

PRODUCTION MANAGEMENT

(ME 3105)

Course Note



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MODULE 1

1. INTRODUCTION

The systems aspects of manufacturing are more important than ever today. The word ‘manufacturing’ was originally derived from two Latin words ‘manus’ (hand) and ‘factus’(make), so that the combination means ‘make by hand’.

In this way manufacturing was accomplished when the word first appeared in English around 1567. Commercial goods of those times were made by hand. The methods were handicraft, accomplished in small shops and the goods were relatively simple. As many years passed, the products become more complex along with processes. Thus factories were developed with many workers at a single site; the work was organized using machines

Modern manufacturing enterprises that manage these production systems must cope with the economic realities of the modern world. These realities include the following:

- Globalization
- International outsourcing
- Local outsourcing
- Contract manufacturing
- Trend toward the service sector
- Quality expectations
- Operational efficiency

1.1. **System:** It consists of elements or components. The elements or components are interlinked together to achieve the objective for which it exists. Eg: human body, educational institutions, business organizations.

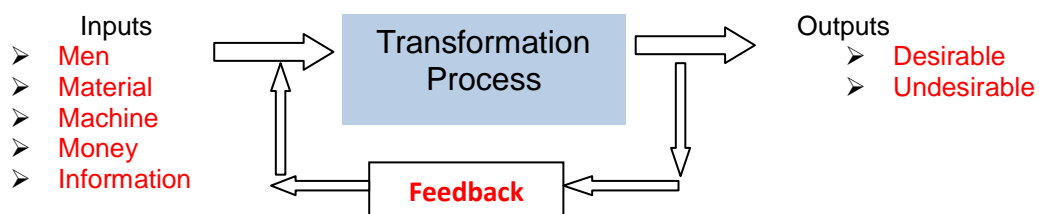


Figure 1.1 Transformation process

- **Components of a system:** The input, processing, output and control of a system are called the components of a system.
- **Control:** There are two types of control, namely Proactive Control and Reactive Control. There are three types of feedback mechanisms such as *feed forward control*, *feedback control* and *concurrent control*

2. What is Production management?

In any manufacturing system, the job of a Production Manager is to manage the process of converting inputs into the desired outputs.

- *It is concerned with the production of goods and services, and involves the responsibility of ensuring that business operations are efficient and effective.*
- *It is also the management of resources, the distribution of goods and services to customers.*

Therefore, **Production 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.

3. Difference between Operations and Production

In the transformation process, the inputs change the form into an output, by adding value to the entity. The output may be a product or service.

- If it is a product centric that is known as **production**,
- If it is a service centric then that is known as **operation**.

4. Production System

A production system is a collection of people, equipment, and procedures organized to perform the manufacturing operations of a company (or other organization)

4.1. Components of a production system:

There are two components for a production system such as:

1. Facilities – the factory and equipment in the facility and the way the facility is organized (plant layout)
2. Manufacturing support systems – the set of procedures used by a company to manage production and to solve technical and logistics problems in ordering materials, moving work through the factory, and ensuring that products meet quality standards

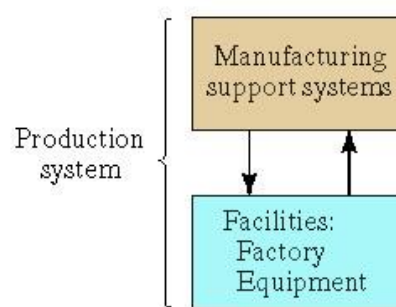


Figure 1.2 Diagrammatic representation for a production system

Facilities include the factory, production machines and tooling, material handling equipment, inspection equipment, and computer systems that control the manufacturing operations. For the facilities, plant layout is a significant factor for the production system to be efficient. The plant layout is the way in which the equipment is physically arranged in the factory

Manufacturing systems include the logical groupings of equipment and workers in the factory. A combination of a group of workers and machines are termed as Production line. There can be instances where there is only one worker and a machine. This arrangement is called as Stand-alone workstation and worker. Based on the human participation in the production processes, the manufacturing system can be classified as the following three systems:

- *Manual work systems* - a worker performing one or more tasks without the aid of powered tools, but sometimes using hand tools. *For example*, filing work carried out in the central workshop

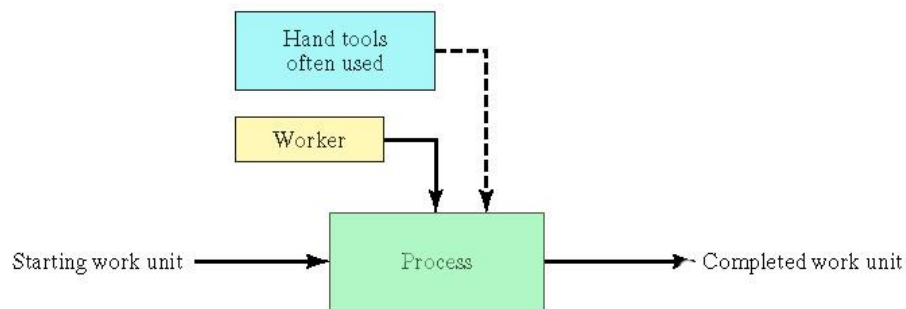


Figure 1.3a Diagrammatic representation a manual work system

- *Worker-machine systems* - a worker operating powered equipment. *For example*, turning done on a work piece using a Lathe.

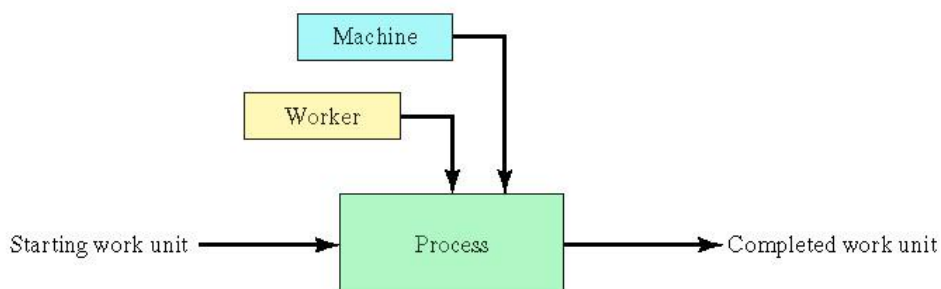


Figure 1.3b Diagrammatic representation a worker-machine system

- *Automated systems* - a process performed by a machine without direct participation of a human *For example*, turning done on a work piece using a CNC machine.

