1.0 INTRODUCTION

In any manufacturing system, the job of an Operations Manager is to manage the process of converting inputs into the desired outputs. Therefore, **Operations Management** can be defined as the management of the conversion process, which converts land, labor, capital, and management inputs into desired outputs of goods and services. It is also concerned with the design and the operation of systems for manufacture, transport, supply or service.

1.1 RELATED ISSUES OF OPERATIONS MANAGEMENT

Some of the related issues of Operations management are production function, productivity, productivity measurements, types of production systems, production modeling, and so on. They all are discussed in this chapter.

1.1.1 PRODUCTION FUNCTION

Production is an organized activity of transforming raw materials into finished products. It is an intentional act of producing something useful. In production systems we have different resources as input. The inputs are processed in a series of operations. The sequence, number, and type of operations (mechanical, chemical, electrical, assembly, inspection, transportation, etc) are specified for each input. The output of the system will be complete parts products, chemicals etc. Production function shows the relationship between the input and the output of an organization. By the study of production function the maximum output which can be achieved with given inputs, or say resources with a given state of technology is determined. The production function can be represented by the simple mathematical equation which relates the outputs as the function of inputs, that is

\[ Y = f(X_1, X_2, \ldots, X_n) \]

Where \( Y \) = units of output, which is the function of the quantity of two or more inputs

\( X_1 \) = unit of labor, and

\( X_2 \) = unit of machinery, and so on.

Some quantities of production are assumed as fixed, that is not varying with change of output, such quantities never enter in the equation.
1.1.2 PRODUCTIVITY
It is a very comprehensive concept, both in its aim and also in its operational content. It is a matter of common knowledge that higher productivity leads to a reduction in cost of production, reduces the sales price of an item, expands markets, and enables the goods to compete effectively in the world market. It yields more wages to the workers, shorter working hours and greater leisure time for the employees. In fact the strength of a country, prosperity of its economy, standard of living of the people and the wealth of the nation are very largely determined by the extent and measure of its production and productivity. By enabling an increase in the output of goods or services for existing resources, productivity decreases the cost of goods per unit, and makes it possible to sell them at lower prices, thus benefiting the consumers while at the same time leaving a margin for increase in the wages of the workers.

Productivity can be defined in many ways. Some of them are as follows:
- Productivity is nothing but the reduction in wastage of resources such as labor, machines, materials, power, space, time, capital, etc.
- Productivity can also be defined as human endeavor (effort) to produce more and more with less and less inputs of resources so that the products can be purchased by a large number of people at affordable price.
- Productivity implies development of an attitude of mind and a constant urge to find better, cheaper, easier, quicker, and safer means of doing a job, manufacturing a product and providing service.
- Productivity aims at the maximum utilization of resources for yielding as many goods and services as possible, of the kinds most wanted by consumers at lowest possible cost.
- Productivity processes more efficient works involving less fatigue to workers due to improvements in the layout of plant and work, better working conditions and simplification of work. In a wider sense productivity may be taken to constitute the ratio of all available goods and services to the potential resources of the group.

1.1.3 DIFFERENCE BETWEEN PRODUCTION AND PRODUCTIVITY
As discussed earlier, production is an organized activity of transforming raw materials into finished products which have higher value. Production of any commodity or service is the volume of output irrespective of the quantity of resources employed to achieve the level of output. Production in an industry can be increased by employing more labor, installing more machinery, and putting in more materials, regardless of the cost of production.

But increase of production does not necessarily mean increase in productivity. Higher productivity results when we put in production system an element of efficiency with which the resources are employed. The combined input of a number of factors such as land, materials, machines, capital, and labor gives an output in an industry. The ratio between output and one of these factors of input is usually known as productivity of the factor considered. Productivity may also be considered as a measure of performance of the economy as a whole. Mathematically,

Productivity = Output Value/Input Value

Factor Productivity = Output due to the factor/ Input factor employed

An example to illustrate the difference between production and productivity follows: For instance, 50 persons employed in an industry may be producing the same volume of goods over the same period
as 75 persons working in another similar industry. Productions of these two industries are equal, but productivity of the former is higher than that of the latter.

