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Chapter 1

Introduction to Operations Management

1.1 Introduction

Every organisation has an operations function, whether or not it is called ‘operations’. The goal or purpose of most organisations involves the production of goods and/or services. To do this, they have to procure resources, convert them into outputs and distribute them to their intended users. The term operations embraces all the activities required to create and deliver an organisation's goods or services to its customers or clients.

Within large and complex organisations operations is usually a major functional area, with people specifically designated to take responsibility for managing all or part of the organisation's operations processes. It is an important functional area because it plays a crucial role in determining how well an organisation satisfies its customers. In the case of private-sector companies, the mission of the operations function is usually expressed in terms of profits, growth and competitiveness; in public and voluntary organisations, it is often expressed in terms of providing value for money.

Operations management is concerned with the design, management, and improvement of the systems that create the organisation's goods or services. The majority of most organisations’ financial and human resources are invested in the activities involved in making products or delivering services. Operations management is therefore critical to organisational success.

In understanding of the principles of operations management is important for all managers, because they provide a systematic way of looking at an organisation's processes. The need to manage manufacturing and service operations efficiently and effectively has led to a considerable increase in interest in operations management in recent years. However, the concept of operations is not new.

1.2 The historical development of operations management

Operations in some form has been around as long as human endeavour itself but, in manufacturing at least, it has changed dramatically over time, and there are three major phases - craft manufacturing, mass production and the modern period. Let's look at each of these briefly in turn.

1.2.1 Craft manufacturing

Craft manufacturing describes the process by which skilled craftspeople produce goods in low volume, with a high degree of variety, to meet the requirements of their individual customers. Over the centuries, skills have been transmitted from masters to apprentices and journeymen, and controlled by guilds. Craftspeople usually worked at home or in small workshops. Such a system worked well for small-scale local production, with low levels of competition. Some industries, such as furniture manufacture and clockmaking, still include a significant proportion of craft working.

1.2.2 Mass production

In many industries, craft manufacturing began to be replaced by mass production in the 19th century. Mass production involves producing goods in high volume with low variety – the opposite of craft manufacturing. Customers are expected to buy what is supplied, rather than goods made to their own specifications. Producers concentrated on keeping costs, and hence prices, down by minimising the variety of both components and products and setting up large production runs. They developed aggressive advertising and employed sales forces to market their products.

An important innovation in operations that made mass production possible was the system of standardised and interchangeable parts known as the ‘American system of manufacture’, which developed in the United States and spread to the United Kingdom and other countries. Instead of being produced for a specific machine or piece of equipment, parts were made to a standard design that could be used in different models. This greatly reduced the amount of work required in cutting, filing and fitting individual parts, and meant that people or companies could specialise in particular parts of the production process.

A second innovation was the development by Frederick Taylor (1911) of the system of 'scientific management’, which sought to redesign jobs using similar principles to those used in designing machines. Taylor argued that the role of management was to analyse jobs in order to find the ‘one best way’ of performing any task or sequence of tasks, rather than allowing workers to determine how to perform their jobs. By breaking down activities into tasks that were sequential, logical and easy to understand, each worker would have narrowly defined and repetitious tasks to perform, at high speed and therefore with low costs.

A third innovation was the development of the moving assembly line by Henry Ford. Instead of workers bringing all the parts and tools to a fixed location where one car was put together at a time, the assembly line brought the cars to the workers. Ford thus extended the ideas of scientific management, with the assembly line controlling the pace of production. This completed the development of a system through which large volumes of standardised products could be assembled by unskilled workers at constantly decreasing costs – the apogee of mass production.

1.2.3 The modern period

Mass production worked well as long as high volumes of mass-produced goods could be produced and sold in predictable and slowly changing markets. However, during the 1970s, markets became highly fragmented, product life cycles reduced dramatically and consumers had far greater choice than ever before.

An unforeseen challenge to Western manufacturers emerged from Japan. New Japanese production techniques, such as total quality management (TQM), just-in-time (JIT) and employee involvement were emulated elsewhere in the developed world, with mixed results.

More recently, the mass production paradigm has been replaced, but there is as yet no single approach to managing operations that has become similarly dominant. The different approaches for managing operations that are currently popular include:

- *Flexible specialisation* in which firms (especially small firms) focus on separate parts of the value-adding process and collaborate within networks to produce whole products. Such an approach requires highly developed networks, effective processes for collaboration and the development of long-term relationships between firms.
- *Lean production* which developed from the highly successful Toyota Production System. It focuses on the elimination of all forms of waste

from a production system. A focus on driving inventory levels down also exposes inefficiencies, reduces costs and cuts lead times.

- *Mass customisation* which seeks to combine high volume, as in mass production, with adapting products to meet the requirements of individual customers. Mass customisation is becoming increasingly feasible with the advent of new technology and automated processes.
- *Agile manufacturing* which emphasises the need for an organisation to be able to switch frequently from one market-driven objective to another. Again, agile manufacturing has only become feasible on a large scale with the advent of enabling technology.

In various ways, these approaches all seek to combine the high volume and low cost associated with mass production with the product customisation, high levels of innovation and high levels of quality associated with craft production.

1.3 Objectives of Operations Management

An important point to be noted at this section is that operations management deals with set of objectives, which are very broad. In general, we can classify operations management impact on the five broad categories of stakeholders; customers, suppliers, shareholders, employees and society.

Stakeholders is a broad term but is generally used to mean anybody who could have an interest in, or is affected by, the operation.

1. **Customers** – These are the most obvious people who will be affected by any business.

2. **Suppliers** – Operations can have a major impact on suppliers, both on how they prosper themselves, and on how effective they are at supplying the operation.

3. **Shareholders** – Clearly, the better operation is at producing goods and services, the more likely the whole business is to prosper and shareholders will be one of the major beneficiaries of this.

4. **Employees** – Similarly, employees will be generally better off if the company is prosperous; if only because they are more likely to be employed in the future.

However operations responsibilities to employees go far beyond this. It includes the general working conditions which are determined by the way the operation has been designed.

5. **Society** – Although often having no direct economic connection with the company, individuals and groups in society at large can be impacted by the way its operations managers behave. The most obvious example is in the environmental responsibility exhibited by operations managers.

We will discuss briefly the five performance objectives, namely, quality, speed, dependability, flexibility, and cost in the following paragraph.

1.4 The role of the operations manager

Some people (especially those professionally involved in operations management!) argue that operations management involves everything an organisation does. In this sense, every manager is an operations manager, since all managers are responsible for contributing to the activities required to create and deliver an organisation's goods or services. However, others argue that this definition is too wide, and that the operations function is about producing the right amount of a good or service, at the right time, of the right quality and at the right cost to meet customer requirements.

So operations managers are responsible for managing activities that are part of the production of goods and services. Their direct responsibilities include managing both the operations process, embracing design, planning, control, performance improvement, and operations strategy. Their indirect responsibilities include interacting with those managers in other functional areas within the organisation whose roles have an impact on operations. Such areas include marketing, finance, accounting, personnel and engineering.

Operations managers' responsibilities include:

- *Human resource management* – the people employed by an organisation either work directly to create a good or service or provide support to those who do. People and the way they are managed are a key resource of all organisations.

- *Asset management* – an organisation's buildings, facilities, equipment and stock are directly involved in or support the operations function.
- *Cost management* – most of the costs of producing goods or services are directly related to the costs of acquiring resources, transforming them or delivering them to customers. For many organisations in the private sector, driving down costs through efficient operations management gives them a critical competitive edge. For organisations in the not-for-profit sector, the ability to manage costs is no less important.

Decision making is a central role of all operations managers. Decisions need to be made in designing the operations system, managing the operations system and improving the operations system.

The five main kinds of decision in each of these relate to:

1. the processes by which goods and services are produced
2. the quality of goods or services
3. the quantity of goods or services (the capacity of operations)
4. the stock of materials (inventory) needed to produce goods or services
5. the management of human resources.

You can put them under the following questions

What: What resources will be needed, and in what amounts?

When: When will each resource be needed? When should the work be scheduled? When should materials and other supplies be ordered? When is corrective action needed?

Where: Where will the work be done?

How: How will the product or service be designed? How will the work be done (organization, methods, equipment)?

How will resources be allocated?

Who: Who will do the work?

The operations function consists of all activities *directly* related to producing goods or providing services. Hence, it exists both in manufacturing and assembly operations, which are *goods-oriented,* and in areas such as health care, transportation, food handling, and retailing, which are primarily *service-oriented.*

A primary function of an operations manager is to guide the system by decision making. Certain decisions affect the design of the system, and others affect the operation of the system.

System design involves decisions that relate to system capacity, the geographic location of facilities, arrangement of departments and placement of equipment within physical structures, product and service planning, and acquisition of equipment. These decisions usually, but not always, require long-term commitments. Moreover, they are typically *strategic* decisions.

System operation involves management of personnel, inventory planning and control, scheduling, project management, and quality assurance. These are generally *tactical* and *operational* decisions.
Feedback on these decisions involves *measurement* and *control*. In many instances, the operations manager is more involved in day-to-day operating decisions than with decisions relating to system design. However, the operations manager has a vital stake in system design because *system design essentially determines many of the parameters of system operation.* For example, costs, space, capacities, and quality are directly affected by design decisions. Even though the operations manager is not responsible for making all design decisions, he or she can provide those decision makers with a wide range of information that will have a bearing on their decisions.

Purchasing has responsibility for procurement of materials, supplies, and equipment. Close contact with operations is necessary to ensure correct quantities and timing of purchases. The purchasing department is often called on to evaluate vendors for quality, reliability, service, price, and ability to adjust to changing demand. Purchasing is also involved in receiving and inspecting the purchased goods.

