CHAPTER 1

Industrial Engineering and Production Systems

1.1 INTRODUCTION

Industrial engineering determines the most effective ways to use the basic factors of production such as men, machines, materials, information, and energy to make a product or a service. These factors of production form the link between management goals and operational performance. Industrial engineering deals with increasing productivity through the management of men, methods and technology.

The American Institute of Industrial Engineering (AIIE, 1955) has defined the term 'industrial engineering' as given below (Maynard 1963):

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, machines, materials, and energy. It draws upon specialized knowledge and skills in the mathematical, physical and social sciences together with the principles and method of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.

A number of definitions have been given for industrial engineering. One more widely used and accepted definition of industrial engineering is given below:

> Industrial engineering may be defined as the art of utilizing scientific principles, psychological data, and physiological information for designing, improving, and integrating industrial, management, and human operating procedures. (Nadler 1955)

Industrial management is closely related to industrial engineering and concerned with the techniques to develop, improve, implement and evaluate the integrated systems of men, materials, money, machines, methods, knowledge, information and energy. It includes the knowledge of various fields to increase the efficiency and effectiveness of an industry. The origin of industrial management has been industrial engineering. It is a process of planning, organizing, directing, controlling and managing the activities of any industry/organization. It organizes and transforms the inputs using various resources of the organization into value-added products in a controlled and an effective manner.

1.2 HISTORICAL DEVELOPMENT OF CONCEPTS IN INDUSTRIAL ENGINEERING AND MANAGEMENT

The evolution of industrial engineering has been defined in five different stages. These stages are mentioned below as:

Phase 1: Pre-Industrial Revolution Era
Phase 2: Industrial Revolution Era
Phase 3: Scientific Management Phase
Phase 4: Operations Research and Quantitative Management Phase
Phase 5: Automation and Computer-Integrated Manufacturing (Modern Management)

1.2.1 Pre-industrial Revolution Era

Prior to the Industrial Revolution in the early 1800s, there was focus on only manual operated manufacturing activities. There was no factory concept; mostly, handicraft and agriculture products, etc. were dominated in the trade. Three major developments in this era are given below as:

1774: James Watt developed the steam engine.
1776: Adam Smith wrote *The Wealth of Nations* and advocated the concept of division of labour, skill development, specialization, etc. (Smith 1776).
1798: Concept of interchangeability of parts was developed by Whitney and was used in manufacturing of musket (Hatfield 2013).

1.2.2 Industrial Revolution

Industrial engineering emerged as a profession during the Industrial Revolution. This was due to the requirement of technically qualified and skilled people, who were needed to plan, organize and control the manufacturing processes. After the industrial revolution, Taylor and Gilbreth (Frank B. Gilbreth and his wife, Lillian Gilbreth) contributed a lot to the field of industrial engineering and later these contributions were known as the base of Scientific Management.

1.2.3 Scientific Management

Following contributions, as mentioned in chronological order, form a major part of Scientific Management:

1910: F. W. Taylor's Scientific Management
1911: Gilbreth's Motion Study
1913: Gantt's Scheduling Chart
1917: Harris Inventory Control
1924: Shewart's Statistical Control Chart
1927–33: Elton Mayo's Motivation Theory
1932: Babbage Wage payment and Time Study
1933: Barnes Work Study

Fredrick Winslow Taylor (Popularly known as F. W. Taylor) is considered the Father of Scientific Management. His ideas influenced by Adam Smith's book *The Wealth of Nations*, published in 1776; Thomas Malthus's *Population Theory*, published in 1798; David Ricardo's *Principles of Political Economy and Taxation*, published in 1817; John Stuart Mill's *Principles of Political Economy*, published in 1848; and Charles W. Babbage's book on the *Economy of Machinery and Manufacturers*, published in 1832.

Taylor's four principles are enumerated as follows (Taylor 1911):

1. Replace working by 'rule of thumb,' use the scientific method to study a work and determine the most efficient way to perform specific tasks.
2. Job specialization, i.e. rather than simply assign workers to do any job, match worker's capability and motivation to their jobs, and train them to work at maximum efficiency.
3. Monitor worker performance, and provide instructions and supervision to ensure that they are using the most efficient ways of working.
4. Allocate the work between managers and workers so that the managers spend their time on management, allowing the workers to perform their tasks efficiently.

