippage?

- **Capability:** A model should be flexible enough to respond to changes in the conditions under which projects are carried out. For example, the model should allow the company to compare different types of projects (long-term versus short-term projects, projects of different technologies or capabilities, projects with different commercial objectives). It should be robust enough to accommodate new criteria and constraints, suggesting that the screening model must allow the company to use it as widely as possible in order to cover the greatest possible range of project types.
- **Flexibility:** The model should be easily modified if trial applications require changes. It must, for example, allow for adjustments due to changes in exchange rates, tax laws, building codes, and so forth.
- **Ease of Use:** A model must be simple enough to be used by people in all areas of the organization, both those in specific project roles and those in related functional positions. Further, the screening model that is applied, the choices made for project selection, and the reasons for those choices should be clear and easily understood by organizational members. The model should also be timely: It should generate the screening information rapidly, and people should be able to assimilate that information without any special training or skills.
- **Cost:** The screening model should be cost effective. A selection approach that is expensive to use in terms of either time or money is likely to have the worst possible effect: causing organizational members to avoid using it because of the excessive cost of employing the screening model. The cost of obtaining selection information and generating optimal results should be low enough to encourage use of the models rather than diminish their applicability. Let's add a sixth criterion for a successful selection model:
- **Comparability:** It must be broad enough to be applied to multiple projects. If a model is too narrowly focused, it may be useless in comparing potential projects or foster biases toward some over others.

A useful model must support general comparisons of project alternatives.

Project selection models come in two general classes: numeric and nonnumeric. Numeric models seek to use numbers as inputs for the decision process involved in selecting projects. These values can be derived either objectively or

subjectively; that is, we may employ objective, external values ("The Bridge's construction will require 800 cubic yards of cement") or subjective, internal values ("You will need to hire two code checkers to finish the software development within eight weeks"). Neither of these two input alternatives is necessarily wrong: An expert's opinion on an issue may be subjective but very accurate. On the other hand, an incorrectly calibrated surveyor's level can give objective but wrong data. The key is to remember that most selection processes for project screening involve a combination of subjective and objective data assessment and decision making. Nonnumeric models, on the other hand, do not employ numbers at decision inputs, relying instead on other data.

Companies spend great amounts of time and effort trying to make the best project selection decisions possible. These decisions are typically made with regard for the overall objectives that the company's senior management staff have developed and promoted based on their strategic plan. These objectives can be quite complex and reflect a number of external factors that can affect a firm's operations. For example, suppose the new head of Sylvania's Lighting Division mandated that the strategic objectives of the organization were to be sales growth at all costs. Any new project opportunity would be evaluated against this key strategic imperative. Thus, a project offering the potential for opening new markets might be viewed more favorably than a competing project that promised a higher potential rate of return.

The list of factors that can be considered when evaluating project alternatives is enormous (see Table). In general terms, we may look at risk and commercial factors, internal operating issues, and other factors. This table is only a partial list of the various elements that a company must address when considering new project alternatives. Although the list can be long, in reality the strategic direction emphasized by top management often highlights certain criteria over others. In fact, if we apply Pareto's 80/20 principle, which states that a few issues (20%) are vital and many (80%) are trivial, it may be fairly argued that for many projects, less than 20% of all possible decision criteria account for over 80% of the decision of whether or not to pursue the project.

This being said, we should also reflect on two final points regarding the use of any decision-making approach to project selection. First, the most complete model in the world is still only a partial reflection of organizational reality. The potential list of inputs into any project selection decision is literally limitless; so much so, in fact, that we must recognize this truth before exploring project selection lest we erroneously assume that it is possible, given enough time and

effort, to identify all relevant issues that play a role. Second, embedded in every decision model are both objective and subjective factors. We may form opinions based on objective data; we may also derive complex decision models from subjective inputs. It is worthwhile acknowledging that there exists a place for both subjective and objective inputs and decisions in any useful screening model.

Issues in Project Screening and Selection

1. Risk—Factors that reflect elements of unpredictability to the firm, including:
   a. Technical risk—risks due to the development of new or untested technologies
   b. Financial risk—risks from the financial exposure caused by investing in the project
   c. Safety risk—risks to the well-being of users or developers of the project
   d. Quality risk—risks to the firm's goodwill or reputation due to the quality of the completed project
   e. Legal exposure—potential for lawsuits or legal obligation
2. Commercial—Factors that reflect the market potential of the project, including:
   a. Expected return on investment
   b. Payback period
   c. Potential market share
   d. Long-term market dominance
   e. Initial cash outlay
   f. Ability to generate future business/new markets
3. Internal operating issues—Factors that refer to the impact of the project on internal operations of the firm, including:
   a. Need to develop/train employees
   b. Change in workforce size or composition
   c. Change in physical environment
   d. Change in manufacturing or service operations resulting from the project
4. Additional factors
   a. Patent protection
   b. Impact on company's image
   c. Strategic fit

Project Screening and Selection Models

A project-screening model that generates useful information for project choices in a timely and useful fashion at an acceptable cost can serve as a valuable tool in helping an organization make optimal choices among numerous alternatives. With these criteria in mind, let's consider some of the more common project-selection techniques.

1. Checklist Model

The simplest method of project screening and selection is developing a checklist, or a list of criteria that pertain to our choice of projects, and then applying them to different possible projects. Let's say, for example, that in our company, the key selection criteria are cost and speed to market. Because of our strategic competitive model and the industry we are in, we favor low-cost projects that can be brought to the marketplace within one year. We would screen each possible project against these two criteria and select the project that best satisfies them. But depending on the type and size of our possible projects, we may have to consider literally dozens of relevant criteria. In deciding among several new product development opportunities, a firm must weigh a variety of issues, including the following:

- **Cost of development:** What is a reasonable cost estimate?
- **Potential return on investment:** What kind of return can we expect? What is the likely payback period?
- **Riskiness of the new venture:** Does the project entail the need to create new-generation technology? How risky is the venture in terms of achieving our anticipated specifications?
- **Stability of the development process:** Are both the parent organization and the project team stable? Can we expect this project to face funding cuts or the loss of key personnel, including senior management sponsors?
- **Governmental or stakeholder interference:** Is the project subject to levels of governmental oversight that could potentially interfere with its development? Might other stakeholders oppose the project and attempt to block completion? For example, environmental groups commonly referred to as "intervener" stakeholders have a long history of opposing natural resource development projects and work in opposition to project objectives.
- **Product durability and future market potential:** Is this project a one-shot opportunity, or could it be the forerunner of future opportunities? A software development firm may, for example, develop an application for a client in hopes that successful performance on this project will lead to future business. On the other hand, they may perceive that the project is simply a one-time opportunity with little potential for future work with the customer.

This is just a partial list of criteria that may be relevant when we are selecting among project alternatives. A checklist approach to the evaluation of project

opportunities is a fairly simple device for recording opinions and encouraging discussion. Thus, checklists may best be used in a consensus-group setting, as a method for initiating conversation, stimulating discussion and the exchange of opinions, and highlighting the group's priorities.

2. Simplified Scoring Models

In the simplified scoring model, each criterion is ranked according to its relative importance. Our choice of projects will thus reflect our desire to maximize the impact of certain criteria on our decision. In order to score our simplified checklist, we assign a specific weight to each of our four criteria:

Criterion	**Importance Weight**
Time to Market	3
Profit Potential	2
Development Risks	2
Cost	1

The simple scoring model consists of the following steps:

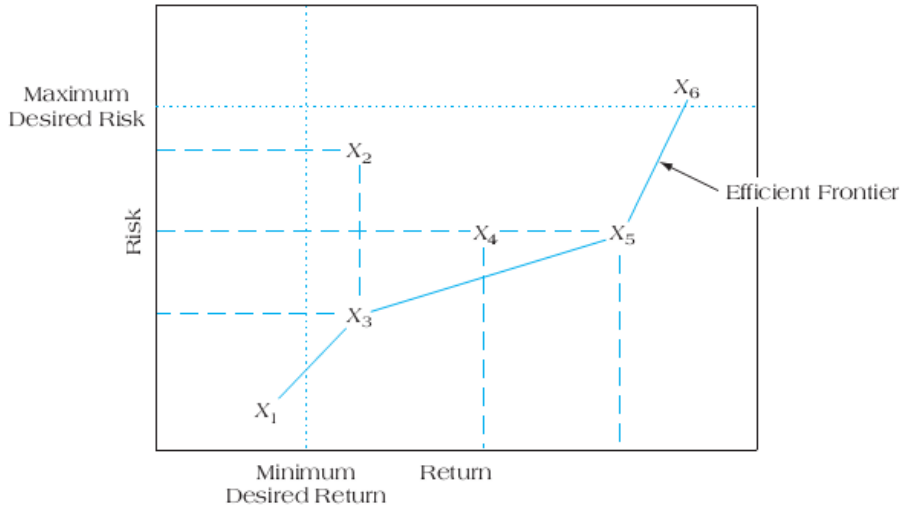
- Assign importance weights to each criterion: Develop logic for differentiating among various levels of importance and devise a system for assigning appropriate weights to each criterion. Relying on collective group judgment may help to validate the reasons for determining importance levels. The team may also designate some criteria as "must" items. Safety concerns, for example, may be stipulated as nonnegotiable. In other words, all projects must achieve an acceptable safety level or they will not be considered further.
- Assign score values to each criterion in terms of its rating (High =3, Medium =2, Low =1): The logic of assigning score values is often an issue of scoring sensitivity—of making differences in scores distinct. Some teams, for example, prefer to widen the range of possible values—say, by using a 1-to-7 scale instead of a 1-to-3 scale in order to ensure a clearer distinction among scores and, therefore, among project choices. Such decisions will vary according to the number of criteria being applied and, perhaps, by team members' experience with the accuracy of outcomes produced by a given approach to screening and selection.

- ❖ Multiply importance weights by scores to arrive at a weighted score for each criterion: The weighted score reflects both the value that the team gives each criterion and the ratings that the team gives each criterion as an output of the project.
- ❖ Add the weighted scores to arrive at an overall project score: The final score for each project becomes the sum of all its weighted criteria.

3. Profile Models

Profile models allow managers to plot risk/return options for various alternatives and then select the project that maximizes return while staying within a certain range of minimum acceptable risk. "Risk," of course, is a subjective assessment: That is to say, it may be difficult to reach overall agreement on the level of risk associated with a given project. Nevertheless, the profile model offers another way of evaluating, screening, and comparing projects.

Let us return to our example of project screening at SAP Corporation. Suppose that instead of the four project alternatives for the new software project we discussed earlier, they had identified six candidates for development. For simplicity's sake, they chose to focus on the two criteria of risk and reward.



In Figure given above, the six project alternatives are plotted on a graph showing perceived Risk on the y-axis and potential Return on the x-axis. Because of the cost of capital to the firm, we will specify some minimum desired rate of return. All projects will be assigned some risk factor value and be plotted relative to the maximum risk that the firm is willing to assume. Therefore the figure graphically represents each of our six alternatives on a profile model. (Risk values have been created here simply for illustrative purposes.) Consider Project

X4 for example. In our example, SAP can employ a variety of measures to assess the likely return offered by this project, including discounted cash flow analysis and internal rate of return expectations. Likewise, it is increasingly common for firms to quantify their risk assessment of various projects, enabling us to plot them along the y-axis. The key lies in employing identical evaluation criteria and quantification approaches across all projects to be profiled on the graph. Clearly, when project risks are unique or we have no way of comparing the relative risks from project to project, it is impossible to accurately plot project alternatives.

We see that Project X2 and Project X3 have similar expected rates of return. Project X3, however, represents a better selection choice. Why? Because SAP can achieve the same rate of return with Project X3 as it can with Project X2 but with less risk. Likewise, Project X5 is a superior choice to X4: Although they have similar risk levels, X5 offers greater return as an investment. Finally, while Project X6offers the most potential return, it does so at the highest level of risk.

The profile model makes use of a concept most widely associated with financial management and investment analysis—the efficient frontier. In project management, the efficient frontier is the set of project portfolio options that offers either a maximum return for every given level of risk or the minimum risk for every level of return. When we look at the profile model in Figure 3.4, we note that certain options (X1, X3, X5, and X6) lie along an imaginary line balancing optimal risk and return combinations. Others (X2 and X4), however, are less desirable alternatives and would therefore be considered inferior choices. The efficient frontier serves as a decision-making guide by establishing the threshold level of risk/return options that all future project choices must be evaluated against.

One advantage of the profile model is that it offers another alternative to compare project alternatives, this time in terms of the risk/return trade-off. It is sometimes difficult to evaluate and compare projects on the basis of scoring models or other qualitative approaches. The profile model, however, gives managers a chance to map out potential returns while considering the risk that accompanies each choice. Thus profile models give us another method for eliminating alternatives, either because they threaten too much risk or promise too little return.

On the other hand, profile models also have disadvantages:

- They limit decision criteria to just two—risk and return. Although an array of issues, including safety, quality, and reliability, can come under the heading of “risk,” the approach still necessarily limit the decision maker to a small set of criteria
- In order to be evaluated in terms of an efficient frontier, some value must be attached to risk. Expected return is a measure that is naturally given to numerical estimate. But because risk may not be readily quantified, it may be misleading to designate “risk” artificially as a value for comparison among project choices.

Lecture 27: Project Management cond….

Modern Tools – Technique

PERT (Project Evaluation and Review Techniques)

The technique of PERT helps give better time estimation for a project, by accounting for the uncertainty when predicting task durations. As an illustration, the project manager could estimate the worse, best and most probable duration of time for each activity and then determine an average completion time. This can be undertaken by assigning probabilities to the three estimates and calculating an expected value. The average time of each activity would then be used to configure the elapsed time of the project.

Advantages of critical path analysis (CPA)

- Identifies interrelationships between different tasks or activities
- Resources can be planned and allocated from using it e.g. staff planning
- Good communication and planning tool for time management

Disadvantages of critical path analysis (CPA)

- Assumes a tradeoff between time and money but most staff cost could be a fixed not variable cost
- The complexity of the diagram will increase as more activities are included
- Key uncertainties often exist when estimating the duration for activities, therefore can be a poor prediction for elapsed time.

RERT (program evaluation and review technique) and CPM (critical path method) are two of the most widely used techniques for planning and coordinating large scale projects.

By using PERT or CPM managers are able to obtain:

- A graphical display of the project activities
- An estimate of how long the project will take

- An indication of which activities are most critical
- An indication of how long an activity can be delayed without lengthening the project

Symbols used to create a network diagram

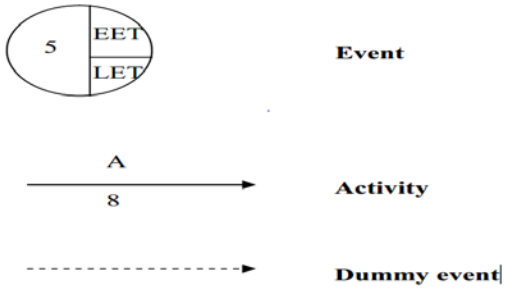
An arrow is used to represent each activity or task to accomplish, the letter above the arrow represents the activity in shorthand and the duration of the activity is recorded below the arrow e.g. Hours, days or months.

Each activity or task that happens, has a preceding event (circle) and each circle is pre-numbered e.g. above circle 5 is used as an example to show this would be the 5th event or circle to be completed in the diagram.

The earliest event time (EET) for an activity is recorded in the circle preceding each activity (represented by an arrow) as you work from left to right. The EET displays the earliest time an activity (represented by an arrow) can start, given the interdependence of other activities that would be completed beforehand.

The latest event time (LET) for an activity is recorded in the circle following the activity (arrow) e.g. The latest time an activity must be completed by, in order to achieve the elapsed time of the project.

A dummy event (or activity) is used when a task or activity (represented by an arrow) follows more than one preceding activity e.g. the arrow could be drawn from more than one potential circle in the diagram. If an activity relies on more than one activity to be completed beforehand, draw the activity (arrow) from the circle with the highest earliest event time (to preserve the diagrams logic), then link all possible circles together, that the activity could have been linked to by using dummy activities e.g. a broken or dotted arrow. This enables understanding that an activity relies on more than one task to be completed beforehand,



before it can actually start itself, therefore this displays better logic.

How to construct a network (critical path) diagram

1. Requires a pencil, ruler and 2P coin (or any stencil or coin for a perfect circle!)
2. Drawn from left to right e.g. A4 page landscape better than portrait
3. Tasks or activities (represented by arrows) will always have one starting circle (before the arrow) and one finishing circle (after the arrow)
4. Numerically label circles displayed e.g. circle 1, 2 , 3 etc
5. No crossing of lines to avoid poor communication
6. Complete the earliest event time for each activity, within the preceding circle, to each activity, whilst completing the diagram, working from left to right
7. Numerically label circles for each one displayed e.g. circle 1, 2 , 3 etc
8. Complete the latest event time for each activity within the succeeding (or following) circle to each activity. The LET cannot be identified until you have determined the elapsed time of the project first, therefore the recording of latest event times, would be the last thing you do to complete the diagram. Work from right to left within the diagram to calculate each activities latest event times (LET)

PERT: A technique for planning, scheduling and controlling the activities

Activity: A specific or set of tasks required by the project. Actions taken to accomplish a task are called activities which consumes time and other organizational sources. Activities are represented by arrows.

Event: Outcome of one or more activities. The starting and ending point of an activity is called event. It is a statement of accomplished task from where another activity starts. Events are represented by circles called nodes.

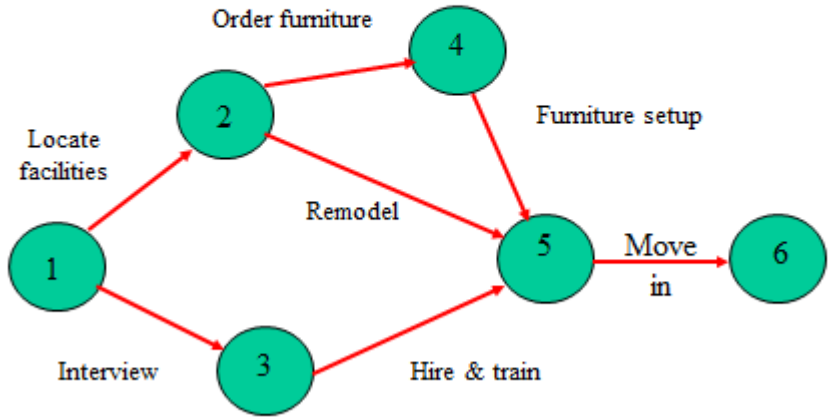
Network: It is combination of all activities and events. It is a systematic diagram showing the logical sequence and interrelationships between events and activities.

Path: Series of connected activities or between any two events

Critical path: Longest – Critical path is the path which has longest total duration of the project. Any delay would delay the project

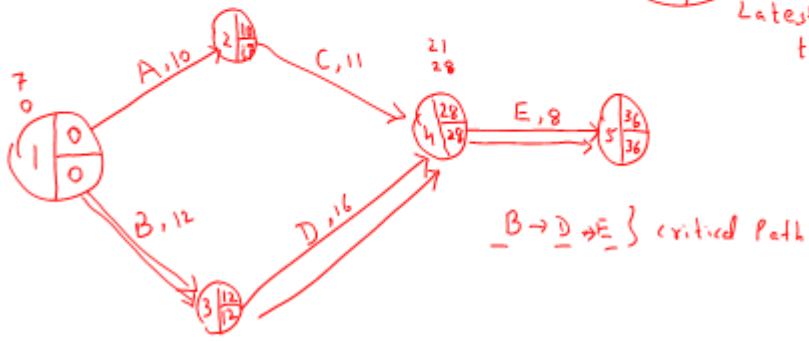
Slack/float: Allowable slippage for a path

A simple project network diagram



Activity	Preceding Activity	Time
A	-	10
B	-	12
C	A	11
D	B	16
E	C, D	8



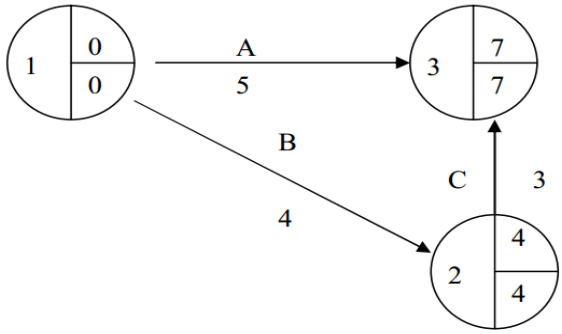


Example *1*

Activity	Duration (Wks)	Preceded by
A	5	-
B	4	-
C	3	B

Each activity is denoted by a letter and the expected duration given. A and B could start immediately, therefore can start on the same circle C must be preceded by B e.g. C cannot start until B has been completed.

Network (critical path) diagram



- The elapsed (expected completion) time of the project is 7 weeks
- The critical path activities are B and C e.g. Both must be completed within their predicted durations, otherwise the project will be longer in duration than 7 weeks.
- Activity A is a non-critical activity and would have a float time of 2 weeks, this is because it only takes 5 weeks to complete, has nothing preceding or succeeding it, therefore given the elapsed time of the project is 7 weeks, it could finish as late as this.

Expected time of completion of a project activity can be computed by the following formula:

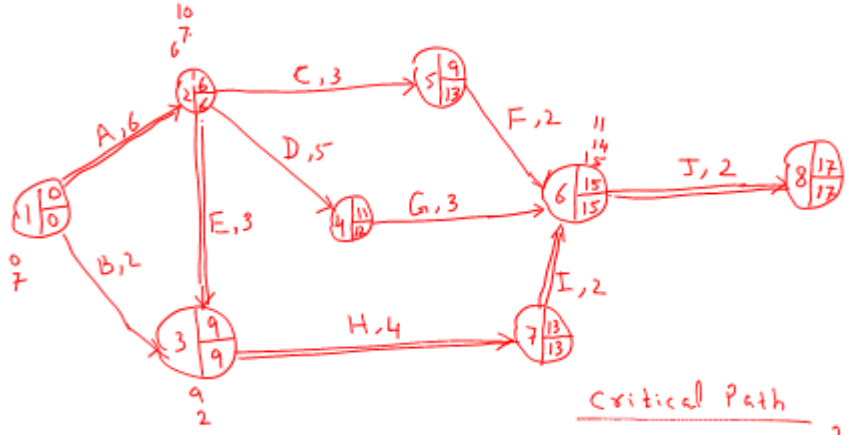
$$\textbf{Expected time} = t = \frac{a + 4m + b}{6}$$

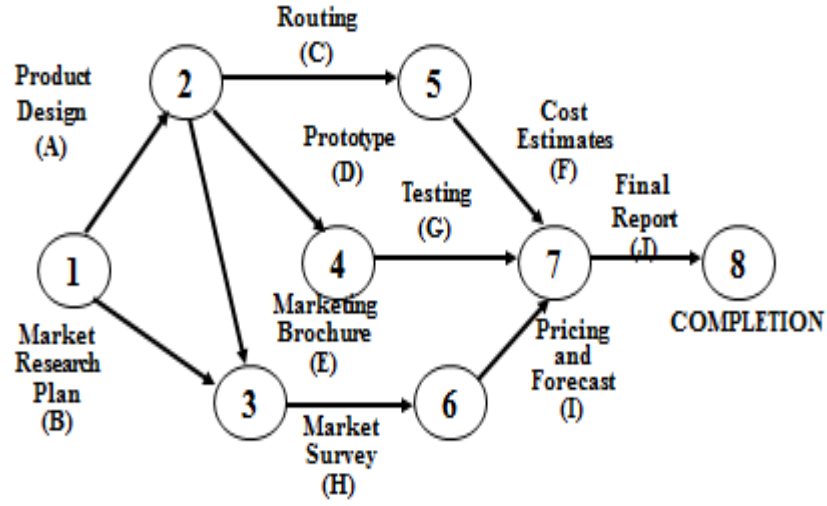
a = Optimistic time: Time taken if every thing progress in an ideal manner with nothing going wrong

m = Most probable time: This is most likely activity time under the normal conditions

b = This is the pessimistic time if there are abnormal conditions for any significant breakdown or delay

Activity	Immediate Predecessor	Time Estimates (Week) Expected time = t =(a + 4m + b)/6
A	-	6 $\frac{4+4(5)+12}{6}=6$
B	-	2
C	A	3
D	A	5
E	A	3
F	C	2
G	D	3
H	B, E	4
I	H	2
J	F, G, I	2



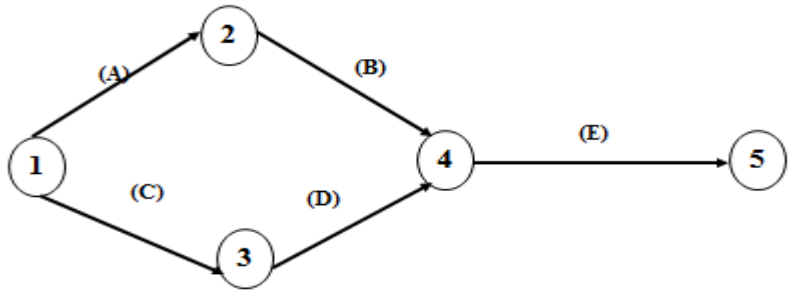


Activity list for the Daugherty Porta-Vac Project

Activity	Description	Immediate Predecessors
A	R&D product design	-
B	Plan market research	-
C	Routing (manufacturing engineering)	A
D	Build prototype model	A
E	Prepare marketing brochure	A
F	Cost estimates (industrial engineering)	C
G	Preliminary product testing	D
H	Market survey	B, E
I	Pricing and forecast report	H
J	Final report	F, G, I

Example

Example



Activity List for a Two-Machine Maintenance Project

Activity	Description	Expected Time (in days)
A	Overhaul machine I	7
B	Adjust machine I	3
C	Overhaul machine II	6
D	Adjust machine II	3
E	Test system	2

PERT Diagram

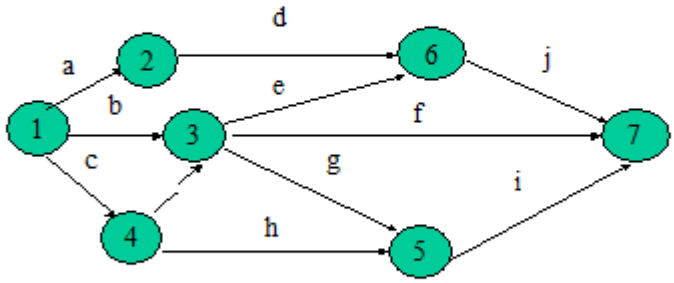
Activity	Preceding Activity
A	--
B	--
C	--
D	A
E	A
F	C
G	C
H	E, B, F
I	E, B, F
J	D, H
K	G, I, J

Example

Make a Network Diagram

Activity	Time (days)	Preceding Activity
A	6	--
B	2	--
C	2	--
D	3	--
E	8	A
F	5	B, E
G	9	C, F, D
H	3	--
I	2	P, H
J	3	B, E
K	10	G
L	1	D
M	10	I, J, K
N	3	L, Q
O	5	M, N
P	4	A
Q	5	G

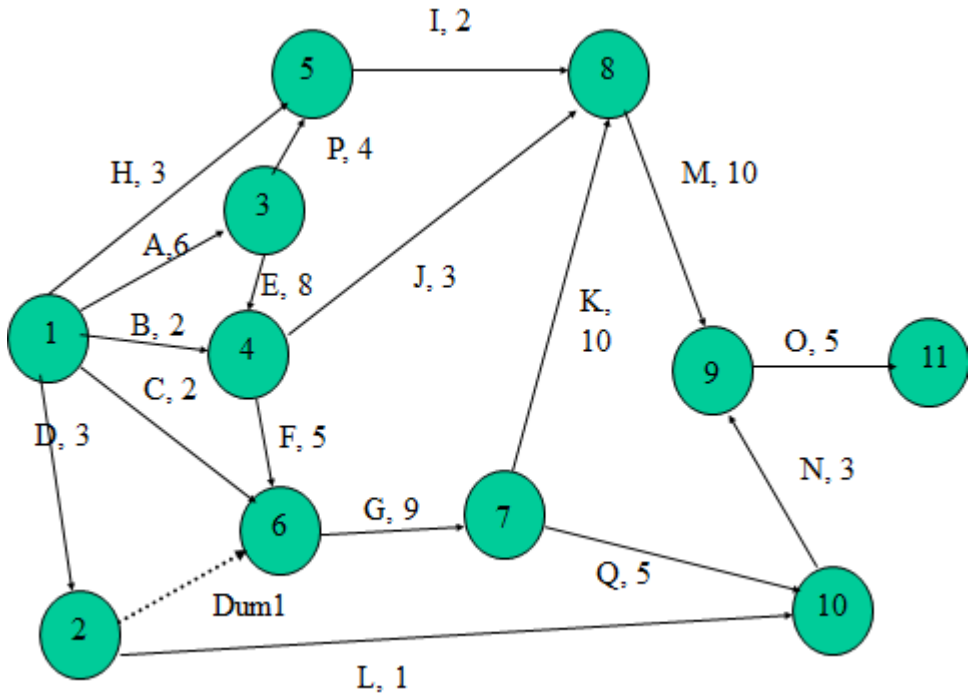
Network Diagram



Example

Make a Network Diagram

Activity	Time (days)	Preceding Activity
A	6	--
B	2	--
C	2	--
D	3	--
E	8	A
F	5	B, E
G	9	C, F, D
H	3	--
I	2	P, H
J	3	B, E
K	10	G
L	1	D
M	10	I, J, K
N	3	L, Q
O	5	M, N
P	4	A
Q	5	G



Critical path analysis (CPA) or network analysis

Gantt charts are a poor time management tools when projects are lengthy and complex. There often exists in large projects a high interdependency between various tasks e.g. some activities cannot start, until others have been completed first, therefore many activities are interrelated. Gantt charts in these circumstances are less desirable because they do not display or indicate interdependencies. Network (or critical path) analysis can display more logically the sequence and timing of each activity, they communicate interdependency and a more effective time management tool for large and complex projects.