Industrial engineering is often concerned with scheduling, performance standards, work methods, quality control, and material handling.

Distribution involves the shipping of goods to warehouses, retail outlets, or final customers.

Maintenance is responsible for general upkeep and repair of equipment, buildings and grounds, heating and air-conditioning; removing toxic wastes; parking; and perhaps security. The operations manager is the key figure in the system: He or she has the ultimate responsibility for the creation of goods or provision of services. The kinds of jobs that operations managers oversee vary tremendously from organization to organization largely because of the different products or services involved. Thus, managing a banking operation obviously requires a different kind of expertise than managing a steelmaking operation. However, in a very important respect, the jobs are the same: They are both essentially *managerial.* The same thing can be said for the job of any operations manager regardless of the kinds of goods or services being created.

1.5 Productions/Operations Management Problems

POM is a functional field of business with clear line management responsibilities. Problems of management in the production/operations function basically concerns two types of decision:

a. Those relating to the design or establishment of the production/operations system.

b. T*hose relating to the operation, performance and running of the production/operations system.*

Problems in the design of production/operations system are as follows:

i. Design/specification of goods/service,

ii. Location of facilities,

iii. Layout of facilities/resources and materials handling,

iv. Determination of capacity/capability,

v. Design of works or jobs,

vi. Involvement in determination of remuneration system and work standards.

Problems in the operation of system are:

i. Planning and scheduling of activities,

ii. Quality control,

iii. Maintenance and replacement,

iv. Involvement in performance measurement.

Every business organization will embrace these problems areas to a greater or lesser extent. The relative emphasis will differ between companies and industries, and over a period of time. Problems in the first section are of long-term nature and will assume considerable importance at only infrequent intervals. Problems in the second section will be of a recurring nature, i.e. they are of short term nature.

Chapter 2

Linking Operations with Operations Strategy and Competitiveness

2.1 Competitiveness

We define **competitiveness** as the ability and performance of a firm to sell and supply goods and services in a given market, in relation to the ability and performance of other firms.[1] In other words, how will one firm win over customers in order to become the product or service of choice.

2.2 Competitive Advantage and Key Purchasing Criteria

Competitive advantage is the leverage a business has over its competitors. This can be gained by offering clients better and greater value. Advertising products or services with lower prices or higher quality piques the interest of consumers. This is the reason behind brand loyalty, or why customers prefer one particular product or service over another.

Each organization needs to have a deep understanding of their customers and what drives their customers to make purchases. We refer to these as **key purchasing criteria**. They are the factors which customers evaluate and consider when making a product choice.

It is important to keep in mind that the customer is not always a consumer purchasing a good at a store. The customer in many instances may be another business. The city of Toronto may be purchasing heavy duty trucks to use in the landscaping of city parks or Toyota may be searching for a new supplier for automobile glass.

2.3 Competitive Priorities

The competitive priorities are the ways in which the Operations Management function focuses on the characteristics of cost, quality, flexibility and speed. The firm's customers will determine which of the competitive priorities are emphasized.

Cost – Firms whose customers prioritize price will be very interested in having processes that enable them to keep their costs low. These companies are typically paying close attention to identifying and eliminating waste within their operations. By reducing defects, they will reduce costs. These firms will closely monitor and seek to improve their productivity. Factors such as resource utilization and efficiency will be important.

Quality – Firms whose customers prioritize quality focus on creating both excellent product and process design. Marketing and Engineering collaborate to design products that meet customers' requirements. Manufacturing must ensure that the process is able to produce the products defect-free. It is only by having excellent design quality and excellent process quality that the organization can ensure that customers will have their expectations satisfied.

Flexibility – Firms whose customers prioritize variety must prioritize the ability to change rapidly. Firms who value flexibility usually do so by carefully choosing equipment that is general-purpose and able to perform multiple functions. They will often strive to keep a small amount of spare capacity in case it is needed. Multi-skilled employees who are able to work in various areas of the firm or operate multiple types of technology are valued. These firms want to ensure that they can get new products to market quickly and transition from making one product to another quickly. Keeping machine set-ups fast is a critical way to do this. They also strive to be able to abruptly modify the volume of their output in case the need or opportunity arises.

Delivery (reliability and speed) – Firms whose customers prioritize speed of product/service delivery must be very efficient and quick at providing their products and services. McDonald's and Amazon are examples of this.

Below is a table summarizing the relationship between a customer's priority and a firm's strategy

Customer's priority	Firm's strategy
Cost	Minimizing product costs and waste, maximizing productivity
Quality	Designing superior, durable products, minimizing defects
Flexibility	Adaptability in product design and output, utilizing general-purpose machinery and multi-skilled workers
Delivery	Maintaining reliable and speedy delivery services

It is a long-held understanding that each major decision that needs to be made within the operations of an organization will include a trade-off because it is impossible for anyone organization to excel on all the competitive priorities at once! An example is a manufacturer who competes based on cost. In order to reduce defects, they may choose to change one of their input components for one with a better quality. This however will increase their costs. Cost and quality are common trade-offs. Flexibility and speed are also considered trade-offs. When organizations increase their number of options and varieties, it adds operational complexity. This will slow down their operations.

2.4 Core Competency (Core Capabilities)

Core competency is a management theory that originated in a 1990 Harvard Business Review article, "The Core Competence of the Corporation."

Core competencies are the resources and capabilities that comprise the strategic advantages of a business. A modern management theory argues that a business must define, cultivate, and exploit its core competencies in order to succeed against the competition.

- Core competencies are the defining characteristics that make a business or an individual stand out from the competition.

- Identifying and exploiting core competencies are as important for a new business making its mark as for an established company trying to stay competitive.
- A company's people, physical assets, patents, brand equity, and capital all can make a contribution to a company's core competencies.

A successful business has identified what it can do better than anyone else, and why. Its core competencies are the "why."

Defining Core Competencies

In the article, C.K. Prahalad, and Gary Hamel review three conditions a business activity must meet in order to be a core competency:

- The activity must provide superior value or benefits to the consumer.
- It should be difficult for a competitor to replicate or imitate it.
- It should be rare.

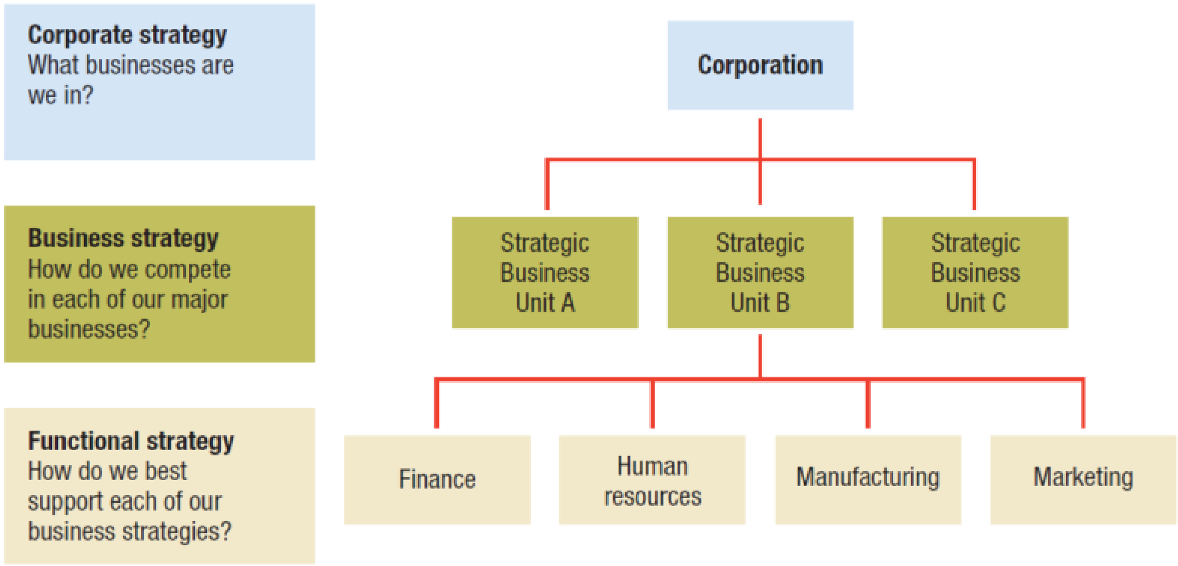
Some examples of core competencies:

- McDonald's has standardization. It serves nine million pounds of French fries every day, and every one of them has precisely the same taste and texture.
- Apple has style. The beauty of its devices and their interfaces gives them an edge over its many competitors.
- Walmart has buying power. The sheer size of its buying operation gives it the ability to buy cheap and undersell retail competitors

2.5 Strategy

2.5.1 The Strategy Hierarchy

In most corporations, there are several levels of management. Strategic management is the highest of these levels in the sense that it is the broadest and applies to all parts of the firm while also incorporating the longest time horizon. It gives direction to corporate values, corporate culture, corporate goals, and corporate missions. Under this broad corporate strategy there are typically business-level competitive strategies and functional unit strategies



Corporate strategy refers to the overarching strategy of the diversified firm. Such a corporate strategy answers the questions of "in which businesses should we compete?" and "how does being in these businesses create synergy and/or add to the competitive advantage of the corporation as a whole?"

Business strategy refers to the aggregated strategies of a single business firm or a strategic business unit (SBU) in a diversified corporation. According to Michael Porter, a firm must formulate a business strategy that incorporates either cost leadership, differentiation or focus in order to achieve a sustainable competitive advantage and long-term success in its chosen arenas or industries.