Second major contributions in the field of scientific management are from Gilbreth family (Frank B. Gilbreth and his wife, Lillian Gilbreth). Frank B. Gilbreth focused on identification, analysis, measurement and setting standards for the fundamental motions, which were required to accomplish a job. His contributions were appreciated to set the standard time and method to perform a task. Lillian Gilbreth worked on a human relation aspect of engineering.

Another major contribution also came from Henry L. Gantt. He provided the concept of planning and scheduling the activities on a graphical chart, widely known as Gantt Chart. This is very helpful in reviewing the progress and updating the schedule of work.

The major development of industrial engineering was emerged during the period 1920–1940. In 1924, W. A. Shewhart developed the concept of Statistical Control Chart to measure the quality. During this period, concepts of inventory control, incentive plans, material handling, plant layout, etc. were evolved. Ralph M. Barnes worked on motion study for his doctoral work.

1.2.4 Operations Research and Quantitative Phase

During World War II, concepts of Operations Research were developed and used to optimize the resources allocated in the war. During this phase, the concept of linear programming (LP) was developed by Dantiz. Some of the major developments observed during this phase are mentioned below as:

1956: First NC machine was developed.
1961: First time Robot was used.
1965: Flexible automation was used.

1.2.5 Automation and Computer-integrated Manufacturing Phase

During this phase, most of the automation and computer-integrated manufacturing concepts were implemented in the industries. Concepts of lean manufacturing and Just-In-Time (JIT) were developed in automobile industries (Toyota manufacturing system).

1.2.6 Factory of the Future

Factory of the future will be highly automated. Robots will be used for various operations such as material handling, loading and unloading of jobs, welding, painting, etc. Most of the manual work will be eliminated.

1.3 PRODUCTION SYSTEMS

Quantitatively, production is concerned with quantity produced. But production implies the activity of producing goods and/or services. It is concerned with the transformation of inputs into the required outputs. In other words, production is a value-addition process through which raw material is converted into finished goods. At each stage of the production process, some values are added. Some examples of production are producing furniture, mobile phone, computer, car, etc.

A production system consists of inputs, i.e. raw materials, conversion subsystems, i.e. man and machine, control system, i.e. quality control and reliability, and outputs, i.e. finished products. All these components are interrelated to each other as shown in Figure 1.1. There are a number of other subcomponents of production systems that can be studied in detail in Chapter 10 'Production Planning and Control' in this book.

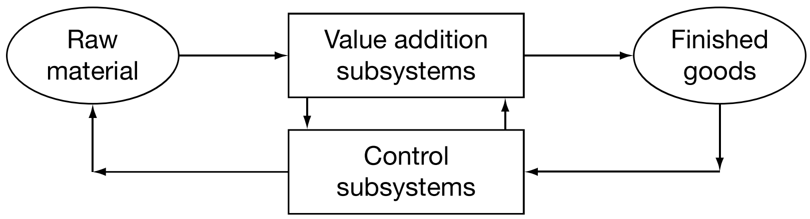

Figure 1-1: Production system of an organization

Type of Production Systems

On the bases of volume and variety of products, production systems can be classified as job-shop production, batch production, mass production and continuous production. The first three production systems can be grouped as discrete types of production. These production systems are shown in Figure 1.2.

In discrete production systems, the production set-up is changed regularly to accommodate the production of different products of different designs and specifications, for example, auto, electronics, textile industries, etc. In continuous production systems, same product is produced continuously in the same sequence or operations, for example, petro-refinery, chemical and power plants. In discrete type of production systems, the products may be produced in different shifts, but in continuous type of production system, production continues to 24 hours without shifts.

1.3.1 Job-shop Production

Job-shop production is characterized by manufacturing of a large variety of products in small quantities that are designed and produced as per specifications given by customers. The main

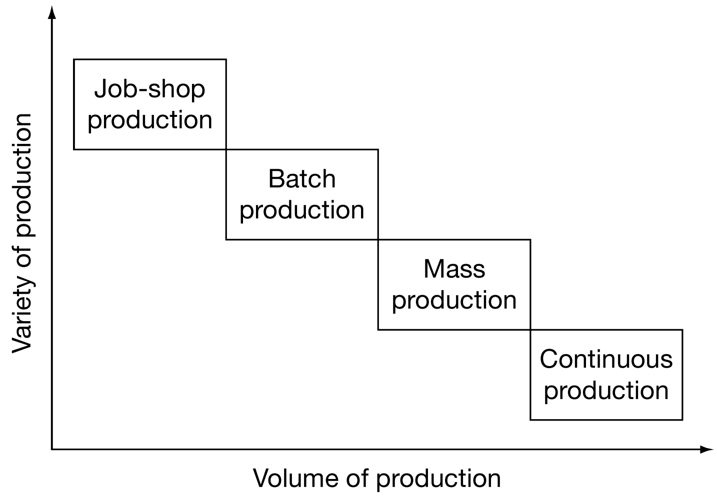

Figure 1-2: Types of production systems

feature of this production system is highly flexible. A job-shop comprises general-purpose machines arranged in different departments. The process layout is most suitable for this type of production system. Each job requires unique technical requirements and processing on machines in a certain sequence.