The use of critical path analysis as a tool

- Good visual communication and planning tool for effective time management.
- Displays clearly interdependent relationships that exist between the different activities or tasks to be completed.

- Arranges tasks or activities into an optimum sequence of events allowing a project to be completed in the most efficient time possible.
- Elapsed time (or estimated time) to complete the project can be calculated.
- Highlights those activities which are critical activities e.g. Those tasks which must be completed within their planned time, otherwise the elapsed time (or estimated time) of the project will not be achieved.
- Enables more effective resource planning, resources can be diverted away from non-critical to critical activities e.g. Staff could be moved from one task to another, should problems of overrunning occur on critical activities. This does assume that resources moved are directly substitutable between tasks.
- Highlights float times for all activities e.g. the amount of time an activity or task can slip past its planned completion time, without delaying the elapsed time (or estimated time) of the project. All critical activities have a float time of zero, because each must be completed within their planned completion time, otherwise the elapsed time of the project won to be achieved.

Process of critical path analysis

1. Break down project into a logical sequence of activities to be completed.
2. Estimate the time duration of each activity.
3. Arrange activities in the most efficient sequence of events and estimate the elapsed time of the project

Resource Loading

Resource loading describes the amount of individual resource an existing schedule requires during specific time periods.

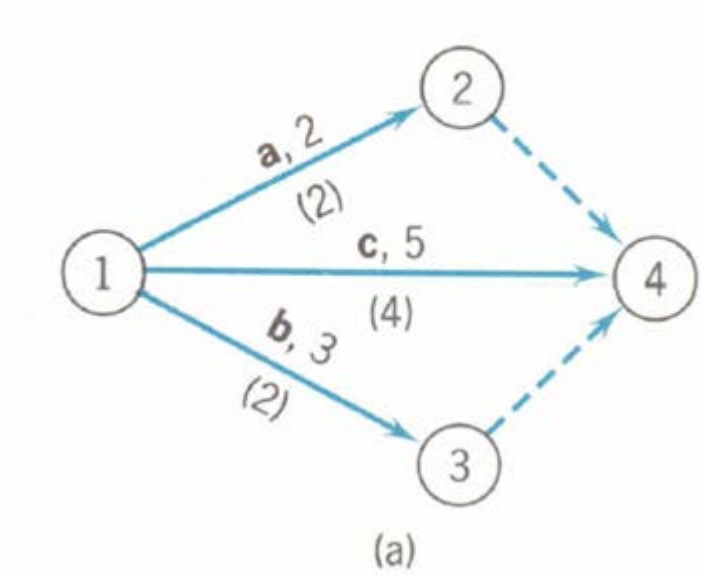
The PERT/CPM network technique is well suited for the job of generating time-phased resource requirements.

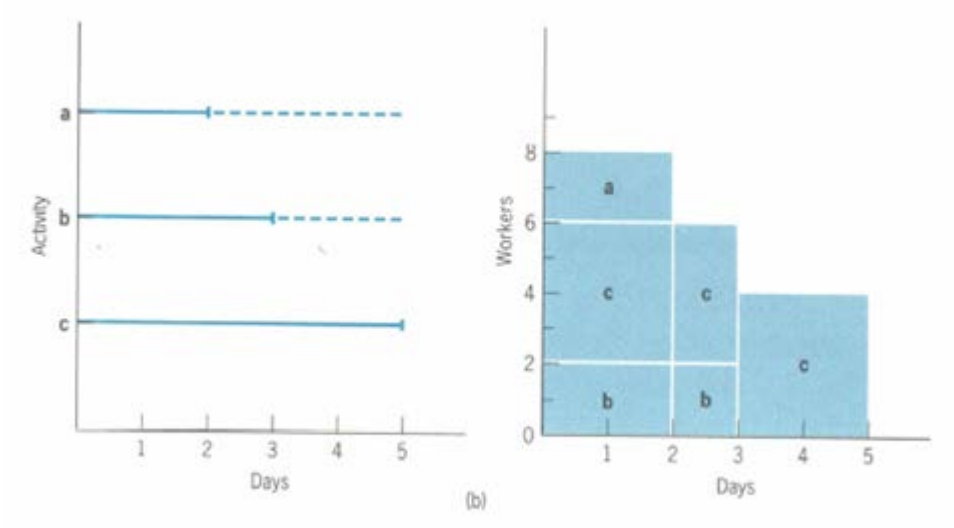
Resource Leveling

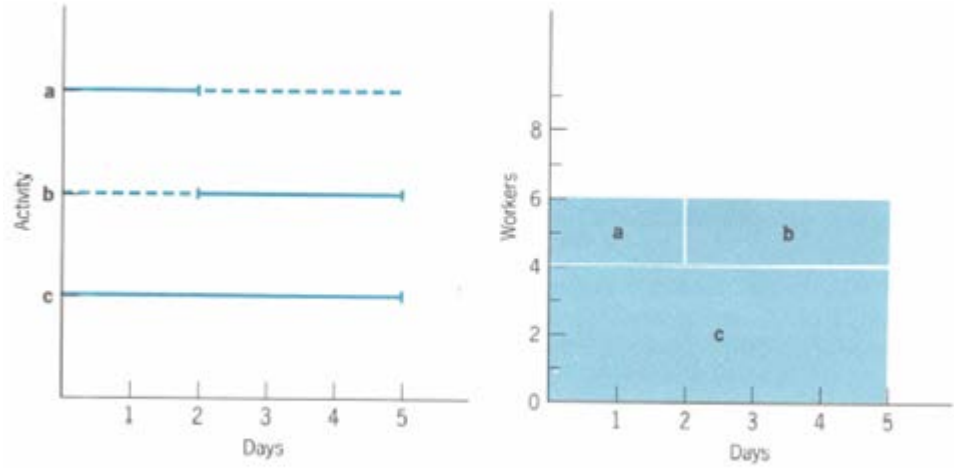
Resource leveling aims to minimize the period-by-period variations in resource lading by shifting tasks within their slack allowances

Example

Suppose there are three activities a, b and c in a project which utilize 2, 3 and 5 human resources respectively. Following is the PERT diagram:




a
b
c
Activity
1
2
3
4
5
Days
(b)
8
6
4
2
0
Workers
a
c
c
b
b
c
1
2
3
4
5
Days


a
b
c
Activity
1
2
3
4
5
Days
8
6
4
2
0
Workers
a
b
c
1
2
3
4
5
Days

Initially, in first two days 8 workers are used. In 2-3 day, 6 workers are used. In 3-5 days, only four workers are utilized. In order to level the resources used, activity ‘a’ and activity ‘c’ can be started at the same time, and activity ‘b’ may be started second day. By doing so, only six workers may be utilized all the five day.

Linear Responsibility Chart

Legend:

- ▲ Responsible
- • Support
- ■ Notification
- ○ Approval

Subproject 4 1/2	Task	Project Manager	Contract Admin.	Project Eng.	Industrial Eng.			
Determine Need	A1	○		•	▲			
	A2	■	○	▲	•			
Solicit Quotations	B1	○	■	▲			•	
Write Approp. Request	C1	■	▲	○	•			
	C2		•	○	▲			
	C3	•	■	▲			■	
"	"							
"	"							
"	"							

Simplified Linear Responsibility Chart

	Vice-president	General manager	Project manager	Manager engineering	Manager software	Manager manfrg	Manager mrktg	Subprogram manager mafrg	Subprogram Manager software	Subprogram Manager hardware	Subprogram Manager services
Establish project plan	6	2	1	3	3	3	3	4	4	4	4
Define WBS		5	1	3	3	3	3	3	3	3	3
Establish hardware specs		2	3	1	4	4	4				
Establish software specs		2	3	4	1		4				
Establish interface specs		2	3	1	4	4	4				
Establish manufacturing specs		2	3	4	4	1	4				
Define documentation		2	1	4	4	4	4				

1 Actual responsibility, 2 General supervision, 3 Must be consulted,
4 May be consulted, 5 Must be noted, 6 Final Approach

Verbal Responsibility Chart

Legend:
IA, ILI, IHI: Product lines
LOB: Line of business
MC: Management committee
M-A Cttee: Marketing administration committee
S&S: Sales and service
MP&R: Marketing planning and research

Activities	Initiate Action	Responsible Individuals Work with	Clear Action with
Distribution System And its Administration		LIL & IHI LOB MCs	Sr VP Mktg
1. Recommend distribution system to be used.	Mktg Officer	M-A Cttee VP & Agcy Dir	
			Sr VP Mktg
	Mktg Officer	Group LOB MC M-A Cttee	
		VP & Agcy Dir	Sr VP Mktg
	Mktg Officer	IA LOB MC M-A Cttee VP & Agcy Dir	
Compensation			
2. Determine provisions of sales compensation programs (e.g., commissions, subsidies, fringes).	Compensation Task Force	Mktg, S&S & Eqty Prod Offrs	President
	Compensation Task Force	Mktg, S&S & Eqty Prod Offrs	
3. Ensure cost-effectiveness testing of sales compensation programs.	Compensation Task Force	Mktg, S&S & Eqty Prod Offrs	President
	Compensation Task Force	Mktg, S&S & Eqty Prod Offrs	President
Territory			
4. Establish territorial strategy for our primary distribution system.	VP & Agcy Dir	Dir MP&R M-A Cttee	Sr VP Mktg

Activities	Responsible Individuals: Initiate Action	Work with	Clear Action with
Territory 5. Determine territories for agency locations and establish priorities for standing.	VP & Agcy Dir	Dir MP&R M-A Cttee	Sr VP Mktg
6. Determine agencies in Which advanced sales personnel Are to operate.	Dir Ret Pln Sls Dir Adv Sls	VP S&S	Sr VP Mktg

Gantt Charts

A time chart devised by Henry Gantt in 1917, an American engineer. A Gantt chart is a horizontal bar chart used for project scheduling. Each activity or task is depicted as a block over time; actual performance is recorded in real time and compared to planned deadlines necessary for achieving completion.

The use of Gantt Charts as a tool

- Can be used to plan time scale for a project
- Can be used to estimate resources required
- Graphical illustration of a schedule of tasks to complete e.g. ideal wall chart for the office and easy to visualize and interpret at meetings
- Helps to plan, coordinate, and track specific tasks for a project
- Good for small projects when the number of tasks or activities are small and not complex e.g. good for simple projects.

The example of a Gantt chart below illustrates the start date, end date and duration of each task; the illustration is for an IT project. The arrow indicates in real time that the project is at the beginning of week 18. No actual time bar has been completed for the last 3 activities because they have not started yet. Often communication can be improved by omitting different time lines e.g. between week 5-12 has been omitted, to reduce the length of the chart. This is only possible if you have no activities starting or completing during any time discontinuance(s) you present.

Illustration of a Gantt chart

		Week number													
	Week	0	1	2	3	4			13	14	15	16	17	18	19	20
Project activities																
Design	Plan															
	Actual															
Integration	Plan															
	Actual															
Testing	Plan															
Going live	Plan															
Training	Plan															

Work breakdown structure (WBS)

The purpose of work breakdown structure (WBS) is to help plan effectively for a project by breaking key tasks or activities down in to more manageable and smaller units of work.

WBS produces a detailed list of tasks to be performed for a project, helping to deliver better costing, scheduling and resource planning for a project.

Cost breakdown structure (CBS) lists every item classified and its expenditure for the project in order to get a more detailed estimate of cost or expenditure.

Examples of how WBS or CBS can aid budgeting planning

- Staff hours for each task or activity assigned x staff hourly rates per hour
- Staff hours for each task or activity assigned x overhead rates per hour
- Equipment, financing or resources more accurately planned for given more detail of the tasks to undertake

During a project, financial control can be achieved by actual expenditure being tracked against each budget allocated for the different tasks assigned. Regular progress can be monitored using budget or time sheets, and control action taken if appropriate e.g. The process of exception reporting

The benefits of using WBS

- Can be used to allocate and delegate responsibility to help accomplish different tasks or activities e.g. control through greater accountability.
- Can help sequence and schedule the timing of different events to improve effectiveness of how time is allocated e.g. the most efficient sequence of accomplishing activities can be understood.
- Improves resource planning and the efficiency of how resources are consumed e.g. accurate forecasts for project staffing to save cost.
- Can be used as a basis of financial exception reporting e.g. Actual budget cost allowances, and also forecast more accurately the project costs.
- Can be used for risk management e.g. to identify risks, and used as an ongoing process for monitoring risks for a project.

Lecture 28: Financial Analysis of Projects

Financial Models

Another important series of models relies on financial analysis to make project selection decisions. In this section, we will examine three common financial models: discounted cash flow analysis, net present value, and internal rate of return. These are not the only financial methods for assessing project alternatives, but they are among the more popular.

1. Time Value of Money

Financial models are all predicated on the time value of money principle. Conceptually, "time value of money" means that the value of a sum of money received today is more than its value received after some time. Conversely, the sum of money received in future is less valuable than it is today. In other words, the present worth of a rupee received after some time will be less than a rupee received today. Since a rupee received today has more value, individuals, as rational human beings, would naturally prefer current receipt to future receipts.

Techniques

In order to have logical and meaningful comparisons between cash flows that result in different time periods it is necessary to convert the sums of money to a common point in time. There are two techniques for doing this:

a) Compounding $F = P\ (1 + I)^n$

b) Discounting $P = \frac{F}{(1+i)^n}$

Compounding Technique

Interest is compounded when the amount earned on an initial deposit (the initial principal) becomes part of the principal at the end of first compounding period. The term principal refers to the amount of money on which interest is received.

Money can earn interest during the time it is invested; a future return is worth less at the present time.

Or

An amount of dollar invested now will be worth more when the principal and its accumulated interest are received n years from now

$F=P(1+i)^n$

F is the future value of the investment

P is the present value of the investment

I is the annual interest rate

n is the number of years.

Example:

- Investment = $ 1,000 (P)
- Interest = 10 % a year (i)
- Compounding annually
- Time = 1 year (n)

$F=P(1+i)^n$

$=\$1,000\ (1.10)^1$

$=\$1,100$

If investment is for 2 years

$=\$1,000\ (1.10)^2$

$=\$1,210$

We can also calculate 2 years compound interest, by investing 1^{st} year's principal and interest.

$=\$1,100\ (1.10)^1$

$=\$1,210$

Quarterly Compounding

Interest is paid at the end of each quarter i.e., four times a year

Example:

Investment = $ 1,000

Interest = 10 % a year

Compounding quarterly

Time = 2 year

$$\mathbf{F=P(1+i/4)^{4(2)}}$$

$$=1{,}000(1.025)^{8}$$

=$1,218.4

Monthly Compounding

Interest is paid at end of each month, twelve times a year

Example:

Investment = $ 1,000

Interest = 10 % a year

Compounding monthly

Time = 2 year

$$\mathbf{F=P\ (1+i/12)^{12(2)}}$$

$$=1{,}000(1.00833)^{24}$$

=$1,220.3

Daily Compounding

There are 360 compound periods per year

Investment = $ 1,000

Interest = 10 % a year

Compounding id done daily

Time = 2 year

$$\mathbf{F=P\ (1+i/360)^{360(2)}}$$

$$=1{,}000(1+0.10/360)^{720}$$

$$=\$1{,}221.4$$

Discounting

If the future value of an investment is known we can easily derive its present value, given an interest rate and the number of compounding periods.

$$\mathbf{P=F/\ (1+i)^{n}}$$

Examples:

How much money to invest now at 10% compounded annually to receive $1,000 in 5 years?

$$P=\$1{,}000/\ (1.10)^{5}$$

$$=1{,}000/1.611$$

$$=\$620.7$$

How much money to invest now at 10% compounded quarterly to receive $1,000 in 5 years?

$$P=\$1{,}000/\ (1.025)^{20}$$

=$ 610.3

2. Net Present Value

The most popular financial decision-making approach in project selection, the net present value (NPV) method, projects the change in the firm's value if a project is undertaken. Thus a positive NPV indicates that the firm will make money—and its value will rise—as a result of the project. Net present value also employs discounted cash flow analysis, discounting future streams of income to estimate the present value of money.

The simplified formula for NPV is as follows:

$$NPV_{(\text{project})} = I_0 + \sum F_t/(1 + r + p_t)^t$$

Where:

Ft = the net cash flow for period t

r =the required rate of return

I =initial cash investment (cash outlay at time 0)

Pt =inflation rate during period t

The optimal procedure for developing an NPV calculation consists of several steps, including the construction of a table listing the outflows, inflows, discount rate, and discounted cash flows across the relevant time periods.

Example:

Cash flows

Years	**0**	**1**	**2**	**3**
Project A	-$2,500	$1,000	$1,500	$1,000
Project B	-$2,500	-$1,000	$2,500	$2,000

- Project A requires initial investment of $2,500
- Project B requires initial investment of $2,500 an additional cash outlay of $1000 in the first year
- Required rate of return is 10%

Solution:

NPV_A = -2,500+1,000(0.9091) +1,500(0.8264) +1,000(0.7513)

=$ 400

NPV_B = -2,500-1,000(0.9091) +2,500(0.8264) +2,000(0.7513)

=$ 160

Since the NPV of project A is larger so it is better

3. Profitability index

The relationship of benefits to the cost of undertaking is provided by the profitability index, or it can also be defined as the ratio of aggregate discounted benefits and aggregate discounted costs

Profitability Index= $\Sigma [A_t / (1+k)^t]$

Profitability Index = BCR_A= $\frac{1,000(0.9091) +1,500(0.8264) +1,000(0.7513)}{2500}$

$= \frac{909.1+1239.6 + 751.3}{2500}$

$= \frac{2900}{2500}$

$= 1.16$

Profitability Index = BCR_B

$$= \frac{2{,}500(0.8264) + 2{,}000(0.7513)}{-2{,}500 - 1{,}000(0.9091)}$$

$$= \frac{2066 + 1502.6}{3409.1}$$

$$= 1.046$$

4. Internal Rate of Return

Internal rate of return (IRR) is an alternative method for evaluating the expected outlays and income associated with a new project investment opportunity. IRR asks the simple question: What rate of return will this project earn? Under this model, the project must meet some required "hurdle" rate applied to all projects under consideration. Without detailing the mathematics of the process, we will say only that IRR is the discount rate that equates the present values of a project's revenue and expense streams. If a project has a life of time t, the IRR is defined as:

$$IO = \sum_{n=1}^{t} \frac{ACF^t}{(1 + IRR)^t}$$

Where:

ACFt =the annual after-tax cash flow for time period t

IO =the initial cash outlay

n =the project's expected life

IRR =the project's internal rate of return

IRR is found through a straightforward process, although it requires tables representing present value of an annuity in order to determine the project's rate of return. Alternatively, many pocket calculators can deter-mine IRR quickly. Without such tables or access to a calculator, it is necessary to employ an iterative process to identify the approximate IRR for the project.

Example

Let's take a simple example. Suppose that a project required an initial cash investment of $5,000 and was expected to generate inflows of $2,500, $2,000, and $2,000 for the next three years. Further, assume that our company's required rate of return for new projects is 10%. The question is: Is this project worth funding?

SOLUTION

Answering this question requires four steps:

I. Pick an arbitrary discount rate and use it to determine the net present value of the stream of cash inflows.
II. Compare the present value of the inflows with the initial investment; if they are equal, you have found IRR.
III. If the present value is larger (or less than) than the initial investment, select a higher (or lower) discount rate for the computation.
IV. Determine the present value of the inflows and compare it with the initial investment. Continue to repeat steps 2–4 until you have determined the IRR.

Using our example, we know:

Cash investment =$5,000

Year 1 inflow =$2,500

Year 2 inflow =$2,000

Year 3 inflow =$2,000

Required rate of return =10%

Step One: Try 12%

Year	Inflows	Discount Factor at 12%	NPV
1	2,500	.893	2,232.50
2	2,000	.797	1,594
3	2,000	.712	1,424
Present value of inflows			5,250.50
Cash investment			– 5,000
Difference			$ 250.50

Decision: Present value difference at 12% is 250.50, which is too high. Try a higher discount rate.

Step Two: Try 15%

Year	Inflows	Discount Factor at 15%	NPV
1	2,500	.870	2,175
2	2,000	.756	1,512
3	2,000	.658	1,316
Present value of inflows			5,003
Cash investment			5,000
Difference			$3

Decision: Present value difference at 15% is $3, which suggests that 15% is a close approximation of IRR.

If the IRR is greater than or equal to the company's required rate of return, the project is worth funding. In the example above, we found that the IRR is 15% for the project, making it higher than the hurdle rate of 10% and a good candidate for investment. The advantage of using IRR analysis lies in its ability to compare alter-native projects from the perspective of expected return on investment (ROI). Projects having higher IRR are generally superior to those having lower IRR.

IRR does, however, have some disadvantages. First, it is not the rate of return for a project. In fact, IRR equals the project's rate of return only when project-generated cash inflows can be reinvested in new projects at similar rates of return. If the firm can reinvest revenues only on lower-return projects, the "real"

return on the project is something less than the calculated IRR. Several other problems with IRR make NPV a more robust determinant of project viability:

- IRR and NPV calculations typically agree (that is, make the same investment recommendations) only when projects are independent of each other. If projects are not mutually exclusive, IRR and NPV may rank them differently. The reason is that NPV employs a weighted average cost of capital discount rate that reflects potential reinvestment while IRR does not. Because of this distinction, NPV is generally preferred as a more realistic measure of investment opportunity.
- If cash flows are not normal, IRR may arrive at multiple solutions. For example, if net outflows follow a period of net cash inflows, IRR may give conflicting results. If, following the completion of plant construction, it is necessary to invest in land reclamation or other incidental but significant expenses, an IRR calculation may result in multiple return rates, only one of which is correct.

The IRR of return for an investment is the rate of return (interest rate) that makes the present value of cash flow equal to the cost of the investment.

or

The IRR of an investment is the discount rate that makes the NPV of the investment equal to zero.

IRR can also be computed by this formula:

$$IRR = LDR + \frac{(HDR - LDR)NPV \text{ of } LDR}{NPV \text{ of } LDR - NPV \text{ of } HDR}$$

5. Payback Period

The intent of project payback period is to estimate the amount of time that will be necessary to recoup the investment in a project; that is, how long it will take for the project to pay back its initial budget and begin to generate positive cash flow for the company. In determining payback period for a project, we must employ a discounted cash flow analysis, based on the principal of the time value of money. The goal of the discounted cash flow (DCF) method is to estimate cash outlays and expected cash inflows resulting from investment in a project. All potential costs of development (most of which are contained in the project budget) are assessed and projected prior to the decision to initiate the project.

They are then com-pared with all expected sources of revenue from the project. For example, if the project is a new chemical plant, projected revenue streams will be based on expected capacity, production levels, sales volume, and so forth.

We then apply to this calculation a discount rate based on the firm's cost of capital. The value of that rate is weighted across each source of capital to which the firm has access (typically, debt and equity markets). In this way we weight the cost of capital, which can be calculated as follows:

$$K_{\text{firm}} = (w_d)(k_d)(1 - t) + (w_e)(k_e)$$

The weighted cost of capital is the percentage of capital derived from either debt (W*d*) or equity (W*e*) times the percentage costs of debt and equity (K*d* and K*e*, respectively). (The value refers to the company's marginal tax rate: Because interest payments are tax deductible, we calculate the cost of debt after taxes.)

There is a standard formula for payback calculations:

Payback period=investment/annual cash savings

The reciprocal of this formula can be used to calculate the average rate of return for the project. Once cost of capital has been calculated, we can set up a table projecting costs and revenue streams that are discounted at the calculated rate. The key is to determine how long it will take the firm to reach the breakeven point on a new project. Breakeven point represents the amount of time necessary to recover the initial investment of capital in the project. Shorter paybacks are more desirable than longer paybacks, primarily because the farther we have to project payback into the future, the greater the potential for additional risk.

6. Discounted Payback

Now that we have considered the time value of money, as shown in the NPV method, we can apply this logic to the simple payback model to create a screening and selection model with a bit more power. Remember that with NPV we use discounted cash flow as our means to decide whether or not to invest in a project opportunity. Now, let's apply that same principle to the discounted payback method. Under the discounted payback method, the time period we are interested in is the length of time until the sum of the discounted cash flows is equal to the initial investment.

Let’s try a simple example to illustrate the difference between straight payback and discounted payback methods. Suppose we require a 12.5% return on new investments and we have a project opportunity that will cost an initial investment of $30,000 with a promised return per year of $10,000. Under the simple payback model, it should only take three years to pay off the initial investment. However when we discount our cash flows at 12.5 percent and start adding them, it actually takes four years to pay back the initial project investment.

The advantage of the discounted payback method is that it allows us to make a more “intelligent” determination of the length of time needed to satisfy the initial project investment. That is, while simple payback is useful for accounting purposes, discounted payback is actually more representative of financial realities that all organizations must consider when pursuing projects. The effects of inflation and future investment opportunities do matter with individual investment decisions and so, should also matter when evaluating project opportunities.