Functional strategies include marketing strategies, new product development strategies, human resource strategies, financial strategies, legal strategies, supply-chain strategies, and information technology management strategies. The emphasis is on short- and medium-term plans and is limited to the domain of each department's functional responsibility. Each functional department attempts to do its part in meeting overall corporate objectives, and hence to some extent their strategies are derived from broader corporate strategies.

Many companies feel that a functional organizational structure is not an efficient way to organize activities, so they are reengineered according to processes or SBUs. A **strategic business unit** is a semi-autonomous unit that is usually responsible for its own budgeting, new product decisions, hiring decisions, and price setting. An SBU is treated as an internal profit centre by corporate headquarters.

An additional level of strategy called **operational strategy** was encouraged by Peter Drucker in his theory of Management By Objectives (MBO). It is very narrow in focus and deals with day-to-day operational activities such as scheduling criteria. Operational level strategies are informed by business level strategies which, in turn, are informed by corporate level strategies.

Operations strategy categories can be broken down into many types of areas that must be addressed. The decisions made in these areas will determine whether the business strategy is executed. Below is a list of 10 critical decisions in operations management.

1. **Design of Goods and Services** – The actual design of the product or service will have the largest impact on the cost to produce and the quality to achieve.
2. **Quality** – The way in which the organization will ensure that the product specifications are met. This may include the use of statistical process control, total quality management or Six Sigma.
3. **Process and Capacity Design** – The type of product along with its volume and variety will have the major impact on which type of process to be chosen.
4. **Location** – Important decisions such as how many locations and where to locate them are critical to organization success. This will be a major factor in terms of how quickly the transformation process can take place, and how quickly goods can be shipped to customers.
5. **Layout Design and Strategy** – Consider the placement of work centres, movement of goods, people and information How materials are delivered and used.
6. **Human Resources and Job Design** – Decisions regarding training for employees, how to motivate employees to achieve operational success.

7. **Supply Chain Decisions** – Decisions in terms of where suppliers are located and the level of supplier collaboration are major considerations that impact cost and delivery speed.
8. **Inventory** – How will inventories be used and controlled in the business and the supply chain
9. **Scheduling** – includes both how to schedule production, resources and employees in order to be effective, efficient and meet commitments to customers.
10. **Maintenance**– This involves maintaining equipment and machinery as well as keeping quality high and processes stable.

2.5.2 Common Operations Strategies

There are many types of Operations strategies; two of the most common are quality-based strategies and time-based strategies.

Quality-based strategies are commonly used when companies wish to elevate their reputation in the marketplace. Improving on their product design and the reduction of errors are the backbone of these initiatives. Firms will often use programs such as ISO9001, Six Sigma, and Total Quality Management in their efforts.

Time-based strategies are used to reduce lead time, which is the amount of time elapsed from the receipt of the customer's order until the products are shipped. Firms that can produce faster will often have lower costs. These companies may use lean production methods to improve the velocity of their processes.

Chapter 3

Capacity Planning

3.1 Capacity

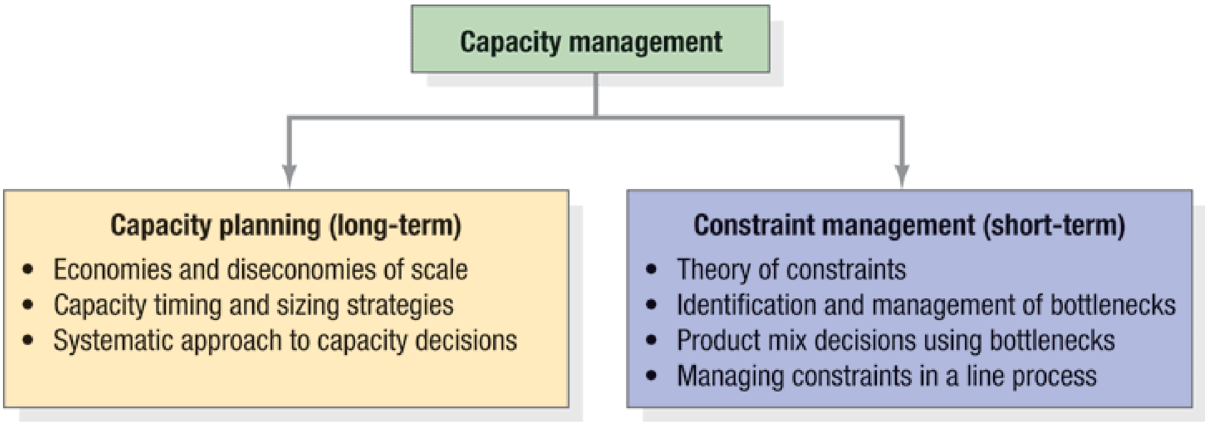
Capacity is the maximum rate of output of a process or a system. Managers are responsible for ensuring that the firm has the capacity to meet current and future demand. Otherwise, the organization will miss out on opportunities for growth and profits.

Capacity decisions related to a process need to be made in light of the role the process plays within the organization and the supply chain as a whole, because changing the capacity of a process will have an impact on other processes within the firm and across the chain. As such, capacity decisions have implications for different functional areas throughout the organization.

- Accounting needs to provide cost information needed to evaluate expansion decisions.
- Finance performs the financial analysis of the proposed capacity expansion decision investments and raises funds to support them.
- Marketing provides demand forecasts needed to indentify capacity gaps.
- Management information systems designs the electronic infrastructure that is needed to make data such as cost information, financial performance measures, demand forecasts, and work standards available to those needing it to analyze capacity options.

3.2 Capacity Management

Increasing or decreasing capacity by itself is not as important as ensuring that the entire supply chain, from order entry to delivery, is designed for effectiveness. Capacity decisions must be made in light of several long-term issues such as the firm's economies and diseconomies of scale, capacity cushions, timing and sizing strategies, and trade-offs between customer service and capacity utilization. The type of capacity decisions differs for different time horizons.



Long-term capacity plans deal with investments in new facilities and equipment at the organizational level and require top management participation and approval because they are not easily reversed. long-term capacity planning is central to the success of an organization. Too much capacity can be as agonizing as too little. When choosing a capacity strategy, managers must consider questions such as the following: How much of a cushion is needed to handle variable, or uncertain, demand? Should we expand capacity ahead of demand, or wait until demand is more certain? Even before these questions can be answered, a manager needs to be able to measure a process's capacity. So a systematic approach is needed to answer these and similar questions and to develop a capacity strategy appropriate for each situation.

3.3 Measures of Capacity & Utilization

- **Output Measures of Capacity**

Best utilized when applied to individual processes within the firm or when the firm provides a relatively small number of standardized services and products. High-volume processes, such as those in a car manufacturing plant, are a good example. In this case, capacity would be measured in terms of the number of cars produced per day.

- **Input Measures of Capacity**

Generally used for low-volume, flexible processes such as those associated with a custom furniture maker. In this case, the furniture maker might measure capacity in terms of inputs such as number of workstations or number of workers.

- **Utilization**

  is the degree to which a resource such as equipment, space, or the workforce is currently being used and is measured as the ratio of average output rate to maximum capacity (expressed as a percent). The average output rate and the capacity must be measured in the same terms—that is, time, customers, units, or dollars. The utilization rate indicates the need for adding extra capacity or

  eliminating unneeded capacity.

$$\text{Utilization} = \frac{\text{Average output rate}}{\text{Maximum capacity}} \times 100\%$$

3.4 Economies and Diseconomies of Scale

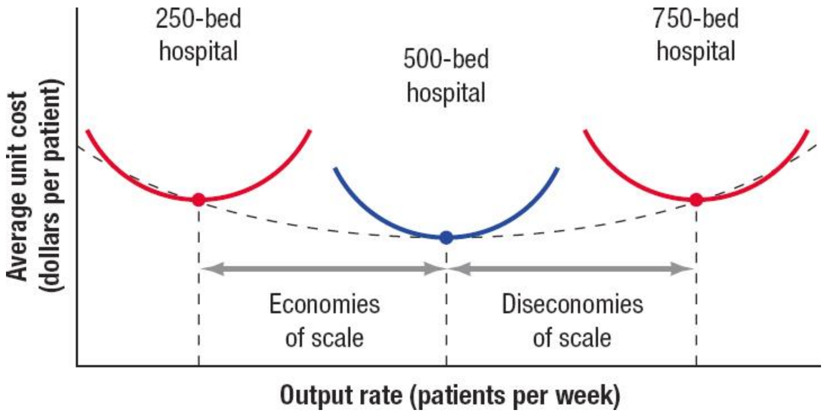
- **Economies of scale**

Deciding on the best level of capacity involves consideration for the efficiency of the operations. A concept known as economies of scale states that the average unit cost of a service or good can be reduced by increasing its output rate. Four principal reasons explain why economies of scale can drive costs down when output increases:

  - Spreading fixed costs
  - Reducing construction costs
  - Cutting costs of purchased materials
  - Finding process advantages

- **Diseconomies of scale**

  At some point, a facility can become so large that diseconomies of scale set in; that is, the average cost per unit increases as the facility's size increases. The reason is that excessive size can bring complexity, loss of focus, and inefficiencies that raise the average unit cost of a service or product. Too many layers of employees and bureaucracy can cause management to lose touch with employees and customers. A less agile organization loses the flexibility needed to respond to changing demand. Many large companies become so involved in analysis and planning that they innovate less and avoid risks.