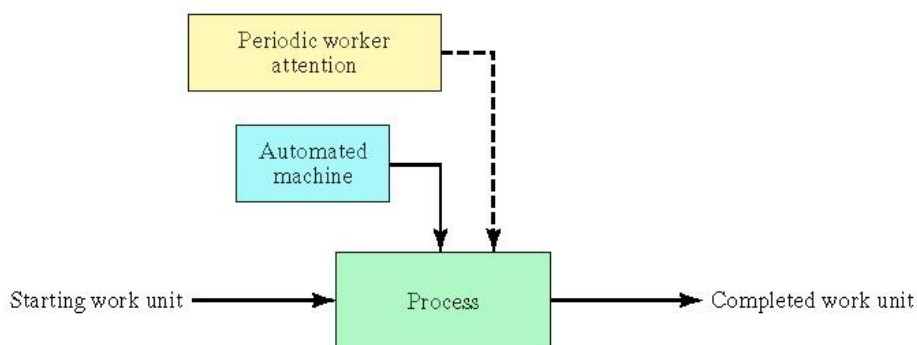


Figure 1.3c Diagrammatic representation an automated system

Manufacturing support systems: To operate the production facilities efficiently, a company must organize itself to design the processes and equipment, plan and control the orders and satisfy product quality requirements. The support systems have no direct contact with the product, but they plan and control its progress throughout the factory. The manufacturing support system involves a cycle of information-processing activities that consists of four functions. The four functions are depicted in Figure 1.4.

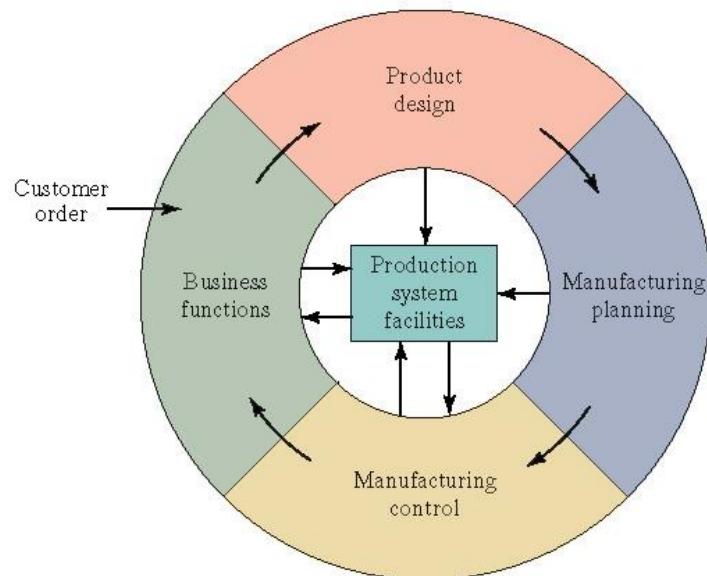


Figure 1.4 Information processing cycle

- i. *Business functions* - sales and marketing, order entry, cost accounting, customer billing
 - This function is the principal means of communication with the customer
 - This represents the beginning and the end of the information-processing cycle
 - It is at this function, the customer comes in contact with the company and places an order
 - The production (or customer) order will be (1) order to manufacture an item to customer's specifications (2) customer order to buy one or more of the manufacture's product and (3) an internal company order based on a forecast of future demand.
- ii. *Product design* - research and development, design engineering, prototype shop
 - The role of the product design team depends on the production order. As mentioned above, the production order may change.
- iii. *Manufacturing planning* - process planning, production planning, MRP, capacity planning
 - Process planning is the sequence of individual processing and assembly operations needed to produce the part.
 - Production planning considers the logistics issues in the production process

- The authorization to produce the product must be translated into the Master Production Schedule (MPS)
- MPS is a list of products to be made, the dates on which they are to be delivered, and the quantities of each are included
- Based on the MPS, individual components and the sub-assemblies that make up each product must be planned.
- MPS must not list more quantities of products than the factory capacity for a period.
- Capacity planning plans the manpower and machine resources of the firm.

iv. *Manufacturing control* - shop floor control, inventory control, quality control

- Managing and controlling physical operations in the factory to implement plans.
- Shop floor control monitors the progress of the product as it is being processed, assembled, moved and inspected in the factory
 - Materials being processed in the factory are called as Work-in-process (WIP) inventory.
 - Both shop floor control and inventory control overlap each other.
- Inventory control tries to strike a balance between the risk of too little inventory (stock-out situation) and the carrying cost of too much inventory.
 - Right quantity to order and when to re-order a given item
- Quality control ensures the quality of product and its components meet the standards specified by the product designer.
 - Raw materials and component parts from outside sources are inspected when they are received and final inspection and testing is done to ensure functional quality and appearance.

4.2. **Aim of production:** The aim of a production system is to provide goods and services for mankind

- In right quantities
- At the appropriate place
- At the desired time
- With the required quantity
- At a reasonable cost

4.3. **Challenges in manufacturing :** The challenges in manufacturing includes

- Changing market conditions – shift from seller's market to buyer's market

- Rate of change is faster
- Global competition
- Need to be pro-active
- Increased customer focus – the customers are less loyal.

4.4. Characteristics features of production system

1. Production is an organized activity.
2. The system transforms the various inputs into useful outputs.
3. Production system does not operate in isolation from the other organizational systems.
4. There exists a feedback about the activities which is essential to control and improve system performance.

4.5. Classification of production system

The production system can be classified on the basis of the following:

- Type of production – Job shop production, Batch production, Mass production
- Size of the plant – Large size plant (eg. Oil refinery), Medium size plant, Small size plant (eg. Printing press)
- Type of product- Complex to manufacture (Aircraft) and simple to manufacture
- Physical flow of material – Automated flow, Semi-automated flow and Manual flow
- Nature of order/demand pattern – Stable demand, Unstable demand
- Variety of jobs – More variety (eg. Automobiles/electronic goods), One variety (eg. Oil refinery)

4.6. Job shop production

- Characterised by make-to-order strategy
- There are three possible situations for production quantity
 - Product is manufactured only once
 - Small quantities of product are repeated at irregular time intervals (demand not certain)
 - Small quantities of product are repeated at regular time intervals
- In Job shop production, first and second situations are common.
- End product is most of the time as per the customer need.