Example

Payback Period (Contd)

Project cash flows ($)

Year	A	B	C
0	-2,400	-2,400	-2,400
1	600	800	500
2	600	800	700
3	600	800	900
4	600	800	1,100
5	600	800	1,300
Conventional payback (years):	4.0	3.0	3.3
Discounted payback (years)	5.2	3.8	4.1
Net present value(i=10%):	-126	633	868

Explanation

					Discounted Cash Flows		
Year	A	B	B		A	B	C
0	-2,400	-2,400	-2,400	i=10%	-2,400	-2,400	-2,400
1	600	800	500	0.909	545.45	727.27	454.55
2	600	800	700	0.826	495.87	661.16	578.51
3	600	800	900	0.751	450.79	601.05	676.18
4	600	800	1100	0.683	409.81	546.41	751.31
5	600	800	1300	0.621	372.55	496.74	807.2
		NPV			-126	633	868
		BCR			0.95	1.26	1.36

			Discounted Cash Flows	
Year	A		A	
0	-2,400	i=6%	-2,400	
1	600	0.943396	566.04	
2	600	0.889996	534.00	
3	600	0.839619	503.77	
4	600	0.792094	475.26	
5	600	0.747258	448.35	
		NPV (6%)	127	

IRR (Project A)

NPV (10%) = -126

NPV (6%) = 127

$$IRR = LDR + \frac{(HDR - LDR)NPV\ of\ LDR}{NPV\ of\ LDR - NPV\ of\ HDR}$$

$$= 6 + \frac{(10 - 6)*127}{127 - (-126)}$$

$$= 8\%$$

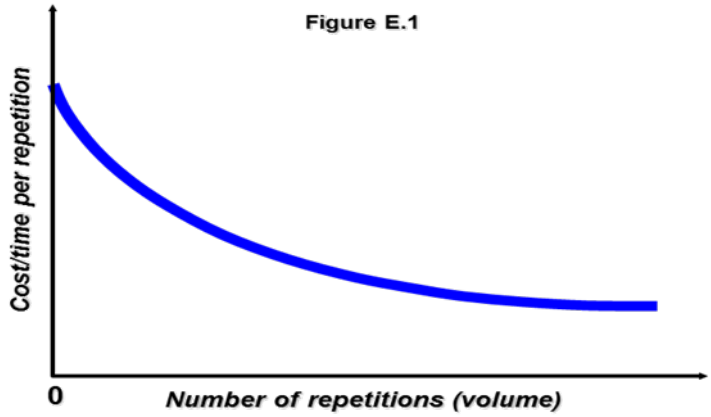
Lecture 29: Learning Curves and Decision Making Tools

What is Learning Curve?

Most organization learns and improves over time. As firms and employees perform a task over and over they learn how to perform more efficiently. This means that task times and costs decrease.

Learning curves are based on the premise that people and organization become better at their task as the tasks are repeated. A learning graph (illustrated in figure E.1) displays labor hours per unit versus the number of units produced. From it we can see that the time needed to produce a unit decrease usually following a negative exponential curve as the person of company produces more units. In other words it takes less time to complete each additional unit a firm produces. However we also see in figure E.1 that the time saving in completing each subsequent unit decreases. These are the major attributes of the learning curves.

Figure E.1



Learning carvers were first applied to industry in a report by T.P. Wright of Curtis – Wright Corp. in 1936. Wright describers how direct labor costs of

making a particular airplane decease with leaning, a theory since confirmed by the other aircraft manufactures. Regardless of the time needed to produce the first plant learning carver are found to apply to various categories of air frames. Learning curves have since been applied not only to labor but also to wide variety of other costs, including material and purchased components. The power of the learning curve is so significant that it plays a major role in many strategic decisions related to employment levels, costs, capacity and pricing.

The learning curve is based on a doubling of production; that is when production doubles the decrease in time per unit affects the rate of the learning curve. So if the learning curve is an 80% rate, the second unit takes 80% of the time of the first unit, the fourth unit takes 80% of the time of the second unit, the eighth unit takes 80% of the time of the fourth unit and so forth. His principle is shown as;

$T \times L^n$ = Time required for the n^{th} unit

Where

T	=	unit cost or unit time of the first unit
L	=	learning curve rate
n	=	number of times T is doubled

If the first unit took 10 labor-hours and if a 70% learning curve is present the hours the fourth unit will require doubling twice — 1 to 2 to 4. Therefore the formula is

Hours required for unit 4 = $10 \times (.7)^2$ = 4.9 hours

Learning Curve Examples

Learning Curves have wide range of application in service and manufacturing industry.

Example	***Improving Parameters***	***Cumulative Parameter***	***Learning-Curve Slope (%)***
Model -T Ford production	*Price*	*Units produced*	86
Aircraft assembly	*Direct labor-hours per unit*	*Units produced*	80
Equipment maintenance at GE	*Average time to replace a group of parts*	*Number of replacements*	76
Steel production	*Production worker labor-hours per unit produced*	*Units produced*	79

Uses of Learning Curves

Learning curves have application services as well as industry. For example 1-year death rates of heart transplant patients at Temple University Hospital follow a 79% learning curve. The results of that hospitals 3-year study of 62 patients receiving transplants found that every three operations resulted in a halving of

the 1-year death rates. As more hospital face pressure from both insurance companies and the government to enter fixed price negotiations for their services their ability to learn from experiences becomes increasingly critical. In addition to having applications in both services and industry learning curves are useful for a variety of purposes. These include:

- Internal: labor forecasting, scheduling, establishing costs and budgets
- External: supply chain negotiations
- Strategic: evaluation of company and industry performance, including costs and pricing

Applying the Learning Curve

A mathematical relationship enables us to express the time required to produce a certain unit. This relationship is a function of how many units have been produced before the unit in question and how long it took to produce them. To gain a mastery of this relationship we will work thorough learning curves scenarios using three different approaches

1. Arithmetic Approach
2. Logarithmic Approach
3. Learning curve coefficient

Arithmetic Approach

The Arithmetic Approach is the simplest approach to learning curve problems. As we noted at the beginning of this schedule, each time production doubles, labor per unit declines by a constant factor, known as the learning rate. So if we know that the learning rata is 80% and that the first unit produced took 100 hours, the hours required to produce the 2^{nd}, 4^{th}, 8^{th} and 16^{th} units are as follows:

Nth Unit Produced	*Hours for Nth Unit*	
1	**100.0**	
2	**80.0**	**= (.8 x 100)**
4	**64.0**	**= (.8 x 80)**
8	**51.2**	**= (.8 x 64)**
16	**41.0**	**= (.8 x 51.2)**

As long as we which to find the hours required to produce N units and N is one of the doubled values, then this approach works. Arithmetic analysis does not tell us how many hours will be needed to produce other units. For this flexibility we must turn to the logarithmic approach.

Logarithmic Approach

The Logarithmic Approach allows us to determine labor for any unit, *T*N, by the formula:

$$T_N = T_1(N^b)$$

Where T_N = *time for the* N^{th} *unit*

T_1 = *hours to produce the first unit*

b = (*log of the learning rate*)/ (*log* 2) slope *of the learning curve*

Some of the values of *b* are presented in table below;

Learning Rate (%)	*b*
70	**– .515**
75	**– .415**
80	**– .322**
85	**– .234**
90	**– .152**

Let's discuss an example which shows how this formula works.

Example No 1:

The learning rate for a typical CPA to conduct a dental proactive audit is 80%. Greg Lattier a new graduate of Lee College completed his first audit in 100 Hours. If the dental offices he audits are about the same, how long should he take to finish his third job?

Solution:

$T_N = T_1(N^b)$

$T_3 = (100\ hours)(3^b)$

$= (100)(3^{log\ .8/log\ 2})$

$= (100)(3^{-.322})$

$= 70.2\ labor\ hours$

Insight: Greg improved quickly form his first to his third audit. An 80% rate means that from just the first to second job, his time decreased by 20%

Learning Curve Coefficient Approach

The Learning Curve Coefficient technique is embodied in table and equation below;

$T_N = T_1 C$

Where T_N = *number of labor-hours required to produce the* N^{th} *unit*

T_1 = *number of labor-hours required to produce the first unit*

C = *learning-curve coefficient found in* Table (below)

The learning curve coefficient, C, depends on both the learning rate (70%, 75%, 80%, and so on) and the unit no of interest.

Table	70%		85%	
Unit Number (N)	Unit Time	Total Time	Unit Time	Total Time
1	1.000	1.000	1.000	1.000
2	.700	1.700	.850	1.850
3	.568	2.268	.773	2.623
4	.490	2.758	.723	3.345
5	.437	3.195	.686	4.031
10	.306	4.932	.583	7.116
15	.248	6.274	.530	9.861
20	.214	7.407	.495	12.402

Example No 2

It took a Korean shipyard a125, 000 labor hours to produce the first of several tugboats that you expect to purchase for your shipping company, Great Lakes, Inc. Boats 2 and 3 have been product by the Koreans with a learning factor of 85%. At $40 per hour, what should you, as purchasing agent, expect to pay for the fourth unit?

Solution:

$T_N = T_1 C$

$T_4 = (125{,}000\ hours)(.723)$

$= 90{,}375\ hours\ for\ the\ 4^{th}\ boat$

90,375 hours x $40/hour = $3,615,000

$T_N = T_1 C$

$T_4 = (125{,}000\ hours)\ (3.345)$

$= 418{,}125\ hours\ for\ all\ four\ boats$

Third boat required 100,000 hours

Learning factor = 85%

New estimate for the first boat

$$\frac{100{,}000}{.773} = 129{,}366\ Hours$$

Limitations of Learning Curves

Before using learning curves some cautions are in order:

- Learning curves differ from company to company as well as industry to industry so estimates should be developed for each organization
- Learning curves are often based on time estimates which must be accurate and should be reevaluated when appropriate

- ❖ Any changes in personnel, design, or procedure can be expected to alter the learning curve
- ❖ The culture of the workplace, resource availability, and changes in the process may alter the learning curve
- ❖ While workers and processes may improve, the same learning curves do not always apply to indirect labor and material.

Decision Modeling

The Decision Process in Operations

The operations managers are not gamblers but they are decision makers. To achieve the goals of their organizations managers must understand how decisions are made and know which decision making tools to use. To a great extent the success of failure of both people are companies depends on the quality of their decagons. Overcoming uncertainty is a manager's challenge.

What makes the difference between a good decision and a bad decision? A "good" decision one that uses analytical decision making is based on logic and considers all available data and possible alternatives. It also follows theses six steps:

1. Clearly define the problems and the factors that influence it
2. Develop specific and measurable objectives
3. Develop a model
4. Evaluate each alternative solution
5. Select the best alternative
6. Implement the decision and set a timetable for completion

Fundamentals of Decision Making

Regardless of the complexity of a decision or the sophistication of the technique used to analyze it, all decision makers are faced with alternatives and "states of nature." The following notation will be used in this module:

1. ***Terms:***

    a. *Alternative* – a course of action or strategy that may be chosen by the decision maker

    b. *State of* nature – an occurrence or a situation over which the decision maker has little or no control

2. ***Symbols used in a decision tree:***

    a. □ – decision node from which one of several alternatives may be selected

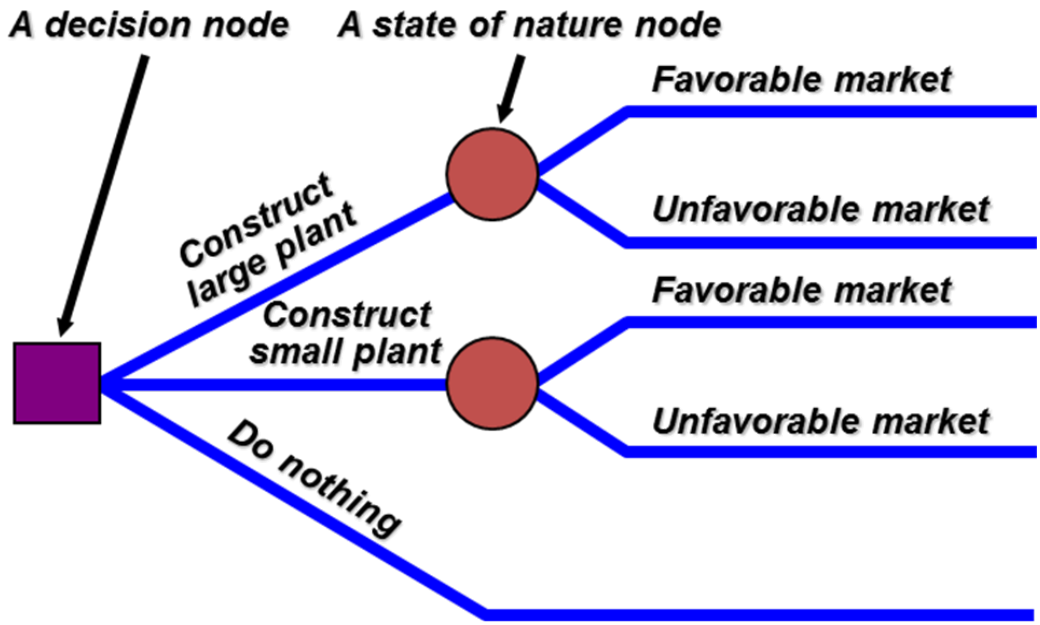
    b. ○ – a state-of-nature node out of which one state of nature will occur

To present a manager's decision alternatives, we can develop decision trees using the above symbols. When constructing a decision tree, we must be sure that all alternatives and states of nature are in their correct and logical places and that we include all possible alternatives and states of nature.

Example No 1: A simple Decision Tree

Getz Products Company is investigating the possibility of producing and marketing backyard storage sheds. Undertaking this project would require the construction of either a large or a small manufacturing plant. To market for the product produced storage sheds could be either factorable or unfavorable. Getz, of course has the option of not developing the new product line at all.

Solution:



Insight:

We never want to overlook the option of doing nothing as that is usually a possible decision.

Decision Tables

We may also develop a decision or payoff table to help Getz Products define its alternatives. For any alternative and a particular state of nature, there is a consequence of outcome, which is usually expressed as monetary value. This is called a conditional value. Note that all of the alternatives in example 2 are listed down the left side of the table, that states of nature (outcomes) are listed across the top, and that conditional values (payoffs) are in the body of the decision table.

Example No 2

Getz Products now wishes to organize the following information into a table. With a favorable market a large facility will give Getz Products a net profit of $200,000. If the market is unfavorable an $180,000 net loss will occur. A small

plant will result in a net profit of $100,000 in a favorable market, but a net loss of $20,000 will be encountered if the market is unfavorable.

Solution:

	State of Nature	
Alternatives	Favorable Market	Unfavorable Market
Construct large plant	$200,000	–$180,000
Construct small plant	$100,000	–$ 20,000
Do nothing	$ 0	$ 0

Insight:

The toughest part of decision tables is obtaining the data to analyze.

Decision-Making Environments

The type of decisions people make depends on how much knowledge or information they have about the situation. There are three decision making environments:

1. Decision making under uncertainty
2. Decision making under risk
3. Decision making under certainty

Decision making under uncertainty

When there is complete uncertainty as to which state of nature in a decision environment may occur (i.e., when we cannot even assess probabilities for each possible outcome), we rely on three decision methods:

Maximax

This method finds the alternative that maximizes the maximum outcome for every alternative. First we find the maximum outcome within every alternative, and then we pick the outcome with the maximum number because this decision criteria locates the alternative with the highest possible gain, it has been called an optimistic decision criteria.

Maximin

This method find the alternative that maximizes the minimum outcome for every alternative First we find the minimum outcome within every alternative, and then we pick the outcome with the minimum number because the decision criteria locates the alternative that has the least possible loss, it has been called a pessimistic decision criteria.

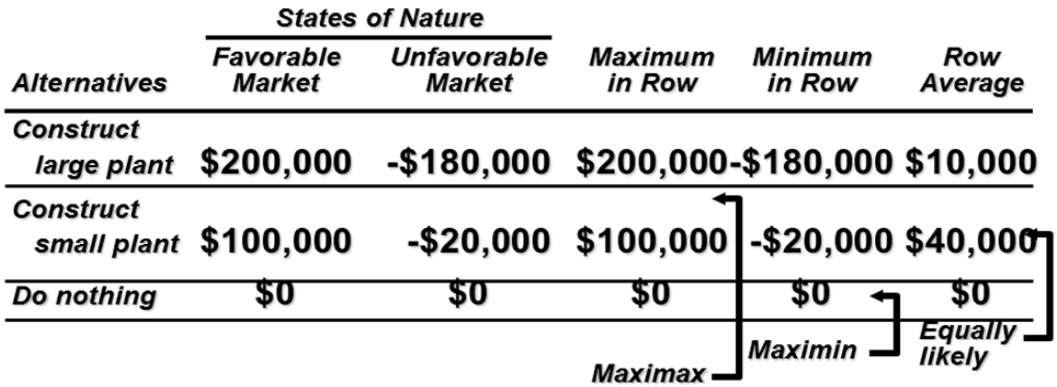
Equally likely

This method find the alternative with highest average outcome for every alternative First we calculate the average outcome for every alternative which is the sum of all outcomes divided by the number of outcome. We then pick the outcome with the maximum number. The equally likely approach assumes that each state of nature is equally likely to occur.

Example no 2

Company would like to apply all of these approaches on decision table of example no 2.

Solution:



1. Maximax choice is to construct a large plant
2. Maximin choice is to do nothing
3. Equally likely choice is to construct a small plant

Insight:

There are optimistic decision makers and pessimistic ones. Maximax and maximin present best case –worst case planning scenarios.

Decision making under risk

Decision making under risk, a more common occurrence, relies on probabilities. Several possible states of nature may occur, each with an assumed probability. The States of nature are mutually exclusive and collectively exhaustive and their probabilities must sum to 1. Given a decision table with conditional values and probability assessments for all states of nature we can determine the **expected monetary value (EMV)** for each alternative. This figure represents the expected value or mean return for each alternative if we could repeat this decision a large no of times.

The EMV for an alternative is the sum of all possible payoffs from the alternative, each weighted by the probability of that payoff occurring:

EMV (Alternative i) = (Payoff of 1st state of nature) x (Probability of 1st state of nature)

\+ (Payoff of 2nd state of nature) x (Probability of 2nd state of nature)

+…+ (Payoff of last state of nature) x (Probability of last state of nature)

Example No 4: Getz would like to find the EMV for each alternative

Getz Products operations manager believes that the probability of a favorable market is exactly the same as that of an unfavorable market; that is each state of nature has a 50 chance of occurring. He can now determine the EMV for each alternative.

Table	States of Nature	
Alternatives	Favorable Market	Unfavorable Market
Construct large plant (A1)	$200,000	-$180,000
Construct small plant (A2)	$100,000	-$20,000
Do nothing (A3)	$0	$0
Probabilities	.50	.50

Solution:

1. EMV(A_1) = (.5)($200,000) + (.5)(-$180,000) = $10,000
2. EMV(A_2) = (.5)($100,000) + (.5)(-$20,000) = $40,000
3. EMV(A_3) = (.5)($0) + (.5)($0) = $0

Insight:

The maximum EMV is seen in alternative A2. Thus according to eh EMV decision criteria Getz would build the small facility.

Decision Making under Certainty

Now suppose that the Getz operations manager has been approached by a marketing research firm that proposed to help him make the decision about whether to build the plant to produce storage sheds. The marketing researchers claim that their technical analyze will tell Getz with certainty whether the market is favorable for the proposed product. In other words it will change the Getz's environment from one of decision making under risk to one of decision making under certainty. This information could prevent Getz from making a very expensive mistake. The marketing research would charge Getz $65,000 for the information. What would you recommend? Should the operations manager hire the firm to make the study? Even if the information from the study is perfectly accurate, is it worth $65,000? What might it be worth? Although some of these questions are difficult to answer, determine the value of such perfect information can be very useful. It places an upper bound on what you would be willing to spend on information, such as that being sold by marketing consultant. This is the concept of expected value of perfect information (EVPI), which we now introduce.

Expected Value of Perfect Information (EVPI)

If a manger was able to determine which state of nature would occur, then he or she would know which decision to make. Once a manager knows which decision to make, the payoff increases because the payoff is now a certainty, not a probability because the payoff will increase with knowledge of which state of nature will occur, this knowledge has value. Therefore we now look at how to determine the value of this information. We call this difference between the payoff under the perfect information and the payoff under risk the expected value of perfect information (EVPI).

EVPI = expected value of perfect information – Maximum EMV

To find the EVPI, we must first compute the expected value with perfect information (EVwPI), which is expected (average) return if we have perfect information before a decision has to be made. To calculate this value, we choose the best alternative for each state of nature and multiply its payoff times the probability of occurrence of that state of nature:

Expected value with perfect information (EVwPI)	=	(Best outcome or consequence for 1st state of nature) x (Probability of 1st state of nature)
	+	Best outcome for 2nd state of nature) x (Probability of 2nd state of nature)
	+	… + Best outcome for last state of nature) x (Probability of last state of nature)

Example No 5

In example no 5 we will use the data and decision table from example no 4 to examine the expected value of perfect information.

Solution:

1. The best outcome for the state of nature "favorable market" is "build a large facility" with a payoff of $200,000. The best outcome for "unfavorable" is "do nothing" with a payoff of $0.

Expected value with perfect information= = ($200,000)(.50) + ($0)(.50) = $100,000

2. The maximum EMV is $40,000, which is the expected outcome without perfect information. Thus:

EVPI = EVwPI - Maximum EMV

= $100,000 – $40,000 = $60,000

The most the company should pay for perfect information is $60,000

Decision Trees

Decisions that lend themselves to display in a decision table also lend themselves to display in a decision tree. We will therefore analyze some decisions using decision trees. Although the use of a decision table is convenient in problems having one set of decisions and one set of states of nature, many problems include sequential decisions and state of nature.

When there are two or more sequential decisions and later decisions are based on the outcome of prior ones, the decision tree approach becomes appropriate. A **decision tree** is a graphic display of the decision process that indicates decision

alternatives, states of nature and their respective probabilities, and payoffs for each combination of decision alternative and state of nature.

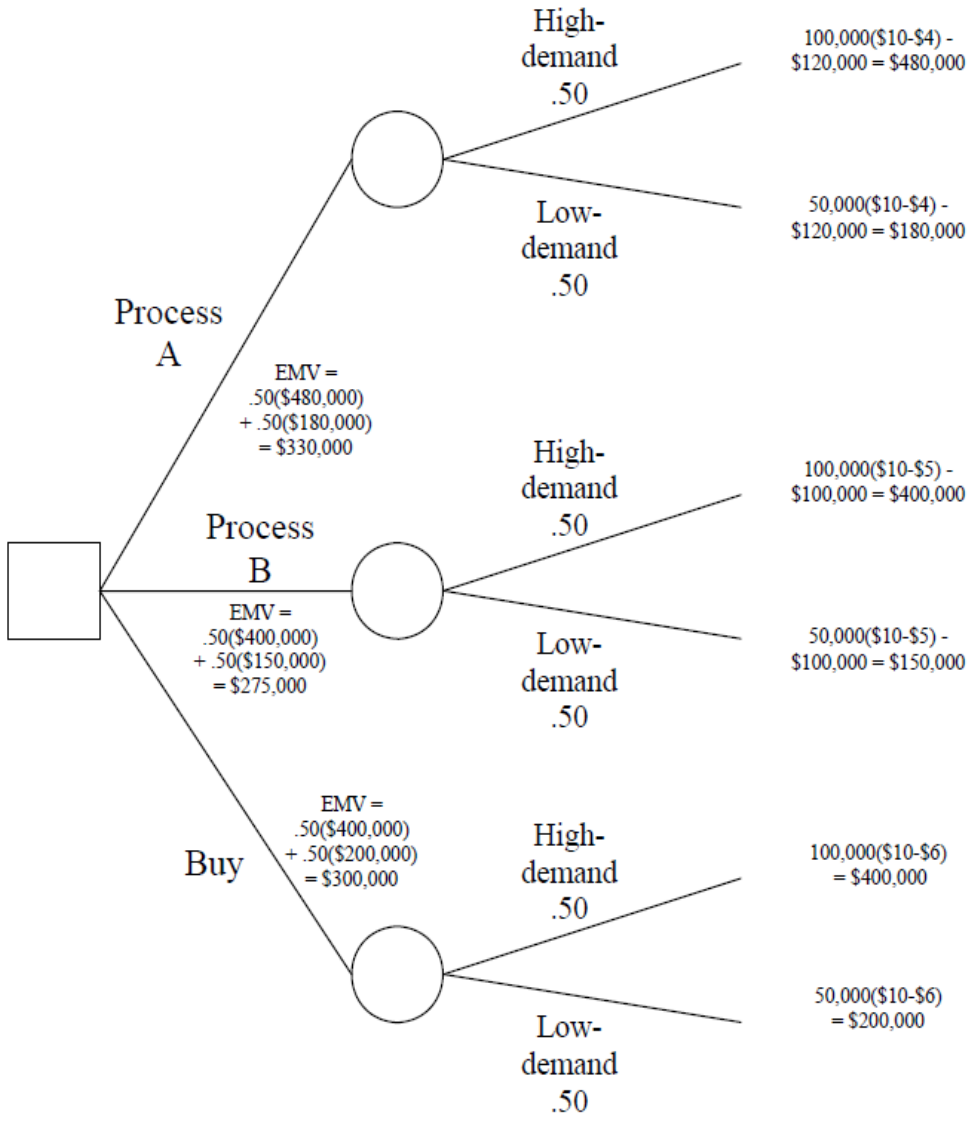
Expected monetary value (EMV) is the most commonly used criteria for the decision tree analysis. One of the first steps in such analysis is to graph the decision tree and to specify the monetary consequences of all outcomes for a particular problem.

Analyzing problems in decision trees involves five steps:

1. Define the problem
2. Structure or draw the decision tree
3. Assign probabilities to state of nature
4. Estimate payoffs for each possible combination of decision alternatives and states of nature
5. Solve the problem by computing the expected monetary values (EMV) for each state of nature node. This is done by working backward that is by starting at the right of the tree and working back to decision nodes on the left.

Example No 6:

Tri-products is trying to decide whether to make-or-buy an accessory item for one of their products. It is projected that this item will sell for $10 each. If the item is outsourced, there is virtually no cost other than the $6 per unit that they would pay their supplier. Internally, they have two choices. Process A requires an investment of $120,000 for design and equipment, but results in a $4 per unit cost. Process B requires only a $100,000 investment, but its per unit cost is $5. Regardless of whether the item is subcontracted or produced internally, there is a 50% chance that they will sell 50,000 units, and a 50% chance that they will sell 100,000 units. Draw the decision tree appropriate to the alternatives and outcomes stated. Using decision trees and EMV, what is their best choice?