Characteristics of Job-shop Production

1. Machines and methods employed are generic type as product changes are quite frequent.
2. Planning and control systems are flexible enough to deal with the frequent changes in product designs.
3. Manpower is skilled enough (cross-functional) to deal with changing work conditions.
4. Schedules are actually not fixed or predetermined in this system as no definite data is available on the product.
5. In-process inventory is usually high as accurate plans and schedules do not exist.
6. The product cost is normally high because of high material and labour costs.
7. Grouping of the machines is done on a functional basis (i.e. lathe section, milling section, etc.)
8. This system is highly flexible as the management has to manufacture varying product types.
9. Material handling systems are also highly flexible to meet changing product requirements.

Advantages of Job-shop Production

1. Most suitable for production of a variety of products due to the use of general-purpose machines.
2. Opportunities for learning multiple skills and getting varied exposure to the workers.
3. The full potential and skill of operators can be utilized.
4. Importance to creativity and innovative ideas.

Limitations of Job-shop Production

1. Higher cost due to low volume of production and lack of economies of scale.
2. Higher inventory cost due to higher level of inventory at all levels.
3. A complicated production planning is used.
4. Unnecessary movement of men and materials cannot be avoided in the shop due to application of functional layout.

1.3.2 Batch Production

Batch production is a type of production in which the job passes through the functional departments in batches, and each batch may have a different routing. Batch production is characterized by the manufacture and stocking of a limited number of products at regular intervals, awaiting sales.

Characteristics of Batch Production

1. Shorter production runs are used.
2. Flexible manufacturing is most suitable.
3. Plant and machinery set-up is used for production of items in a batch and a change in set-up may be required for processing the next batch.
4. Manufacturing lead time and cost of production are lower as compared to job-shop production due to higher volume.
5. As the final product is standard compared to job-shop production and manufactured in batches, economy of scale can be achieved up to some extent.
6. Machines are grouped on a functional basis similar to the job-shop manufacturing.
7. Semi-automatic and special-purpose automatic machines are generally used to take advantage of the similarity among the products.
8. Labours are multi-skilled and work upon different product batches.
9. In-process inventory is usually high owing to the type of layout and material handling policies adopted.
10. Semi-automatic material handling systems are most appropriate in conjunction with the semi-automatic machines.
11. Normally, production planning and control is difficult due to the odd size and the non-repetitive nature of order.

Advantages of Batch Production

1. There is better utilization of plant and machinery compared to job-shop production.
2. Batch production promotes functional specialization.
3. Cost per unit is lower as compared to job-shop production.
4. Investment is lower in plant and machinery.
5. It is flexible enough to accommodate and process a number of products.
6. Job satisfaction exists for operators.

Limitations of Batch Production

1. Material handling is complex because of irregular and zigzag flows.
2. Production planning and control becomes complicated.
3. Work-in-process inventory is higher compared to mass/continuous production.
4. Higher set-up costs due to frequent changes in the set-up.

1.3.3 Mass Production

Manufacture of discrete components or assemblies in a very large volume is called mass production. Machines are arranged in a line according to the sequence of operations on the product in product layout. Product and process standardization exists and all outputs follow the same path.

Characteristics of Mass Production

1. Product and process sequences are standardized.
2. Special-purpose machines having higher production rate are used.
3. Production volume is large.
4. Production cycle time is shorter compared to job-shop and batch production systems.
5. In-process inventory is low.
6. Flow of materials, components and parts is continuous and without any backtracking.
7. Material handling can be completely automatic.

Advantages of Mass Production

1. It has high production rate with reduced cycle time.
2. Less skilled operators may be employed.
3. Low in-process inventory is used.
4. Manufacturing cost per unit is low.

Limitations of Mass Production

1. Breakdown of one machine stops the entire production line.
2. The line layout needs major change with changes in the product design, that is, the layout is less flexible.
3. Higher investment in production facilities is required.
4. The cycle time is determined by the slowest operation.