- No standard methods and time standards can be developed as the job is not regularly produced.
- Machines and resources must be of general purpose and flexible.
- Highly skilled workforce is needed to work on product variety.
- In-process inventory is high.
- Machines are grouped as per their functional capabilities.
- System is flexible
- Planning and control is very difficult.
- Job-shops are typically inefficient and have long lead times, large work-in-process inventory and high costs.
- Example: Commercial printer, Boiler manufacture, Tailoring shop

4.7. Batch production

- Batch of identical articles are manufactured
- The demand rate is lesser than the rate of production and hence batch production method is traditionally adopted
- There is a built-up of inventory in batch production
- There are three possible situations
 - A batch is manufactured only once (make-to-order)
 - Batch is repeated at irregular time intervals (make-to-order)
 - Batch is repeated at regular time intervals (make-to-stock)
- Final product is usually standard. The basic design is same.
- Such production of standardized items on a continuous basis is called repetitive production.
- Customer may be external or internal. For example, in an automobile plant, the engine assembly plant will be an internal customer for gear assembly plant)
- Machines and resources must be of general purpose or semi-automated.
- Skilled workforce is needed to work on product variety.
- Less supervision is need in comparison with job-shop
- Less flexible than job-shop
- Machines are grouped as per their functional capabilities.

4.8. Mass production

- The demand rate is more than the rate of production.
- Similar product is manufactured and hence, standard method and time standard is to be analysed.
- Most of the machines used in mass production are special purpose. The equipment is dedicated to the manufacture of a single product type such as light bulbs, medicines etc.
- The system is capital intensive and a long term planning needed before the investment.
- Semi-skilled labour is only needed as the product design is similar mostly.
- This system is a rigid production system.

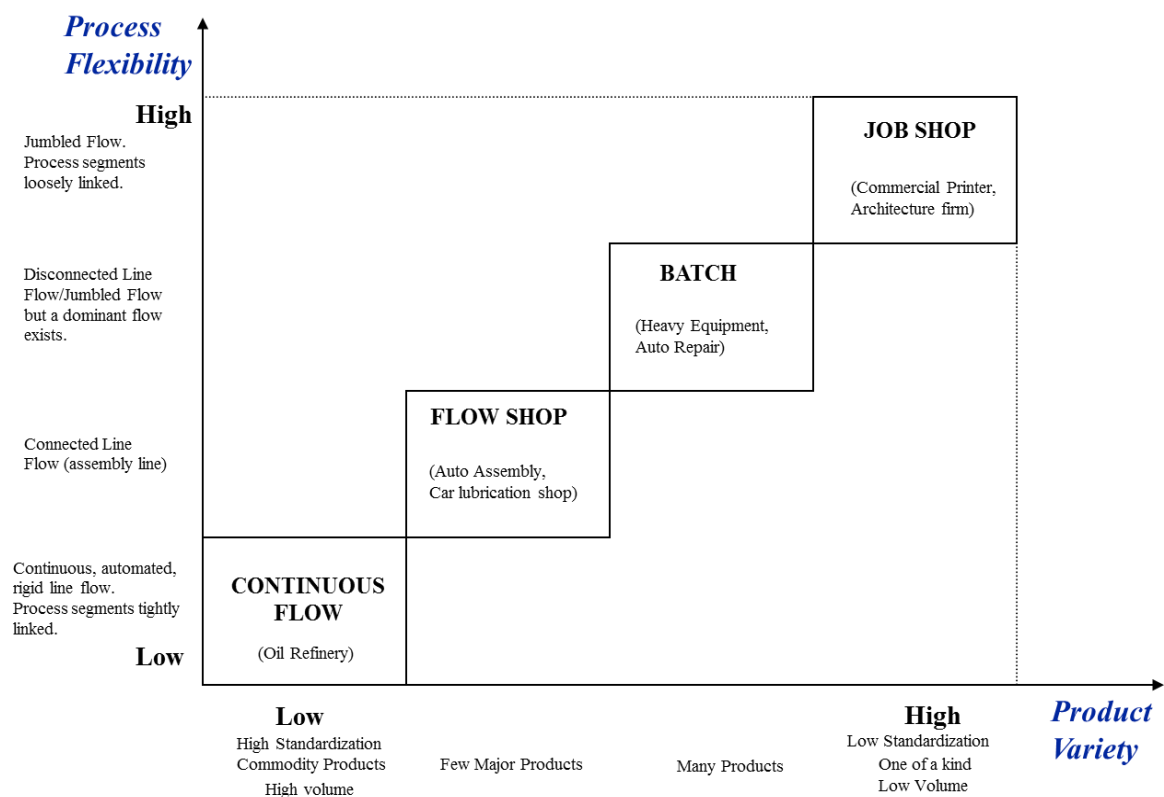


Figure 1.5 Process flexibility Vs. Product variety

5. Product design

Product design is the process of deciding on the unique characteristics and features of the company's product. Process selection is the development of the process necessary to produce the designed product. Product design and process selection are typically made together. Product design must support product manufacturability (the ease with which a product can be made). Product design defines a product's characteristics of;

- appearance,

- materials,
- dimensions,
- tolerances, and
- performance standards

Service design is unique in that the service and entire service concept are being designed. When a service is designed, the designer must define both the service and service concept.

Service design defines a service's characteristics such as: Physical elements, aesthetic & psychological benefits. For example, promptness in service, friendliness during the service, ambiance of the service premises. In addition, product and service design must match the needs and preferences of the targeted customer group

5.1. Phases of product development

The phases of product development are encapsulated in Table 1.1. The activities carried out in the product development phase with regard to the different departments in the organization is explained.

- **Phase 0: Planning**

Planning phase is referred as phase zero; precedes the project approval and launch of actual product development process. The output of this phase is the project mission statement which specifies the target market for the product, business goals, key assumptions and constraints.

- **Phase 1: Concept Development**

In Concept development, needs of the target market is identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing.

- **Phase 2: System-Level design**

System level design includes product architecture and decomposition of products into sub-systems and components.

- Final assembly of the product is decided
- Geometric layout of the product
- Functional specification of each of the layout sub-system
- Preliminary process flow diagram for final assembly process

- **Phase 3: Design Detail**

Complete specification of the geometry, materials, and tolerances of all the unique parts in the product.

- Identification of standard parts

- Tooling is designed

- **Phase 4: Testing and Refinement**

Construction and evaluation of multiple pre-production versions of the product

- Will product work?
- Whether product satisfies customer needs

- **Phase 5: Production Ramp-up**

- Train the work force
- Work out remaining problems
- Products supplied to preferred customers and evaluated.