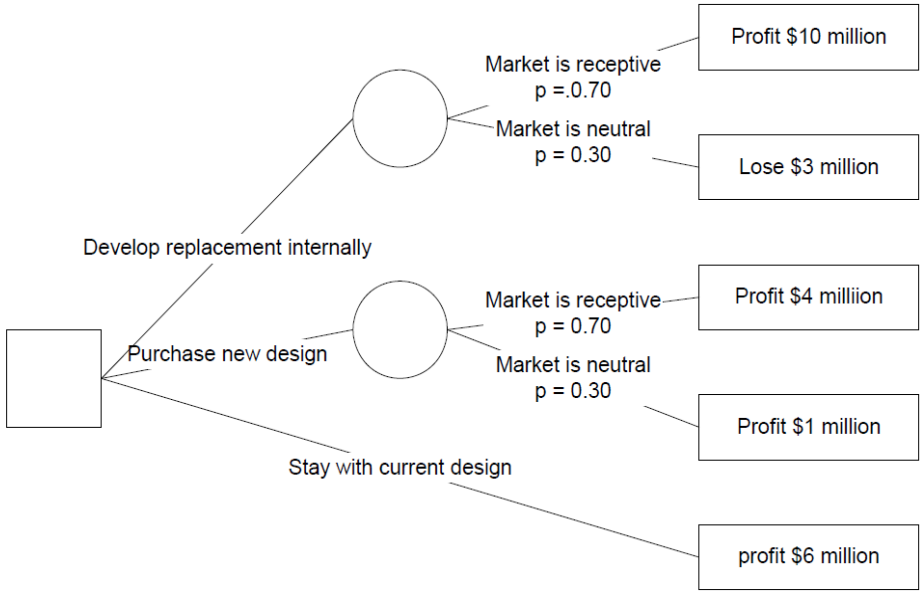


Process A promises the highest profit with an EMV of $330,000.

Example No 6:

A company manufactures specialty pollution-sensing devices for the offshore oil industry. One particular device has reached maturity, and the company is considering whether to replace it with a newer model. Technologies have not changed dramatically, so the new device would have similar functionality to the existing one, but would be smaller and lighter in weight. The firm's three choices are: keep the old model; design a replacement device with internal resources; and purchase a new design from a firm that is one of its suppliers. The market for these devices will be either "receptive" or "neutral" of the replacement model. The financial estimates are as follows: Keeping the old design will yield a profit of $6 million dollars. Designing the replacement internally will yield $10 million if the market is "receptive," but a $3 million loss if the market is "neutral." Acquiring the new design from the supplier will profit $4 million under "receptive," $1 million under "neutral." The company feels that the market has a 70 percent chance of being "receptive" and a 30 percent chance of being "neutral." Draw the appropriate decision tree. Calculate expected value for all courses of action. What action yields the highest expected value?

Solution:



The three expected monetary values are:

- Develop replacement internally: $10,000,000 x .7 -$3,000,000 x .3 = $6.1 million
- Purchase new design: $4,000,000 x .7 + $1,000,000 x .3 = $3.1 million
- Stay with current design: $6 million

The company should choose the highest value, and develop a replacement product design with internal resources.

Lecture 30: - Operations Strategy in a Global Environment

- Human Resources and Job Design

Reasons to Globalize:

Following are the main reasons for globalize.

1. **Reduce costs (labour, taxes, tariffs, etc.)**
2. **Improve supply chain**
3. **Provide better goods and services**
4. **Understand markets**
5. **Learn to improve operations**
6. **Attract and retain global talent**

Tangible Reasons



Intangible Reasons

Reduce Costs

Foreign locations with lower wage rates can lower the costs. International trade agreements also help reduce the tariff and operating business in foreign countries.

Improve the Supply Chain

This path to Supply Chain Excellence will position your organization for success now and into the future, says Jim Tompkins, president of Tompkins Associates, a Raleigh, NC-based supply chain consulting and material handling integration firm. He's talking about the Supply Chain Improvement Strategies, designed to transcend the shifts taking place in technology, channel structures, globalization, sourcing, and customer demands, and help you decide on a clear path to improvement.

1. Educate. All departments within your link and all links in your supply chain must have a common understanding of the supply chain.
2. Benchmark. Understand how your performance compares to your competitors, to other industries, and to best in class.
3. Assessment. Understand the status of all departments within your link and all links in your supply chain. Compare them to the Six Levels of Supply Chain Excellence:

- Level I, Business as Usual
- Level II, Link Excellence
- Level III, Visibility
- Level IV, Collaboration
- Level V, Synthesis
- Level VI, Velocity

4. Prioritize. Use the information from your benchmark and assessment efforts to identify specific targets for supply chain enhancements.

5. Weakest Link. Be aware that the weakest department within your link and the weakest link in your supply chain will drive performance.

6. Communicate. Even over-communicate with all involved in your supply chain so that everyone understands what, why, when, who and when. Let there be no surprises.

7. Partnerships. Only join with supply chain partners who are ready to partner. Partnering with a link that has not achieved Level II Link Excellence will not net positive results.

8. Leadership. On each supply chain initiative, identify the proper skill sets required to lead the effort. Assure clarity of roles and responsibilities and cultural compatibility.

9. Core Competencies. Identify these, focus on them and outsource the rest. Determine the unique business processes that make you successful, and then use a robust process to outsource other functions.

10. Continuous Improvement. An ongoing process is required for you to pursue Supply Chain Excellence. Never stop pushing for the next level of excellence.

By following these strategies, says Tompkins, you will be aware of coming trends and be able to choose the ones that best fit your company's goals and culture.

Provide Better Goods and Services

Although the characteristics of goods and services can be objective and measureable (e.g., number of on- time deliveries), they can also be subjective ences in culture and of the way business is handled in different countries. Improved understandings the result of a local presence permits firms to customize products and services to meet unique cultural needs in foreign markets.

Another reason to have international operations is to reduce response time to meet customer`s changing products and services requirements. Customer s that purchase goods and services from U.S firms are increasingly localed in foreign countries. Providing them with quick and adequate services is often improved by locating facilities in their home countries.

Understand Markets

Because international operation require interaction with foreign customers, suppliers, and other competitive businesses, international firms inevitably learn about opportunities for new products and services, Europe led the way with cell phones innovation , and now the japans lead with the latest cell phone fads. Knowledge of these markets not only helps firms understand where the market is going but also helps firms diversify their customer's base, add production flexibility, and smooth the business cycle.

Learn to Improve Operations

Learning does not take place in isolation .Firms serve themselves and their customers well when they remain open to free flow of idea. For example, GM found that it could improve operations by jointly buildings operations by jointly buildings and running, with the Japanese, an auto assembly plant in San Jose, California. This strategy allowed GM to contributed production and inventory ideas. Similarly, Operations manager have improved equipment and layout by learning from the ergonomic competence of Scandinavians.

Attract and Retain Global Talent

Global organizations can attract and retain better employees by offering more employment opportunities. They need people in all functional areas and areas of expertise worldwide. Global firms can recruit and retain good employees because they provide both greater growth opportunities and insulation against

unemployment during times the mean to relocate unneeded personnel to more prosperous locations.

S, to recap, successfully achieving a competitive advantage in our shrinking world means maximizing all of possible opportunities, from tangible to intangible that international operation can offer.

Cultural and Ethical Issues

While there are great forces driving ferns toward globalization, many challenges remain. One of these challenges is reconciling differences in social and culture behavior. With issues ranging from bribery, to child labor, to the enjoinment, mangers sometime do not know how to respond when operating in different culture. What one country`s culture deems acceptable may be considered unacceptable or illegal in other. It is not by chance that there are fever female managers in the Middle East than in India.

In the last decade, changes in international laws, agreements, and codes of conduct have been applied to define ethical behavior among managers around the world. The WTO, for example, helps to make uniform the protection of both governments and industries from foreign firms that engage in unethical conduct. Even on issues where significant differences between cultures exist, as in the area of bribery or the protection of intellectual property, global uniformity is slowly being accepted by most nations.

In spite of cultural and ethical differences, we live in a period of extraordinary mobility of capital, information, goods, and even people. We can expect this to continue. The financial sector, the telecommunications sector, and the logistics infrastructure of the world are healthy institutions that foster efficient and effective use of capital, information, and goods. Globalization, with all its opportunities and risks, is here and will continue. It must be embraced as managers develop their missions and strategies.

Issues in Operations Strategy

Whether the OM strategy is differentiation, cost, or response OM is a critical player. Therefore, prior to establishing and attempting to implement a strategy, some alternate perspectives may be helpful. One perspective is to take a resources view. This means thinking in terms of the financial, physical, human, and technological resources available and ensuring that the potential strategy is compatible with those resources. Another perspective is Porter's value-chain analysis. Value-chain analysis is used to identify activities that represent strengths, or potential strengths, and may be opportunities for developing competitive advantage. These are areas where the firm adds its unique value through product research, design, human resources, supply-chain management, process innovation, or quality management. Porter also suggests analysis of competitors via what he calls his five forces model. These potential competing forces are immediate rivals, potential entrants, customers, suppliers, and substitute products.

In addition to the competitive environment, the operations manager needs to understand that the firm is operating in a system with many other external factors. These factors range from political, to legal, to cultural. They influence strategy development and execution and require constant scanning of the environment. The firm itself is also undergoing constant change. Everything from resources, to technology, to product life cycles is in flux. Consider the significant changes required within the firm as its products move from introduction, to growth, to maturity, and to decline. These internal changes, combined with external changes, require strategies that are dynamic.

In this chapter's Global Company Profile, Boeing provides an example of how strategy must change as technology and the environment change. Boeing can now build planes from carbon fiber , using a global supply

chain. Like many other OM strategies, Boeing's strategy has changed with technology and globalization. Microsoft has also had to adapt quickly to a changing environment. Faster processors, new computer languages, changing customer preferences, increased security issues, the internet, and Google have all driven changes at Microsoft. These forces have moved Microsoft's product strategy from operating systems to office products, to internet service provider, and now to integrator of computers, cell phones, games, and television.

The more thorough the analysis and understanding of both the external and internal factors, the more likely that a firm can find the optimum use of its resources. Once a firm understands it and the environment, a SWOT analysis, which we discuss next, is in order.

Strategy Development and Implementation

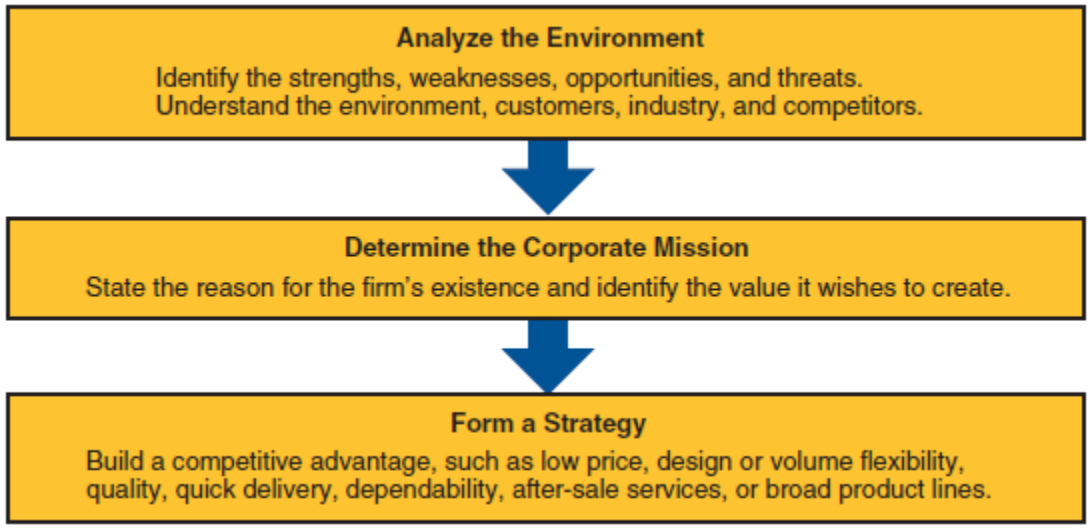
A **SWOT analysis** is a formal review of the internal Strengths and Weakness and the external Opportunity and Threats. Beginning with SWOT analyses, organizations position themselves, through their strategy, to have a competitive advantage. A firm may have excellent design skills or great talent at identifying outstanding locations. However, it may recognize limitations of its manufacturing process or in finding good suppliers. The idea is to maximize opportunities and minimize threats in the environment while maximizing the advantages of the organization's strengths and minimizing the weaknesses. Any preconceived ideas about mission are then reevaluated to ensure they are consistent with the **SWOT analysis.** Subsequently, a strategy for achieving the mission is developed. This strategy is continually evaluated against the value provided customers and competitive realities. Key success factors are identified.

KEY SUCCESS FACTORS AND CORE COMPETENCIES

Because no firm does everything exceptionally well, a successful strategy requires determining the firm's critical success factors and core competencies.

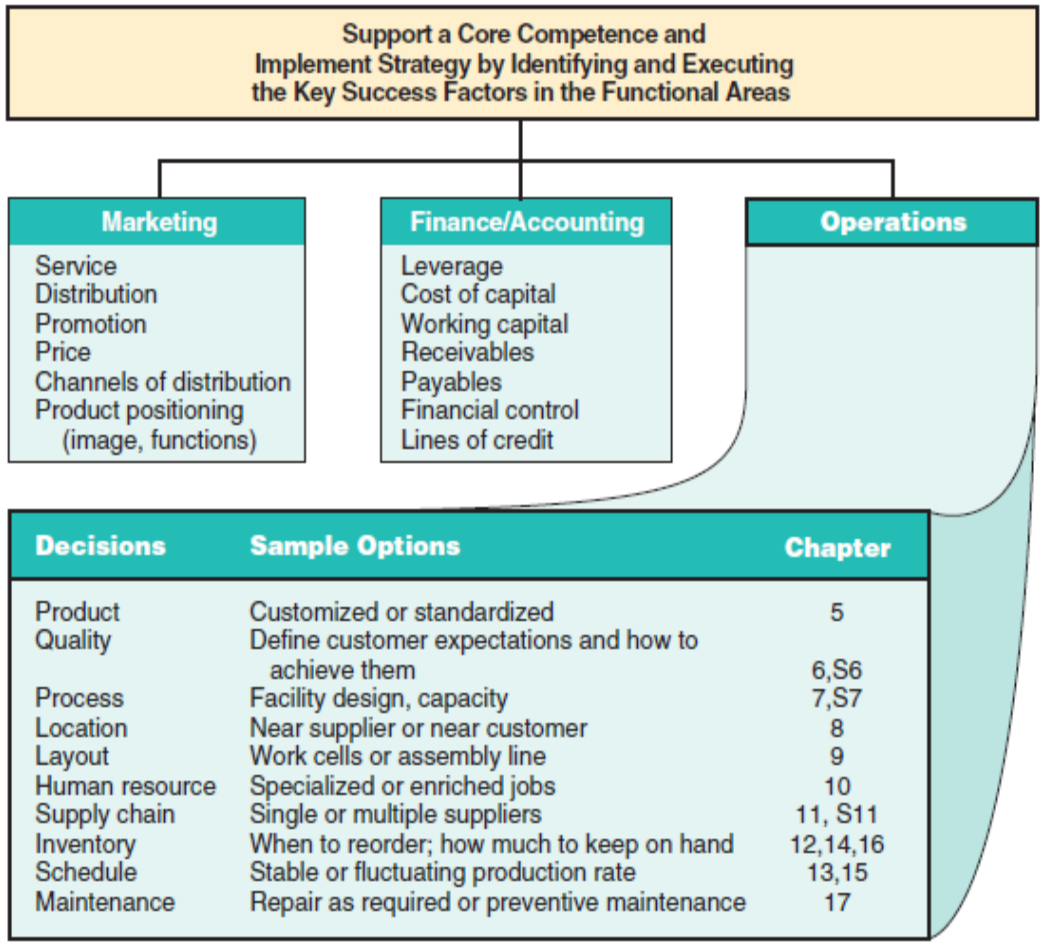
Key success factors (KSFs) are those activities that are necessary for a firm to achieve its goals. Key success factors can be so significant that a firm must get them right to survive in the industry. A KSF for McDonald's, for example, is layout. Without a play area, an effective drive-thru, and an efficient kitchen, McDonald's cannot be successful. KSFs are often necessary, but not sufficient for competitive advantage. On the other hand, **core competencies** are the set of unique skills, talents, and capabilities that a firm does at a world-class standard. They allow a firm to set it apart and develop a competitive advantage. Organizations that prosper identify their core competencies and nurture them. While McDonald's KSFs may include layout, its core competency may be consistency and quality. Honda Motors's core competence is gas-powered engines—engines for automobiles, motorcycles, lawn mowers, generators, snow blowers, and more. The idea is to build KSFs and core competencies that provide a competitive advantage and support a successful strategy and mission. A core competence may be a subset of KSFs or a combination of KSFs. The operations manager begins this inquiry by asking:

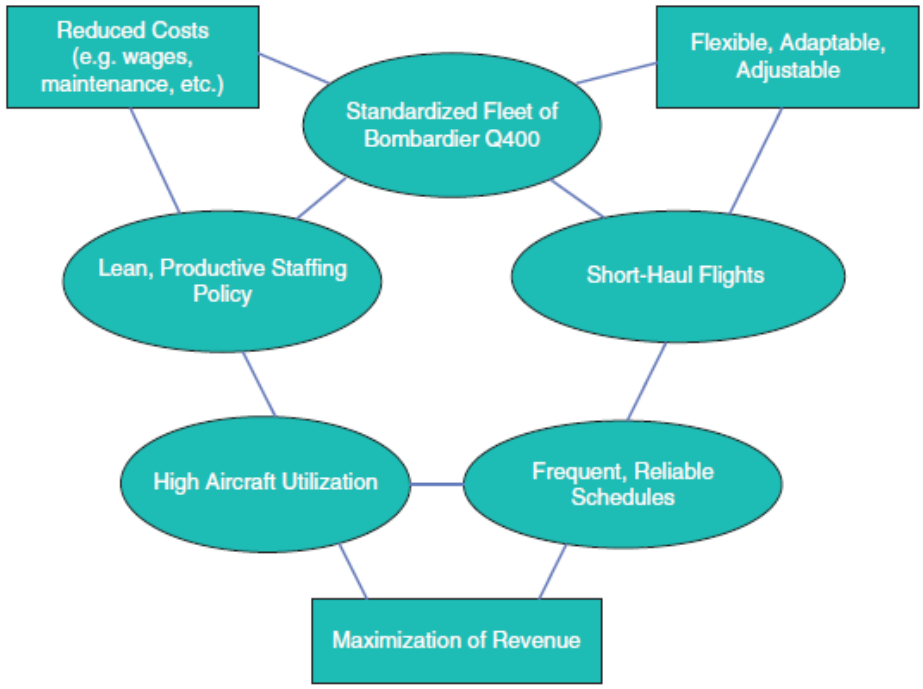
• "What tasks must be done particularly well for a given strategy to succeed?"
• "Which activities will help the OM function provide a competitive advantage?"
• "Which elements contain the highest likelihood of failure, and which require additional commitment of managerial, monetary, technological, and human resources?"



Only by identifying and strengthening key success factors and core competencies can an organization achieve sustainable competitive advantage? In this text we focus on the 10 OM decisions that typically include the KSFs. Potential KSFs for marketing, finance, and operations are shown. The 10 OM decisions we develop in this text provide an excellent initial checklist for determining KSFs and identifying core competencies within the operations function. For instance, the 10 decisions, related KSFs, and core competencies can allow a firm to differentiate its product or service. That differentiation may be via a core competence of innovation and new products, where the KSFs are product design and speed to market, as is the case for 3M and Rubbermaid. Similarly, differentiation may be via quality, where the core competence is institutionalizing quality, as at Toyota. Differentiation may also be via maintenance, where the KSFs are product reliability and after-sale service, as is the case at IBM and Canon. Whatever the KSFs and core competences, they must be supported by the related activities. One approach to identifying the activities is an **activity map**, which links competitive advantage, KSFs, and supporting activities. For example, Figure 2.8 shows how Porter Airlines, whose core competence is operations, built a set of integrated activities to support its low-cost competitive advantage. Notice how the KSFs support operations and in

turn are supported by other activities. The activities fit together and reinforce each other. And the better they fit and reinforce each other, the more sustainable the competitive advantage. By focusing on enhancing its core competence and KSFs with a supporting set of activities, Porter Airlines has become one of the great airline success stories.





▲ **FIGURE 2.8 Activity Mapping of Porter Airline's Low-Cost Competitive Advantage**

To achieve a low cost competitive advantage, Porter Airlines addresses a number of key success factors. As the figure illustrates, a low cost advantage is highly dependent on a very well-run operations function.

BUILD AND STAFF THE ORGANIZATION

The operations manager's job is a three-step process. Once a strategy and key success factors have been identified, the second step is to group the necessary activities into an organizational structure. The third step is to staff it with personnel who will get the job done. The manager works with subordinate managers to build plans, budgets, and programs that will successfully implement strategies that achieve missions. Firms tackle this organization of the operations function in a variety of ways. The organization charts shown in Chapter 1 (Figure 1.1) indicate the way some firms have organized to perform the required activities.

INTEGRATE OM WITH OTHER ACTIVITIES

The organization of the operations function and its relationship to other parts of the organization

vary with the OM mission. Moreover, the operations function is most likely to be successful when the operations strategy is integrated with other functional areas of the firm, such as marketing, finance, information technology, and human resources. In this way, all of the areas support the company's objectives. For example, short-term scheduling in the airline industry is dominated by volatile customer travel patterns. Day-of-week preference, holidays, seasonality, school schedules, and so on all play a role in changing flight schedules. Consequently, airline scheduling although an OM activity can be a part of marketing. Effective scheduling in the trucking industry is reflected in the amount of time trucks travel loaded. However, scheduling of trucks requires information from delivery and pickup points, drivers, and other parts of the organization.When the OM function results in effective scheduling in the air passenger and commercial trucking industries, a competitive advantage can exist. The operations manager transforms inputs into outputs. The transformations may be in terms of storage, transportation, manufacturing, dissemination of information, and utility of the product or service. *The operations manager's job is to implement an OM strategy, provide competitive advantage, and increase productivity.*\

Global Operations Strategy Options

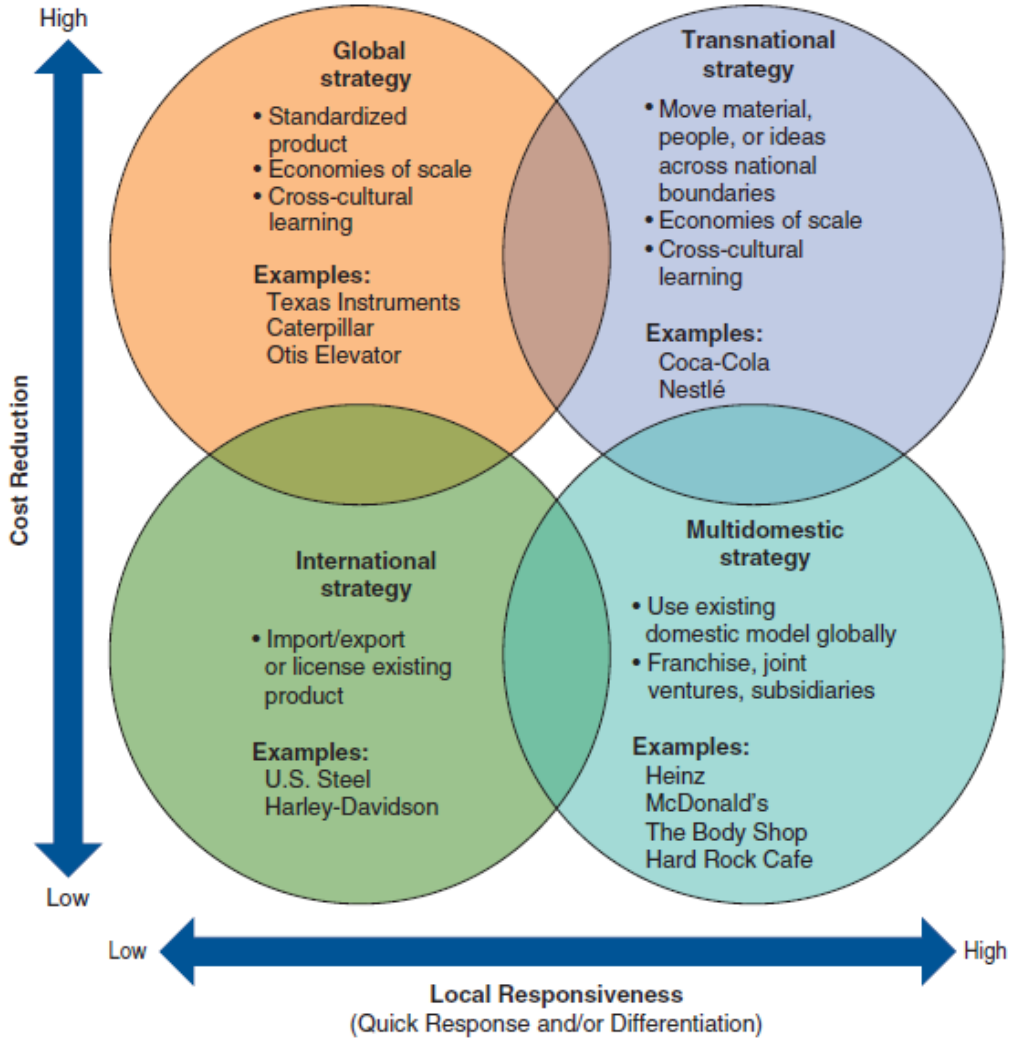
As we suggested early in this chapter, many operations strategies now require an international dimension. We tend to call a firm with an international dimension an international business or a multinational corporation. An international business is any firm that engages in international trade or investment. This is a very broad category and is the opposite of a domestic, or local, firm.

A multinational corporation (MNC) is a firm with extensive international business involvement MNCs buy resources, create goods or services, and sell goods or services in a variety of countries. The term

multinational corporation applies to most of the world's large, well-known businesses. Bombardier is a good example of an MNC. It has a presence in 60 countries worldwide, including 76 production and engineering sites. Bombardier acquires parts and raw materials from around the world, and ships its finished products (including planes, trains and buses) toits customers where ever they may be. Operations managers of international and multinational firms approach global opportunities with one of four operations strategies: international, multi domestic, global, or transnational (see Figure 2.9). The matrix of Figure 2.9 has a vertical axis of cost reduction and a horizontal axis of local responsiveness. Local responsiveness implies quick response and/or the differentiation necessary for the local market. The operations manager must know how to position the firm in this matrix. Let us briefly examine each of the four strategies.

INTERNATIONAL STRATEGY

An international strategy uses exports and licenses to penetrate the global arena. As Figure 2.9 suggests, the international strategy is the least advantageous, with little local responsiveness and little cost advantage. There is little responsiveness because we are exporting or licensing goods from the home country. And the cost advantages may be few because we are using the existing production process at some distance from the new market. However, an international strategy is often the easiest, as exports can require little change in existing operations, and licensing agreements often leave much of the risk to the licensee.



MULTI DOMESTIC STRATEGY

The multi domestic strategy has decentralized authority with substantial autonomy at each business. Organizationally these are typically subsidiaries, franchises, or joint ventures with substantia independence. The advantage of this strategy is maximizing a competitive response for the local market; however, the strategy has little or no cost advantage. Many food producers, such as Heinz, use a multi domestic strategy to accommodate local tastes because global integration of the production process is not critical. The concept is one of "we were successful in the home market; let's export the management talent and processes, not necessarily the product, to accommodate another market." McDonald's is

operating primarily as a multi domestic, which gives it the local responsiveness needed to modify its menu country by country. McDonald's can then serve beer in Germany, wine in France, McHuevo (poached egg hamburger) in Uruguay, and hamburgers without beef in India. With over 2000 restaurants in Japan and a presence for more than a generation, the average Japanese family thinks Japan invented McDonald's. Interestingly, McDonald's prefers to call itself multi local.