3.5 Capacity Sizing & Timing Strategies

Average utilization rates for any resource should not get too close to 100 percent over the long term, though it may occur for some processes from time to time in the short run. If the demand keeps increasing over time, then long-term capacity must be increased as well to provide some buffer against uncertainties. When average utilization rates approach 100 percent, it is usually a signal to increase capacity or decrease order acceptance to avoid declining productivity.

3.5.1 Sizing Capacity Cushions

The capacity cushion is the amount of reserve capacity a process uses to handle sudden increases in demand or temporary losses of production capacity; it measures the amount by which the average utilization (in terms of total capacity) falls below 100 percent.

- Capacity cushion = 100 % - Average utilization rate %

And the decision about the cushion size depends on the following factors:

- Capital
- Service time

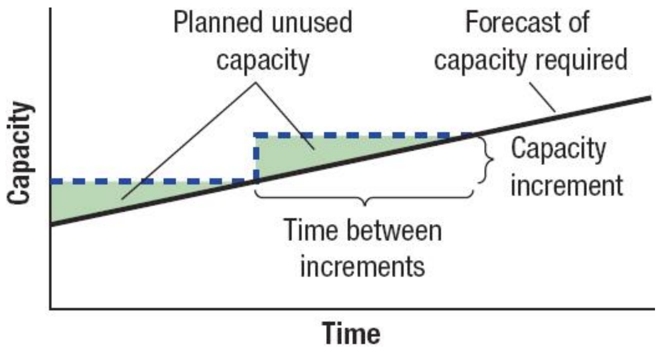
- Demand variation
- Resource flexibility / availability

3.5.2 Timing and Sizing Expansion

The second issue of capacity strategy concerns when to adjust capacity levels and by how much. At times, capacity expansion can be done in response to changing market trends. The timing and sizing of expansion are related; that is, if demand is increasing and the time between increments increases, the size of the increments must also increase.

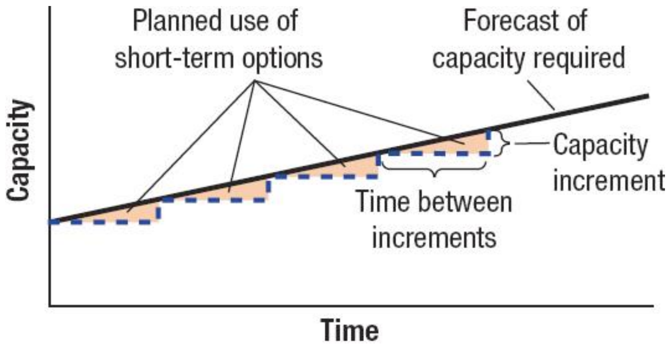
3.5.3 Expansionist strategy

The expansionist strategy, which stays ahead of demand, minimizes the chance of sales lost to insufficient capacity. Several factors favor the expansionist strategy. Expansion can result in economies of scale and a faster rate of learning, thus helping a firm reduce its costs and compete on price. This strategy might increase the firm's market share or act as a form of preemptive marketing.



3.5.4 Wait-and-see strategy

The conservative wait-and-see strategy is to expand in smaller increments, such as by renovating existing facilities rather than building new ones. The wait-and-see strategy lags behind demand. To meet any shortfalls, it relies on short-term options, such as use of overtime, temporary workers, subcontractors, stockouts, and the postponement of preventive maintenance on equipment. It reduces the risks of overexpansion based on overly optimistic demand forecasts, obsolete technology, or inaccurate assumptions regarding the competition. However, this strategy has its own risks, such as being preempted by a competitor or being unable to respond if demand is unexpectedly high.



3.6 A Systematic Approach to Long-Term Capacity Decisions

1. Step 1: Estimate capacity requirements
   a. Begin with a forecast of demand, productivity, competition, and technological change for several periods in a time horizon.
   b. Long-range forecast errors will be large.
   c. Capacity may be defined in terms of outputs or inputs.
      - Using output measures
        ⇒ Simplest way is output rate
        ⇒ Appropriate for high-volume processing
      - Using input measures
        ⇒ Brings together demand forecasts, process time estimates, and the desired capacity cushion.
2. Step 2: Identify gaps
   a. This is the difference (positive or negative) between projected capacity requirement and current capacity.
   b. Expanding the capacity of some operations may increase overall capacity.
3. Step 3: Develop alternatives
   a. Base case, is to do nothing
   b. Alternative timing and size of capacity additions/closings
      - Expansionist strategy
      - Wait-and-see strategy

- Expanding at a different location and using short-term options, such as overtime, temporary workers, subcontracting
- Reducing capacity include the closing of plants or warehouses, laying off employees, or reducing the days or hours of operation

4. Step 4: Evaluate the Alternatives

   a. Qualitative concerns

   - Fit with overall capacity strategy
   - Uncertainties in demand, competitive reaction, technological change, and cost

   b. Quantitative concerns

   - Cash flows

Estimate Capacity requirements

Capacity cushion = 100 % - Average utilization rate %

Single Product

$$\text{Capacity requirement} = \frac{\text{Processing hours required for year's demand}}{\text{Hours available from a single capacity unit (such as an employee or machine) per year, after deducting desired cushion}}$$

$$M = \frac{Dp}{N[1-(C/100)]}$$

Multiple Products

$$\text{Capacity requirement} = \frac{\text{Processing and setup hours required for year's demand, summed over all services or products}}{\text{Hours available from a single capacity unit per year, after deducting desired cushion}}$$

$$M = \frac{[Dp+(D/Q)s]_{\text{product 1}} + [Dp+(D/Q)s]_{\text{product 2}} + \ldots + [Dp+(D/Q)s]_{\text{product } n}}{N[1-(C/100)]}$$

Caselet : Aerospace Ancillary unit

Dhruv is planning to start an ancillary unit for manufacturing aerospace components. He has been in talks with a major Aircraft manufacturer. He does detailed research and understood that there is a good opportunity in the area of CNC machining for aerospace industry and also for automobile industry. He plans to install CNC machines and start an Ancillary unit with production of one variety of a critical machined component for which the annual demand is 90 numbers. The processing time for each component is 240 Hours. The machines are planned to run for 2 shifts of 8 hours with 25 working days per month. How many machines will he need to install in the unit to cater to this planned demand?

It is felt that there should be a cushion of 20% to cater to any rush orders or other exigencies. What should be the number of machines in this case? Do you think it would be better to install additional machines to have this cushion or operate the existing machines on overtime, on need basis, if an additional machine costs 25 lakhs and the overtime cost is 5000 Rs/Hour.

The Ancillary unit started the operations and the customer is happy with the supplies. Dhruv has been delivering quality components as per the promised timelines. As the customer is facing some problem with the supplies of another critical component from another supplier, he expresses his interest to place orders on Dhruv's ancillary unit for another critical component also for the next year. The projected demand for the new component is 30 numbers with a processing time of 320 Hours. The supplies for both the components are to be done in batches of 10 and the setup time for each batch is 8 hours. How many additional machines do you need to install for the next year?

If you are in the place of Dhruv, what will be your long term and short-term strategies for your Ancillary unit with respect to the operations, capacity management and expansion? You got inspiration from Dhruv and want to start a unit of your own. Prepare a Business plan to approach a VC for funding.

3.7 Managing existing capacity

Demand Management

- Vary prices
- Vary promotion
- Change lead times (e.g., backorders)
- Offer complementary products

Capacity Management

- Vary staffing
- Change equipment & processes
- Change methods
- Redesign the product for faster processing

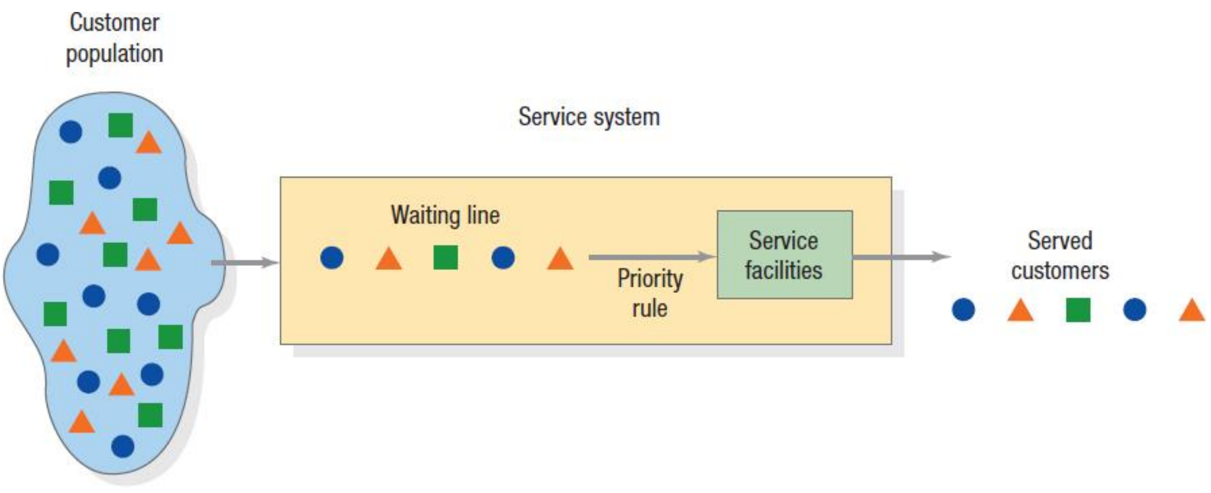
3.8 Tools for Capacity Planning

- Waiting-line models
    - Useful in high customer-contact processes
- Simulation
    - Useful when models are too complex for waiting-line analysis
- Decision trees
    - Useful when demand is uncertain and sequential decisions are involved