In order to assure that productivity measurement captures what the company is trying to do with respect to such vague issues as customer satisfaction and quality, some firms redefined productivity as

\[ \text{Productivity} = \frac{\text{Effectiveness or value to customer}}{\text{Efficiency or cost to producer}} \]

As it has been said so many times productivity measurement is the ratio of organizational outputs to organizational inputs. Thus productivity ratios can be

- Partial productivity measurement
- Multi-factor productivity measurement
- Total productivity measurement

**Partial Productivity Measurement**
Partial productivity measurement is used when the firm is interested in the productivity of a selected input factor. It is the ratio of output values to one class of input.

\[ \text{PPM} = \frac{\text{Outputs}}{\text{Labor Input}} \quad \text{or} \quad \frac{\text{Outputs}}{\text{Material Input}} \quad \text{or} \quad \frac{\text{Outputs}}{\text{Capital}} \]

**Multi-factor Productivity Measurement**
This productivity measurement technique is used when the firm is interested to know the productivity of a group of input factors but not all input factors.

\[ \text{MFPM} = \frac{\text{Outputs}}{\text{Labor + Capital}} \quad \text{or} \quad \frac{\text{Outputs}}{\text{Labor + Material}} \]

**Total (Composite) Productivity Measures**
A firm deals about composite productivity when it is interested to know about the overall productivity of all input factors. This technique will give us the productivity of an entire organization or even a nation.

\[ \text{TPM} = \frac{\text{Outputs}}{\text{Inputs}} \quad \text{or} \quad \frac{\text{Goods and services provide}}{\text{All resources Used}} \]

The above measurement techniques can be grouped into two popular productivity measurement approaches the first uses a group-generated model and is called normative productivity measurement methodology. The second is less participative in that one model can be modified to fit any organization scheme. It is called multi-factor productivity measurement model.

**1.1.4 EFFECTIVENESS**
It is the degree of accomplishment of the objectives that is: How well a set of result is accomplished? How well are the resources utilized? Effectiveness is obtaining the desired results. It may reflect output quantities, perceived quality or both. *Effectiveness can also be defined as doing the right things.*

**1.1.5 EFFICIENCY**
This occurs when a certain output is obtained with a minimum of inputs. The desired output can be increased by minimizing the down times as much as possible (down times are coffee breaks, machine failures, waiting time, etc). But as we decrease down times the frequency of occurrence of defective products will increase due to fatigue. The production system might efficiently produce defective (ineffective) products. *Efficiency can be defined as doing things right. Operational efficiency refers to a ratio of outputs to inputs (like land, capital, labor, etc.)*
Example 1.1. Management of a hotel is concerned with labor efficiency, especially when labor is costly. To determine how efficient labor is in a given situation, management sets an *individual standard*, a goal reflecting an average worker’s output per unit of time under normal working conditions. Say that the standard in a cafeteria is the preparation of 200 salads per hour. If a labor input produces 150 salads per hour, how efficient is the salad operation?

\[
\text{Labor efficiency} = \frac{\text{Labor Outputs}}{\text{Labor Input}} = \frac{150 \text{ salads}}{200 \text{ salads}} \times 100\% = 75\%
\]

So, compared with the standard, this operation is 75% efficient in the preparation of salads.

1.2 OPERATIONS FUNCTION IN ORGANIZATIONS

The operations system of an organization is the part that produces the organization’s products. In some organizations the product is a physical good (refrigerators, breakfast cereal), while in others it is a service (insurance, health care for the old people). However, these organizations have something in common as shown in Figure 1.1. They have a *conversion process*, some resource *inputs* into that process, the *outputs* resulting from the conversion of the inputs, and *information* feedback about the activities in the operations system. Once goods and services are produced, they are converted into cash (sold) to acquire more resources to keep the conversion process alive.

Example 1.2. On a farming situation, the *inputs* are: land, equipment, labor, etc and the *outputs* are: corn, wheat, milk, fruits, and so on.

For all operations, the goal is to create some kind of *value-added*, so that the outputs are worth more to consumers than just the sum of the individual inputs. Some of the examples of input, conversion process, and output are shown in Table 1.1. Students are advised to collect some inputs and outputs of some of the industries visited by them. The *random fluctuations* in Figure 1.1 consist of unplanned or uncontrollable influences that cause the actual output to differ from the expected output. Random fluctuations can arise from external sources (fire, floods, earthquake, lightening, or even some diseases like SARS), or they can result from internal problems (defects in materials and equipment, human error). In fact, fluctuations are the rule rather than the exception in
production system and reducing fluctuations (variations) is a major task of management. It may be noted that SARS (Severe Acute Respiratory Syndrome) has affected all aspects of life (airlines, tourism, schools, industries, etc.) in many countries especially in China.