5.2. Economic analysis of product development

Economic analysis can only capture those factors that are measurable and have both positive and negative implications that are difficult to quantify. Economic analysis is useful in at least two different circumstances using the following measurable factors to help determine:

- Operational design and development decisions – should we outsource to save time? Should we launch the product in four months at a unit cost of 10000 INR or wait for six months, when we can reduce to 8500 INR?
- Go/no-go milestones – should we try to develop a product to address market opportunity? Should we proceed? Should we launch?

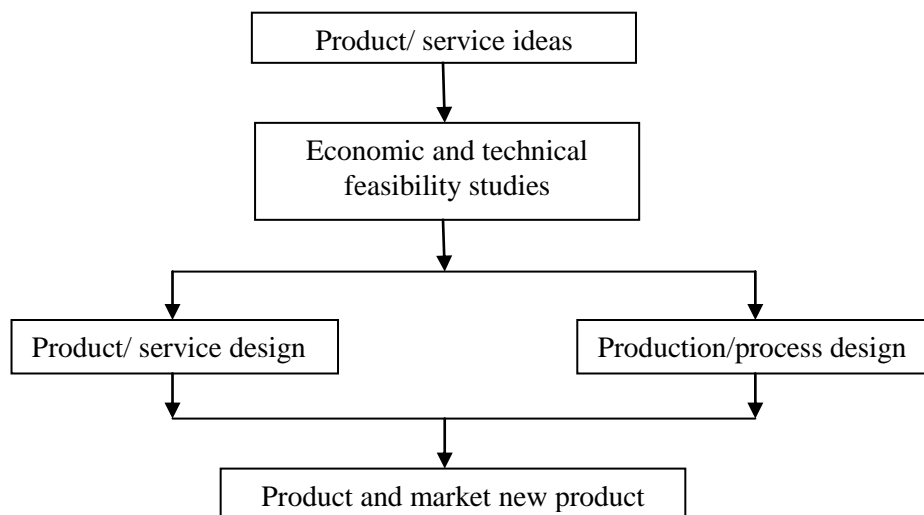


Figure 1.6 Product development process

If initial feasibility studies are favourable, engineers prepare an initial prototype design. This prototype design should exhibit the basic form, fit and function of the final product, but it will not necessarily be identical to the production model.

Table 1.1 Product development phase in different departments of an organization

PHASE 0: PLANNING	PHASE 1: CONCEPT DEVELOPMENT	PHASE 2: SYSTEM-LEVEL DESIGN	PHASE 3: DETAIL DESIGN	PHASE 4: TESTING AND REFINEMENT	PHASE 5: PRODUCTION RAMP-UP
MARKETING					
<ul style="list-style-type: none"> Articulate market opportunity. Define market segments. 	<ul style="list-style-type: none"> Collect customer needs. Identify lead users. Identify competitive products. 	<ul style="list-style-type: none"> Develop plan for product options and extended product family. Set target sales price point(s). 	<ul style="list-style-type: none"> Develop marketing plan. 	<ul style="list-style-type: none"> Develop promotion and launch materials. Facilitate field testing. 	<ul style="list-style-type: none"> Place early production with key customers.
DESIGN					
<ul style="list-style-type: none"> Consider product platform and architecture. Assess new technologies. 	<ul style="list-style-type: none"> Investigate feasibility of product concepts. Develop industrial design concepts. Build and test experimental prototypes. 	<ul style="list-style-type: none"> Generate alternative product architectures. Define major subsystems and interfaces. Refine industrial design. 	<ul style="list-style-type: none"> Define part geometry. Choose materials. Assign tolerances. Complete industrial design control documentation. 	<ul style="list-style-type: none"> Reliability testing. Life testing. Performance testing. Obtain regulatory approvals. Implement design changes. 	<ul style="list-style-type: none"> Evaluate early production output.
MANUFACTURING					
<ul style="list-style-type: none"> Identify production constraints. Set supply chain strategy. 	<ul style="list-style-type: none"> Estimate manufacturing cost. Assess production feasibility. 	<ul style="list-style-type: none"> Identify suppliers for key components. Perform make-buy analysis. Define final assembly scheme. Set target costs. 	<ul style="list-style-type: none"> Define piece-part production processes. Design tooling. Define quality assurance processes. Begin procurement of long-lead tooling. 	<ul style="list-style-type: none"> Facilitate supplier ramp-up. Refine fabrication and assembly processes. Train work force. Refine quality assurance processes. 	<ul style="list-style-type: none"> Begin operation of entire production system.
OTHER FUNCTIONS					
<ul style="list-style-type: none"> Research: Demonstrate available technologies. Finance: Provide planning goals. General Management: Allocate project resources. 	<ul style="list-style-type: none"> Finance: Facilitate economic analysis. Legal: Investigate patent issues. 	<ul style="list-style-type: none"> Finance: Facilitate make-buy analysis. Service: Identify service issues. 		<ul style="list-style-type: none"> Sales: Develop sales plan. 	

Performance testing and re-design of the prototype continues until this design-test-redesign process produces a satisfactorily performing prototype. Market sensing and evaluation is accomplished by demonstrations to potential customers, market tests or market surveys. If the response to the prototype is favourable, economic evaluation of the prototype design is performed to estimate production volume, costs and profits for the product.

5.3. Break-even analysis

Break-even analysis is a technique widely used in production management. It is based on categorising production costs between those which are "variable" (costs that change when the production output changes) and those that are "fixed" (costs not directly related to the volume of production). The variable and fixed costs are compared with sales revenue in order to determine the level of sales volume, sales value or production at which the business makes neither a profit nor a loss (the "break-even point").

- The Break-Even Chart: The break-even chart is a graphical representation which represents the relationship between the various costs of production with the volume of production.

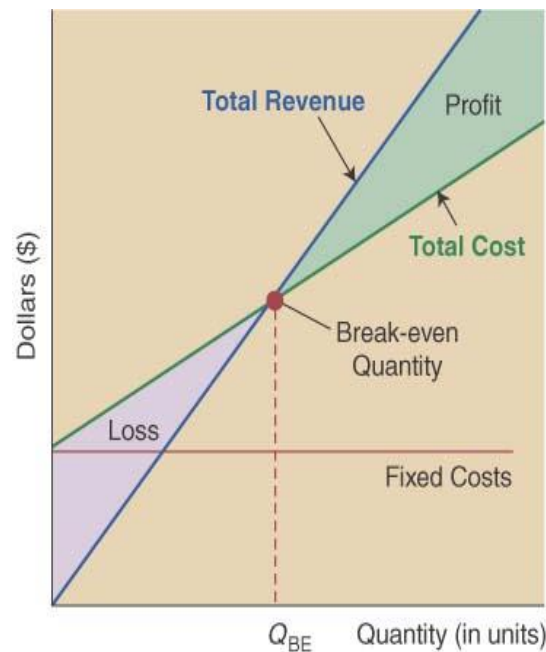


Figure 1.7a Break-even chart

- The point at which neither profit nor loss is made is known as the "break-even point (BEP)" and is represented on the break-even chart by the intersection of the lines representing total cost and total revenue.
- As output increases, variable costs incurred increases, meaning that total costs (fixed + variable) also increase. At low levels of output, costs are greater than revenue or income. At the point of intersection, BEP, total costs are exactly equal to total revenue or income, and hence neither profit nor loss is made.