1.3.4 Continuous Production

Production facilities for continuous production are arranged as per a predetermined sequence of production operations from the first operation to the finished product. The items are made to flow in a sequence of operations through material handling devices such as conveyors, transfer devices, etc. A highly rigid type of machine layout is used for continuous production.

Characteristics of Continuous Production

1. Dedicated plant and equipment is employed.
2. Material handling is fully automated.
3. The production process follows a predetermined sequence of operations.
4. Component materials cannot be readily identified with the final product.
5. Planning and scheduling are a routine action.

Advantages of Continuous Production

1. Product and process sequences are highly standardized.
2. The production rate is very high with reduced cycle time.
3. Capacity utilization is higher than the other production systems due to line balancing.
4. Manpower is not required for material handling, as it is completely automated.
5. A person with limited skills can be used on the production line.
6. The unit cost is lower due to the high volume of production.

Limitations of Continuous Production

1. Flexibility to accommodate and process a number of products does not exist.
2. Very high investment is required for setting flow lines.
3. Product differentiation is limited.

1.4 SELECTION OF PRODUCTION SYSTEMS

Any manufacturing system cannot be an ideal system for production of a product considering all the factors simultaneously. The choice of the system depends on various factors, but basic factors that influence the selection of production system are specification of the final product and cost-effective production process. Other factors which determine the choice of the production system are given below as:

Effect of volume/variety: One of the major considerations in the selection of production system is the volume/variety of the products. High product variety requires highly skilled labour, general-purpose machines, detailed production planning and control system. On the other hand, low product variety (i.e. one or few products produced in large volumes) enables the use of semi-skilled labour, highly automated production processes using special-purpose machines and simple production planning and control systems. The relationship between volume and variety of products is already shown in Figure 1.2.

Capacity of the plant: The projected sales volume is a major influencing factor in determining whether the firm should go in for discrete/intermittent or continuous process. Fixed costs are high for continuous process and low for discrete process while variable costs are more in the discrete process and less for continuous process. Discrete process therefore will be cheaper to install and operate at low volumes and continuous process will be economical to use at high volume.

Flexibility: Flexibility implies the ability of the company to meet the changes required in the market regarding product design and volume. If more varieties are to be manufactured, the manufacturing facilities will have to be generalized depending upon the volume. Greater commonalities demand discrete manufacturing, which results in high inventories, large manufacturing lead times and elaborate planning and control.

Lead time: The lead time, more appropriately used in production system is delivery lead time expected by the customers. It is another major influencing factor in the selection of a production system. As a general rule, faster deliveries are expected by customers. The product, therefore, may require to be produced to stock using principles of batch production/mass production. If customers are ready to wait for the product, then the product may be produced to meet the order only.

Efficiency: Efficiency measures the speed and the cost of the transformation process. Efficiency will be higher for the products which are produced in mass. But for mass production of a product, greater demands are required. Therefore, depending upon the demand, product variety is to be considered and the process which gives the best efficiency in terms of machine and manpower utilization will have to be selected.

1.5 PRODUCTIVITY

Production and productivity are two different terms having different meanings. Higher production does not mean higher productivity, and vice versa. Production is related to the activity of producing goods or services. It is a process of converting inputs into some useful, value-added products/services. Productivity is concerned with how effectively the resources are utilized to increase the output of production. The productivity can be improved by increasing the output for same inputs or keeping constant output for deceased amount of inputs or increasing the output in greater proportion than the increase in inputs. Productivity may be calculated using the following formula:

$$\text{Productivity} = \text{Output/Input}$$

Productivity relates the efficient utilization of input resources for producing goods or services. Production is a measure of the output or volume produced. The emphasis is only on volume of production and not on how well the inputs or resources are utilized. In contrast, productivity emphasizes only on the ratio of the output produced to the inputs used. Productivity may be divided into two categories: partial productivity and total productivity.

1.5.1 Partial Productivity

Partial productivity is the ratio of the total output and individual input in the case of multifactor productivity (MFP) (Solow 1957). This term is used to measure the productivity of an individual input such as manpower, capital invested and energy utilized in production. Partial productivity is defined on the basis of the class of the input being considered. For example, if the labour was increased by 18 per cent during the last financial year, its effect on the increased output is represented by partial productivity. Similarly, partial productivity of capital, material and other inputs may be defined. The various components of partial productivity and their uses are shown in Table 1.1.