<table>
<thead>
<tr>
<th>Input</th>
<th>Conversion process</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>Transformation</td>
<td>Useful products</td>
</tr>
<tr>
<td>Materials</td>
<td>Machines</td>
<td>Products</td>
</tr>
<tr>
<td>Data</td>
<td>Interpretation</td>
<td>Knowledge</td>
</tr>
<tr>
<td>Energy</td>
<td>Skill</td>
<td>Services</td>
</tr>
<tr>
<td>Variable cost</td>
<td>Fixed cost</td>
<td>Revenue</td>
</tr>
</tbody>
</table>

An unit of output normally needs several types of inputs. The inputs account for most of the variable cost of production. Conversion process/facilities are associated with fixed cost, and the output produces the revenue.

Any system is a collection of interacting components. Each component could be a system unto itself in a descending order of simplicity. Systems are distinguished by their objectives; the objective of one system could be to produce a component which is to be assembled with other components to achieve the objective of a larger system.

1.2.1 MANUFACTURING OPERATIONS Vs SERVICE OPERATIONS

A conversion process that includes manufacturing (or production) yields a tangible output: a product. In contrast, a conversion process that includes service yields an intangible output: a deed, a performance, an effort. For example, Mesfin Industries produces a lot of tangible products, whereas Ethiopian Airlines provides air transport services to passengers which is an intangible output.

1.2.1.1 Distinguishing Between Manufacturing and Service Operations

Generally the following characteristics are used to distinguish between manufacturing and service operations:

- Tangible and intangible nature of output
- Consumption of output
- Nature of work (jobs)
- Degree of customer contact
- Customer participation in conversion
- Measurement of performance

Put simply, the manufacturing is characterized by tangible outputs (products), outputs that customers consume over time, jobs that use less labor and more equipment, little customer contact, no customer participation in the conversion process (in production), and sophisticated methods for measuring production activities and resource consumption as products are made.

Service, on the other hand, is characterized by intangible outputs, outputs that customers consume immediately, jobs that use more labor and less equipment, direct customer contact, frequent customer participation in the conversion process, and elementary methods for measuring conversion activities and resource consumption. However, some service is equipment-based like Computer software services, Internet services, telephone services, etc. Some service is people-based like tax accounting services, hair styling, and golf instruction.
Let’s see the customers’ participation aspects in conversion process. In service operations, managers sometimes find it useful to distinguish between output and throughput types of customer participation. Output is a generated service, throughput is an item going through the process. In a pediatrics clinic the output is the medical service to the child, who by going through the conversion process, is also a throughput. Same is the case with the students undergoing training in Addis Ababa University. At a fast-food restaurant, in contrast, the customer does not go through the conversion process. The outputs are burgers, pizzas, and French fries served in a hurry (both goods and services), while the throughputs are the food items as they are prepared and converted. The customer is neither a throughput nor an output. Both the clinic and the restaurant provide services, even though the outputs and throughputs differ considerably.

We will use the term operations to include both manufacturing and service in this book.

**1.2.1.2 Historical Background of Production and Operations Management**

For over two centuries, operations management has been recognized as an important factor in economic development of a country. POM has passed through a series of names like: manufacturing management, production management, and operations management. All of these describe the same general discipline.

The traditional view of manufacturing management began in the 8th century when Adam Smith recognized the economic benefits of specialization of labor. He recommended breaking jobs down into subtasks and reassigning workers to specialized tasks in which they become highly skilled and efficient. In the early 20th century, Fredrick W. Taylor implemented Smith’s theories and crusaded for scientific management in the manufacturing sectors of his day. From then until about 1930, the traditional view prevailed, and many techniques we still use today were developed. A brief sketch of these and other contributions to manufacturing management is given in Table 1.2.