Fixed Costs: Fixed costs are those business costs that are not directly related to the level of production or output. In other words, even if the business has a zero output or high output, the

level of fixed costs will remain broadly the same. In the long term fixed costs can alter - perhaps as a result of investment in production capacity (e.g. adding a new factory unit) or through the growth in overheads required to support a larger, more complex business.

Examples of fixed costs:

- Rent and rates
- Depreciation
- Research and development
- Marketing costs (non- revenue related)
- Administration costs

Variable Costs: Variable costs are those costs which vary directly with the level of output. They represent payment output-related inputs such as raw materials, direct labour, fuel and revenue-related costs such as commission.

A distinction is often made between "Direct" variable costs and "Indirect" variable costs.

Direct variable costs are those which can be directly attributable to the production of a particular product or service and allocated to a particular cost centre. Raw materials and the wages those working on the production line are good examples.

Indirect variable costs cannot be directly attributable to production but they do vary with output. These include depreciation (where it is calculated related to output - e.g. machine hours), maintenance and certain labour costs.

5.3.1 Computation of Break-even point:

BEP is the quantity of goods, the company needs to sell to cover its costs.

$$Q_{BE} = \frac{F}{(SP - VC)}$$

where, Q_{BE} – Break even quantity

F – Fixed costs

SP – selling price/unit

VC – Variable cost

Break-even analysis also includes calculating

- Total cost = sum of fixed cost and variable cost

$$\text{Total cost (TC)} = F + (VC) \times Q$$

- Revenue – amount of money brought in from sales

$$\text{Revenue (TR)} = (SP) \times Q$$

Q = number of units sold

As a production manager, the focus will be to shift the BEP towards left, by moving the total cost curve down. This is possible only by reducing the variable cost. Here lies the importance of value analysis/value engineering concepts. The concept of value analysis is dealt in

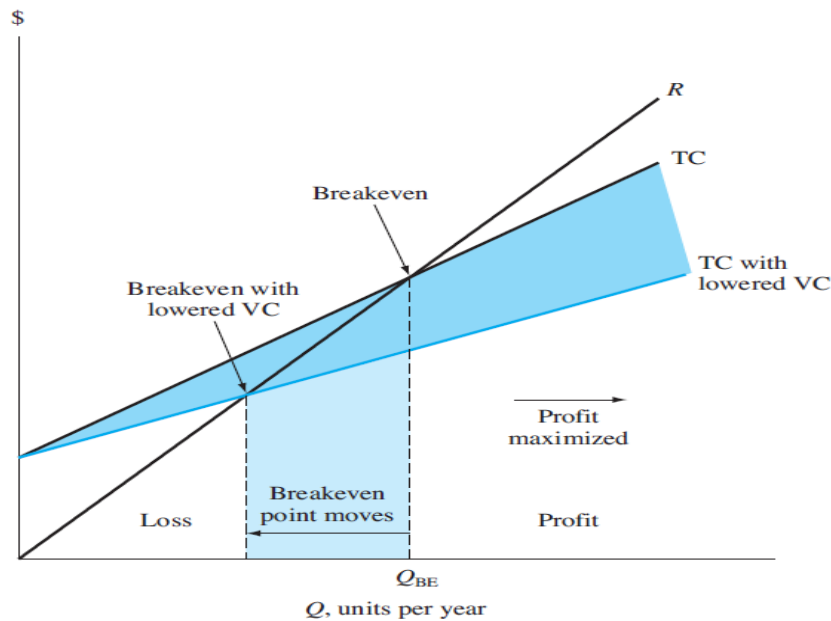


Figure 1.7 b Change of Break-even chart as variable cost changes

Example Problem 1: A Company manufacturer ball-point pens that it is able to sell at INR 15 per piece. The variable cost of the pen is INR 10 per unit. If the company has a total investment in fixed costs to the tune of INR 30,000. What is the break-even sale for the pen?

5.4. Designing for the customer

- A formal method is needed for making sure that everyone working on a design project knows the design objectives and is aware of the interrelationships of the various parts of the design. Similar communications are needed to translate the voice of the customer to technical design requirements. Such a process is called quality function deployment (QFD).
- Designing products for aesthetics and for the user is generally termed as Industrial design.
- One approach to getting the voice of the customer into the design specification of a product is quality function deployment (QFD).
- This approach credited by Toyota Motor Corporation for reducing costs on its car by more than 60% by significantly shortening design times.

- QFD uses a series of matrix diagrams that resemble connected houses. The first matrix, dubbed the house of quality, converts customer requirements into product-design characteristics.
- As shown in Figure 1.8, the house of quality has six sections: a customer requirements section, a competitive assessment section, a design characteristics section, a relationship matrix, a trade-off matrix, and a target values section.
- Quality Function Deployment begins with
 1. Studying and listening to customers – market research consumer’s product needs and preferences are defined and broken down into categories called customer requirements.
 2. Requirements are weighted based on their relative importance.
 3. Customer is asked to compare and rate the company’s products with the products of competitors
 - To evaluate its product in relation to others
 - Better understanding and focus on product characteristics that require improvement
 4. A set of technical characteristics of the product is developed
 - Evaluate the strengths and weaknesses of the product in terms of technical characteristics.

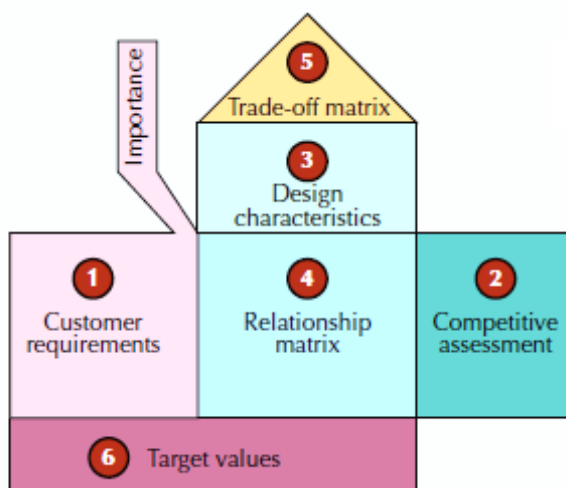


Figure 1.8 Outline of QFD

5.5. Value analysis

- The purpose of value analysis/value engineering is to simplify products and processes.
- Value analysis (VA) (also known as value engineering) was developed by General Electric in 1947 to eliminate unnecessary features and functions in product designs.