GLOBAL STRATEGY

A global strategy has a high degree of centralization, with headquarters coordinating the organization to seek out standardization and learning between plants, thus generating economies of scale. This strategy is appropriate when the strategic focus is cost reduction but has little to recommend it when the demand for local responsiveness is high. Caterpillar, the world leader in earth-moving equipment, and Texas Instruments, a world leader in semiconductors, pursue global strategies. Caterpillar and Texas Instruments find this strategy advantageous because the end products are similar throughout the world. Earth-moving equipment is the same in Nigeria as in Prince Edward Island, which allows Caterpillar to have individual factories focus on a limited line of products to be shipped worldwide. This results in economies of scale and learning within each facility. A global strategy also allows Texas Instruments to build optimum-size plants with similar processes and to then maximize learning by aggressive communication between plants. The result is an effective cost reduction advantage for Texas Instruments.

TRANSNATIONAL STRATEGY

A transnational strategy exploits the economies of scale and learning, as well as pressure for responsiveness, by recognizing that core competence does not reside in just the “home” country but can exist anywhere in the organization. Transnational describes a condition in which material, people, and ideas cross—or transgress —national boundaries. These firms have the potential to pursue all three operations strategies (i.e., differentiation, low cost, and response). Such firms can be thought of as “world companies” whose country identity is not as important as its interdependent network of worldwide operations. Key activities in a transnational company are neither centralized in the parent company nor decentralized so that each subsidiary can carry out its own tasks on a local basis. Instead, the resources and activities are dispersed, but specialized, so as to be both efficient and flexible in an interdependent network. Nestlé is a good example of such a company. Although it is legally Swiss, 95% of its assets are held and 98% of its sales are made outside Switzerland. Fewer than 10% of its workers are Swiss. Similarly, service firms such as Asea Brown Boveri (an engineering firm that is Swedish but headquartered in Switzerland), Reuters (a news agency), Bertelsmann (a publisher), and Citicorp (a banking corporation) can be viewed as transnational’s. We can expect the national identities of these transnational’s to continue to fade.

Human Resource Strategy

The objective of a human resource strategy is to manage labor and design jobs so people are effectively and efficiently utilize.

1. People should be effectively utilized within the constraints of other operations management decisions
2. People should have a reasonable quality of work life in an atmosphere of mutual commitment and trust

Labor Planning

Following are the different Employment Stability Policies with respect to Labor Planning:

1. ***Follow demand exactly***
    - Matches direct labor costs to production
    - Incurs costs in hiring and termination, unemployment insurance, and premium wages
    - Labor is treated as a variable cost
2. ***Hold employment constant***
    - Maintains trained workforce
    - Minimizes hiring, termination, and unemployment costs
    - Employees may be underutilized during slack periods
    - Labor is treated as a fixed cost

Work Schedules

Following work schedules can be applied in the organizations:

1. Standard work schedule

- Five eight-hour days

2. Flex-time

- Allows employees, within limits, to determine their own schedules

3. Flexible work week

- Fewer but longer days

4. Part-time

- Fewer, possibly irregular, hours

Job Classification and Work Rules

Following are important considerations:

- Specify who can do what
- Specify when they can do it
- Specify under what conditions they can do it
- Often result of union contracts
- Restricts flexibility in assignments and consequently efficiency of production

Job Design

It involves specifying the tasks that constitute a job for an individual or a group

- Job specialization
- Job expansion
- Psychological components
- Self-directed teams
- Motivation and incentive systems

Labor Specialization

It involves the division of labor into unique tasks. It helps faster learning by the employees to complete specialized tasks in time. It helps to compensate the employees for the required specialized skills

Job Expansion

It involves adding more variety to jobs and intended to reduce boredom associated with labor specialization: It may have following forms:

- Job enlargement
- Job rotation
- Job enrichment
- Employee empowerment

Job enlargement involves adding the job responsibilities horizontally and job enrichment involves adding the job responsibilities vertically. Job rotation is periodic shifting of employees from one job to another. Job empowerment involves the authority to employees related to a particular job.

Core Job Characteristics

Following are the core job characteristics which makes a job more attractive:

- Skill variety: Job which requires different skills on part of employees
- Job identity: The job which is more identifiable to the whole
- Job significance: The job which has significant impact
- Autonomy: Job with more independence and freedom

- Feedback: Job with a specific mechanism of feedback

Self-Directed Teams

These are group of empowered individuals working together to reach a common goal. These may be organized for long-term or short-term objectives. These are effective because it provides employee empowerment, ensure core job characteristics and meet individual psychological needs. In order to maximize the effectiveness of teamwork, managers should:

- Ensure those who have legitimate contributions are on the team
- Provide management support
- Ensure the necessary training
- Endorse clear objectives and goals
- Financial and non-financial rewards
- Supervisors must release control

Following are the benefits of teams and expanded job desing

- Improved quality of work life
- Improved job satisfaction
- Increased motivation
- Allows employees to accept more responsibility
- Improved productivity and quality
- Reduced turnover and absenteeism

Motivation and Incentive Systems

In order to motivate employees, following incentive systems may be used:

- Bonuses – Providing cash or stock options to employees
- Profit-sharing - profits for distribution to employees
- Gain sharing - rewards for improvements. Rewards are generally based on productivity level

- Incentive plans - typically based on production rates
- Knowledge-based systems - reward for knowledge or skills of different employees

Ethics and Work Environment

It ensures fairness, equity, and ethics as important constraints of job design. Important issues may relate to equal opportunity, equal pay for equal work, and safe working conditions. It ensures to be more helpful to work with government agencies, trade unions, insurers, and employees.

Lecture 31: Location Strategies and Layout Strategies

Location strategy

Objective of Location Strategy

The main objective of location strategy is to maximize benefit of location to the firm.

Industrial Location Decisions

Cost focus

- ♦ Revenue varies little between locations
- ♦ Location is a major cost factor
- ♦ Affects shipping & production costs (e.g., labor)
- ♦ Costs vary greatly between locations

Revenue focus

- ♦ Costs vary little between market areas
- ♦ Location is a major revenue factor
- ♦ Affects amount of customer contact
- ♦ Affects volume of business

In General Location decisions are

♦Long-term decisions

♦ Difficult to reverse

♦ Affect fixed & variable costs

♦ Transportation cost

♦ As much as 25% of product price

♦ Other costs: Taxes, wages, rent etc.

Objective: Maximize benefit of location to firm

Factors Affecting Location decisions

Factors Affecting Country

♦ Government rules, attitudes, political risk, incentives

♦ Culture & economy

♦ Market location

♦ Labor availability, attitudes, productivity, and cost

♦ Availability of supplies, communications, energy

♦ Exchange rates and currency risks.

Region Location Decisions

♦ Corporate desires

♦ Attractiveness of region (culture, taxes, climate, etc.)

♦ Labor, availability, costs, attitudes towards unions

♦ Costs and availability of utilities

♦ Environmental regulations of state and town

♦ Government incentives

♦ Proximity to raw materials & customers

♦ Land/construction costs

Factors Affecting Site

♦ Site size and cost

♦ Air, rail, highway, and waterway systems

♦ Zoning restrictions

♦ Nearness of services/supplies needed

♦ Environmental impact issues

CSF in Location Analysis

Critical Success Factors	Country 1	Country 2	Country 3	Country 4
Technology				
Rate of technology change	3	5	2	1
Innovations in process design	5	3	1	5
Level of education				
Number of skilled workers	5	4	3	4
National education rate	4	1	1	2
Political and Legal Aspects				
Stability of government	5	5	2	5
Product liability laws	4	3	3	5
Export restrictions	4	3	3	1

Critical Success Factors	Country 1	Country 2	Country 3	Country 4
Social and Cultural Aspects				
Similarity in language	5	1	5	4
Work ethic	4	2	3	1
Economic factors				
Tax rates	3	3	2	5
Inflation	3	5	5	5
Availability of raw materials	2	4	3	5
Interest rates	3	4	2	5
Total Rating Points	50	43	35	48

Organizations That Need To Be Close to Markets

- **Government agencies**
  - Police & fire departments
  - Post Office
- **Retail Sales and Service**
  - Fast food restaurants, supermarkets, gas stations
  - Drug stores, shopping malls
  - Bakeries
- **Services**
  - Doctors, lawyers, accountants, barbers
  - Banks, auto repair, motels

Location Evaluation Methods

1. Factor-rating method
2. Locational break-even analysis
3. Center of gravity method
4. Transportation model

1. Factor-Rating Method

♦ most widely used location technique

♦ Useful for service & industrial locations

♦ Rates locations using factors

- ♦ Tangible (quantitative) factors
  - ♦ Example: Short-run & long-run costs
- ♦ Intangible (qualitative) factors
  - ♦ Example: Education quality, labor skills

Factors Affecting Location Selection

♦ Labor costs (including wages, unionization, and productivity)

♦ Labor availability (including attitudes, age, distribution, and skills)

♦ Proximity to raw materials and suppliers

♦ Proximity to markets

♦ Government fiscal policies (including incentives, taxes, unemployment compensation)

♦ Environmental regulations

♦ Utilities (including gas, electric, water, and their costs)

♦ Site costs (including land, expansion, parking, and drainage)

♦ Transportation availability (including rail, air, water, and interstate roads)

♦ Quality-of-life issues in the community (including all levels of education, cost of living, health care, sports, cultural activities, transportation, housing, entertainment, religious facilities)

♦ Foreign exchange Including rates and stability

♦ Quality of government (including stability, honesty, attitudes toward new business – whether overseas or local)

Steps in Factor Rating Method

♦ List relevant factors

♦ Assign importance weight to each factor (such as 0 – 1)

♦ Develop scale for each factor (such as 1 – 100)

♦ Score each location using factor scale

♦ multiply scores by weights for each factor & total

♦ Select location with maximum total score

2. Locational Break-Even Analysis

Method of cost-volume analysis used for industrial locations

♦ **Steps**

♦ Determine fixed & variable costs for each location

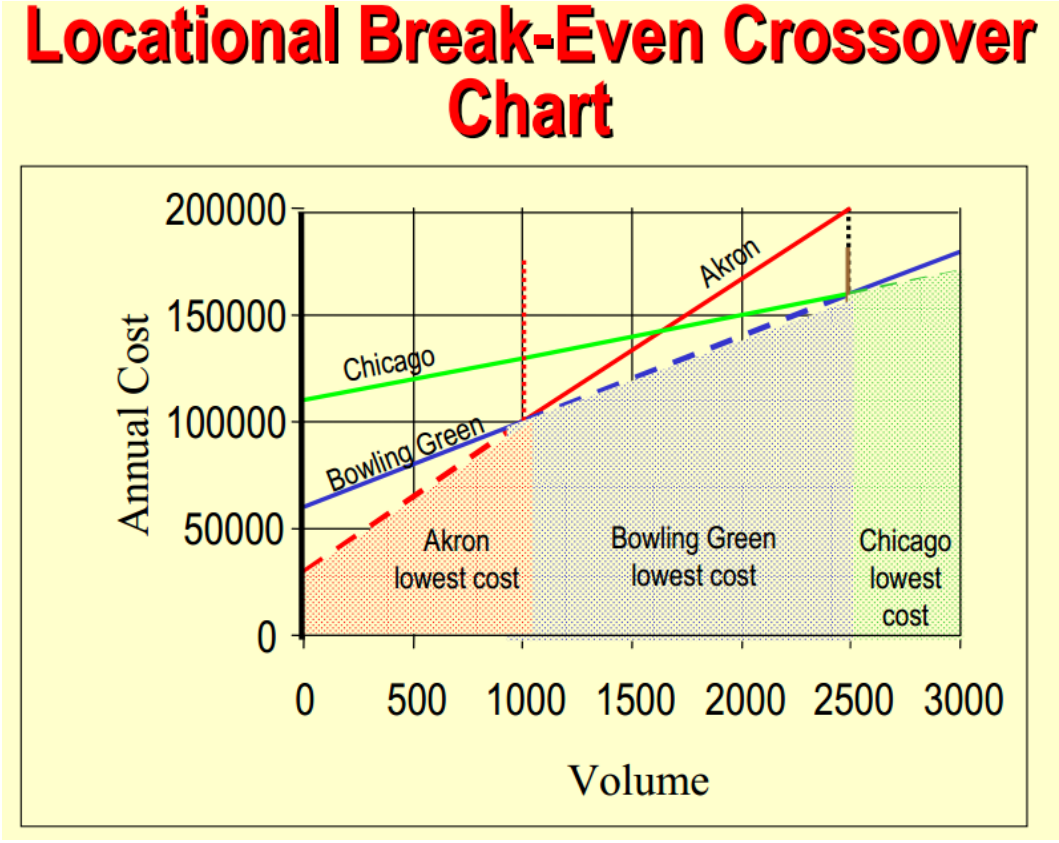
♦ Plot total cost for each location (Cost on verticalaxis, Annual Volume on horizontal axis)

♦ Select location with lowest total cost for expected production volume

♦ Must be above break-even

Example

You're an analyst for AC Delco. You're considering a new manufacturing plant in Akron, bowling green, or Chicago. Fixed costs per year are $30k, $60k, & $110k respectively. Variable costs per case are $75, $45, & $25 respectively. The price per case is $120. What is the best location for an expected volume of 2,000 cases per year?



3. Center of Gravity Method

♦ Finds location of **single** distribution center serving several destinations

♦ Used primarily for services

♦ Considers

♦ Location of existing destinations

- ♦ Example: Markets, retailers etc.

- ♦ Volume to be shipped

- ♦ Shipping distance (or cost)

  - ♦ Shipping cost/unit/mile is constant.

Method Steps

♦ Place existing locations on a coordinate grid

- ♦ Grid has arbitrary origin & scale

- ♦ Maintains relative distances

♦ Calculate X & Y coordinates for 'center of gravity'

- ♦ Gives location of distribution center

- ♦ Minimizes transportation cost

Center of Gravity Method Equations

X Coordinate

$$C_x = \frac{\sum_i d_{ix} W_i}{\sum_i W_i}$$

d_{ix} = x coordinate of location i

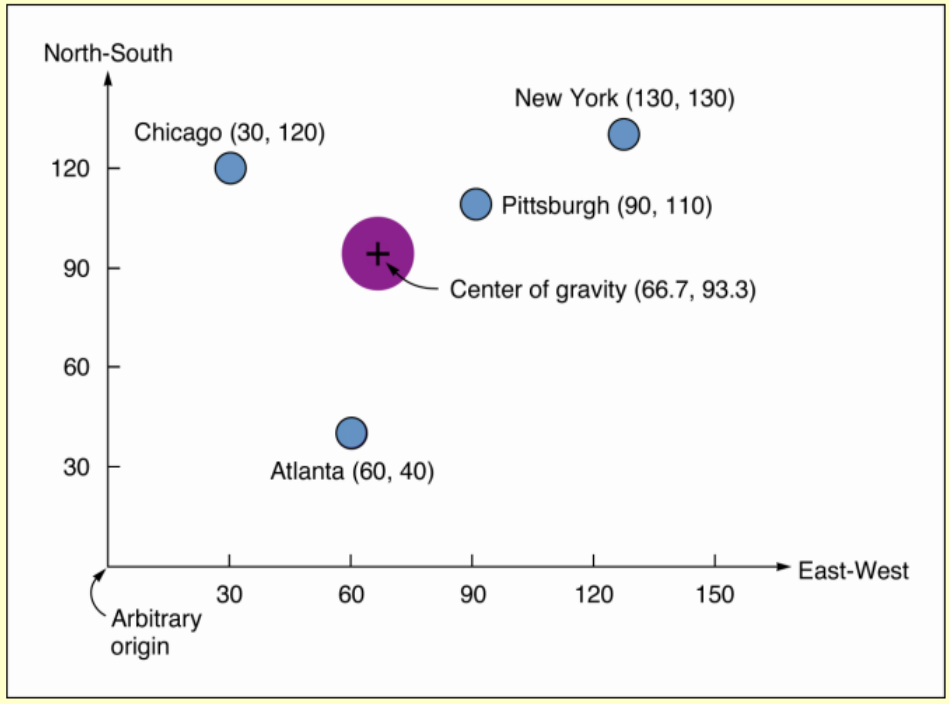
W_i = Volume of goods moved to or from location i

Y Coordinate

$$C_y = \frac{\sum_i d_{iy} W_i}{\sum_i W_i}$$

d_{iy} = y coordinate of location i

Coordinate Locations of Four Quain's Department Stores and the Center of Gravity



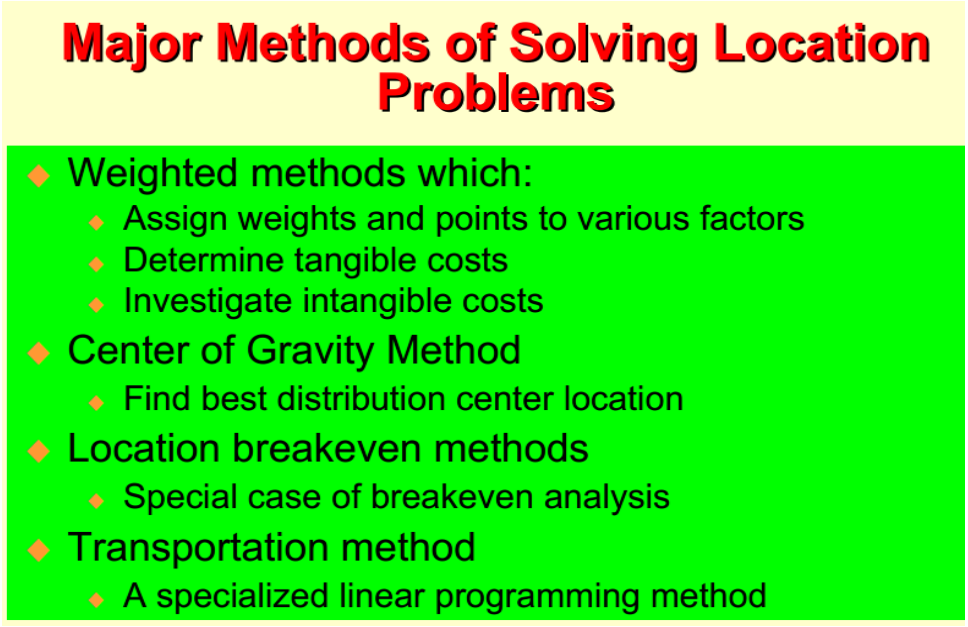
4. Transportation Model

♦ Finds amount to be shipped from several sources to **several** destinations

♦ Used primarily for industrial locations

♦ Type of linear programming model

- ♦ Objective: Minimize total production & shipping costs
- ♦ Constraints
  - ♦ Production capacity at source (factory)
  - ♦ Demand requirement at destination



Final Thought

The ideal location for many companies in the future will be a floating factory ship that will go from port to port, from country to country – wherever cost per unit is lowest.

Layout strategy

Objectives of the Layout Strategy

♦ Develop an economical layout which will meet the requirements of:

♦ Product design and volume (product strategy)

♦ Process equipment and capacity (process strategy)

♦ Quality of work life (human resource strategy)

♦ Building and site constraints (location strategy)

What is Facility Layout

♦ Location or arrangement of everything within & around buildings

♦ Objectives are to maximize

- ♦ Customer satisfaction
- ♦ Utilization of space, equipment, & people
- ♦ Efficient flow of information, material, & people
- ♦ Employee morale & safety

Strategic Importance of Layout

Proper layout enables:

♦ Higher utilization of space, equipment, and people

♦ Improved flow of information, materials, or people

♦ Improved employee morale and safer working conditions

♦ Improved customer/client interaction

♦ Flexibility

Types of Layouts

1. Fixed-position layout
2. Process-oriented layout
3. Office layout
4. Retail layout
5. Warehouse layout
6. Product-oriented layout

Six Layout Strategies

1. **Fixed-position layout**
   ♦ large bulky projects such as ships and buildings

2. **Process-oriented layout**
   ♦ deals with low-volume, high-variety production ("job shop", intermittent production)

3. **Office layout**
   ♦ positions workers, their equipment, and spaces/offices to provide for movement of information

4. **Retail/service layout**
   ♦ allocates shelf space and responds to customer behavior

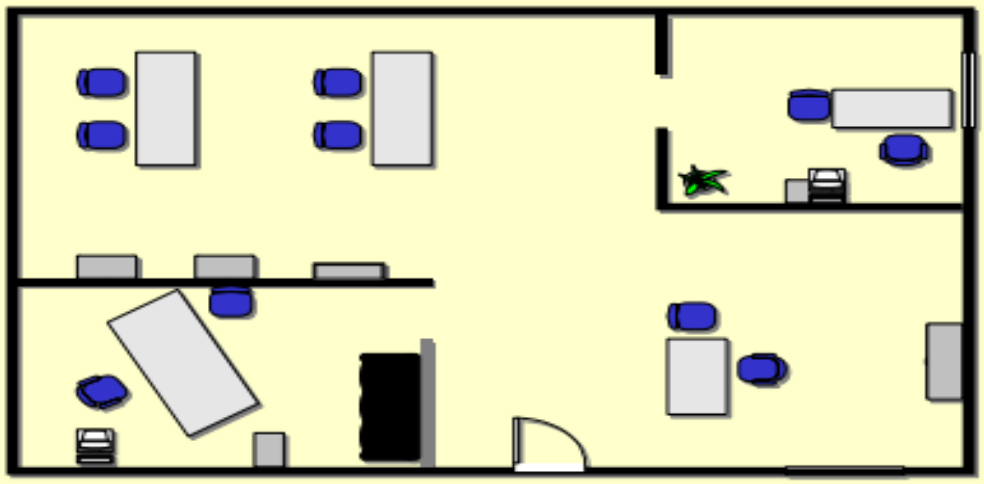
5. **Warehouse layout**
   ♦ addresses trade-offs between space and material handling

6. **♦ Product-oriented layout**
   ♦ seeks the best personnel and machine use in repetitive or continuous production

Layout Strategies

Project (fixed-position)	Job Shop (Process-oriented)	Office	Retail	Warehouse (storage)	Repetitive /Continuous (product-oriented)
Examples					
Ingal Ship Building Corp.	Shouldice Hospital	Allstate Insurance	Kroger's Supermarket	Federal-Mogul's Warehouse	Sony's TV Assembly Line
Trump Plaza	Olive Garden	Microsoft	Walgreens	The Gap's distribution center	Dodge Caravans Minivans
Pittsburgh Airport			Bloomingdales		
Problem					
Move material to the limited storage areas around the site	Manage varied material flow for each product	Locate workers requiring frequent contact close to each other	Expose customer to high-margin items	Balance low-cost storage with low-cost material handling	Equalize the task time at each workstation

Layout Example - Office



Requirements of a Good Layout

- An understanding of capacity and space requirements
- Selection of appropriate material handling equipment
- Decisions regarding environment and aesthetics
- Identification and understanding of the requirements for information flow
- Identification of the cost of moving between the various work areas

Constraints on Layout Objectives

♦ Product design & volume

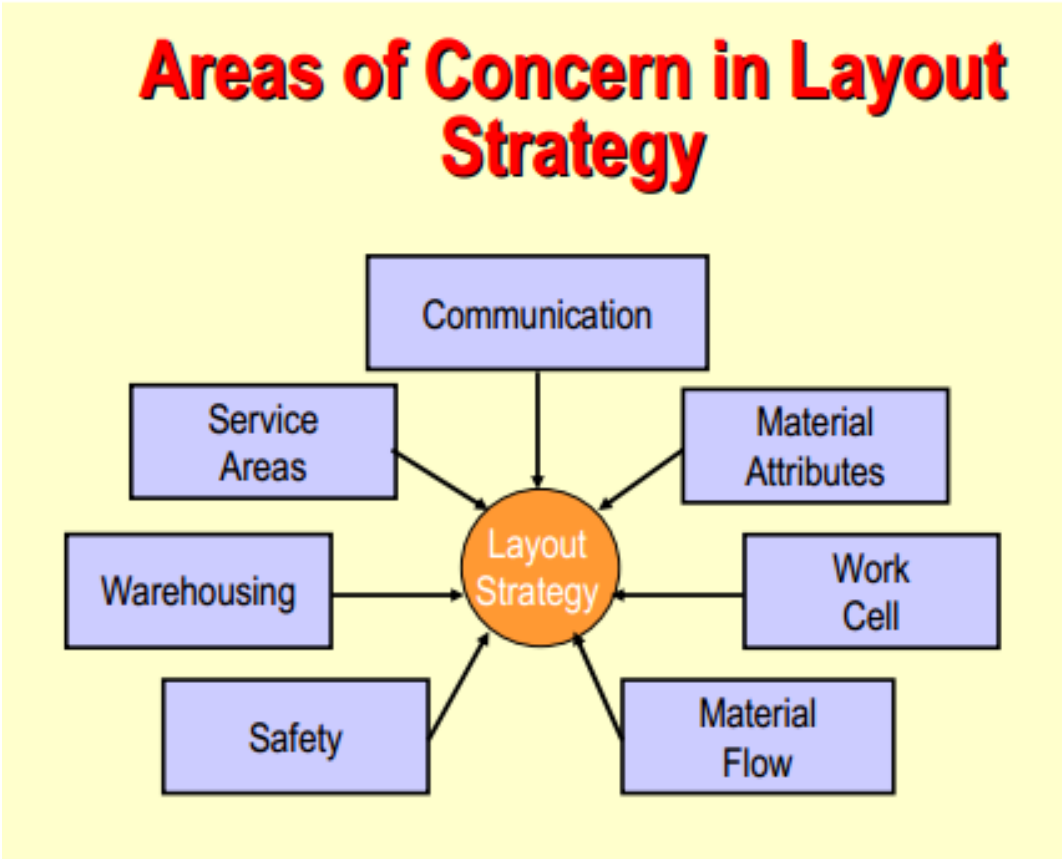
♦ Process equipment & capacity

♦ Quality of work life

♦ Building and site

Layout Strategies, Examples, and Criteria

Layout strategy	Example	Criteria
Service/retail	Drug store Grocery store Department store	Expose customer to high margin items
Storage	Distributor Warehouse	Minimize storage and handling costs
Product oriented	TV assembly line	Minimize line imbalance, delay, and idle time



Fixed-Position Layout

♦ Design is for stationary project

♦ Workers and equipment come to site

♦ Complicating factors

- ♦ Limited space at site
- ♦ Changing material needs

Factors Complicating a Fixed Position Layout

♦ There is limited space at virtually all sites

♦ At different stages in the construction process, different materials are needed – therefore, different items become critical as the project develops.