**Table 1.2. Historical summary of Operations Management**

<table>
<thead>
<tr>
<th>Date (approx)</th>
<th>Contribution</th>
<th>Contributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1776</td>
<td>Specialization of labor in manufacturing</td>
<td>Adam Smith</td>
</tr>
<tr>
<td>1799</td>
<td>Interchangeable parts, cost accounting</td>
<td>Eli Whitney and others</td>
</tr>
<tr>
<td>1832</td>
<td>Division of labor by skill; assignment of jobs by skill; basics of time study</td>
<td>Charles Babbage</td>
</tr>
<tr>
<td>1900</td>
<td>Scientific management; time study and work study developed; dividing planning and doing of work</td>
<td>Frederick W. Taylor</td>
</tr>
<tr>
<td>1900</td>
<td>Motion study of jobs</td>
<td>Frank B. Gilbreth</td>
</tr>
<tr>
<td>1901</td>
<td>Scheduling techniques for employees, machines, jobs in manufacturing</td>
<td>Henry L. Gantt</td>
</tr>
<tr>
<td>1915</td>
<td>Economic lot sizes for inventory control</td>
<td>F. W. Harris</td>
</tr>
<tr>
<td>1927</td>
<td>Human relations; the Hawthorne studies</td>
<td>Elton Mayo</td>
</tr>
<tr>
<td>1931</td>
<td>Statistical inference applied to product quality; quality control charts</td>
<td>Walter A. Shewhart</td>
</tr>
<tr>
<td>1935</td>
<td>Statistical sampling applied to quality control; inspection sampling plans</td>
<td>H. F. Dodge and H. G. Romig</td>
</tr>
</tbody>
</table>
As Frederick Taylor’s work became more widely known, managers developed techniques that focused on economic efficiency in manufacturing. Workers were ‘put under a microscope’ and studied in great detail to eliminate wasteful efforts and achieve greater efficiency. At this same time, however, management also began discovering that workers have multiple needs, not just economic needs. Psychologists, sociologists, and other social scientists began to study people and human behavior in the work environment. In addition, economists, mathematicians, and computer scientists contributed newer, more sophisticated analytical approaches.

With the 1970’s emerges two distinct changes in our views. The most obvious of these, reflected in the new name—operations management—was a shift in the service and manufacturing sectors of the economy. As the service sector became more prominent, the change from ‘production’ to ‘operations’ emphasized the broadening of our field to service organizations. The second, more subtle change was the beginning of an emphasis on synthesis, rather than just analysis, in management practices. These days, organizational goals are more focused to meet consumers’ needs throughout the world. Quality concepts like TQM, ISO-9000, Quality function deployment, etc. are all examples of this attitude of management.

1.2.2 TYPES OF PRODUCTION SYSTEM

There are eight types of production which may be classified in three or four broad groups according to the quantities of production involved [Samuel Eilon]. They are shown in Figure 1.2 in terms of product variety and production volume—the figure is self-explanatory.

1. **Job Shop Production system which has the following features:**

   (a) A small number of items produced only once,
   (b) A small number of items produced intermittently when the need is felt,
   (c) A small number of items produced periodically at known time interval.
2. **Batch Production** which has the following characteristics:
   (a) A batch of items produced only once,
   (b) A batch of items produced at irregular intervals when a need is felt,
   (c) A batch of items produced periodically at known intervals to satisfy the continuous demand.

3. **Continuous Production** which consists of
   (a) Mass production
   (b) Flow production

![Different Types of Production Systems.](image)

### 1.2.2.1 Job Production

This is the oldest method of production on a very small scale. It is also popularly known as 'job-shop or Unit' production. With this method individual requirements of consumers can be met. Each job order stands alone and may not be repeated. Some of the examples include manufacturing of aircrafts, ships, space vehicle, bridge and dam construction, ship building, boilers, turbines, machine tools, things of artistic nature, die work, etc. Some of the features of this system are as follows:

- This system has a lot of flexibility of operation, and hence general purpose machines are required.
- Generally no automation is used in this system, but computer-aided-design (CAD) is used.
- It deals with 'low volume and large variety' production. It can cater to specific customer order, or job of one kind at a time.
- It is known for rapid value addition.

**Advantages**

- Low risk of loss to the factory adopting this type of production. Due to flexibility, there is no chance of failure of factory due to reduction in demand. It can always get one or the other job orders to keep it going.
- Requires less money and is easy to start.
- Less or no management problem because of very small work force.