- VA is a set of activities undertaken to investigate the design components in a product development process strictly from a cost-value perspective and alert the product development team to alternatives that could bring down the cost of improve value in terms of functionality and performance without increasing the cost.
 - *Tata Nano project* – Rane group which makes rack-and pinion steering system focussed on reducing weight of the materials used, the steel rod of the steering with steel tube which could reduce cost.
 - *GKN Driveline India* designed shaft of small diameter which made it lighter and saved material costs.
- It has re-emerged as a technique for use by multifunctional design teams.
- Usually several questions are raised which include the following:
 1. Can we eliminate certain features from the design? Does the item have any design features that are not necessary?
 2. Are there instances of overdesign in certain components, increasing the cost? Can two or more parts be combined into one?
 3. Are there certain features of design that cost more than they are worth?
 4. Is it possible to replace the proposed method of manufacture with less costly one?
 5. Is it possible for someone else to produce certain components cheaper, faster and better? (make or buy decision)
 6. How can we cut down the weight?
 7. Are there nonstandard parts that can be eliminated?
- The objective of VA is to achieve equivalent or better performance at a lower cost while maintaining all functional requirements defined by the customer.
- The design team defines the essential functions of a component, assembly, or product using a verb and a noun. For example, the function of a container might be described as holds fluid.
- Then the team assigns a value to each function and determines the cost of providing the function. With that information, a ratio of value to cost can be calculated for each item.
- The team attempts to improve the ratio by either reducing the cost of the item or increasing its worth.
- VA/VE does this by identifying and eliminating unnecessary cost/features.
- Updated versions of value analysis also assess the environmental impact of materials, parts, and operations. This leads us to the next section on design for environment.

5.6. Process and capacity analysis

- One of the important decision points in the design and operational control of an operations system concerns the capacity to be deployed in the system.
- Often hear of excessive delays and waiting time in service systems. Similarly, we hear that some factories work with near 100% utilization of their resources.
- Improper choice in the amount of capacity deployed and poor planning of the existing capacity will lead to loss of productivity and overall profitability of the operating system.
- The basic building block of capacity analysis is process analysis.
- A process is the basic building block of operations. Process consists of a set of activities that need to be performed by consuming some resources and time.
- Process design determine aspects such as the time taken to serve the customer, the cost involved, the productivity of people, and utilization of resources.
- An operations manager may need to understand the following issues in the process design:
 - Do I have adequate resources to meet the demand? If I need to add some extra resources, where should I add them?
 - What is the extent to the utilization of my resources?
 - To increase the capacity of my system, how should I modify the process? Should I add more resources? What will happen to the cost of my operations?

Process analysis tools include the following:

Process flow analysis: In process analysis, we use some analytical mechanisms to understand the impact of the process design on output, cost, or any other performance metric.

Process flowchart: is the use of a diagram to present the major elements of a process using the symbols as shown in Figure 1.9. The basic elements can include tasks or operations, flows of materials or customers, decision points, and storage areas or queues. It is an ideal methodology by which to begin analysing a process.

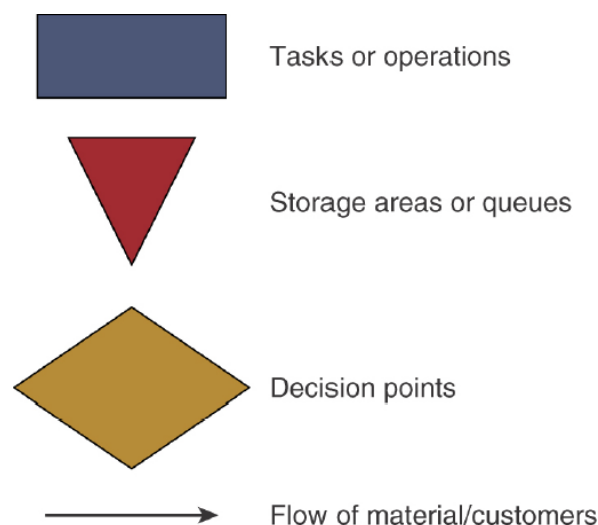


Figure 1.9 Symbols used for process flow charting

5.7. Common terms used in process analysis

A **buffer** refers to a storage area between stages where the output of a stage is placed prior to being used in a downstream stage.

Blocking occurs when the activities in a stage must stop because there is no place to deposit the item just completed. If there is no space for an employee to place a unit of work down, the employee will hold on to it and not able to continue working on the next unit.

Starving occurs when the activities in a stage must stop because there is no work. If an employee is waiting at a work station and no work (job) is coming to the employee to process, the employee will remain idle until the next unit of work comes.

Bottleneck occurs when the limited capacity of a process causes work to pile up or become unevenly distributed in the flow of a process. If an employee works slowly in a multi-stage process, work will begin to pile up in front of that employee. In this case, the employee represents the limited capacity causing the bottleneck.

Pacing refers to the fixed timing of the movement of items through the process. This can be observed in assembly line operations.

Example problem 1: Consider a shirt-manufacturing process. There are five steps of manufacturing and three storage points. The store stocks raw material and other materials such as buttons and thread. The cloth is moved to the first stage of processing where it is systematically spread out and the relevant markings are made. After this, it is sent for cutting. Once the cutting operation is complete, various individual pieces that make up one shirt when put together are segregated into two bundles. One bundle goes to the first stitching operation while the other bundle goes to the second stitching operation. After stitching is complete, they are temporarily stored. The assembly process consists of matching the pieces and attaching them into a completed shirt. Assembly operation is followed by an inspection and pressing operation. Finally the shirt is stored. Prepare a process chart for the above process.

5.8. Process performance metrics

Process performance metrics are to be determined to review whether a process is functioning properly as required. The process performance metrics measures the different process characteristics that tell us how a process is performing.

The commonly used process performance metrics are as follows:

Efficiency: is a ratio of the actual output of a process relative to some standard.