♦ The volume of materials needed is dynamic

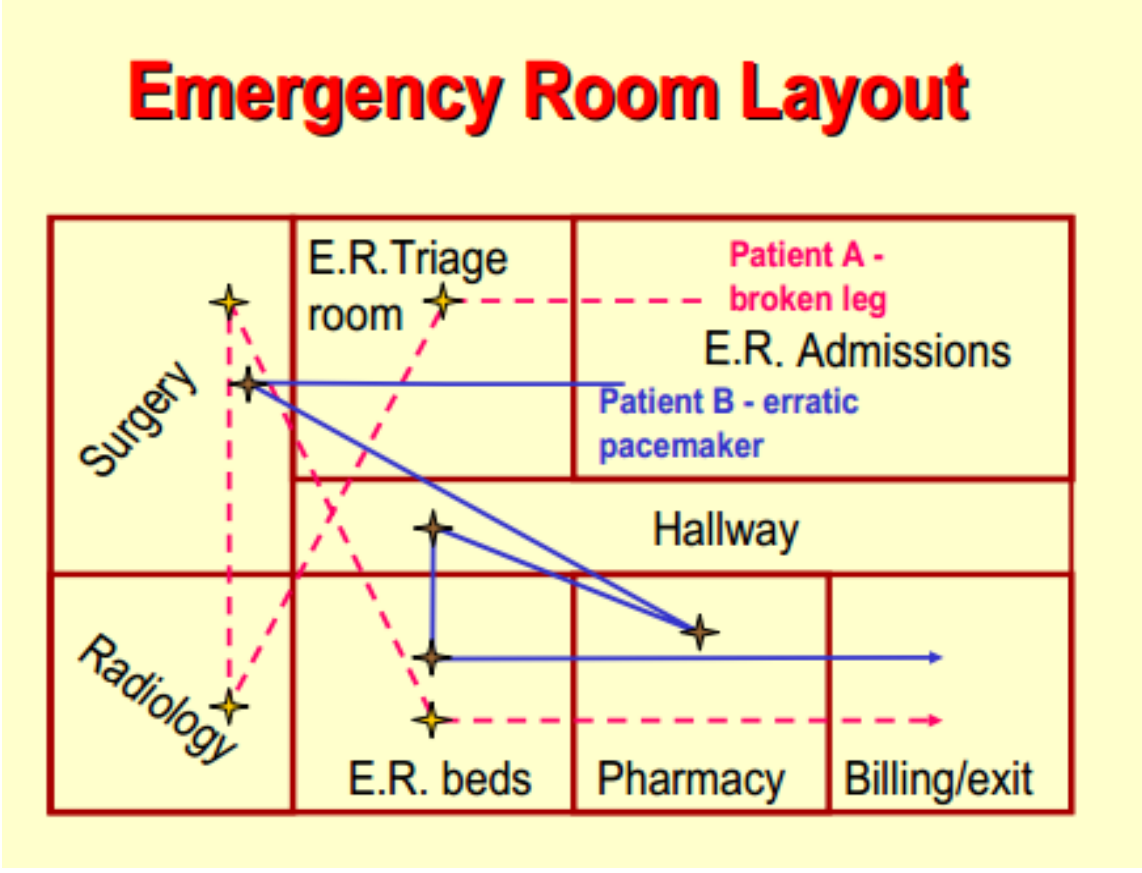
Process-Oriented Layout

♦ Design places departments with large flows of material or people together

♦ Department areas having similar processes located in close proximity

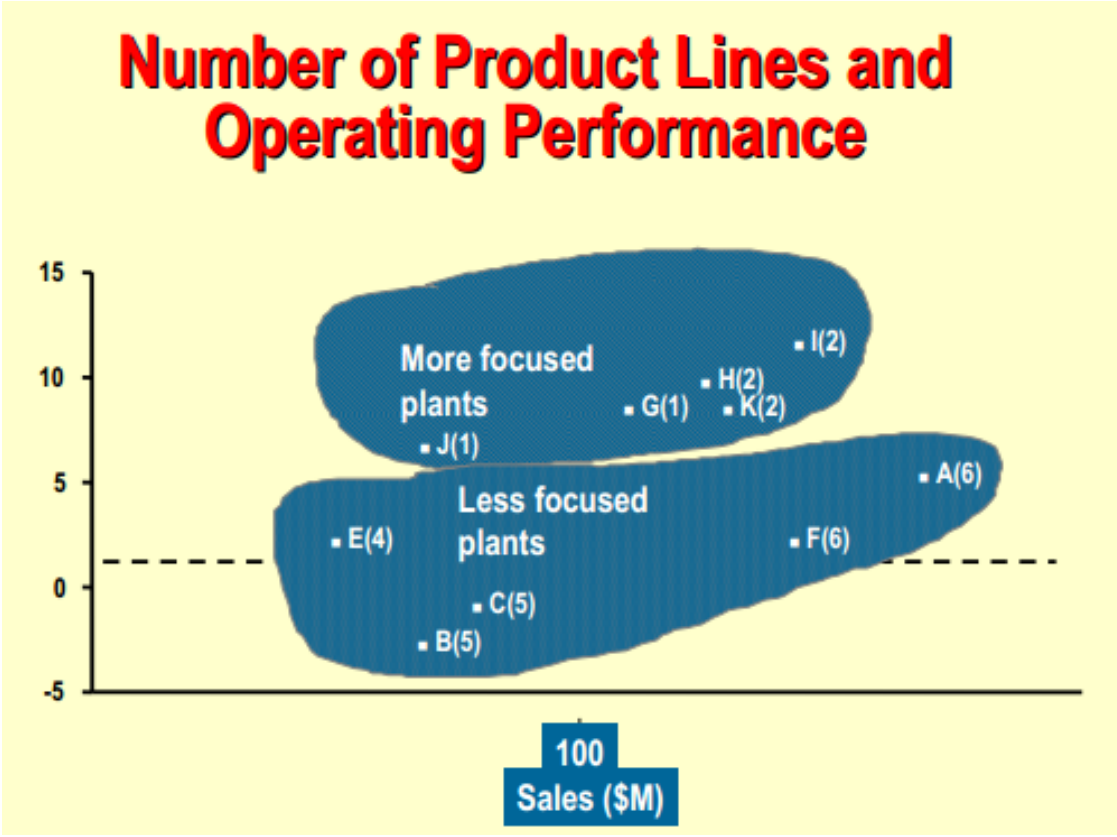
♦ e.g., All x-ray machines in same area

♦ Used with process-focused processes



Steps in developing process-Oriented Layout

1. Construct a “from-to matrix”
2. Determine space requirements for each department
3. Develop an initial schematic diagram
4. Determine the cost of this layout
5. By trial-and-error (or more sophisticated means), try to improve the initial layout
6. Prepare a detailed plan that evaluates factors in addition to transportation cost



Office Layout

♦ Design positions people, equipment, & offices for maximum information flow

♦ Arranged by process or product

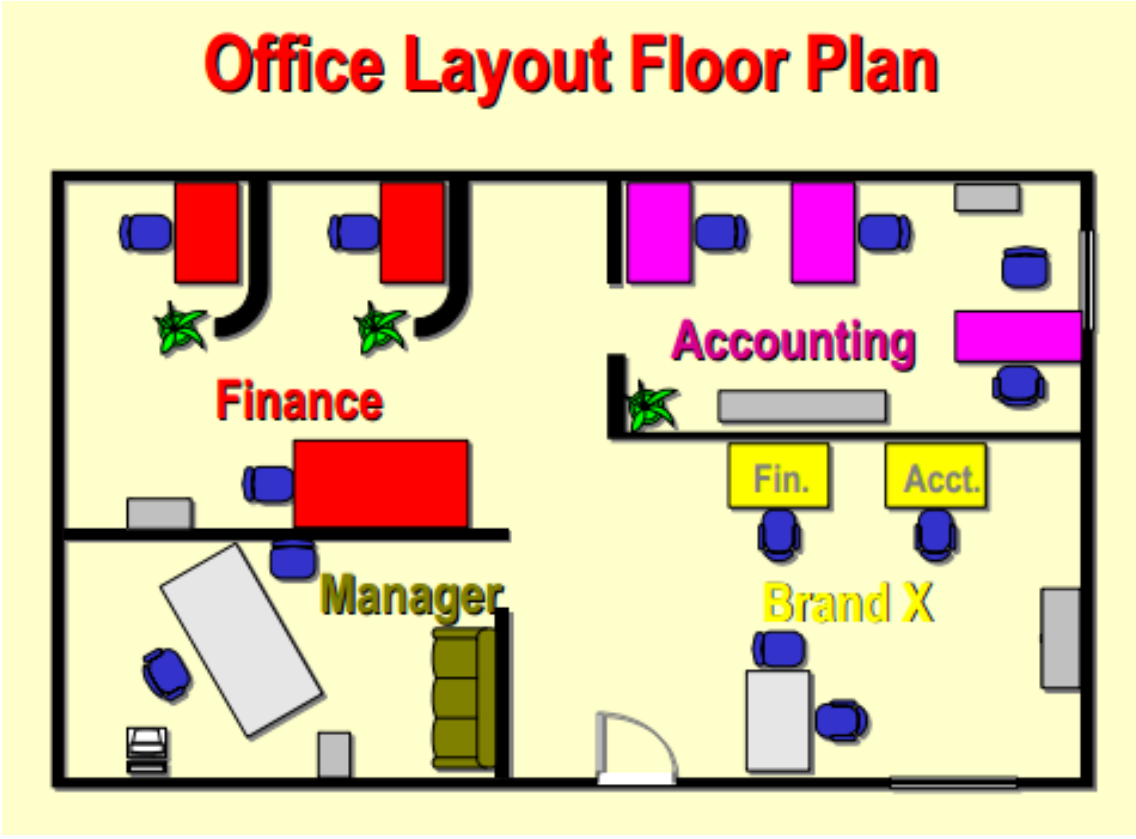
♦ Example: Payroll dept. is by process

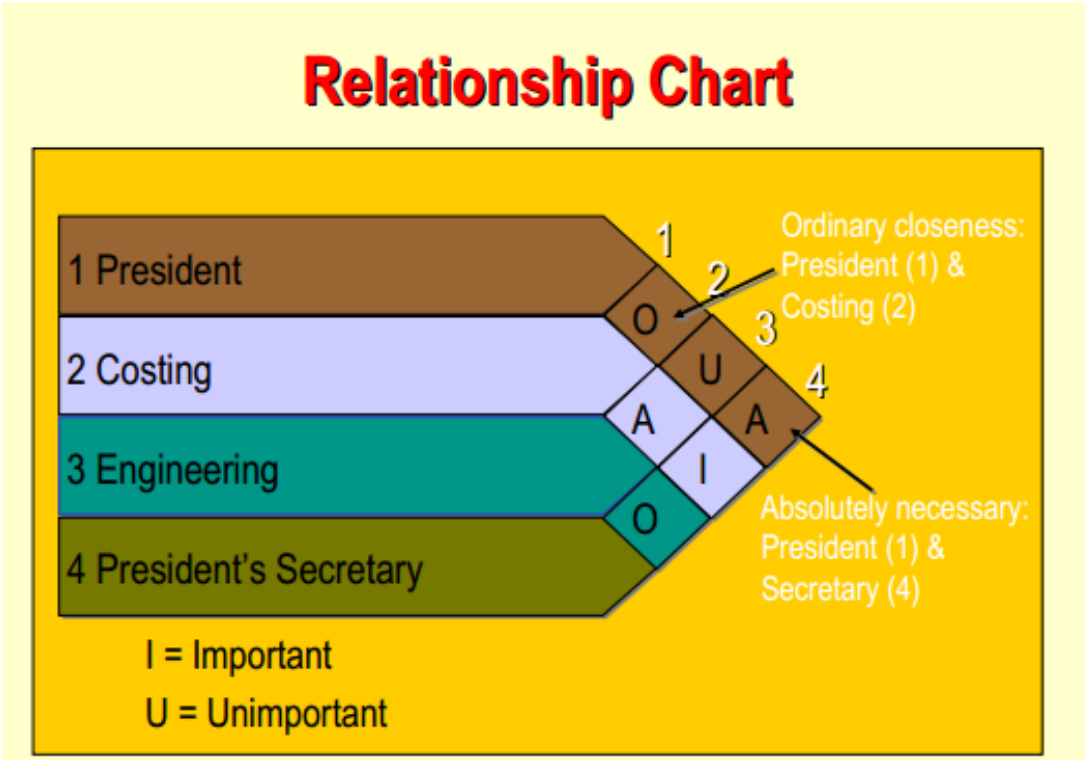
♦ Relationship chart used

♦ **Examples**

♦ Insurance company

♦ Software company





Retail/Service Layout

♦ Design maximizes product exposure to customers

♦ **Decision variables**

- ♦ Store flow pattern
- ♦ Allocation of (shelf) space to products

♦ **Types**

- ♦ Grid design
- ♦ Free-flow design

Retail Layouts -Some Rules of Thumb

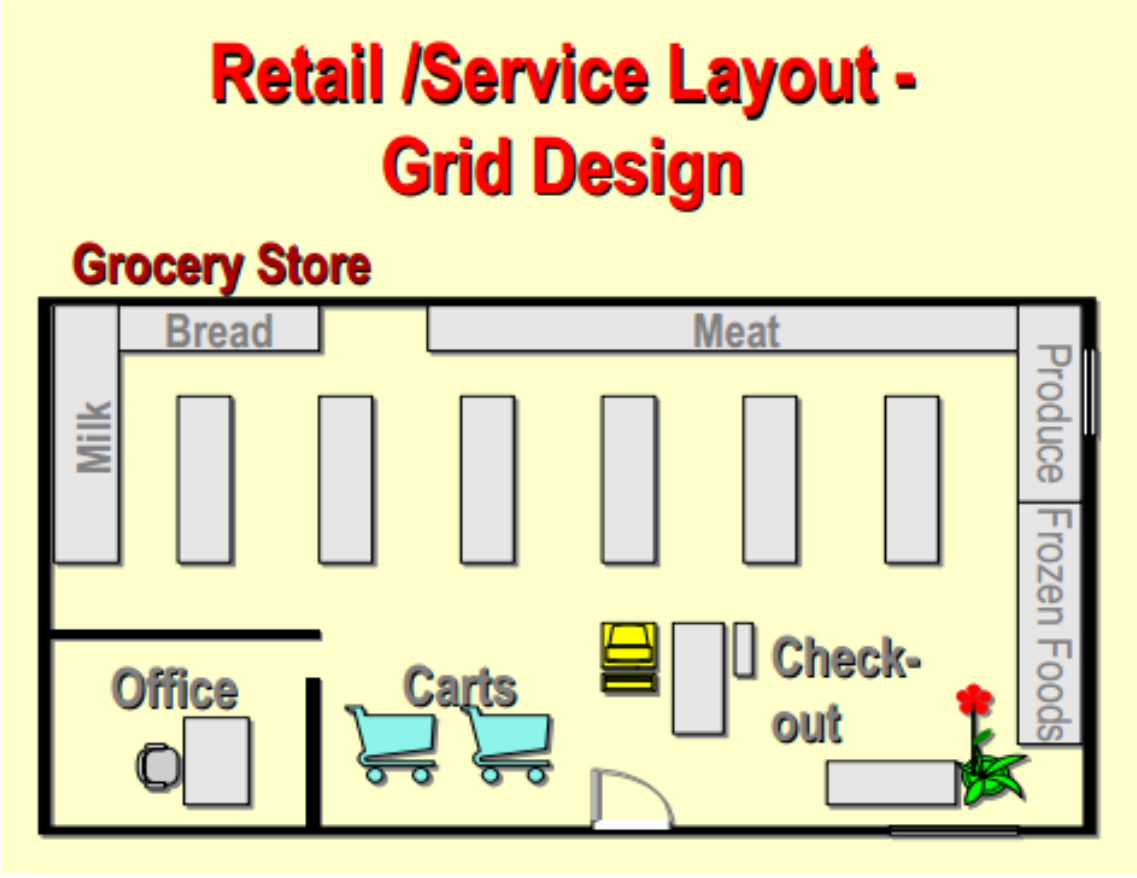
♦ Locate high-draw items around the periphery of the store

♦ Use prominent locations such as the first or last aisle for high-impulse and high margin items

♦ Remove crossover aisles that allow customers the opportunity to move between aisles

♦ Distribute what are known in the trade as “power items”(items that may dominate a shopping trip) to both sides of an aisle, and disperse them to increase the viewing of other items

♦ Use end aisle locations because they have a very high exposure rate



Warehouse Layout

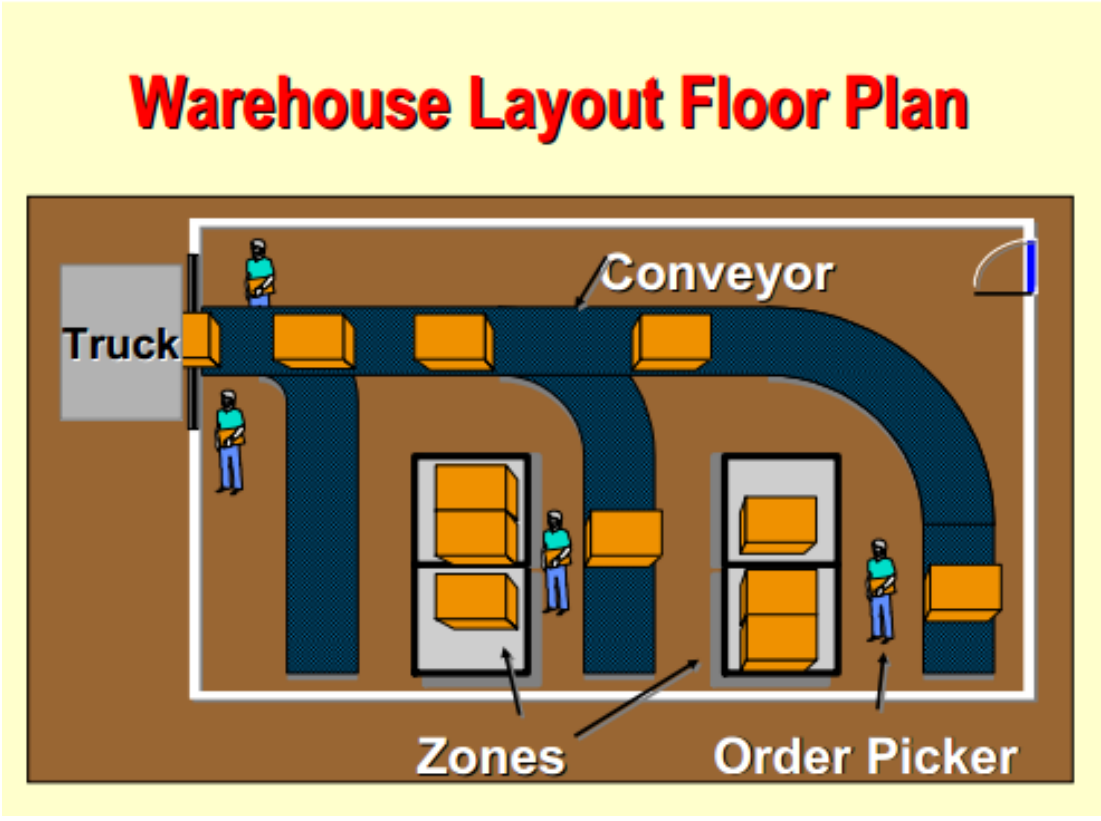
♦ Design balances space (cube) utilization & handling cost

♦ Similar to process layout

♦ Items moved between dock & various storage areas

♦ Optimum layout depends on

- ♦ Variety of items stored
- ♦ Number of items picked



Product-Oriented Layout

♦ Facility organized around product

♦ Design minimizes line imbalance

♦ Delay between work stations

♦ Types: Fabrication line; assembly line

Product-Oriented Requirements

♦ Standardized product

♦ High production volume

♦ Stable production quantities

♦ Uniform quality of raw materials & components

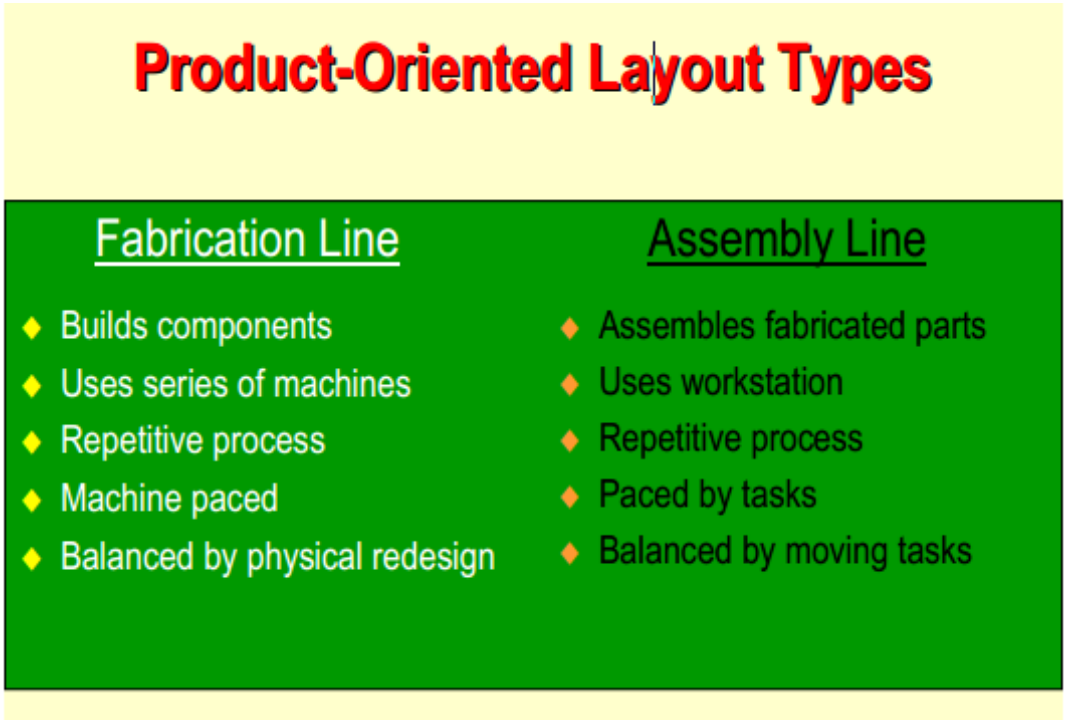
Product-Oriented Layout - Assumptions

♦ Volume is adequate for high equipment utilization

♦ Product demand is stable enough to justify high investment in specialized equipment

♦ Product is standardized or approaching a phase of its life cycle that justifies investment in specialized equipment

♦ Supplies of raw materials and components are adequate and of uniform quality to ensure they will work with specialized equipment



Product-Oriented Layout Advantages

♦ Lower variable cost per unit

♦ Lower material handling costs

♦ Lower work-in-process inventories

♦ Easier training & supervision

♦ Rapid throughput

Product-Oriented Layout Disadvantages

♦ **Higher capital investment**

♦ Special equipment

♦ Any work stoppage stops whole process

♦ **Lack of flexibility**

♦ Volume

♦ Product

Assembly Line Balancing

♦ Analysis of production lines

♦ Nearly equally divides work between workstations while meeting required output

♦ Objectives

♦ Maximize efficiency

♦ Minimize number of work stations

Assembly Line Balancing Steps

1. Determine tasks (operations)

2. Determine sequence

3. Draw precedence diagram

4. Estimate task times

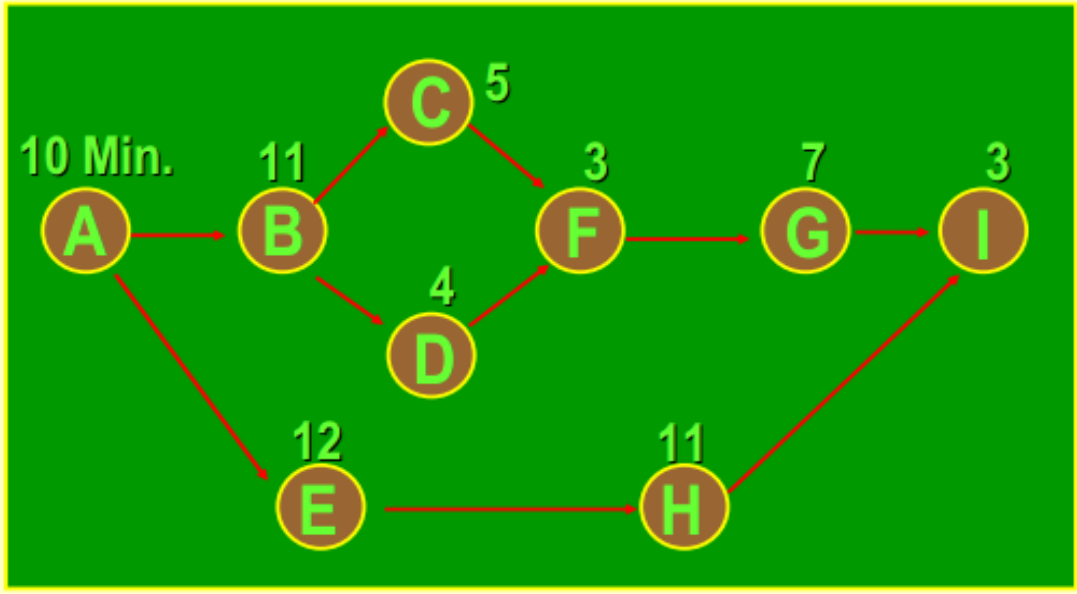
5. Calculate cycle time

6. Calculate number of work stations

7. Assign tasks

8. Calculate efficiency

Precedence Diagram Example



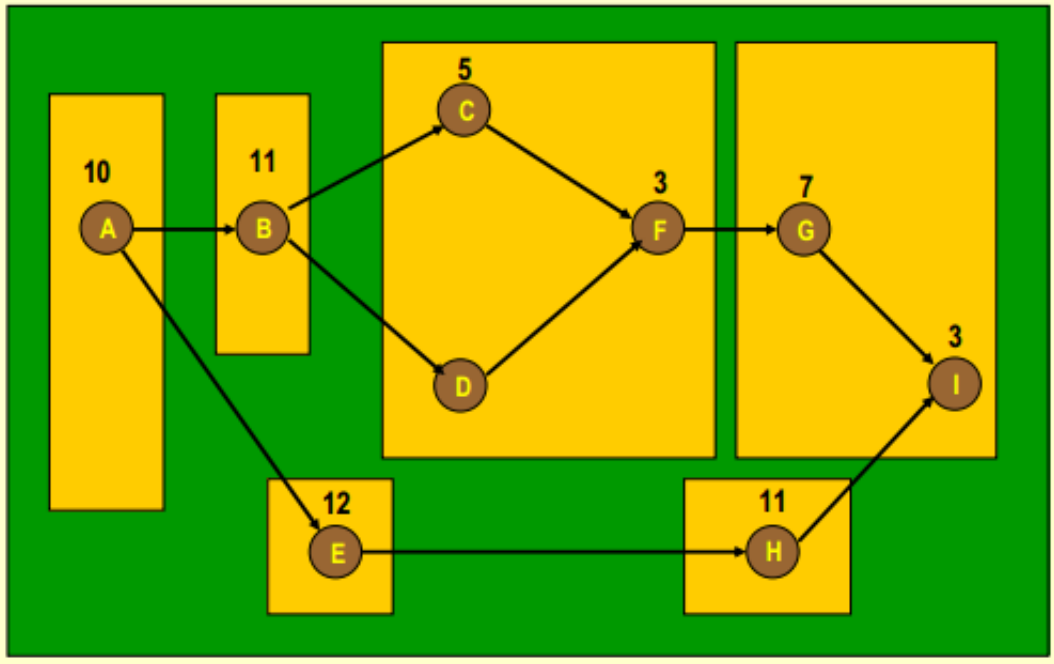
Assembly Line Balancing Equations

$$\text{Cycle time} = \frac{\text{Production time available}}{\text{Demand per day}}$$

$$\text{Minimum number of work stations} = \frac{\Sigma \text{ Task times}}{\text{Cycle time}}$$

$$\text{Efficiency} = \frac{\Sigma \text{ Task times}}{(\text{Actual number of work stations}) * (\text{Cycle time})}$$

Six Station Solution



Lecture 32: - *Supply Chain Management*

- *Inventory Management*

Supply Chain Management

If you go to a Supermarket and pick up a few items of the shelf from electronics and white goods or even clothes and look at the labels, chances are that you will find them having been manufactured in China or Mexico. The coffee pods you buy to use for your everyday use comes from Africa. Computers have been shipped out of South American Factories and Soft furnishings on the shelves are from India and Hong Kong.