Table 1-1: Different forms of partial productivity

Partial productivity	Formula
1. Labour productivity	Output/Labour input
2. Material productivity	Output/Material input
3. Capital productivity	Output/Capital input
4. Energy productivity	Output/Energy input
5. Advertising and media planning productivity	Output/Advertising and media planning input
6. Other expense productivity	Output/Other expense input

Advantages of Partial Productivity Measure

1. It is a good diagnostic measure to identify areas where improvements are required.
2. It is easy to calculate because it is independent of other inputs.
3. The management finds it easy to understand and pinpoint the logic for its improvement.
4. It is easy to benchmark (compare) with other industries.
5. Data may be easily generated for it.

Limitations of Partial Productivity Measure

1. It can be misleading if used out of context.
2. It does not represent the overall effect of the system performance since it is concerned with the contribution of a specific input only and not all the resources.
3. Focused areas of improvements are difficult to identify. Therefore, sometimes wrong areas of management control may be identified for improvement.
4. It gives a myopic view of the performance of production systems. This means, only limited factors, which affect the output or performance, are considered.
5. It misses the holistic (or totality) approach.

Example 1.1: A mobile phone manufacturing company is producing 44,000 mobile phones per month by employing 200 workers in 8-hour shift. The company gets an additional order to supply 6000 mobile phones. The management has decided to employ additional workers. What will be production and productivity levels when the number of additional workers employed is: (a) 20 (b) 25 and (c) 30.

Solution:

$$\text{Present production} = 44{,}000 \text{ mobile phones}$$

$$\text{Present productivity (of labour)} = \frac{\text{Present production (i.e., output)}}{\text{Total worker hours (i.e., input)}}$$

$$= \frac{44{,}000 \text{ components}}{(200 \text{ workers})(8 \text{ hours})(30 \text{ days of the month})}$$

$$= 44{,}000/48{,}000 = 0.916 \text{ mobile phone/man-hour}$$

With increased order

(a) When additional 20 workers are hired

Production = 44,000 + 6000 = 50,000 mobile phones

Productivity (of labour) = Increased total production/Total man-hours

= 50,000/(200 + 20) (8) (30)

= 0.946 mobile phones/man-hour

(b) When additional 25 workers are hired

Production = 44,000 + 6000 = 50,000 mobile phones

Productivity (of labour) = 50,000/(200 + 25) (8) (30)

= 0.925 mobile phones/man-hour

(c) When additional 30 workers are hired

Production = 44,000 + 6000 = 50,000 mobile phones

Productivity (of labour) = 50,000/(200 + 30) (8) (30)

= 0.905 mobile phones/man-hour

In this example, it is clear that production has increased by 6000 units. Therefore,

Increase in production = (50,000 – 44,000/44,000) $\times$ 100 = 13.6 per cent

1.5.2 Total Factor Productivity

TFP is the ratio of net output to the sum of associated labour and capital inputs. Net output means total output minus intermediate goods and services purchased. Notice that the denominator of this ratio is made up of only the labour and capital input factors.

$$\text{Total factor productivity (TFP)} = \frac{\text{Net output}}{\text{Total factor input}}$$

$$= \frac{\text{Total output} - \text{Materials and services purchased}}{(\text{Labour} + \text{Capital})\ \text{Inputs}}$$

$$\text{Total productivity} = \frac{\text{Total output}}{\text{Total input}}$$

Advantage of TFP

(a) It is relatively easy to compare data from company records.
(b) Industrialist prefers this as it is easy to compare in cross-industrial context.

Limitations of TFP

(a) Many important inputs, such as material, energy, etc., are ignored.
(b) The net output does not reflect the efficiency of the production system in a proper way.

Example 1.2: The data for output produced and inputs consumed for a particular type of a manufacturing organization are given below in constant money value. Find out the partial, total factor and total productivity values.