3.8.1 Waiting line

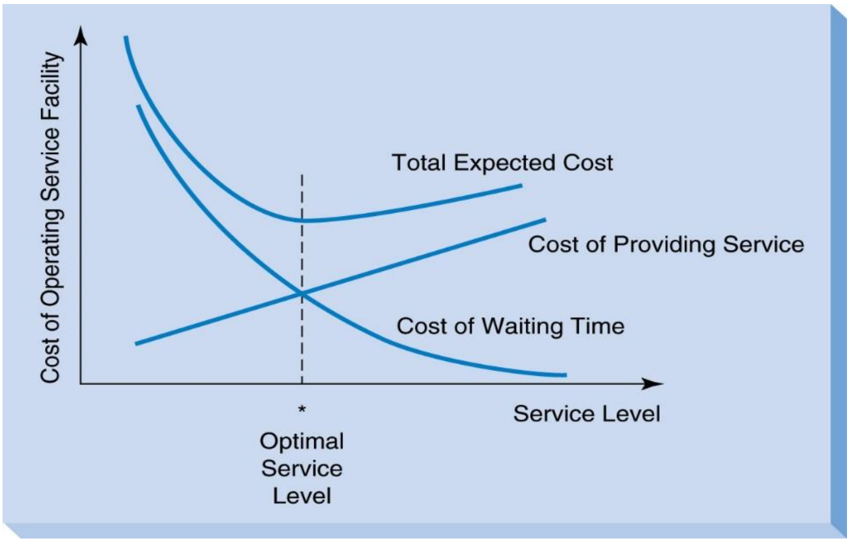
One or more “customers” waiting for service.

- Waiting Lines form due to a temporary imbalance between the demand for service and the capacity of the system to provide the service.



Queuing System Costs

- Cost of providing service
- Cost of <u>not</u> providing service (waiting time)



<u>Takt Time</u> - In Lean, Takt time is the rate at which a finished product needs to be completed in order to meet customer demand.

- For example, a factory operates 1,000 minutes per day. Customer demand is 500 units per day.

Takt time = *1,000 / 500 = 2 minutes*

<u>Cycle Time</u> - Cycle Time is the total elapsed time to move a unit of work from the beginning to the end of a physical process.

Throughput - User-measured processing speed of a machine expressed as total output in a unit period under normal operating conditions.

WIP - The amount of work that has entered the process but has not been completed.

Little's Law

A fundamental law that relates the number of customers in a waiting-line system to the arrival rate and waiting time of customers.

The work in-process inventory in a stable system is equal to the average flow rate, multiplied by the average processing time. Mathematically it can be expressed as

$$L = \lambda W$$

where

L = Work in process inventory OR Queue length

λ = Rate of –processing OR –arrival, etc.

W= Average –Processing time OR –waiting time, etc.

Apply Little's Law

	Rate	WIP	Cycle Time
Semiconductor factory	1000 wafers/day	45000 wafers	
Email messenger	50 msg/day	150 msg	
Toll booth	3600 vehicles/hour	20 vehicles	
Real estate		25 houses	120 days

Doughnut shop		10 customers	3 minutes
Logistics provider	10000 toys/day		5 days
Hospital ward	5 patients/day		90% for 2 days 10% for 7 days

Queue length and population

- Finite queue length, infinite population

  eg. A garage with space to park 10 cars

- Infinite queue length, infinite population

  eg. Doctor, railway reservation

- Finite population

  eg. Maintenance team taking care of 30 machines in a machine shop

Queueing Discipline

- First-come, first-served (FCFS)
- Last-come, first-served (LCFS)
- Service In Random Order (SIRO)
- Earliest due date (EDD)
- Shortest processing time (SPT)
- Priority Queueing (PQ)

Single server, infinite queue length

What are we interested in?

P_n = Probability that there are 'n' people in the system

L_s = Length of the system - number of customers in the system

L_q = Length of the queue - number of customers waiting in the queue

W_s = Waiting time in the system

W_q = Waiting time in the queue

$\rho = \lambda/\mu$ (utilization factor)

$P_o = 1-\rho$

$P_n = (\rho)^n * P_o$

$L_s = \rho/(1- \rho) = \lambda W_s$

$L_q = L_s - \rho = \lambda W_q$

3.8.2 Simulation

The act of reproducing the behavior of a system using a model that describes the processes of the system.

Reasons for Using Simulation

- To analyze a problem when the relationship between variables is nonlinear, or when the situation involves too many variables or constraints to handle with optimizing approaches.
- To conduct experiments without disrupting real systems.
- To obtain operating characteristic estimates in much less time (time compression).
- To sharpen managerial decision-making skills through gaming.

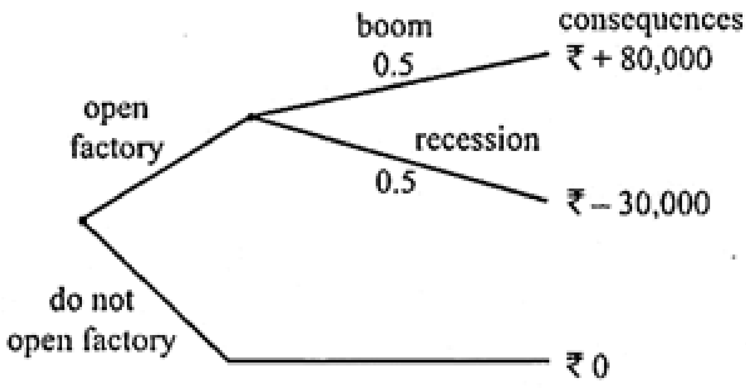
3.8.3 Decision Trees

Decision trees are useful whenever we have to evaluate interdependent decisions that must be made in sequence and when there is uncertainty about events. For that reason, they are especially useful for evaluating capacity expansion alternatives given that future demand is uncertain. Remember that our main decision is whether to purchase a large facility or a small one with the possibility of expansion later. You can see that the decision to expand later is dependent on choosing a small facility now. Which alternative ends up being best will depend on whether demand turns out to be high or low.

A decision tree is a diagram that models the alternatives being considered and the possible outcomes. Decision trees help by giving structure to a series of decisions and providing an objective way of evaluating alternatives. Decision trees contain the following information:

Decision points: These are the points in time when decisions, such as whether or not to expand, are made. They are represented by squares, called "nodes."

Decision alternatives: Buying a large facility and buying a small facility are two decision alternatives. They are represented by "branches" or arrows leaving a decision point.



3.9 Process – Product mix

Product-process mix helps us understand why and how manufacturing organizations change their production operations. With changes in products, market requirements and competition, the equipments, processes, procedures and human resources skills also will change. If process changes are not carried out to accommodate process life cycles, products and processes become incompatible, resulting in competitive disadvantage.

As the product shifts to a different stage, the manufacturing process structure also shifts and new manufacturing priorities emerge. Manufacturing flexibility and quality are the competitive priorities in start up and rapid growth stages. Priorities shift towards dependable delivery and competitive cost in the later stages, viz., maturity and decline.

3.9.1 Deciding among Processing Alternatives

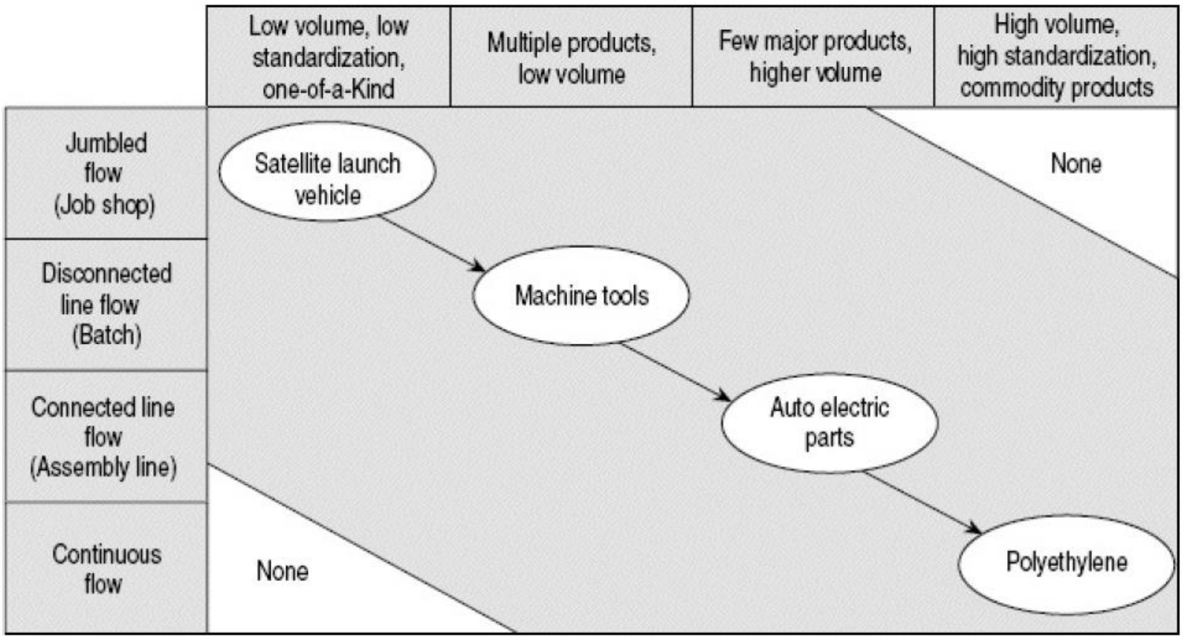
Production systems tend to evolve as products move through their products life cycles. Two principles, fundamental to the concept of process life cycles:

1. Product life cycles and process life cycles are interdependent, and each affects the other. The production processes affect production costs, quality and production volume, which in turn affects the volume of products that can be sold.