**Disadvantages**

- For handling different types of jobs, only workers with multiple skills are needed. This increases the labor cost.
• Low equipment utilization.
• As the raw materials are purchased in less quantity, the cost of material procurement is more.

1.2.2.2 Batch Production

The batch production system is generally adopted in medium size enterprises. Batch production is a stage in between mass production and job-shop production. As in this system, two or more than two types of products are manufactured in lots or batches at regular interval, which justifies its name the ‘batch production system’. It has the following features:

• A batch production turns into flow production when the rest period vanishes. In flow production, the processing of materials is continuous and progressive.
• Batch production is bigger in scale than job production, but smaller than that of mass production.
• Material handling may be automated by robots as in case of CNC machining centers.
• A medium size lots (5 to 50) of same items is produced in this system. Lot may be produced once in a while or on regular interval generally to meet the continuous customer demands.
• Plant capacity generally is higher than demand.

Advantages

• It is flexible in the sense that it can go from one job to another with almost zero cost. It needs general purpose machine having high production rate.
• If demand for one product decreases then production rate for another product may be increased, thus the risk of loss is very less.
• Most suitable for computer-aided-manufacturing (CAM).

Disadvantages

• As the raw materials to be purchased are in smaller quantity than in case of mass production, the benefits of discount due to large lot purchasing is not possible.
• It needs specially designed jigs and fixtures.

1.2.2.3 Continuous Production

In this, the production activity continues for 24 hours or on three shifts a day basis. A steel plant, for example, belongs to this type. It is impossible to stop the production process on a short notice without causing a great damage to its blast furnace and related equipment. Other examples include bottling plant, soft drink industry, fertilizer plant, power plant, etc. Mass production and Flow production belong to continuous type only. They are explained below:

Mass production: In this type, a large number of identical items is produced, however, the equipment need not be designed to produce only this type of items. Both plant and equipment are flexible enough to deal with other products needing the same production processes. For example, a highly mechanized press shop that can be utilized to produce different types of components or products of steel metal without the need of major changes.

Flow production: In this type, the plant, its equipment, and layout have been chiefly designed to produce a particular type of product. Flexibility is limited to minor modifications in layout or design of models. Some famous examples are automobiles, engines, house-hold machinery, chemical plants, etc. If the management decides to switch over to a different type of product, it will result in extensive change in tooling, layout, and equipment.
Continuous production, in general, has the following features:

- It is very highly automated (process automation), and highly capital intensive. Items move from one stage to another automatically in a continuous manner.
- It has a fixed or hard automation which means there is very less or no flexibility at all. Layout of the plant is such that it can be used for only one type of product. Each machine in the system is assigned a definite nature of work.
- To avoid problem of material handling, use of cranes, conveyors etc. are made.
- Work-in-process (WIP) inventory in this system is zero.

Advantages

- It gives better quality, large volume but less variety of products.
- Wastage is minimum.
- As the raw materials are purchased on a large scale, higher margin of profit can be made on purchase.
- Only a few skilled, and many semi-skilled workers are required. This reduces the labor cost substantially.

Disadvantages

- During the period of less demand, heavy losses on invested capital may take place.
- Because all the machines are dedicated and special purpose type, the system is not changeable to other type of production.
- Most of the workers handle only a particular operation repetitively, which can make them feel monotonous.
- As this type of production is on the large scale, it cannot fulfill individual taste.

1.3 ROLE OF MODELS IN OPERATIONS MANAGEMENT

The context in which we use the term mathematical modeling refers to the creation of mathematical representations of management problems and organizations in order to determine outcomes of proposed courses of action. In spite of their utility, we must recognize that models cannot duplicate the real environment completely. However, this shortcoming should not be taken as a negative feature in a strict sense. In fact, it can be desirable, because it clears away extraneous elements and frills, and concentrates on the core problem. The modeling process can give us a simplified version of the situation with clear visibility of major factors.

1.3.1 TYPES OF MODELS IN PRODUCTION OPERATIONS MANAGEMENT (POM)

In operations management, we use several types of models of varying levels of sophistication.

1.3.1.1 Verbal Models

Verbal or written models express in words the relationships among variables. Verbal models are descriptive. Suppose a passing motorist asks you to give directions to the nearest gas station. If you tell him the way, you are giving a verbal model. If you write the directions in words (not pictures), you are giving a descriptive model.