Output = Rs 3000.00
Labour input = Rs 600.00
Material input = Rs 300.00
Capital input = Rs 800.00
Energy input = Rs 150.00
Other expenses input = Rs 75.00

Solution:

Partial productivities

$$\text{Labour productivity} = \frac{\text{Output}}{\text{Labour input}} = \frac{3000}{600} = 5$$

$$\text{Material productivity} = \frac{\text{Output}}{\text{Material input}} = \frac{3000}{300} = 10$$

$$\text{Capital productivity} = \frac{\text{Output}}{\text{Capital input}} = \frac{3000}{800} = 3.75$$

$$\text{Energy productivity} = \frac{\text{Output}}{\text{Energy input}} = \frac{3000}{150} = 20$$

$$\text{Other expenses productivity} = \frac{\text{Output}}{\text{Other expenses input}} = \frac{3000}{75} = 40$$

$$\text{Total factor productivity (TFP)} = \frac{\text{Net output}}{\text{Total factor input}}$$

$$= \frac{\text{Total output} - \text{Materials and services purchased}}{(\text{Labour} + \text{Capital})\text{ inputs}}$$

$$= \frac{3000 - (300 + 150 + 75)}{600 + 800} = 1.76$$

$$\text{Total productivity} = \frac{\text{Output}}{\text{Total input}} = \frac{3000}{600 + 300 + 800 + 150 + 75} = 1.55$$

Example 1.3: Table 1.2 gives the comparative study of several items of a motherboard for the years 2013 and 2014. Compute the changes in all productivity indices.

Table 1-2: Comparative study of productivity for the years 2013 and 2014

Items	2013	2014
Number of output at the rate of Rs 5000 per unit	10,000	16,000
Direct labour cost (Rs)	32,000	60,000

(*Continued*)

Table 1-2: (Continued)

Items	2013	2014
Capital depreciation (Rs)	8000	11,000
Capital book value (Rs)	32,000	45,000
Total indirect cost (Rs)	48,000	56,000
Energy used @ Rs 4/kW (in kW)	5000	8000
Raw materials used (Rs)	32,000	36,000
Services of consultant hired (Rs)	20,000	25,000

Solution:

(a) Direct labour productivity index $= \dfrac{16{,}000/60{,}000}{10{,}000/32{,}000} \times 100$

$= 85.33$ per cent

(b) Capital depreciation productivity index $= \dfrac{16{,}000/11{,}000}{10{,}000/8000} \times 100$

$= 109.09$ per cent

(c) Capital book value productivity index $= \dfrac{16{,}000/45{,}000}{10{,}000/32{,}000} \times 100$

$= 113.77$ per cent

(d) Total indirect cost productivity index $= \dfrac{16{,}000/56{,}000}{10{,}000/48{,}000} \times 100$

$= 137.14$ per cent

(e) Energy productivity index $= \dfrac{16{,}000/8000}{10{,}000/5000} \times 100 = 100$ per cent

(f) Raw material productivity index $= \dfrac{16{,}000/36{,}000}{10{,}000/32{,}000} \times 100$

$= 142.22$ per cent

(g) Consultant productivity index $= \dfrac{16{,}000/25{,}000}{10{,}000/20{,}000} \times 100$

$= 128$ per cent

Example 1.4: Using the information given in Table 1.3, calculate the index for the following:

(a) Direct labour productivity
(b) Capital depreciation productivity
(c) Capital book value productivity
(d) Direct cost productivity
(e) Total cost productivity
(f) Energy productivity

Table 1-3: Comparative study of productivity for the years 2012 and 2013

Item	2012	2013
Number of outputs (all of one kind) (in Rs) (10,000 per unit)	250	300
Direct labour cost (in Rs)	50,000	60,000
Capital depreciation (in Rs)	4000	5000
Capital book value (in Rs)	16,000	24,000
Total indirect cost (in Rs)	40,000	44,000
Energy used (@ Rs. 4 per watt) (in kW)	700	2400
Raw material used (@ Rs 1000 per ton) (in tonnes)	12	16

Solution:

Calculation of productivity index

(a) Direct labour productivity index $= \frac{300}{60,000} \times \frac{50,000}{250} \times 100 = 100$ per cent

(b) Capital depreciation productivity index $= \frac{300}{5000} \times \frac{4000}{250} \times 100$

$= 96.0$ per cent

(c) Capital book value productivity index $= \frac{300}{24,000} \times \frac{16,000}{250} \times 100 = 80$ per cent

(d) Direct cost productivity index $= \frac{300}{44,000} \times \frac{40,000}{250} \times 100 = 109.01$ per cent

(e) Energy used productivity index $= \frac{300}{2400 \times 4} \times \frac{700 \times 4}{250} \times 100 = 35$ per cent

(f) Raw material productivity index $= \frac{300}{16,000} \times \frac{12,000}{250} \times 100 = 90$ per cent

1.5.3 Efficiency

It is the ratio of output to standard output expected. Therefore, efficiency indicates a measure of how well the resources are utilized to accomplish a target or result. Efficiency may be calculated using the following formula:

$$\text{Efficiency} = \text{Output/Standard output}$$

Here standard output means output without loss, e.g. for a student 100 (full marks) is the standard output and the marks obtained by him is simply output.