Similarly, the volume of products that are sold affects the type of production processes that can be justified.

2. Seldom do production processes move continuously along the ideal diagonal.

Business strategies are developed for each major product line, the determination of the volume of demand that is expected for each product and the number of product models necessary to appeal to the market are important factors in choosing the type of process design.



Process–product matrix talks about the relationship between process choices and flow patterns in a manufacturing system. One dimension of the matrix represents product characteristics and the other process characteristics. Product characteristics essentially indicate the degree of customization and the volume of production. On the other hand, process characteristics indicate the complexity and divergence in the process. When organizations have a high volume of production, the flow will be streamlined. Similarly, when the variety is high, the flow will be jumbled.

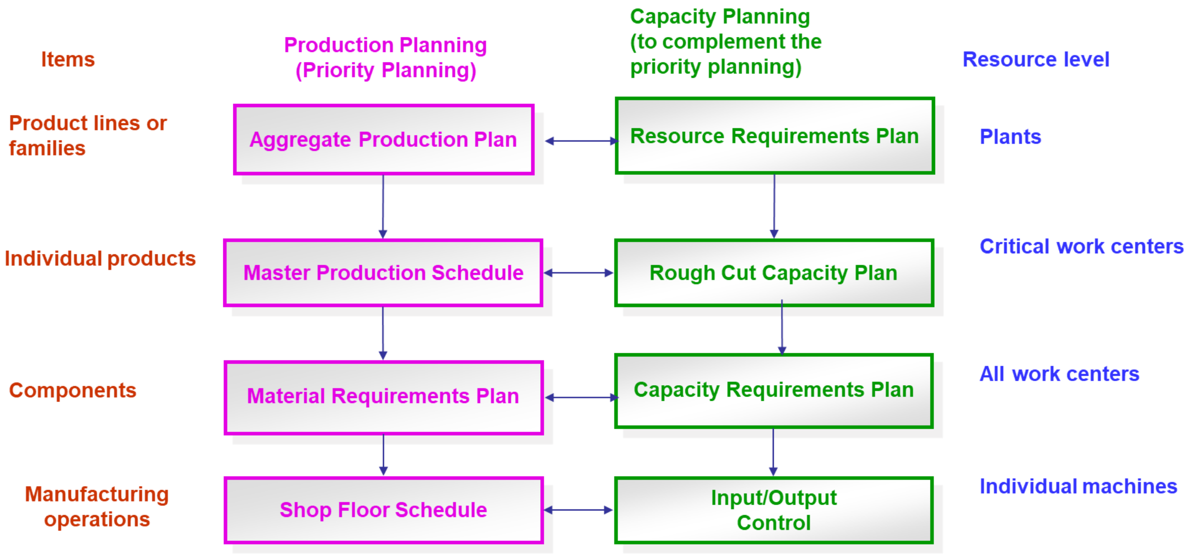
Chapter 4

Operations Planning & Scheduling

4.1 Introduction

Operations planning & scheduling is the process of **balancing supply with demand**, from the **aggregate** level down to the **short-term scheduling** level. Operations planning and scheduling lies at the core of supply chain integration, around which plans are made up and down the supply chain, from supplier deliveries to customer due dates and services. Operational planning and scheduling systems depend on the utilization of operations capacity, the volume and timing of outputs, and on balancing of outputs with capacity at desired levels for competitive effectiveness.

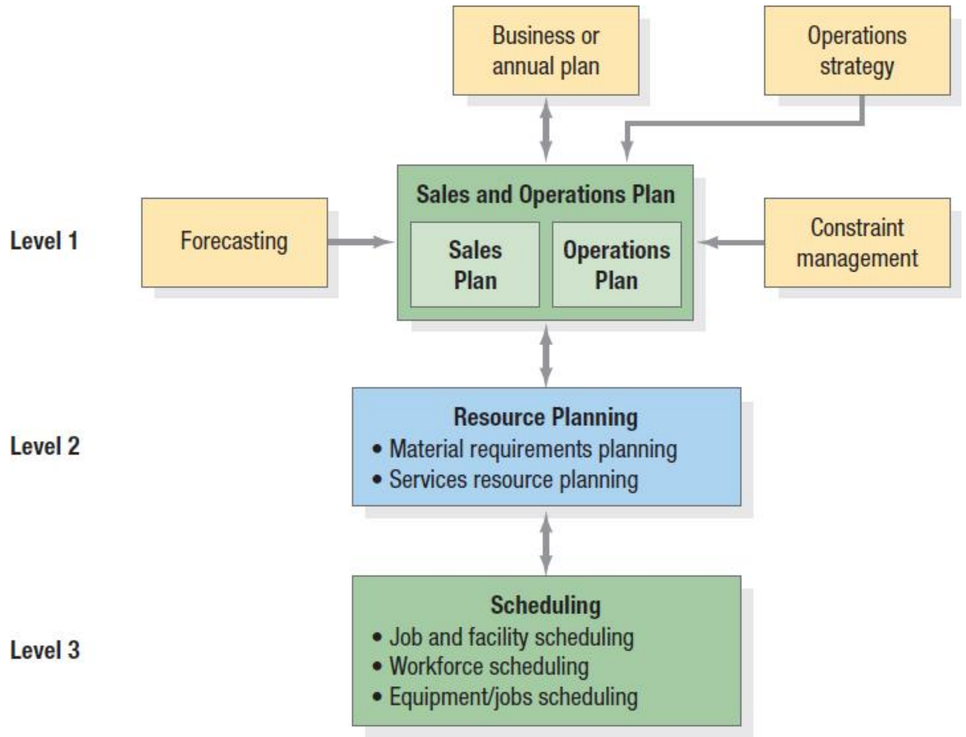
4.2 Hierarchical Planning Process



Hierarchical planning and control process reduces complexity by having each layer guide the next. The total planning and control process thus gets done in several steps in sequence.

4.3 Levels in Operations Planning and Scheduling

Managers develop plans for their operations covering varying time spans, from the long term to the short term. These plans form a hierarchy: the long-term plans form an umbrella under which short-term plans exist. Sales and operations plans exist at Level 1 and represent the long-term operations plans. These plans form the basis for major outlays for materials and resources and consequently cannot be very specific regarding products or services. Resource plans exist at Level 2 and are more detailed than the sales and operations plans and cover a shorter term. The most detailed plans are the schedules in Level 3, which cover very short time horizons and relate to specific products and resources. Level 2 plans must be consistent with Level 1 plans, and Level 3 plans must be consistent with Level 2 plans.



Level 1: Sales and Operations Planning

Aggregation of Services or products

Level 2: Resource Planning

A process that takes sales and operations plans; processes time standards, routings, and other information on how services or products are produced; and then plans the timing of capacity and material requirements.

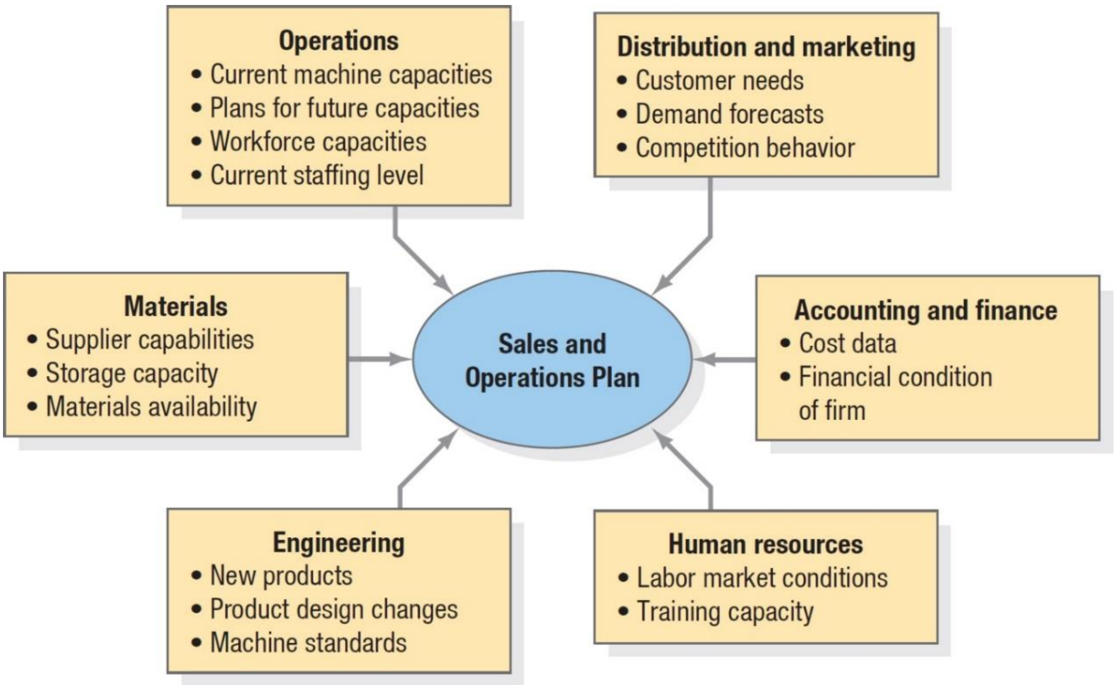
Level 3: Scheduling

A process that takes the resource plan and translates it into specific operational tasks on a detailed basis.

4.4 Aggregate / Sales & Operations Plan

- It balances demand and supply on an aggregate basis and forms the linkage between the company's overall Business Plan and the detailed plans for sales, production, and procurement.
- As such, the decision-making element of S&OP cannot be delegated to middle management.