1.3.1.2 Schematic Models

Schematic models show a pictorial relationship among variables. If you give the passing motorist a map showing the way to the nearest gas station, you would be giving a schematic model. Charts and
diagrams are also schematic; they are very useful for showing relationships among variables, as long as all the legends, symbols, and scales are explained.

1.3.1.3 Iconic Models
Iconic models are scaled physical replicas of objects or processes. Architectural models of new buildings and highway engineering replicas of a proposed overpass system are iconic models.

1.3.1.4 Mathematical Models
Mathematical models show functional relationships among variables by using mathematical symbols and equations. In any equation, \( x, y \), and similar symbols are used to express precise functional relationships among the variables.

1.3.2 MATHEMATICAL MODELS IN PRODUCTION AND OPERATIONS MANAGEMENT

Optimization: Operations managers often use models to help analyze problems and suggest solutions. To assist, they find it helpful to use an algorithm, a prescribed set of steps (a procedure) that attains a goal. In optimization models, for example, we want to find the best solution (the goal), and an optimization algorithm identifies the steps for doing so. In operations management we strive for optimization algorithms as aids in problem solving.

Heuristics: In other cases, a heuristic approach is used. A heuristic is a way (a strategy) of using rules of thumb or defined decision procedures to attack a problem. In general, when we use heuristics we do not expect to attain the best possible solution to a problem; instead, we hope for a satisfactory solution quickly. Formally developed heuristic procedures are called heuristic algorithms. They are useful for problems for which optimization algorithms have not yet been developed.

1.3.3 MODELING BENEFITS
The extensive use of models, especially schematic and mathematical models, is sometimes questioned by students and practitioners of POM. Using models often requires making questionable assumptions, applying hard-to-get cost and other data, and figuring in future events that are not easily predicted. Even so, the knowledge gained from working with models and attempting to apply them can yield valuable insights about a particular problem and what types of decisions are required. Simply recognizing the decision points can be a major step forward in many situations. Moreover, by using models, managers can recognize

- Variables that can be controlled to affect performance of the system
- Relevant costs and their magnitudes, and
- The relationship of costs to variables, including important tradeoffs among costs.

1.4 CLASSIFYING PROBLEMS
Since the operations analyst comes across different types of problems, it is a good idea to classify them into some groups. This will make it easier to select models and criteria to use in the analysis. There can be two ways of classifying problems: by the degree to which the outcome is uncertain, and by the degree to which the decisions are independent.

1.4.1 UNCERTAINTY OF OUTCOMES
When we know for sure what the outcome of each decision will be, we are dealing with a problem under control of certainty. When a decision has more than one possible outcome and we know the
likelihood of each outcome, we are dealing with a problem under conditions of *risk*. Finally, when a decision has more than one possible outcome and we do not know the likelihood of each outcome, we are dealing with a problem under conditions of *uncertainty*. Some examples may clarify these conditions of certainty, risk, and uncertainty.

**Example 1.3. (Certainty)** A chain of supermarkets is going to open a new store at one of four possible locations. Management wishes to select the location that will maximize profitability over the next ten years. An extensive analysis was performed to determine the costs, revenues, and profits for each alternative. The results are shown below.

<table>
<thead>
<tr>
<th>Location</th>
<th>10 year annual profit ($ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>0.60</td>
</tr>
<tr>
<td>4</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Management has a high degree of confidence in these figures. The decision criterion (profit) has been explicitly identified and accurately calculated for each alternative. Management’s strategy is to select the alternative with the highest criterion value, in this case location 2.

**Solution.** Under conditions of certainty, the best location is easily identified. Location 2 clearly yields the highest profit.

**Example 1.4. (Risk)** Further analysis of the supermarket chain’s problem reveals that the profit associated with each location is not known for sure. Management is convinced that the ten-year profitability of each location will depend upon regional population growth. Therefore management cannot predict the outcome with certainty. Three possible rates of population growth were identified: *low*, *medium*, and *high*. The profitability ($ millions) associated with each location and each rate of population growth was calculated, as shown below.