1.5.4 Effectiveness and Productivity Index

The term 'effectiveness' is a measure of the degree of accomplishment or achievement of an objective (target). For example, a man rushes to the market to buy some medicines for a patient. He could go by a car, or by a bicycle or on foot. The cost and time are different for different modes of travel. Now suppose by the time the medicine is brought the patient dies, then the effort is not effective.

Effectiveness represents the degree of success in accomplishing objectives. Therefore, effectiveness indicates a measure of how well a set of targets or results are accomplished. Productivity is the integration of both efficiency and effectiveness. It indicates a combined effect of resource utilization (i.e. efficiency) and performance (i.e. effectiveness). The combined effect of efficiency and effectiveness is used in defining a term called *productivity index*:

$$\text{Productivity index} = \frac{\text{Performance achieved}}{\text{Input resources consumed}} = \frac{\text{Productivity in current year}}{\text{Productivity in base year}}$$

$$= \frac{\text{Effectiveness}}{\text{Efficiency}}$$

1.5.5 Productivity Cycle

The productivity cycle consists of four phases: productivity target planning, productivity comparison, productivity improvement and productivity measurement (see Fig. 1.3). In the first phase, a target of productivity is to be fixed considering various factors such as availability of resources and the production demand. In the second phase, productivity is compared with the productivity of competitor firms or the productivity of other sections in the same firm. In the third phase, the opportunities and scope of productivity improvement are highlighted and used for improvement. Finally, in the fourth phase, productivity is measured in other terms like efficiency. Efficiency represents the system's ability to produce very close to standard output, i.e. output/standard output. But it is also used frequently as output/input, mathematically.

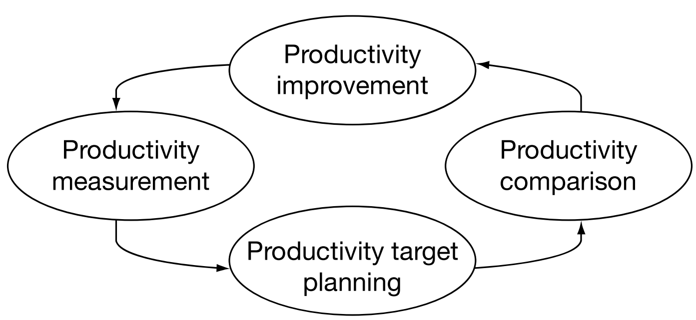

Figure 1-3: Productivity cycle

1.5.6 Factors Influencing the Productivity

There are various factors that influence productivity of an organization, such as man, machine, materials, space, energy, time and finance. Man is one of the important parts of the production system. The number of employees, their skills and motivation affect the productivity of the system. Machines play an important role in improving the productivity. To improve the machine's availability, proper maintenance is required. Similarly, the third important component of production system is material's cost and quality. A high-quality material at low cost increases the productivity of the system. The time consumed in different processes such as inspection, maintenance, production affects the productivity of the system. In a similar way, proper utilization of space, energy saving and effective use of money increases the productivity.

Man: The productivity of man depends on the following processes:

1. Selection of an employee
2. The training given to employees
3. Number of personnel required for a job
4. Provision of incentive for workers

Machine: The productivity of a machine depends on the following factors:

1. Number of machines employed
2. Replacement policy for existing machines
3. Maintenance plans to avoid machine breakdown

Material: The following factors affect the productivity of a material:

1. Right quality
2. Right quantity
3. Substitutes for the existing material
4. Inspection and quality control programmes
5. Cost of material procurement and handling

Time: It affects the productivity in the following ways:

1. Inspection time for raw material
2. Inspection time for finished products
3. Production time
4. The time required to repair and maintenance work

Space: Utilization of space affects the productivity in the following ways:

1. Plant layout
2. The total area covered for production work
3. Location of different departments and shops

Energy: Use of energy affects the productivity in the following ways:

1. Energy-saving schemes
2. Use of renewable energy sources
3. Use of solar energy

Finance: Availability and efficient use of financial facilities affect the productivity.

1.5.7 Reasons for Lower Productivity

There are various reasons of poor productivity. Some of them are mentioned as follows:

1. Poor production planning and control
2. Low motivation of people
3. Lack of coordination
4. Unavailability of right tools, material and human force
5. Poor product design
6. Lack of standardization
7. Poor working environment
8. Non-standard methods of working
9. No accountability for loss of production
10. Government rules and regulations
11. Old age of plant and equipments
12. Weak R & D.