4.4.1 Managerial Inputs from Functional Areas to S & OP



4.5 Sales & Operations Plan Strategies

- **Chase Strategy**

The chase strategy involves hiring and laying off employees to match the demand forecast over the planning horizon. Varying the workforce's regular-time capacity to equate supply to demand requires no inventory investment, overtime, or undertime. The drawbacks are the expense of continually adjusting workforce levels, the potential alienation of the workforce, and the loss of productivity and quality because of constant changes in the workforce.

- **Level Strategy**

The level strategy involves keeping the workforce constant (except possibly at the beginning of the planning horizon). It can vary its utilization to match the demand forecast via overtime, undertime (paid or unpaid), and vacation planning (i.e., paid vacations when demand is low). A constant workforce can be sized at many levels: Managers can choose to maintain a large workforce so as to minimize the planned use of overtime during peak periods (which, unfortunately, also maximizes the need for undertime during slack periods). Alternately, they can choose to maintain a smaller workforce and rely heavily on overtime during the peak periods (which places a strain on the workforce and endangers quality).

- **Mixed Strategy**
    - A strategy that considers the full range of supply options

4.6 Sales & Operations Supply options and Costs

Supply Options	Costs
• Anticipation Inventory	• Regular time
• Workforce Adjustment	• Overtime
• Workforce Utilization	• Hiring and layoff
• Part-Time Workers	• Inventory holding
• Subcontractors	• Backorder and stockout
• Vacation Schedules	

Example 1

- A large distribution center must develop a staffing plan that minimizes total costs using part-time stock pickers (using chase and level plans)
- For the level strategy, need to meet demand with the minimum use of undertime and not consider vacation scheduling
- Each part-time employee can work a maximum of 20 hours per week on regular time
- Instead of paying undertime, each worker's day is shortened during slack periods and overtime can be used during peak periods

	1	2	3	4	5	6	Total
Forecasted demand	6	12	18	15	13	14	78

Currently, 10 part-time clerks are employed. They have not been subtracted from the forecasted demand shown. Constraints and cost information are as follows:

a. The size of training facilities limits the number of new hires in any period to no more than 10.

b. No backorders are permitted; demand must be met each period.

c. Overtime cannot exceed 20 percent of the regular-time capacity in any period.

d. The following costs can be assigned:

Regular-time wage rate	
Overtime wages	150% of the regular-time rate
Hires	$1,000 per person
Layoffs	$500 per person

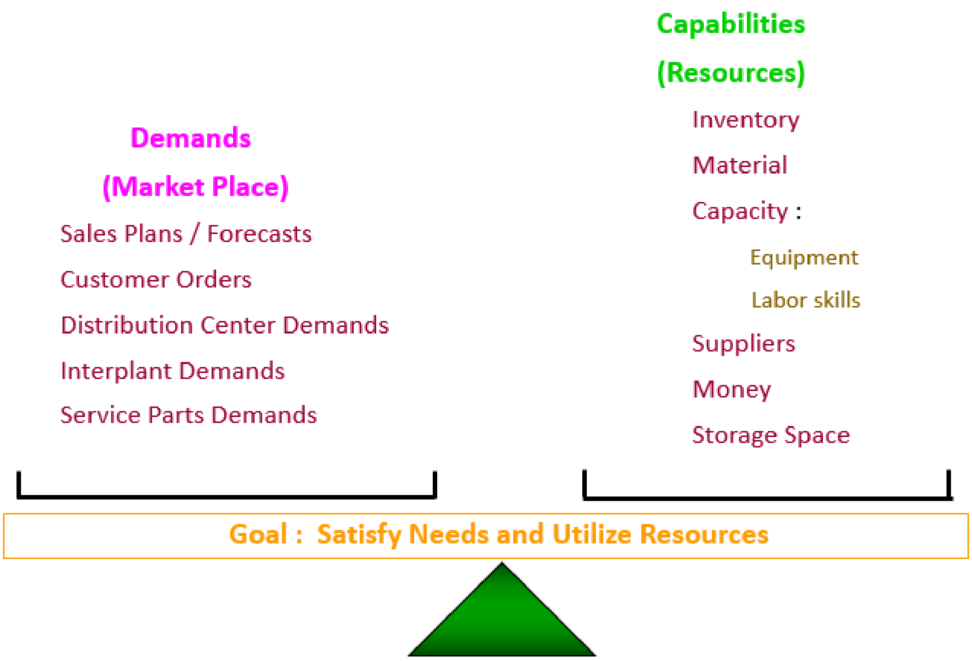
4.7 Master Production Schedule

- details how many end items will be produced within specified periods of time

- In a Master Production Schedule:

- Sums of quantities must equal sales and operations plan.
- Production quantities must be allocated efficiently over time.
- Capacity limitations and bottlenecks may determine the timing and size of M P S quantities.

4.7.1 MPS as a Balancing Process



4.7.2 Information needed to build the MPS

1. The ‘aggregate’ production plan
2. Forecasts for individual end items
3. Actual orders received from customers and for stock replenishment
4. Inventory levels for individual end items (initial inventories and pending receipts)
5. Capacity constraints

4.7.3 Time Fencing In Master Scheduling

A good master scheduling system will have some policy guidelines as to when an unplanned input can be accepted. typical guidelines might be as follows:

1. **Demand Time Fence**: A fence is established at the shortest reasonable lead time. within that lead time no major reschedules are normally accepted from marketing ('FROZEN' portion of master schedule). Do not change orders in the frozen zone

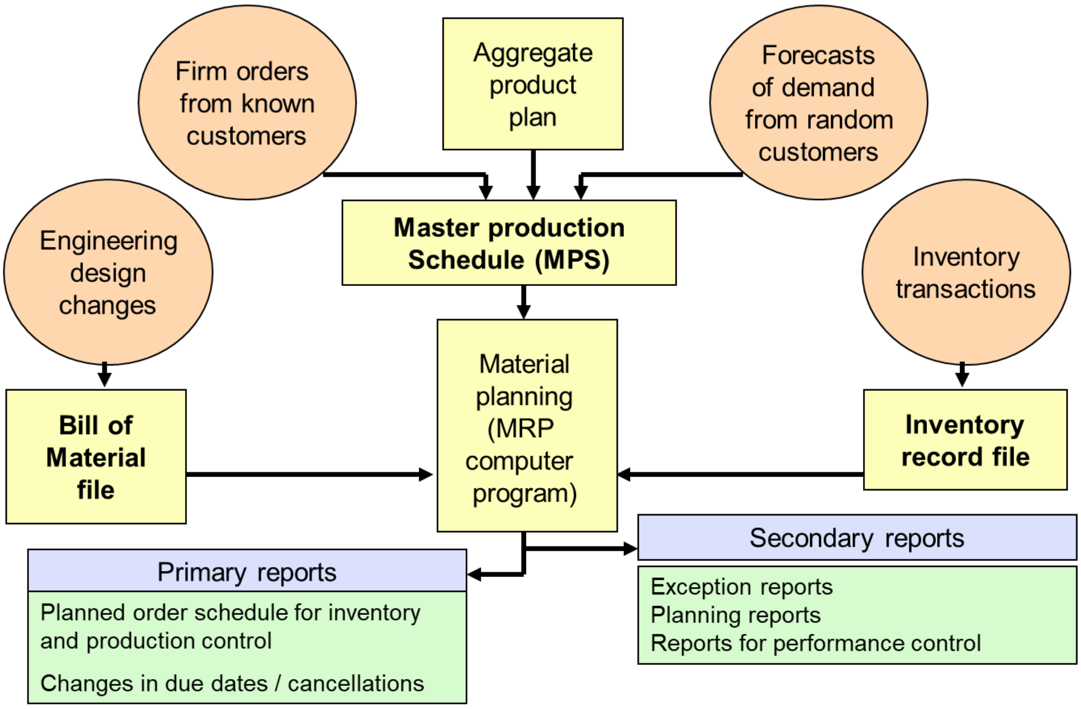
2. **Planning Time Fence:** Between the shortest reasonable lead time and the total average lead time is the period when it is usually wise to change the <u>timing</u> of items in the master schedule, but leave the <u>quantity</u> fixed. ('SLUSHY' portion of master schedule)

Beyond the total average lead time, any change to the master schedule that is not likely to have a great impact on capacity can be accepted. ('LIQUID' portion of master schedule.)

4.8 Materials requirements planning (MRP)

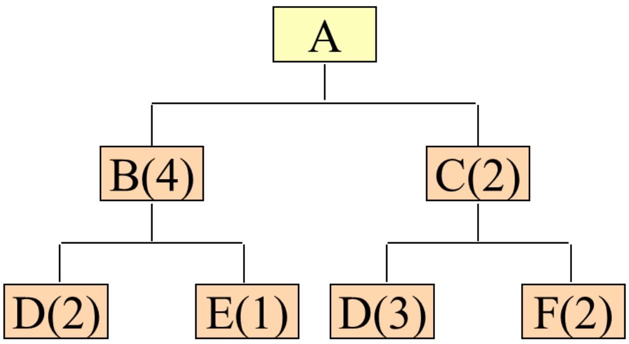
MRP is a means for determining the number of parts, components, and materials needed to produce a product MRP provides time scheduling information specifying when each of the materials, parts, and components should be ordered or produced. It determines the dates when orders for those materials should be released, based on lead times. Dependent demand drives MRP.