<table>
<thead>
<tr>
<th>Rate of population growth</th>
<th>Location</th>
<th>Low (5% or less)</th>
<th>Medium (above 5% but below 10%)</th>
<th>High (10% or more)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3 million $</td>
<td>0.8 million $</td>
<td>0.9 million $</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.6</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Probability (p)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

The figures at the bottom of the table gives the probability (likelihood) of each rate of population growth. Decision strategy in this situation is more difficult than it is under conditions of certainty.

**Solution.** Under conditions of risk, the choice is not so easy. We do not know which location will be best because the rate of future population growth is not known for certain. In analyzing this situation, the data need to be arranged differently (see Table 1.4). The table arranged like this is called a *matrix*. Which alternative is the best?

If population growth turns out to be low, then location 4 is the best (0.6 million $). If growth is medium, then location 1 is the best (0.8 million $), and if the growth is high, then location 2 is the best (1.1 million $). In the analyst’s language, the three rates of population growth are called *states of nature*.
Table 1.5. Calculation of Expected Value in $ million

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Expected Value (Profit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>0.8</td>
<td>0.9</td>
<td>(.3*.2) + (.8*.3) + (.9*.5) = .75</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.6</td>
<td>1.1</td>
<td>(.2*.2) + (.6*.3) + (1.1*.5) = .77</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>(.4*.2) + (.5*.3) + (.6*.5) = .53</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>(.6*.2) + (.7*.3) + (.8*.5) = .73</td>
</tr>
</tbody>
</table>

A concept of expected value has been applied to our problem (Table 1.5). The expected value is highest for alternative 2 ($ .77 million). If management faced this situation many times and always chose alternative 2, its average profit would be higher than for any other alternative.

Example 1.5. (Uncertainty) Even further analysis has cast doubt on the probability of the rates of population growth. New management doesn’t know the probabilities of low, medium, or high growth, and is faced with a problem under conditions of uncertainty. Obviously, strategy is much harder to come by in this case.

Solution. We discuss three approaches from a set of several options that analysts use in the situation of uncertainty: maximax, maximin, and principles of insufficient reason.

(i) The maximax is an optimistic approach. Here the analyst considers only the best outcome for each alternative regardless of probability. Looking at Table 1.4 and ignoring the probability row, the outcomes that would be considered are: $9 million for alternative 1, $1.1 million for alternative 2, $6 million for alternative 3, and $8 million for alternative 4. Among these, alternative 2 gives the best profit, and thus selected in this situation.

(ii) The second approach is maximin - a pessimistic approach. Here, the analyst considers only the worst outcome for each alternative and selects the ‘best of the worst’. In Table 1.4, the outcomes to be considered are: $3 million for alternative 1, $2 million for alternative 2, $4 million for alternative 3, and $6 million for alternative 4. The best of these is alternative 4.

(iii) The third approach, the principles of insufficient reason, assumes that since we know absolutely nothing about the probabilities of any state of nature, we should treat each with equal probability, calculate the expected values accordingly, and choose the alternative whose expected value is highest. Using this approach, we would select alternative 4.

Table 1.6. Calculation of Expected Value in $ million

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Expected Value (Profit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>0.8</td>
<td>0.9</td>
<td>(.3*.33) + (.8*.33) + (.9*.33) = .660</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.6</td>
<td>1.1</td>
<td>(.2*.33) + (.6*.33) + (1.1*.33) = .627</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>(.4*.33) + (.5*.33) + (.6*.33) = .495</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>(.6*.33) + (.7*.33) + (.8*.33) = .693</td>
</tr>
</tbody>
</table>

1.4.2 Maximin Rule (Weather Problem)
A person needs to go to his office. The two possible states of weather are: (A) it may rain, (B) it might shine. The following three possible strategies for the person are: X: go without protection, Y: go with an umbrella, Z: go with an umbrella and a rain coat. The pay-off matrix is given as follows:
Table 1.7. Pay-off matrix

<table>
<thead>
<tr>
<th>Strategy</th>
<th>A (Rain)</th>
<th>B (Shine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (No Protection)</td>
<td>−10</td>
<td>10</td>
</tr>
<tr>
<td>Y (Umbrella)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Z (Umbrella + Coat)</td>
<td>12</td>
<td>−5</td>
</tr>
</tbody>
</table>

Decide on the basis of (i) Maximin, and (ii) Maximax what decision the person should take under the given situation?