Throughput time: is the elapsed time from the first stage of the process to the last stage of the process. It is also known as lead time.

Run time: is the time required to produce a batch of products. (time required to produce each unit x batch size)

Set-up time: is the time required to prepare a machine to make a particular item.

Operation time = Run time + Set-up time

Cycle time: is the elapsed time between two successive outputs from a process that is continuously operating in the given period of time.

Bottle neck: that stage of the process that dictates the output of a process.

Process velocity (or throughput ratio): is the ratio of the total throughput time to the value-added time.

Throughput rate: is the output rate that the process is expected to produce over a period of time. For example, Throughput rate of the assembly line is 120 units per hour. Also, Throughput rate is the mathematical inverse of the cycle time.

Example problem 1: A toy manufacturer receives crafted toys from local carpenters and performs the final operations before stocking it for sale. The process consists of five steps. The first step is to arrange a set of four toys in a pallet. After this, the pallet moves to the next station where the toys are pre-treated. This is to increase the toy's life. The next step is to send it to the spray painting chamber, where it is painted as per the specifications. At present there is only one spray painting machine. After painting it is left in an open area for drying. The painting process and the pre-treatment process are specialized so the paint dries quickly. Finally the toys are inspected and packed.

Step 1: Preparation of toys	8 minutes
Step 2: Pre-treatment	12 minutes
Step 3: Painting	20 minutes
Step 4: Drying	10 minutes
Step 5: Inspection and packing	5 minutes

Develop a process flow diagram for these steps and answer the following.

- What is the throughput time for this manufacturing process
- Identify the bottleneck for this process?
- What is the cycle time for this process?
- What is the productive capacity of the process?
- What are the assumptions behind this computation?

5.9. **Design strategy:** The design considerations include the following strategies.

- Make-to-stock strategy: In the make-to-stock environment, goods are produced before customers place orders. The retail environment is an example of make-to-stock.

Goods are produced and put into inventory at the retailer. The make-to-stock strategy typically allows manufacturers to produce goods in long production runs, taking advantage of production efficiencies. Because the make-to-stock environment produces goods on a consistent basis, a master production schedule determines the exact number of units to produce for each production run.

- Assemble-to-order strategy: Certain fast-food restaurants use an assemble-to-order strategy. A customer walks in, places an order for a pizza; and the pizza gets assembled from a stock selection of ingredients. This strategy forces the restaurant to carry enough ingredients to make every pizza combination a customer might request. Automobile manufacturers also use the assemble-to-order strategy. A customer can pick and choose from many features including interior fabrics, exterior paints, and seat, engine, wheel or tire options. Once the dealer places the customer order, the manufacturing plant assembles the standard component parts to the customer. Dell can be another example for assemble to order.
- Make-to-order strategy: Companies that use a make-to-order strategy produce goods after receiving an order from the customer. Most often a company that uses the make-to-order strategy produces one-of-a-kind goods. Examples include custom-tailored clothing, custom machinery and few jewellery shops.

The various strategies are depicted in Figure 1.10

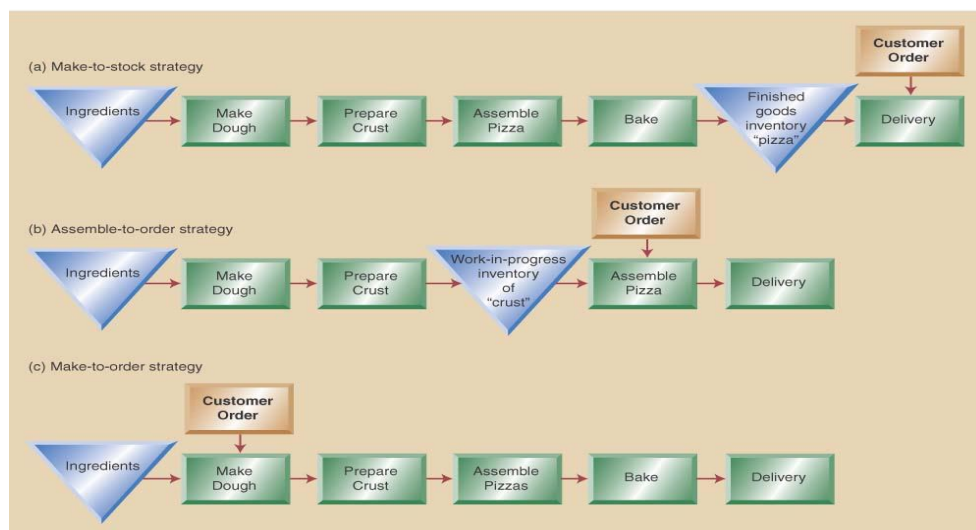


Figure 1.10 Different design strategies

6. 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. 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 labour, machines, materials, power, space, time, capital, etc.
- Productivity can also be defined as human endeavour (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.

Productivity is a common measure on how well resources are being used. In the broadest sense, it can be defined as the following ratio:

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

A firm deals about Total (or 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.

$$\text{Total Measure Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Goods and services produced}}{\text{All resources produced}}$$

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.

$$\text{Partial measures of productivity} = \frac{\text{Output}}{\text{Labour}} = \frac{\text{Output}}{\text{Capital}} = \frac{\text{Output}}{\text{Materials}} = \frac{\text{Output}}{\text{Energy}}$$

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.

$$\begin{aligned} \text{Multifactor measures of productivity} &= \frac{\text{Output}}{\text{Labour} + \text{Capital} + \text{Energy}} \\ &= \frac{\text{Output}}{\text{Labour} + \text{Capital} + \text{Materials}} \end{aligned}$$

Example Problem 1: You have just determined that your service employees have used a total of 2400 hours of labor this week to process 560 insurance forms. Last week the same crew used only 2000 hours of labor to process 480 forms. Which productivity measure should be used? Is productivity increasing or decreasing?

Answer: This problem can be classified as a Total Measure or Partial Measure.

Last week's productivity = $480/2000 = 0.24$, and this week's productivity is = $560/2400 = 0.23$.

So, productivity is decreasing slightly.

Problem 2: As operations manager, you are concerned about being able to meet the sales requirements in the coming months. You have just been given the following production report. Find the average monthly productivity.

	Jan	Feb	Mar	Apr
Units Produced	2300	1800	2800	3000
Hours per machine	325	200	400	320
Number of machines	3	5	4	4

Problem 3: An electronics company makes communication devices for military contracts. The company just completed two contracts. The navy contract was for 2,300 devices and took 25 workers two weeks (40 hours per week) to complete. The army contract was for 5,500 devices that were produced by 35 workers in three weeks. On which contract were the workers more productive?