Global markets are expanding beyond borders and re-defining the way demand and supplies are managed. Global companies are driven by markets across continents. In order to keep the cost of manufacturing down, they are forced to keep looking to set up production centers where cost of raw materials and labor is cheap. Sourcing of raw materials and vendors to supply the right quality, quantity and at right price calls for dynamic procurement strategy spanning across countries.

With the above scenario you find companies procuring materials globally from various vendors to supply raw materials to their factories situated in different continents. The finished goods out of these different factory locations then pass through different chains of distribution network involving warehouses, exports to different countries or local markets, distributors, retailers and finally to the end customer.

In simple language, managing all of the above activities in tandem to manage demand and supply on a global scale is Supply Chain Management. As per definition SCM is the management of a network of all business processes and activities involving procurement of raw materials, manufacturing and distribution management of Finished Goods. SCM is also called the art of management of providing the Right Product, At the Right Time, Right Place and at the Right Cost to the Customer.

SCM strategy is important for an Organization

Supply Chain Strategies are the critical backbone to Business Organizations today. Effective Market coverage, Availability of Products at locations which hold the key to revenue recognition depends upon the effectiveness of Supply Chain Strategy rolled out. Very simply stated, when a product is introduced in the market and advertised, the entire market in the country and all the sales counters need to have the product where the customer is able to buy and take delivery. Any glitch in product not being available at the right time can result in drop in customer interest and demand which can be disastrous. Transportation network design and management assume importance to support sales and marketing strategy.

Inventory control and inventory visibility are two very critical elements in any operations for these are the cost drivers and directly impact the bottom lines in the balance sheet. Inventory means value and is an asset of the company. Every business has a standard for inventory turnaround that is optimum for the business. Inventory turnaround refers to the number of times the inventory is sold and replaced in a period of twelve months. The health of the inventory turn relates to the health of business.

In a global scenario, the finished goods inventory is held at many locations and distribution centers, managed by third parties. A lot of inventory would also be

in the pipeline in transportation, besides the inventory with distributors and retail stocking points. Since any loss of inventory anywhere in the supply chain would result in loss of value, effective control of inventory and visibility of inventory gains importance as a key factor of Supply Chain Management function.

Important activities include determining

1. Transportation vendors
2. Credit and cash transfers
3. Suppliers
4. Distributors
5. Accounts payable and receivable
6. Warehousing and inventory
7. Order fulfillment
8. Sharing customer, forecasting, and production information

Make-or-Buy Decisions

The act of choosing between manufacturing a product in-house or purchasing it from an external supplier In a make-or-buy decision, the two most important factors to consider are cost and availability of production capacity.

An enterprise may decide to purchase the product rather than producing it, if is cheaper to buy than make or if it does not have sufficient production capacity to produce it in-house. With the phenomenal surge in global outsourcing over the past decades, the make-or-buy decision is one that managers have to grapple with very frequently.

Factors that may influence a firm's decision to buy a part rather than produce it internally include lack of in-house expertise, small volume requirements, desire for multiple sourcing, and the fact that the item may not be critical to its strategy. Similarly, factors that may tilt a firm towards making an item in-house include existing idle production capacity, better quality control or proprietary technology that needs to be protected.

Reasons for Making

1. Maintain core competence
2. Lower production cost
3. Unsuitable suppliers
4. Assure adequate supply (quantity or delivery)
5. Utilize surplus labor or facilities
6. Obtain desired quality
7. Remove supplier collusion
8. Obtain unique item that would entail a prohibitive commitment for a supplier
9. Protect personnel from a layoff
10. Protect proprietary design or quality
11. Increase or maintain size of company

Reasons for Buying

1. Frees management to deal with its core competence
2. Lower acquisition cost

3. Preserve supplier commitment
4. Obtain technical or management ability
5. Inadequate capacity
6. Reduce inventory costs
7. Ensure alternative sources
8. Inadequate managerial or technical resources
9. Reciprocity
10. Item is protected by a patent or trade ***secret***

Outsourcing

A practice used by different companies to reduce costs by transferring portions of work to outside suppliers rather than completing it internally.

Outsourcing is an effective cost-saving strategy when used properly. It is sometimes more affordable to purchase a good from companies with comparative advantages than it is to produce the good internally. An example of a manufacturing company outsourcing would be Dell buying some of its computer components from another manufacturer in order to save on production costs. Alternatively, businesses may decide to outsource book-keeping duties to independent accounting firms, as it may be cheaper than retaining an in-house accountant.

- Transfers traditional internal activities and resources of a firm to outside vendors
- Utilizes the efficiency that comes with specialization

- Firms outsource information technology, accounting, legal, logistics, and production

Ethics in the Supply Chain

- Opportunities for unethical behavior are enormous and temptations are high
- Many companies have strict rules and codes of conduct that define acceptable behavior
- Institute for Supply Management has developed a detailed set of principles and standards for ethical behavior

Supply Chain Strategies

- Negotiating with many suppliers
- Long-term partnering with few suppliers
- Vertical integration
- Keiretsu
- Virtual companies that use suppliers on an as needed basis

Supply chain strategy is closely linked to, and supports, your overall business strategy. The supply chain strategy defines the vision and guidelines for your supply chain concept, which are used to define the network setup, measurements, performance targets and governance structure to transform strategy into execution.

Key to defining a supply chain strategy is a firm understanding of your business strategy and customer promise, as well as the surrounding business environment. Understanding your product and market requirements – e.g. high quality products with no stock outs – you can define the right balance among your supply chain performance objectives. These can include cost reduction, flexibility, reliability, speed or sustainability.

> A powerful supply chain strategy balances cost reduction, flexibility, reliability, speed and sustainability.

Tangible measures of performance as well as improvement areas need to be defined across your end-to-end supply chain. The set of measures will ultimately be aligned to your business strategy and targets, balanced to meet the constraints of your surrounding business environment. Improvement areas can range from a change of incoterms as a way of gaining control over cash flows and cost to an overall re-engineering of your go-to-market approach.

To bring your supply chain strategy to life, a clear supply chain governance model provides the framework for effective delivery. Allocating responsibilities and accountability will speed the decision-making process to allow you to respond quickly where required, for example when market changes take place.

Leading practice methodologies such as Targets-Processes-Organization (TPO) and Supply Chain Operations Reference (SCOR) mapping are examples of the methodologies that can be applied to define your supply chain governance. In turn, this will not only support your supply chain but enable your overall business strategy.

The Example

A leading German engineering and manufacturing company was serving the Eastern European market with a complex structure of more than 15 domestic warehouses scattered across the region. The challenge was to define a new setup that would reduce their supply chain costs while maintaining customer service levels.

The Strategic Logistics Consulting team developed a new supply chain strategy incorporating direct distribution to customers from a central hub. Considering local regulations and market developments, bundling in one carefully chosen location enabled cost savings of up to EUR 1mn and a reduction of complexity in the network flows. The new supply chain strategy incorporated a phased approach to provide for a smooth transition into the new model.

In addition, a new supply chain governance structure provided the backbone to run the supply chain on a daily basis. Central decision-making and clearly assigned ownership reduced the time needed to make decisions and enabled effective implementation.

Many Suppliers

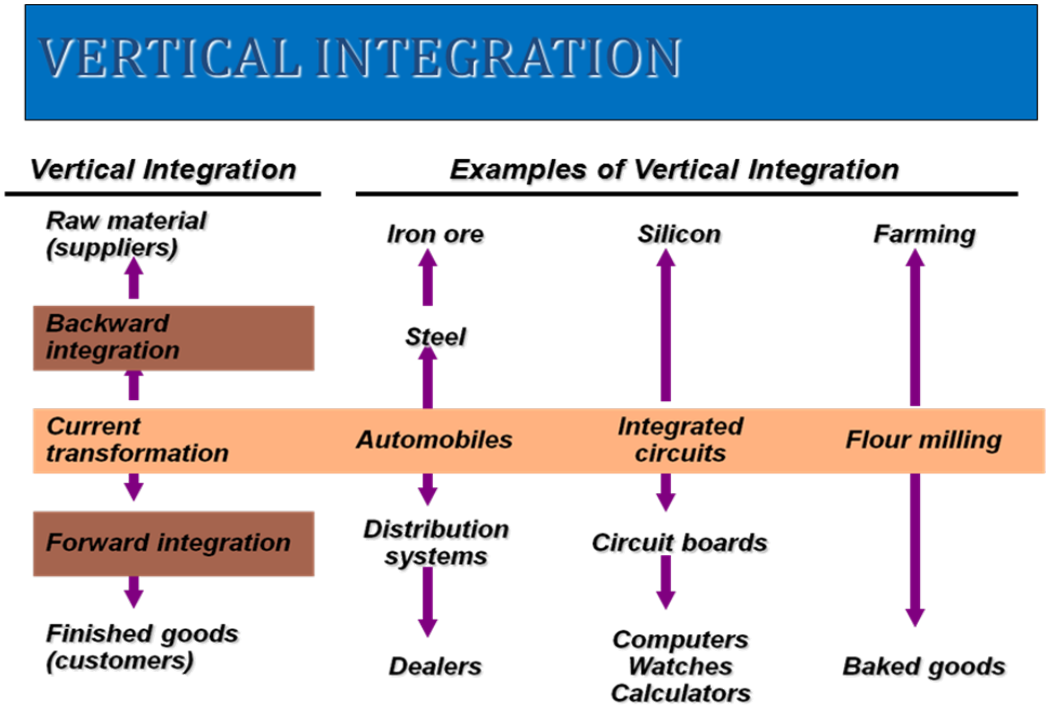
- Commonly used for commodity products
- Purchasing is typically based on price
- Suppliers compete with one another
- Supplier is responsible for technology, expertise, forecasting, cost, quality, and delivery.

Successful supplier relationships require two-way information, recommendations, metrics and incentives, says Pat Leemputte, director of

consulting firm Bridge Strategy Group. He suggests manufacturers adopt the following strategies to manage suppliers throughout a contract's life:

- Understand the cost and value of the entire supply chain. Without a thorough understanding of all costs, from raw materials through the end product or service, and the value provided by each supplier in the process, a supplier cannot be evaluated.
- Realize that supplier strategies go two ways. Most companies focus on what suppliers can do for them rather than on what they can do with the supplier to lower costs. A true partnership leverages the total production cost to both parties' advantage.
- Accept accountability. Companies should plan sufficiently in order to request orders from suppliers with acceptable lead time and without multiple changes. If every order requires emergency handling, the relationship will never work.
- Incorporate appropriate service levels and metrics into agreements. A relationship based on a handshake is far more likely to encounter problems than one in which expectations are clearly established and agreed upon.
- Spend equal time aligning incentives and penalties. It is natural to worry about the worst case, such as if a shipment is not received and a plant grinds to a halt. Conversely, the extra value created when production and asset utilization is optimized should be the basis of improving the value proposition for both parties.
- Share critical information as early as possible. Information is the grease that makes an integrated supply chain work. Waiting to share critical volume and timing information with suppliers can create lost business for the company or excess inventory and added costs for suppliers. Sharing information constantly, with appropriate security and confidentiality, is critical for successfully managing a supplier relationship.

- Plan for everyday exceptions. Sometimes emergencies will occur, especially in complex, multiparty supply chains. Agree ahead of time how emergencies will be handled and analyze why they occur so that the number of emergencies is minimized.
- Plan for major contingencies. Unavoidable events that stress the supply chain should be planned and practiced. Some industries, such as utilities, implement plans for natural disasters. Every supply chain strategy requires similar foresight and joint planning so that disruptive events can be managed smoothly.
- Expect and reward honesty. As in personal relationships, the best supplier relationships require honesty when exceptions to normal operations occur. Companies should require immediate notification without penalty when critical supplier situations occur.
- Make relationship meetings meaningful. Companies often hold formal quarterly meetings without appropriate representation in which the vast majority of time is spent on information best provided through other communication forums. Instead, relationship meetings should focus on critical issues, areas for supplier improvement and discussions on how the buying organization can improve the relationship.



Vertical Integration

- Developing the ability to produce goods or service previously purchased
- Integration may be forward, towards the customer, or backward, towards suppliers
- Can improve cost, quality, and inventory but requires capital, managerial skills, and demand
- Risky in industries with rapid technological change

Keiretsu Networks

A network of businesses that own stakes in one another as a means of mutual security, especially in Japan, and usually including large manufacturers and their suppliers of raw materials and components.

A Japanese term describing a loose conglomeration of firms sharing one or more common denominators. The companies don't necessarily need to own equity in each other.

This term has been in the news every now and then, especially when they talk about Silicon Valley. One example would be the close relationship between AOL and Sun Micro. The two firms don't have ownership in each other, but they work closely on various projects.

- A middle ground between few suppliers and vertical integration
- Supplier becomes part of the company coalition
- Often provide financial support for suppliers through ownership or loans
- Members expect long-term relationships and provide technical expertise and stable deliveries
- May extend through several levels of the supply chain

Inventory

The word inventory doesn't have the same meaning in the USA and in the UK:

- In American English and in a business accounting context, the word inventory is commonly used to describe the goods and materials that a business holds for the ultimate purpose of resale (or repair). In American English, the word stock is commonly used to describe the capital invested in a business, while in British English, the sentence stock shared is used in the same context.

- In the rest of the English speaking world stock is more commonly used, although the word inventory is recognized as a synonym. In British English, the word inventory is more commonly thought of as a list compiled for some formal purpose, such as the details of an estate going to probate, or the contents of a house let furnished.

In both British and American English, stock is the collective noun for one hundred shares as shares were usually traded in stocks on Stock Exchanges. For this reason the word stock is used by both American and British English in the term Stock Exchange.

Inventory management is primarily about specifying the size and placement of stocked goods. Inventory management is required at different locations within a facility or within multiple locations of a supply network to protect the regular and planned course of production against the random disturbance of running out of materials or goods. The scope of inventory management also concerns the fine lines between replenishment lead time, carrying costs of inventory, asset management, inventory forecasting, inventory valuation, inventory visibility, future inventory price forecasting, and physical inventory, available physical space for inventory, quality management, replenishment, returns and defective goods and demand forecasting and also by replenishment Or can be defined as the left out stock of any item used in an organization

Inventory management

Inventory management is a science primarily about specifying the shape and percentage of stocked goods. It is required at different locations within a facility or within many locations of a supply network to precede the regular and planned course of production and stock of materials.

The scope of inventory management concerns the fine lines between replenishment lead time, carrying costs of inventory, asset management, inventory forecasting, inventory valuation, inventory visibility, future inventory price forecasting, physical inventory, available physical space for inventory, quality management, replenishment, returns and defective goods, and demand forecasting. Balancing these competing requirements leads to optimal inventory

levels, which is an on-going process as the business needs shift and react to the wider environment.

Inventory management involves a retailer seeking to acquire and maintain a proper merchandise assortment while ordering, shipping, handling, and related costs are kept in check. It also involves systems and processes that identify inventory requirements, set targets, provide replenishment techniques, report actual and projected inventory status and handle all functions related to the tracking and management of material. This would include the monitoring of material moved into and out of stockroom locations and the reconciling of the inventory balances. It also may include ABC analysis, lot tracking, cycle counting support, etc. Management of the inventories, with the primary objective of determining/controlling stock levels within the physical distribution system, functions to balance the need for product availability against the need for minimizing stock holding and handling costs.

Business inventory

The reasons for keeping stock

There are four basic reasons for keeping an inventory:

1. Time - The time lags present in the supply chain, from supplier to user at every stage, requires that you maintain certain amounts of inventory to use in this lead time. However, in practice, inventory is to be maintained for consumption during 'variations in lead time'. Lead time itself can be addressed by ordering that many days in advance.
2. Uncertainty - Inventories are maintained as buffers to meet uncertainties in demand, supply and movements of goods.
3. Economies of scale - Ideal condition of "one unit at a time at a place where a user needs it, when he needs it" principle tends to incur lots of

costs in terms of logistics. So bulk buying, movement and storing brings in economies of scale, thus inventory.

4. Appreciation in Value - In some situations, some stock gains the required value when it is kept for some time to allow it reach the desired standard for consumption, or for production. For example; beer in the brewing industry All these stock reasons can apply to any owner or product

Special terms used in dealing with inventory

- Stock Keeping Unit (SKU) is a unique combination of all the components that are assembled into the purchasable item. Therefore, any change in the packaging or product is a new SKU. This level of detailed specification assists in managing inventory.
- Stock out means running out of the inventory of an SKU.
- "New old stock" (sometimes abbreviated NOS) is a term used in business to refer to merchandise being offered for sale that was manufactured long ago but that has never been used. Such merchandise may not be produced anymore, and the new old stock may represent the only market source of a particular item at the present time.

Typology

1. Buffer/safety stock
2. Reorder level
3. Cycle stock (Used in batch processes, it is the available inventory, excluding buffer stock)
4. De-coupling (Buffer stock held between the machines in a single process which serves as a buffer for the next one allowing smooth flow of work instead of waiting the previous or next machine in the same process)

5. Anticipation stock (Building up extra stock for periods of increased demand - e.g. ice cream for summer)
6. Pipeline stock (Goods still in transit or in the process of distribution - have left the factory but not arrived at the customer yet)

Inventory examples

While accountants often discuss inventory in terms of goods for sale, organizations - manufacturers, service-providers and not-for-profits - also have inventories (fixtures, furniture, supplies, etc.) that they do not intend to sell. Manufacturers', distributors', and wholesalers' inventory tends to cluster in warehouses. Retailers' inventory may exist in a warehouse or in a shop or store accessible to customers. Inventories not intended for sale to customers or to clients may be held in any premises an organization uses. Stock ties up cash and, if uncontrolled, it will be impossible to know the actual level of stocks and therefore impossible to control them.

While the reasons for holding stock were covered earlier, most manufacturing organizations usually divide their "goods for sale" inventory into:

- Raw materials - materials and components scheduled for use in making a product.
- Work in process, WIP - materials and components that have begun their transformation to finished goods.
- Finished goods - goods ready for sale to customers.
- Goods for resale - returned goods that are salable.
- Stocks in Transit.
- Consignment Stocks.

For example:

Manufacturing

A canned food manufacturer's materials inventory includes the ingredients to form the foods to be canned, empty cans and their lids (or coils of steel or aluminum for constructing those components), labels, and anything else (solder, glue, etc.) that will form part of a finished can. The firm's work in process includes those materials from the time of release to the work floor until they become complete and ready for sale to wholesale or retail customers. This may be vats of prepared food, filled cans not yet labeled or sub-assemblies of food components. It may also include finished cans that are not yet packaged into cartons or pallets. Its finished good inventory consists of all the filled and labeled cans of food in its warehouse that it has manufactured and wishes to sell to food distributors (wholesalers), to grocery stores (retailers), and even perhaps to consumers through arrangements like factory stores and outlet centers.

Principle of inventory proportionality

Purpose

Inventory proportionality is the goal of demand-driven inventory management. The primary optimal outcome is to have the same number of days' (or hours', etc.) worth of inventory on hand across all products so that the time of run out of all products would be simultaneous. In such a case, there is no "excess inventory," that is, inventory that would be left over of another product when the first product runs out. Excess inventory is sub-optimal because the money spent to obtain it could have been utilized better elsewhere, i.e. to the product that just ran out.

The secondary goal of inventory proportionality is inventory minimization. By integrating accurate demand forecasting with inventory management, rather than to past averages, a much more accurate and optimal outcome.

Integrating demand forecasting into inventory management in this way also allows for the prediction of the "can fit" point when inventory storage is limited on a per-product basis.

Applications

The technique of inventory proportionality is most appropriate for inventories that remain unseen by the consumer, as opposed to "keep full" systems where a retail consumer would like to see full shelves of the product they are buying so as not to think they are buying something old, unwanted or stale; and differentiated from the "trigger point" systems where product is reordered when it hits a certain level; inventory proportionality is used effectively by just-in-time manufacturing processes and retail applications where the product is hidden from view.

One early example of inventory proportionality used in a retail application in the United States was for motor fuel. Motor fuel (e.g. gasoline) is generally stored in underground storage tanks. The motorists do not know whether they are buying gasoline off the top or bottom of the tank, nor need they care. Additionally, these storage tanks have a maximum capacity and cannot be overfilled. Finally, the product is expensive. Inventory proportionality is used to balance the inventories of the different grades of motor fuel, each stored in dedicated tanks, in proportion to the sales of each grade. Excess inventory is not seen or valued by the consumer, so it is simply cash sunk (literally) into the ground. Inventory proportionality minimizes the amount of excess inventory carried in underground storage tanks. This application for motor fuel was first developed and implemented by Petrol soft Corporation in 1990 for Chevron Products Company. Most major oil companies use such systems today.

Roots

The use of inventory proportionality in the United States is thought to have been inspired by Japanese just-in-time parts inventory management made famous by Toyota Motors in the 1980s.

High-level inventory management

It seems that around 1880 there was a change in manufacturing practice from companies with relatively homogeneous lines of products to horizontally integrated companies with unprecedented diversity in processes and products. Those companies (especially in metalworking) attempted to achieve success through economies of scope - the gains of jointly producing two or more products in one facility. The managers now needed information on the effect of product-mix decisions on overall profits and therefore needed accurate product-cost information. A variety of attempts to achieve this were unsuccessful due to the huge overhead of the information processing of the time. However, the burgeoning need for financial reporting after 1900 created unavoidable pressure for financial accounting of stock and the management need to cost manage products became overshadowed. In particular, it was the need for audited accounts that sealed the fate of managerial cost accounting. The dominance of financial reporting accounting over management accounting remains to this day with few exceptions, and the financial reporting definitions of 'cost' have distorted effective management 'cost' accounting since that time. This is particularly true of inventory.

Hence, high-level financial inventory has these two basic formulas, which relate to the accounting period:

1. Cost of Beginning Inventory at the start of the period + inventory purchases within the period + cost of production within the period = cost of goods available

2. Cost of goods available − cost of ending inventory at the end of the period = cost of goods sold

The benefit of these formulas is that the first absorbs all overheads of production and raw material costs into a value of inventory for reporting. The second formula then creates the new start point for the next period and gives a figure to be subtracted from the sales price to determine some form of sales-margin figure.

Manufacturing management is more interested in *inventory turnover ratio* or *average days to sell inventory* since it tells them something about relative inventory levels.

> Inventory turnover ratio (also known as inventory turns) = cost of goods sold / Average Inventory = Cost of Goods Sold / ((Beginning Inventory + Ending Inventory) / 2) and its inverse
>
> Average Days to Sell Inventory = Number of Days a Year / Inventory Turnover Ratio = 365 days a year / Inventory Turnover Ratio

This ratio estimates how many times the inventory turns over a year. This number tells how much cash/goods are tied up waiting for the process and is a critical measure of process reliability and effectiveness. So a factory with two inventory turns has six months stock on hand, which is generally not a good figure (depending upon the industry), whereas a factory that moves from six turns to twelve turns has probably improved effectiveness by 100%. This improvement will have some negative results in the financial reporting, since the 'value' now stored in the factory as inventory is reduced.

While these accounting measures of inventory are very useful because of their simplicity, they are also fraught with the danger of their own assumptions. There

are, in fact, so many things that can vary hidden under this appearance of simplicity that a variety of 'adjusting' assumptions may be used. These include:

- Specific Identification
- Weighted Average Cost
- Moving-Average Cost
- FIFO and LIFO.

Inventory Turn is a financial accounting tool for evaluating inventory and it is not necessarily a management tool. Inventory management should be forward looking. The methodology applied is based on historical cost of goods sold. The ratio may not be able to reflect the usability of future production demand, as well as customer demand.

Business models, including Just in Time (JIT) Inventory, Vendor Managed Inventory (VMI) and Customer Managed Inventory (CMI), attempt to minimize on-hand inventory and increase inventory turns. VMI and CMI have gained considerable attention due to the success of third-party vendors who offer added expertise and knowledge that organizations may not possess.

Accounting for inventory

Each country has its own rules about accounting for inventory that fit with their financial reporting rules.

For example, organizations in the U.S. define **inventory** to suit their needs within US Generally Accepted Accounting Practices (GAAP), the rules defined by the Financial Accounting Standards Board (FASB) (and others) and enforced by the U.S. Securities and Exchange Commission (SEC) and other federal and state agencies. Other countries often have similar arrangements but with their own accounting standards and national agencies instead.

It is intentional that financial accounting uses standards that allow the public to compare firms' performance, cost accounting functions internally to an organization and potentially with much greater flexibility. A discussion of inventory from standard and Theory of Constraints-based (throughput) cost accounting perspective follows some examples and a discussion of inventory from a financial accounting perspective.

The internal costing/valuation of inventory can be complex. Whereas in the past most enterprises ran simple, one-process factories, such enterprises are quite probably in the minority in the 21st century. Where 'one process' factories exist, there is a market for the goods created, which establishes an independent market value for the good. Today, with multistage-process companies, there is much inventory that would once have been finished goods which is now held as 'work in process' (WIP). This needs to be valued in the accounts, but the valuation is a management decision since there is no market for the partially finished product. This somewhat arbitrary 'valuation' of WIP combined with the allocation of overheads to it has led to some unintended and undesirable results.

Financial accounting

An organization's inventory can appear a mixed blessing, since it counts as an asset on the balance sheet, but it also ties up money that could serve for other purposes and requires additional expense for its protection. Inventory may also cause significant tax expenses, depending on particular countries' laws regarding depreciation of inventory, as in Thor Power Tool Company v. Commissioner.

Inventory appears as a current asset on an organization's balance sheet because the organization can, in principle, turn it into cash by selling it. Some organizations hold larger inventories than their operations require in order to inflate their apparent asset value and their perceived profitability.

In addition to the money tied up by acquiring inventory, inventory also brings associated costs for warehouse space, for utilities, and for insurance to cover staff to handle and protect it from fire and other disasters, obsolescence, shrinkage (theft and errors), and others. Such holding costs can mount up: between a third and a half of its acquisition value per year.

Businesses that stock too little inventory cannot take advantage of large orders from customers if they cannot deliver. The conflicting objectives of cost control and customer service often pit an organization's financial and operating managers against its sales and marketing departments. Salespeople, in particular, often receive sales-commission payments, so unavailable goods may reduce their potential personal income. This conflict can be minimized by reducing production time to being near or less than customers' expected delivery time. This effort, known as "Lean production" will significantly reduce working capital tied up in inventory and reduce manufacturing costs (See the Toyota Production System).

Role of inventory accounting

By helping the organization to make better decisions, the accountants can help the public sector to change in a very positive way that delivers increased value for the taxpayer’s investment. It can also help to incentivize progress and to ensure that reforms are sustainable and effective in the long term, by ensuring that success is appropriately recognized in both the formal and informal reward systems of the organization.

To say that they have a key role to play is an understatement. Finance is connected to most, if not all, of the key business processes within the organization. It should be steering the stewardship and accountability systems that ensure that the organization is conducting its business in an appropriate, ethical manner. It is critical that these foundations are firmly laid. So often they

are the litmus test by which public confidence in the institution is either won or lost.

Finance should also be providing the information, analysis and advice to enable the organizations' service managers to operate effectively. This goes beyond the traditional preoccupation with budgets – how much have we spent so far, how much do we have left to spend? It is about helping the organization to better understand its own performance. That means making the connections and understanding the relationships between given inputs – the resources brought to bear – and the outputs and outcomes that they achieve. It is also about understanding and actively managing risks within the organization and its activities.