Solution.

(i) Decision based on Maximin rule

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Minimum satisfaction for strategy</th>
<th>Maximum of these minima</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>−10</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>1</td>
<td>1 (the person will go with umbrella)</td>
</tr>
<tr>
<td>Z</td>
<td>−5</td>
<td></td>
</tr>
</tbody>
</table>

(ii) Decision based on Maximax rule

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Max. satisfaction for the strategy</th>
<th>Maximum of these maxima</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>12</td>
<td>12 (The person will go with umbrella and coat)</td>
</tr>
</tbody>
</table>

1.4.3 INTERDEPENDENCE AMONG DECISIONS

A second way to classify problems relates to the number of decision stages that must be considered. At one extreme are single-stage (or static) problems; at the other are multistage (or sequential) problems. Static problems entail essentially 'one-time-only' decisions. Decisions concerning inventory, 'make-vs-buy', product mix, and location of new facility are often treated as static problems. Our supermarket chain example was treated this way. To simplify the situation, the decision is treated as if it were independent of other decisions.

Multistage problems, on the other hand, entail several sequential decisions related to one another. The outcome of the first decision affects the attractiveness of choices at the next decision stage, and so on down the line at each decision point. With multistage problems, the concern is not how to get the best outcome at any single stage but how to make a series of choices that will finally result in the best overall set of outcomes from beginning to end. Some of the examples of multistage problems are encountered by operation managers in project management, capacity planning, and aggregate scheduling.

UNSOLVED PROBLEMS

1.1 The labor output standard for an Insurance claims office is 150 claims processes per day. So far this week, 160, 125, 140, and 100 claims have been processed daily. The claims backlog is building up. Prepare a graph of daily efficiency. What does the graph indicate?
1.2 The manager of a bottling plant came to work early on Friday, having been out of town throughout the week. Before others arrived, he checked the daily labor efficiency report for the bottling plant. He finds that daily efficiency was 102% on Monday, 94% on Tuesday, and 87% on Wednesday. Going to the assistant manager’s desk, he found that on Thursday employees worked 96 hours and bottled 1,025 cases. The standard for labor output is 12.5 cases per hour. What, if any, questions should the manager ask when employees arrive on Friday?

1.3 A company is thinking to purchase a used truck. Its useful service life is estimated to be 3 years with a probability of 0.1; 4 years with a probability of 0.4; 5 years with a probability of 0.3; and 6 years with a probability of 0.2. What is the expected useful life of the used truck?

1.4 A cab company is considering three makes of autos-A, B, or C-to add to its taxi fleet. The daily operating cost of each make depends on daily usage rate (demand) as shown here:

<table>
<thead>
<tr>
<th>Make</th>
<th>Daily Usage Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>A</td>
<td>$100</td>
</tr>
<tr>
<td>B</td>
<td>190</td>
</tr>
<tr>
<td>C</td>
<td>150</td>
</tr>
</tbody>
</table>

Which make is best according to the principles of insufficient reason? If the probabilities of low, moderate, and high usage are .5, .2, and .3, respectively, which make has the highest expected value?

1.5 Four alternative manufacturing methods are being considered for a new product. Profitability, which depends on method of manufacture and level of consumer acceptance, is anticipated as shown here.

<table>
<thead>
<tr>
<th>Manufacturing Method</th>
<th>Projected Consumer Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>$100</td>
</tr>
<tr>
<td>2</td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Probability</td>
<td>.25</td>
</tr>
</tbody>
</table>

(a) What is the best manufacturing method according to each of these approaches?

- Expected value
- Maximin
- Maximax
- Insufficient reason

(b) Which manufacturing method should be selected and why?

1.6 A glass factory is experiencing a substantial backlog, and the management is considering three courses of action: (A) arrange for subcontracting, (B) begin overtime production, or (C) construct new facilities. The correct choice depends largely upon future demand, which may be low, medium, or high. By consensus, the management ranks the respective probabilities as 0.1, 0.5, and 0.4. A cost analysis reveals the effect upon profits that is shown in Table 1.
(a) State which course of action would be taken under a criterion of (i) maximax, (ii) maximin, (iii) maximum probability, and (iv) maximum expected value.

(b) Show this decision situation schematically in the form of a decision tree.