1.5.8 Ways to Improve Productivity

The productivity of any system can be improved either by proper use of resources or by effective utilization of the system or its processes. Some action plans for productivity improvement are listed below:

Machine

1. Manual labour is replaced by machines
2. Reliable machines
3. Automation.

Management

1. Motivated workforce
2. Better planning and coordination
3. Effective control over the system.

Process

1. Computerization of the system
2. Use of Management Information System (MIS)
3. Improvement in scheduling
4. Better material flow
5. Fast and accurate retrieval of parts.

Work design

1. Improved job design
2. Better work method
3. On-job training.

Work environment

1. Better lighting and illumination
2. Better ventilation
3. Safe workplace
4. Total quality management (TQM).

Programme

1. Quality circle
2. Suggestion scheme
3. Incentive scheme
4. Revise pay or policy.

Technology

1. Acquiring new technology such as Electro-Chemical Machining (ECM), etc.
2. Acquiring automated assembly line, for example, Surface-Mounting Technology (SMT) for printed circuit board assembly unit.
3. Acquiring computer-controlled machines, such as Computer Numerical Control (CNC) or Direct Numerical Control (DNC).
4. Using Automated Guided Vehicle (AGV) for material transportation.

Manufacturing strategy

1. Changing the manufacturing system from functional to a cellular layout if it is a batch production unit.
2. Adopting stockless production strategy and JIT framework in the production unit.
3. Keeping the workplace clean and environment-friendly (also termed as green-production system).
4. Opting for total change in the process/product or strategy if the system is not working properly (also known as Business Process Re-engineering or BPR).

External environment

1. Better political stability
2. Boosting economy and purchasing capacity of buyers
3. Globalization and open market economy

1.5.9 The Technology used to Improve Productivity

1. Technology-based techniques: Computer-Aided Design (CAD), Computer-Aided Design and Drafting (CADD), Computer-Aided Engineering (CAE), Computer-Aided Process Planning (CAPP), Computer-Aided Quality Control (CAQC), Computer-Aided Instruction (CAI), Computer-Aided Manufacturing (CAM), robotics, Group Technology (GT) and Total Productive Maintenance (TPM).
2. Product-based techniques: Reliability, simplification, standardization, diversification and Research and Development (R & D).

3. Material-based techniques: Material Requirement Planning (MRP), Economic Batch Quantity (EBQ), Economic Order Quantity (EOQ), JIT and material handling.
4. Task-based techniques: Work simplification, work measurement, time study, method study, job analysis, job evaluation, merit rating, job safety and production scheduling.
5. Employee-based techniques: Incentive scheme, management by objective, job enlargement, job enrichment, recognition and punishment, Total Quality Management (TQM) and zero defects.

1.5.10 Guidelines for Productivity Measurement Systems

Productivity measurement is directly related to the productivity improvement programme. A good productivity measurement should have the following characteristics.

1. It should be simple in calculation, meaningful, easy to understand and use, and provide the status of productivity in the organization.
2. It should be accurate enough to present a realistic assessment as perfect accuracy is an unreasonable expectation.
3. It should help in identifying the areas of low productivity so that productivity efforts can be applied to that area for improvement.
4. It should provide indices and information for comparison of performance for different periods.
5. It should provide indices and information for comparison of performance with other similar organizations/operations.
6. It should provide the information on interrelationship of different subsystems.
7. It should incorporate both tangible and intangible outputs and inputs to the system.
8. The productivity measurement system should be hierarchical in nature; the productivity at lower levels gives productivity of subsystem and the productivity of subsystems translates into overall productivity of the system.
9. It should facilitate to devise a reward or an incentive scheme for the workers.
10. It should lead to the participation and involvement of employees of various levels.
11. It should be economical and administratively easy to run the productivity measurement system.
12. It should be independent from the changes in monetary values and external disruptions.

SUMMARY

We have discussed basic concepts of industrial engineering and about the various phases of its conceptual development. Four types of production systems, their characteristics, advantages and disadvantages have been discussed in detail. These production systems are job-order production, batch size production, mass production and continuous production. Total productivity and partial productivity have been explained with the help of some numerical illustrations. Finally, factors affecting the productivity, the reason for poor productivity, methods to improve productivity have been outlined.