7. Learning curves

A learning curve is a line displaying the relationship between unit production time and the cumulative number of units produced. Learning (or experience) curve theory has a wide range of application in the business world.

- In manufacturing, it can be used to estimate the time for product design and production, as well as costs.
- Learning curves are important and are sometimes overlooked as one of the trade-offs in just-in-time (JIT) systems, where sequencing and short runs achieve lower inventories by forfeiting some benefits of experience from long product runs.
- Learning curves are also an integral part in planning corporate strategy, such as decisions concerning pricing, capital investment, and operating costs based on experience curves.
- Learning curves can be applied to individuals or organizations. *Individual learning* is improvement that results when people repeat a process and gain skill or efficiency from their own experience. That is, "practice makes perfect."
- *Organizational learning* results from practice as well, but it also comes from changes in administration, equipment, and product design. In organizational settings, we expect to see

both kinds of learning occurring simultaneously and often describe the combined effect with a single learning curve.

Learning curve theory is based on three assumptions:

- The amount of time required to complete a given task or unit of a product will be less each time the task is undertaken.
- The unit time will decrease at a decreasing rate.
- The reduction in time will follow a predictable pattern.

In this application, it is observed that, as production doubled, there is a 20 percent reduction in direct production worker-hours per unit between doubled units. Thus, if it took 100,000 hours for Plane 1, it will take 80,000 hours for Plane 2, 64,000 hours for Plane 4, and so forth. Because the 20 percent reduction meant that, say, Unit 4 will take only 80 percent of the production time required for Unit 2, the line connecting the coordinates of output and time is referred to as an “80 percent learning curve.”

Learning Curves Plotted as Times and Numbers of Units

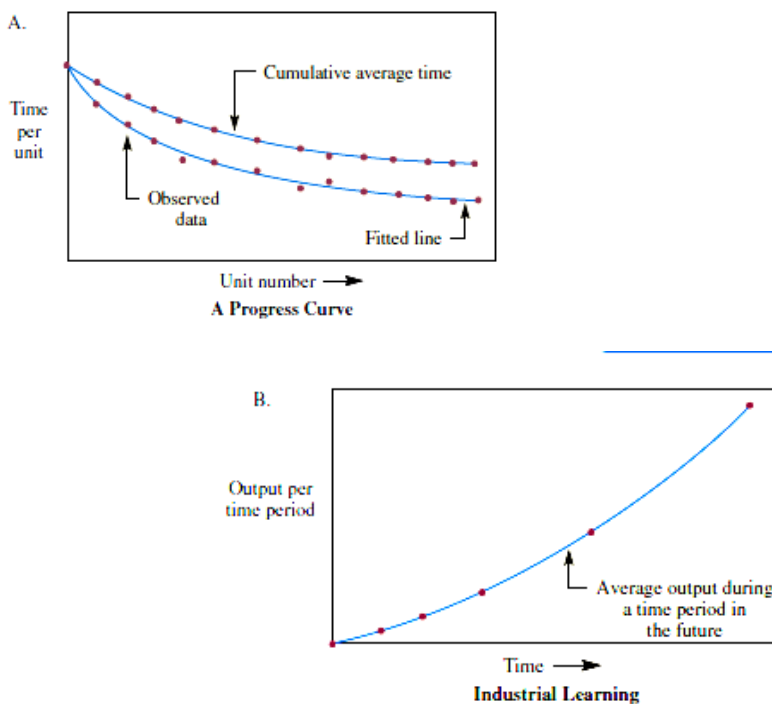


Figure 1.10 Learning curves

Example Problem 1: Captain Nemo, owner of the Suboptimum Underwater Boat Company (SUB), is puzzled. He has a contract for 11 boats and has completed 4 of them. He has observed that his production manager, young Mr. Overick, has been reassigning more and more people to torpedo assembly after the construction of the first four boats. The first boat, for example, required 225 workers, each working a 40-hour week, while 45 fewer workers were required for the second boat. Overick has told them that “this is just the beginning” and that he will complete the last boat in the

current contract with only 100 workers! Overick is banking on the learning curve, but has he gone overboard? (Chase *et al.* 2010)

Because the second boat required 180 workers, a simple exponential curve shows that the learning percentage is 80 percent ($180 \div 225$). To find out how many workers are required for the 11th boat, we look up unit 11 for an 80 percent improvement ratio in learning curve table and multiply this value by the number required for the first sub. By interpolating between Unit 10 and Unit 12 we find the improvement ratio is equal to 0.4629. This yields 104.15 workers (0.4269 interpolated from table $\times 225$). Thus, Overick's estimate missed the boat by four people.

Example Problem 2: A manufacturer of diesel locomotives needs 50,000 hours to produce the first unit. Based on the past experience with similar products, you know that the rate of learning is 80 percent. Use the logarithmic analysis to estimate the direct labour required for the 40th diesel locomotive and the cumulative average number of labour hours per unit for the first 40 units. Also, plot a learning curve for this situation.

Example Problem 3: The manager of a turbine manufacturer has just received a production schedule for an order for 30 turbines. Over the next 5 months, the company is to produce 2, 3, 5, 8, 12 turbines respectively. The first unit took 30000 direct labour hours and experience on past projects indicates that a 90% learning curve is appropriate. Each employee works an average of 150 hours per month. Estimate the total number of full-time employees needed each month for the next 5 months.

Month	No. of units in the month	Cumulative no. of units
1	2	2
2	3	5
3	5	10
4	8	18
5	12	30

Month 1:

$$\begin{aligned} \text{First unit} &= 30000 \text{ hours} \\ \text{Second unit} &= 30000 \times 0.9 = 27000 \text{ hours} \\ \text{Total hours} &= 30000 + 27000 = 57000 \\ \text{Number of employees needed} &= \frac{57000}{150} = 380 \end{aligned}$$

Month 2

$$\begin{aligned} \text{Third unit} &= 30000 \times 0.846 = 25386 \text{ hours} \\ \text{Fourth unit} &= 30000 \times 0.810 = 24300 \text{ hours} \\ \text{Fifth unit} &= 30000 \times 0.783 = 23490 \text{ hours} \\ \text{Total hours} &= 25386 + 24300 + 23490 = 73176 \\ \text{Number of employees needed} &= \frac{73176}{150} = 488 \end{aligned}$$

Month 3: Number of employees needed = 731

Month 4: Number of employees needed = 1067

Month 5: Number of employees needed = 1480.