FIFO vs. LIFO accounting

When a merchant buys goods from inventory, the value of the inventory account is reduced by the cost of goods sold (COGS). This is simple where the CoG has not varied across those held in stock; but where it has, then an agreed method must be derived to evaluate it. For commodity items that one cannot track individually, accountants must choose a method that fits the nature of the sale. Two popular methods that normally exist are: FIFO and LIFO accounting (first in - first out, last in - first out). FIFO regards the first unit that arrived in inventory as the first one sold. LIFO considers the last unit arriving in inventory as the first one sold. Which method an accountant selects can have a significant effect on net income and book value and, in turn, on taxation. Using LIFO accounting for inventory, a company generally reports lower net income and lower book value, due to the effects of inflation. This generally results in lower taxation. Due to LIFO's potential to skew inventory value, UK GAAP and IAS have effectively banned LIFO inventory accounting.

Standard cost accounting

Standard cost accounting uses ratios called efficiencies that compare the labour and materials actually used to produce a good with those that the same goods would have required under "standard" conditions. As long as actual and standard conditions are similar, few problems arise. Unfortunately, standard cost accounting methods developed about 100 years ago, when labor comprised the most important cost in manufactured goods. Standard methods continue to emphasize labor efficiency even though that resource now constitutes a (very) small part of cost in most cases.

Standard cost accounting can hurt managers, workers, and firms in several ways. For example, a policy decision to increase inventory can harm a manufacturing manager's performance evaluation. Increasing inventory requires increased production, which means that processes must operate at higher rates. When (not if) something goes wrong, the process takes longer and uses more than the standard labor time. The manager appears responsible for the excess, even though s/he has no control over the production requirement or the problem.

In adverse economic times, firms use the same efficiencies to downsize, right size, or otherwise reduce their labor force. Workers laid off under those circumstances have even less control over excess inventory and cost efficiencies than their managers.

Many financial and cost accountants have agreed for many years on the desirability of replacing standard cost accounting. They have not, however, found a successor.

Theory of constraints cost accounting

Eliyahu M. Goldratt developed the Theory of Constraints in part to address the cost-accounting problems in what he calls the "cost world." He offers a

substitute, called throughput accounting, that uses throughput (money for goods sold to customers) in place of output (goods produced that may sell or may boost inventory) and considers labor as a fixed rather than as a variable cost. He defines inventory simply as everything the organization owns that it plans to sell, including buildings, machinery, and many other things in addition to the categories listed here. Throughput accounting recognizes only one class of variable costs: the truly variable costs, like materials and components, which vary directly with the quantity produced

Finished goods inventories remain balance-sheet assets, but labor-efficiency ratios no longer evaluate managers and workers. Instead of an incentive to reduce labor cost, throughput accounting focuses attention on the relationships between throughput (revenue or income) on one hand and controllable operating expenses and changes in inventory on the other.

National accounts

Inventories also play an important role in national accounts and the analysis of the business cycle. Some short-term macroeconomic fluctuations are attributed to the inventory cycle.

Distressed inventory

Also known as distressed or expired stock, distressed inventory is inventory whose potential to be sold at a normal cost has passed or will soon pass. In certain industries it could also mean that the stock is or will soon be impossible to sell. Examples of distressed inventory include products that have reached their expiry date, or have reached a date in advance of expiry at which the planned market will no longer purchase them (e.g. 3 months left to expiry), clothing that is defective or out of fashion, music that is no longer popular and old newspapers or magazines. It also includes computer or consumer-electronic

equipment that is obsolete or discontinued and whose manufacturer is unable to support it. One current example of distressed inventory is the VHS format.

In 2001, Cisco wrote off inventory worth US $2.25 billion due to duplicate orders. This is one of the biggest inventory write-offs in business history.

Stock Rotation

Stock Rotation is the practice of changing the way inventory is displayed on a regular basis. This is most commonly used in hospitably and retail - particularity where food products are sold. For example, in the case of supermarkets that a customer frequents on a regular basis, the customer may know exactly where they want and where it is. This results in many customers going straight to the product they seek and do not look at other items on sale. To discourage this practice, stores will rotate the location of stock to encourage customers to look through the entire store. This is in hopes the customer may pick up items they may have not normally of seen.

Inventory credit

Inventory credit refers to the use of stock, or inventory, as collateral to raise finance. Where banks may be reluctant to accept traditional collateral, for example in developing countries where land title may be lacking, inventory credit is a potentially important way of overcoming financing constraints. This is not a new concept; archaeological evidence suggests that it was practiced in Ancient Rome. Obtaining finance against stocks of a wide range of products held in a bonded warehouse is common in much of the world. It is, for example, used with Parmesan cheese in Italy. Inventory credit on the basis of stored agricultural produce is widely used in Latin American countries and in some Asian countries. A precondition for such credit is that banks must be confident that the stored product will be available if they need to call on the collateral; this implies the existence of a reliable network of certified warehouses. Banks also

face problems in valuing the inventory. The possibility of sudden falls in commodity prices means that they are usually reluctant to lend more than about 60% of the value of the inventory at the time of the loan.

Inventory Record Accuracy

Can you imagine driving a car through a rain storm, without engaging the windshield wipers?

Most of us wouldn't dare try this. It is simply too dangerous. The performance capabilities of the car beneath us - be it a 20-year-old sedan or a brand new SUV – would matter less to us than whether the windshield wipers were working properly.

And so it is with inventory record accuracy. With most companies involved in distribution, wholesaling, manufacturing and retailing, having access to reliable inventory numbers at the SKU level is critical. A five-star ERP system cannot operate effectively without accurate data input. If one does not know what one has on hand, one is operating as blindly as the driver whose windshield wipers fail in a rain storm.

While doing cause-and-effect work in a number of my past assignments, I have often found that the root cause to many customer service-related problems lies in a firm's inability to keep accurate inventory records.

Becky Partida, a knowledge specialist in supply chain management with APQC wrote a relevant article for *Industry Week.* She concisely answers the question of why we ought to be vigilant about this operational fundamental, and how we might achieve that all-important "extra one percent" accuracy:

Inventory accuracy is the variance between perpetual inventory and physical inventory. It is an important part of supply chain management because

organizations that allow their inventory accuracy to drop run several risks. Misleading inventory levels may make it seem that these organizations have more inventory than they actually do, which leads the organizations to sell stock that is not there and can result in dissatisfied customers. Inaccurate inventory data may also mask inventory that is actually there, which can lead to stock remaining in a warehouse until it becomes obsolete.

A related issue is increased inventory carrying cost. To get a better idea of how much additional cost can be related to carrying inventory, APQC reviewed data from its Open Standards Benchmarking in logistics. The data shows a nearly 11 percent difference between top performing and bottom performing organizations regarding inventory value as a percentage of revenue:

16.0% — Bottom performers

9.4% — Median

5.2% — Top performers

For an organization with $5 billion in revenue, this difference translates into $540 million in inventory carrying cost.

Aside from lower inventory carrying cost and more satisfied customers, higher inventory accuracy can lead to improved performance in other logistics processes. APQC's Open Standards Benchmarking database indicates that an increase in inventory accuracy from 98 percent to 99 percent is associated with an increase in supplier orders delivered on time, faster dock-to-stock cycle time, and an increase in the amount of sales orders delivered on time (Table 1).

Improvements in the metrics listed in Table 1 can affect the entire supply chain. When inbound deliveries to an organization arrive within the scheduled time frame and are quickly moved into the warehouse, those materials are available for customer orders sooner. Faster processing and delivery of products leads to

satisfied customers and lower inventory carrying cost.

Table 1
1% Increase in Inventory Accuracy and Performance on Key Metrics

	98% Inventory Accuracy		99% Inventory Accuracy	
	Median	N	Median	N
Percentage of supplier orders delivered on time	87%	16	90%	57
Dock-to-stock cycle time for supplier deliveries in hours	6 hours	17	4 hours	68
Percentage of sales orders delivered on time	92%	19	96%	70

Independent versus Dependent Demand

Dependent versus independent demand

The choice of how to control inventory depends upon the fact of whether or not the demand of the items has a dependent or an independent character.
This difference is important in selecting an adequate inventory management approach.

Dependent demand exists for those items for which demand is linked to the use of other items (for example, subassemblies which go into a higher-level component or finished item, such as the motherboard for a computer).

The essential aspect of dependent demand is that inventory items can be calculated. Controlling can take place by means of the 'MRP' system (see chapter 5).

Independent demand exists where the rate of use for an item does not relate directly to the use of another item (for example, finished goods such as a computer). Controlling can take place by means of an 'Order Point' system (see chapter 4.5). It is obvious that most organizations have items which fall into each category, namely the category of dependent and independent demand. If this is the case, then the organization will have to use both systems, because it would be a mistake to suppose that you can use a dependent system for an independent item and, the other way around, to use an independent system for a dependent item.

To control the inventory of independent items:

- you need the past demand in connection with future requirements
- you need a mechanism for initiating the order to replenish inventory

To lay down the character of controls to use here, one has to understand the relative values of inventory. In understanding this, it is possible to decide the type of controls to apply to each item of inventory.

This is due to maximizing the return (i.e. reduced inventory investment versus the involved control costs).

For the organization it is important to know where to put most effort in controlling inventory, in other words which items are - in this respect - the most important ones. In achieving this, the organization can make use of a 'Pareto' diagram. The organization can take a sample at random of its total inventory. From such a sample you make a list with the inventory items placed in order of decreasing Annual Dollar Usage (ADU). ADU stands here for the product of the

‘unit value’ and ‘annual usage’ of each item of inventory. This list can be transformed into a ‘Pareto’ diagram.

Holding, Ordering, and Setup Costs

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

EOQ Model

EOQ Model

The first model we will present is called the economic order quantity (EOQ) model. This model is studied first owing to its simplicity. Simplicity and restrictive modeling assumptions usually go together, and the EOQ model is not an exception. However, the presence of these modeling assumptions does not mean that the model cannot be used in practice. There are many situations in which this model will produce good results. For example, these models have been effectively employed in automotive, pharmaceutical, and retail sectors of the economy for many years. Another advantage is that the model gives the optimal solution in closed form. This allows us to gain insights about the behavior of the inventory system. The closed-form solution is also easy to compute (compared to, for example, an iterative method of computation). In this chapter, we will develop several models for a single-stage system in which we manage inventory of a single item. The purpose of these models is to determine how much to purchase (order quantity) and when to place the order (the reorder point). The common thread across these models is the assumption that demand occurs continuously at a constant and known rate. We begin with the simple model in which all demand is satisfied on time. In Section 2.2, we develop a

model in which some of the demand could be backordered. In Section 2.3, we consider the EOQ model again; however, the unit purchasing cost depends on the order size. In the final section, we briefly discuss how to manage many item types when constraints exist that link the lot size decisions across items.

Model Development: Economic Order Quantity (EOQ) Model We begin with a discussion of various assumptions underlying the model. This discussion is also used to present the notation.

1. Demand arrives continuously at a constant and known rate of l units per year. Arrival of demand at a continuous rate implies that the optimal order quantity may be non-integer. The fractional nature of the optimal order quantity is not a significant problem so long as the order quantity is not very small; in practice, one simply rounds off the order quantity. Similarly, the assumption that demand arrives at a constant and known rate is rarely satisfied in practice. However, the model produces good results where demand is relatively stable over time.
2. Whenever an order is placed, a fixed cost K is incurred. Each unit of inventory costs \$$I$ to stock per year per dollar invested in inventory. Therefore, if a unit's purchasing cost is C, it will cost $I \cdot C$ to stock one unit of that item for a year.
3. The order arrives t years after the placement of the order. We assume that t is deterministic and known.
4. All the model parameters are unchanging over time.
5. The length of the planning horizon is infinite.
6. All the demand is satisfied on time.

Our goal is to determine the order quantity and the reorder interval. Since all the parameters are stationary over time, the order quantity, denoted by Q, also remains stationary. The reorder interval is related to when an order should be placed, since

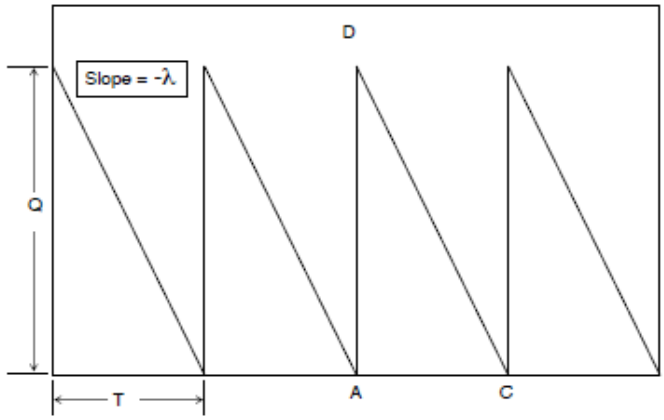


Fig. 2.1. Change in inventory over time for the EOQ model.

a reorder interval is equal to the time between two successive epochs at which an order is placed and is called the cycle length. A cycle is the time between the placing of two successive orders. The question of when to place an order has a simple answer in this model. Since demand occurs at a deterministic and fixed rate and the order once placed arrives exactly t years later, we would want the order to Fig. 2.1. Change in inventory over time for the EOQ model. arrive exactly when the last unit is being sold. Thus the order should be placed t years before the depletion of inventory.

The first step in the development of the model is the construction of cost expressions. Since total demand per year is l , the total purchasing cost for one year is *C*l . Similarly, the number of orders placed per year is equal to l /*Q*. Therefore, the total annual average cost of placing orders is *K*l /*Q*. The derivation of the total holding cost per year is a bit more involved. We will begin by first computing the average inventory per cycle. Since each cycle is identical to any other cycle, the average inventory per year is the same as the average inventory per cycle. The holding cost is equal to the average inventory per year times the cost of holding one unit of inventory for one year. Using Figure 2.1, we find the average inventory per cycle is equal to:

$$\frac{\text{Area of triangle } ADC}{\text{Length of the cycle}} = \frac{\frac{1}{2}QT}{T} = \frac{Q}{2}.$$

The annual cost of holding inventory is thus equal to $ICQ/2$. Adding the three types of costs together, we get the following objective function, which we want to minimize over Q:

$$\min_{Q \geq 0} Z(Q) = C\lambda + \frac{K\lambda}{Q} + \frac{ICQ}{2}. \qquad (2.1)$$

Before we compute the optimal value of Q, let us take a step back and think about what the optimal solution should look like. First, the higher the value of the fixed cost K, the fewer the number of orders that should be placed every year. This means that the quantity ordered per order will be high. Second, if the holding cost rate is high, placing orders more frequently is economical since inventory will on average be lower. A higher frequency of order placement leads to lower amounts ordered per order. Therefore, our intuition tells us that the optimal order quantity should increase as the fixed ordering cost increases and decrease as the holding cost rate increases. To compute the optimal order quantity, we take the first derivative of $Z(Q)$ with
respect to Q and set it equal to zero:

$$\frac{dZ}{dQ} = 0 - K\frac{\lambda}{Q^2} + \frac{IC}{2} = 0$$

$$\text{or} \quad Q^* = \sqrt{\frac{2K\lambda}{IC}}, \qquad (2.2)$$

where $Q*$ is the optimal order quantity. Note that the derivative of the purchasing cost Cl is zero since it is independent of Q. The following examples illustrate the computation of the optimal order quantity using (2.2). In our first

example, we assume an office supplies store sees a uniform demand rate of 10 boxes of pencils per week. Each box costs $5. If the fixed cost of placing an order is $10 and the holding cost rate is .20 per year, let us determine the optimal order quantity using the EOQ model. Assume 52 weeks per year. In this example K = 10, I = .20, C = 5, and the annual demand rate is l = (10)(52) = 520. Substituting these values in (2.2), we get

$$Q^* = \sqrt{\frac{2(520)(10)}{(0.2)(5)}} = 101.98 \approx 102.$$

In our second example, suppose the regional distribution center (RDC) for a major auto manufacturer stocks approximately 20,000 service parts. The RDC fulfills demands of dozens of dealerships in the region. The RDC places orders with the national distribution center (NDC), which is also owned by the auto manufacturer. Given the huge size of these facilities, it is deemed impossible to coordinate the inventory management of the national and regional distribution centers. Accordingly, each RDC manages the inventory on its own regardless of the policies at the NDC. We consider one part, a tail light, for a specific car model. The demand for this part is almost steady throughout the year at a rate of 100 units per week. The purchasing cost of the tail light paid by the RDC to the NDC is $10 per unit. In addition, the RDC spends on average $0.50 per unit in transportation. A breakdown of the different types of costs is as follows:

1. The RDC calculates its interest rate to be 15% per year.

2. The cost of maintaining the warehouse and its depreciation is $100,000 per year,

which is independent of the amount of inventory stored there. In addition, the costs of pilferage and misplacement of inventory are estimated to be 5 cents per dollar of average inventory stocked.

3. The annual cost of a computer-based order management system is $50,000 and is not dependent on how often orders are placed.

4. The cost of invoice preparation, postage, time, etc. is estimated to be $100 per order.

5. The cost of unloading every order that arrives is estimated to be $10 per order.

Let us determine the optimal order quantity. The first task is to determine the cost parameters. The holding cost rate I is equal to the interest rate (.15) plus the cost rate for pilferage and misplacement of inventory (.05). Therefore, I = .20. This rate applies to the value of the inventory when it arrives at the RDC. This value includes not only the purchasing cost ($10) but also the value added through transportation ($0.5). Therefore, the value of C is $10.50. Finally, the fixed cost of order placement includes all costs that depend on the order frequency. Thus, it includes the order receiving cost ($10) and the cost of invoice preparation, etc. ($100), but not the cost of the order management system. Therefore, K = 110. We now substitute these parameters into (2.2) to get the optimal order quantity:

$$Q^* = \sqrt{\frac{2\lambda K}{IC}} = \sqrt{\frac{2(5200)(110)}{(0.2)(10.5)}} = 738.08 \text{ units.}$$

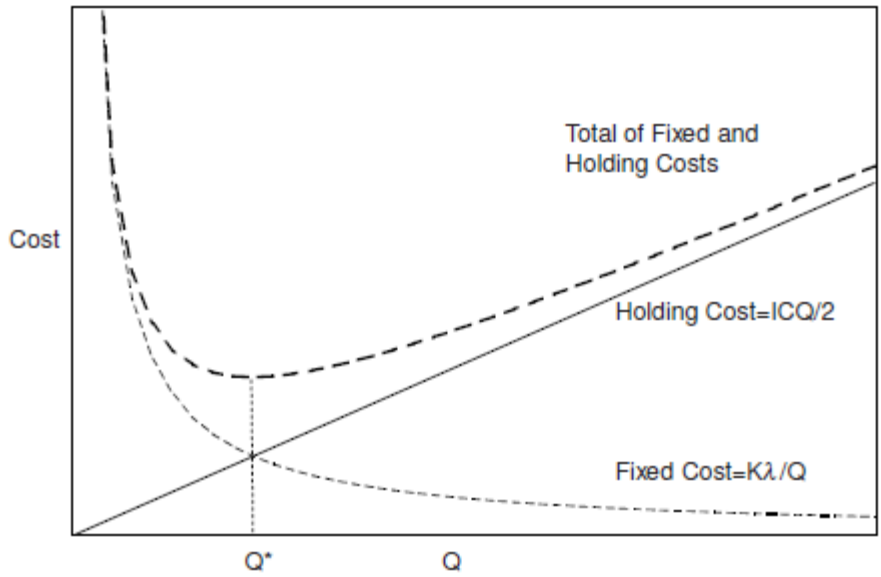


Fig. 2.2. Fixed and holding costs as functions of the order quantity.

Next, let us determine whether or not the optimal EOQ solution matches our intuition. If the fixed cost K increases, the numerator of (2.2) increases and the optimal order quantity $Q*$ increases. Similarly, as the holding cost rate I increases, the denominator of (2.2) increases and the optimal order quantity $Q*$ decreases. Clearly, the solution fulfills our expectations. To gain more insights, let us explore additional properties the optimal solution possesses. Figure 2.2 shows the plot of the average annual fixed order cost $K\lambda /Q$ and the annual holding cost $ICQ/2$

as functions of Q. The average annual fixed order cost decreases as Q increases because fewer orders are placed. On the other hand, the average annual holding cost increases as Q increases

since units remain in inventory longer. Thus the order quantity affects the two types of costs in opposite ways. The annual fixed ordering cost is minimized by making Q as large as possible, but the holding cost is minimized by having Q as small as possible. The two curves intersect at $Q = Q1$. By definition of $Q1$,

$$K\frac{\lambda}{Q_1} = \frac{ICQ_1}{2} \Rightarrow Q_1 = \sqrt{\frac{2K\lambda}{IC}}$$

And, in this case, $Q1 = Q*$. The exact balance of the holding and setup costs yields the optimal order quantity. In other words, the optimal solution is the *best compromise* between the two types of costs. (As we will see throughout this book, inventory models are based on finding the best compromise between opposing costs.) Since the annual holding cost $ICQ*/2$ and the fixed cost $K\lambda/Q*$ are equal in the optimal solution, the optimal average annual total cost is equal to

$$\begin{aligned} Z(Q^*) &= C\lambda + \frac{ICQ^*}{2} + K\frac{\lambda}{Q^*} = C\lambda + 2K\frac{\lambda}{Q^*} \\ &= C\lambda + 2K\frac{\lambda}{\sqrt{\frac{2\lambda K}{IC}}} = C\lambda + \sqrt{2\lambda KIC}, \end{aligned} \tag{2.3}$$

where we substitute for $Q*$ using (2.2).

Let us compute the optimal average annual cost for the office supplies example. Using (2.3), the optimal cost is equal to

$$C\lambda + \sqrt{2\lambda KIC} = (5)(520) + \sqrt{2(520)(10)(5)(0.2)} = \$2701.98.$$

The purchasing cost is equal to ($5)(520) = $2600, and the holding and order placementcosts account for the remaining cost of $101.98.

Robustness of the EOQ Model

In the real world, it is often difficult to estimate the model parameters accurately. The cost and demand parameter values used in models are at best an approximation to their actual values. The policy computed using the approximated parameters, henceforth referred to as approximated policy, cannot be optimal. The optimal policy cannot be computed without knowing the true values of the model's parameters. Clearly, if another policy is used, the realized cost will be greater than the cost of the true optimal policy.

The following example illustrates this point.

Suppose in the office supplies example that the fixed cost of order placement is estimated to be \$4 and the holding cost rate is estimated to be .15. Let us calculate the alternative policy and the cost difference between employing this policy and the optimal policy. Recall that the average annual cost incurred when following the optimal policy is \$2701.98. To compute the alternative policy, we substitute the estimated parameter values into (2.2):

$$Q^* = \sqrt{\frac{2(520)(4)}{(0.15)(5)}} = 74.48.$$

The realized average annual cost if this policy is used when $K = 10$ is

$$\begin{aligned} Z(Q^*) &= C\lambda + \frac{K\lambda}{Q^*} + \frac{ICQ^*}{2} \\ &= (5)(520) + \frac{(10)(520)}{74.48} + \frac{(0.2)(5)(74.48)}{2} = \$2707.06. \end{aligned}$$

Thus the cost difference between the alternative and optimal policies is \$2707.06 − \$2701.98 = \$5.08. Note that the cost of implementing the alternative policy is calculated using the actual cost parameters.

Let us now derive an upper bound on the realized average annual cost of using the approximate policy relative to the optimal cost. Suppose the *actual* order quantity is denoted by Q_a^*. This is the answer we would get from (2.2) if we could use the true cost and demand parameters. Let the true fixed cost and holding cost rate be denoted by K_a and I_a, respectively. We assume that the purchasing cost C and the demand rate λ have been estimated accurately. The estimates of the fixed cost and holding cost rate are denoted by K and I, respectively. The estimated order quantity is denoted by Q^*. Let $Q^*/Q^* = \alpha$ or $Q^* = \alpha\, Q^*$. Thus

$$Q_a^* = \sqrt{\frac{2\lambda K_a}{I_a C}}$$

$$Q^* = \sqrt{\frac{2\lambda K}{IC}} = \alpha\sqrt{\frac{2\lambda K_a}{I_a C}}$$

$$\Rightarrow \alpha = \sqrt{\left(\frac{K}{I}\right)\left(\frac{I_a}{K_a}\right)}.$$

Since the purchasing cost $C\lambda$ is not influenced by the order quantity, we do not include it in the comparison of costs. The true average annual operating cost (the sum of the holding and order placement costs) is equal to

$$Z(Q_a^*) = \sqrt{2K_a\lambda I_a C}.$$

The *actual* incurred average annual cost (sum of the holding and order placement costs) corresponding to the estimated order quantity Q^* is equal to

$$\begin{aligned} Z(Q^*) &= \frac{K_a\lambda}{Q^*} + \frac{I_a C Q^*}{2} \\ &= \frac{K_a\lambda}{\alpha Q_a^*} + \frac{I_a C(\alpha Q_a^*)}{2} \\ &= \frac{K_a\lambda}{\alpha\sqrt{\frac{2\lambda K_a}{I_a C}}} + \frac{I_a C\alpha\sqrt{\frac{2\lambda K_a}{I_a C}}}{2} \\ &= \frac{1}{2}\left(\alpha + \frac{1}{\alpha}\right)\sqrt{2K_a\lambda I_a C} = \frac{1}{2}\left(\alpha + \frac{1}{\alpha}\right) Z(Q_a^*). \end{aligned}$$

Therefore, if the estimated order quantity is α times the optimal order quantity, the average annual cost corresponding to the estimated order quantity is $\frac{1}{2}\left(\alpha + \frac{1}{\alpha}\right)$ times the optimal cost. For example, if $\alpha = 2$ (or $\frac{1}{2}$), that is, the estimated order quantity is 100% greater (or 50% lower) than the optimal order quantity, then the cost corresponding to the estimated order quantity is 1.25 times the optimal cost. Similarly, when $\alpha = 3$ (or $\frac{1}{3}$), the cost corresponding to the estimated order quantity is approximately 1.67 times the optimal cost.

Two observations can be made. First, and importantly, even for significant inaccuracies in the order quantity, the cost increase is modest. As we showed, the cost increase is only 25% for a 100% increase in the estimated order quantity from the optimal order quantity. The moderate effect of inaccuracies in the cost parameters on the actual incurred average annual cost is very profound. Second, the cost increase is symmetric around $\alpha = 1$ in a multiplicative sense. That is, the cost increase is the same for $Q^*/Q_a^* = \alpha$ or $Q^*/Q_a^* = \frac{1}{\alpha}$. This observation will be useful in the discussion presented in the following chapter.

How do we estimate α? Clearly, if we could estimate α precisely, then we could compute Q_a^* precisely as well and there would be no need to use the estimated order quantity. Since we cannot ascertain its value with certainty, perhaps we can estimate upper and lower bounds for α. These bounds can give us bounds on the cost of using the estimated order quantity relative to the optimal cost. The following example illustrates this notion in more detail.

Suppose in the office supplies example that the retailer is confident that his *actual* fixed cost is at most 120% but no less than 80% of the estimated fixed cost. Similarly, he is sure that his actual holding cost rate is at most 110% but no less than 90% of the estimated holding cost rate. Let us determine the maximum deviation from the optimal cost by implementing a policy obtained on the basis of the estimated parameter values.