4.8.1 Inputs and Outputs of Material Requirements Planning



4.8.2 Example of MRP Logic and Product Structure Tree

Given the *product structure tree* for "A" and the lead time and demand information below, provide a materials requirements plan that defines the number of units of each component and when they will be needed



Lead Times	
A	1 day
B	2 days
C	1 day
D	3 days
E	4 days
F	1 day

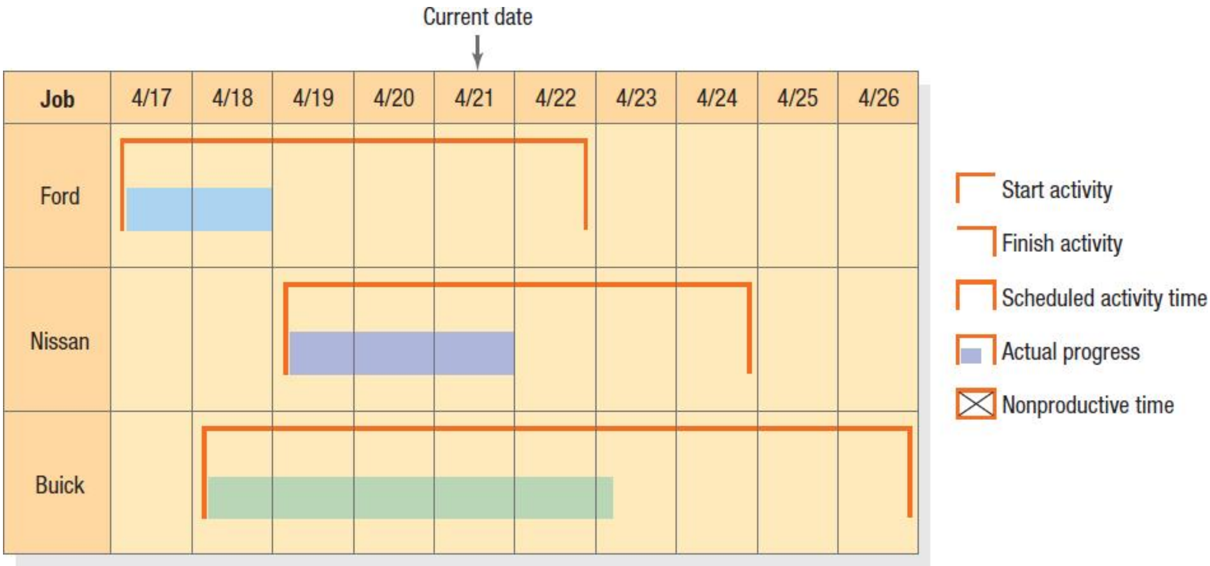
Total Unit Demand	
Day 10	50 A
Day 8	20 B (Spares)
Day 6	15 D (Spares)

4.9 Scheduling

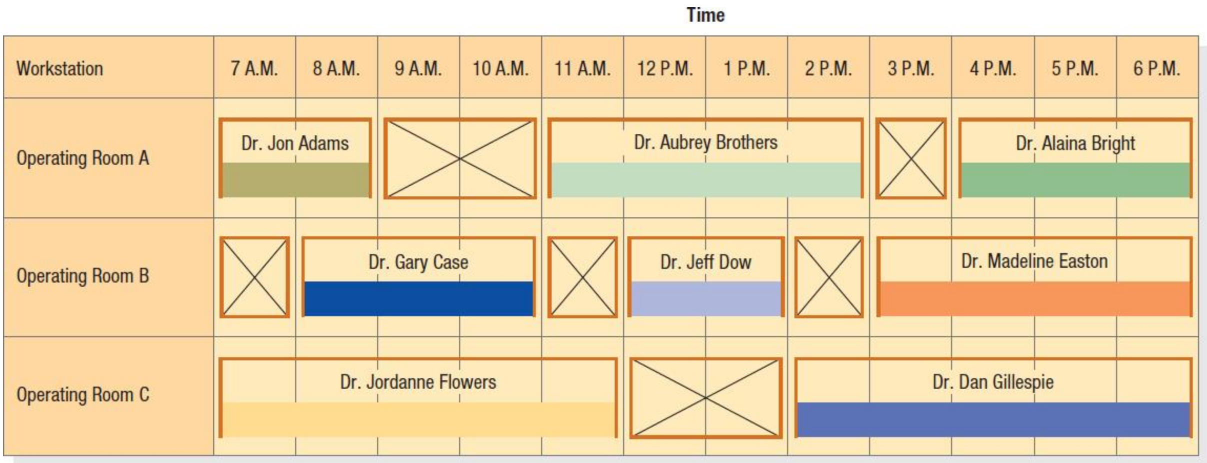
It requires gathering data from sources such as demand forecasts or specific customer orders, resource availability from the sales and operations plan, due dates for resource or material requirements from resource planning activities, and specific constraints to be reckoned with from employees and customers. It then involves generating a schedule for the supply of resources or materials to meet the needs determined in resource planning.

- **Job and Facility Scheduling**
    - Gantt progress chart
    - Gantt workstation chart
- **Gantt Progress Chart**

The Gantt progress chart graphically displays the current status of each job or activity relative to its scheduled completion date.



Gantt Workstation Chart



4.10 Sequencing of Jobs

- **Priority Sequencing Rules**
    - First-come, first-served (F C F S)
    - Earliest due date (E D D)
    - Shortest Processing Time (SPT)
- **Performance Measures**
    - Flow Time
        - Flow time = Finish time + Time since job arrived at workstation
    - Past Due (Tardiness)

Example

- Currently a consulting company has five jobs in its backlog.
- Determine the schedule by using the F C F S rule, and calculate the average days past due and flow time.
- How can the schedule be improved, if average flow time is the most critical?

Customer	Time Since Order Arrived (days ago)	Processing Time (days)	Due Date (days from now)
A	15	25	29
B	12	16	27
C	5	14	68
D	10	10	48
E	0	12	80

a. The F C F S rule states that Customer A should be the first one in the sequence, because that order arrived earliest—15 days ago. Customer E'sorder arrived today, so it is processed last. The sequence is shown in the following table, along with the days past due and flow times.

Customer Sequence	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Due	Days Ago Since Order Arrived	Flow Time (days)
A	0	+	25	=	25	29	0	15	40
B	25	+	16	=	41	27	14	12	53
D	41	+	10	=	51	48	3	10	61
C	51	+	14	=	65	68	0	5	70
E	65	+	12	=	77	80	0	0	77

$$\text{Average days past due} = \frac{0 + 14 + 3 + 0 + 0}{5} = \mathbf{3.4\ days}$$

$$\text{Average flow time} = \frac{40 + 53 + 61 + 70 + 77}{5} = \mathbf{60.2\ days}$$

Workout the Average Days past Due and Average Flow Time with Priority rules EDD and SPT.

4.11 Resource constrained Scheduling

It consists in scheduling a set of activities, with associated processing times and resources limited per time instant, and precedence relations between activities. The aim is to find the minimal scheduling that respects the precedence relations and resource limits.

The resource-constrained project scheduling problem (RCPSP) can be stated as follows:

Given are *n* activities *1, ... , n* and r renewable resources. A constant amount of *k R* units of resource *k* is available at any time. Activity *i* must be processed for *pi* time units; preemption is not allowed. During this time period a constant amount of *ri, k* units of resource *k* is occupied. The values *Rk, Pi* and *rik* are supposed to be non-negative integers. Furthermore, there are precedence relations defined between activities. The objective is to determine starting times *si* for the activities *i* = *1, ... , n* in such a way that

- at each time *t* the total resource demand is less than or equal to the resource availability for each resource type,

- the given precedence constraints are fulfilled and,

- the make span is minimized.

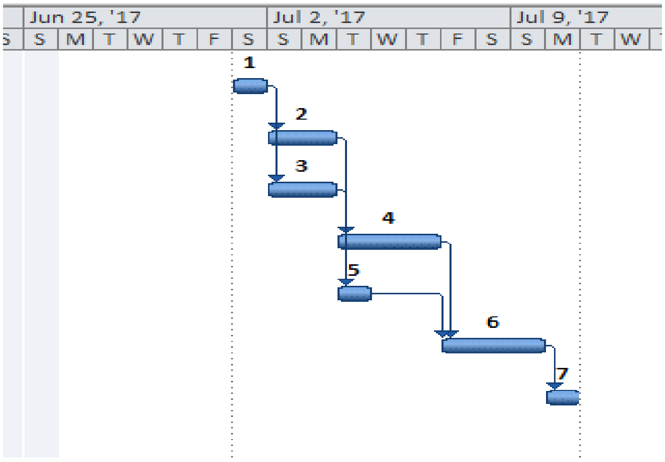
Assembly job-shop scheduling problems that optimize lead time, and tardiness are usually much more computationally complex and are classified as strongly Non deterministic Polynomial (NP) hard type. Earlier research studies in scheduling of operations in job shops processing multi-level assembly jobs have revealed that no single rule was able to perform well for all measures of performance. The dispatching rules that performed well in simple job shops are not necessarily appropriate for assembly job shops

The combinatorial search space increases exponentially with increase in resources, and thus the generation of consistently good schedule is particularly difficult. Exact methods such as the dynamic programming, branch and bound take considerable computing time provided that an optimum solution exists. In order to overcome this difficulty, it is more sensible to obtain a good solution which is near-optimal. Search techniques such as Heuristics can be used to achieve this objective i.e., to find near-optimal solutions for a wide range of combinatorial optimization problems.

To illustrate the difficulty of resource-constrained scheduling, a small project is used below. It is fortunate that these effects can be seen at this scale, because, due to the inherent complexity of the resource-constrained scheduling problem, it is difficult / impossible to visualize what is occurring for larger networks.

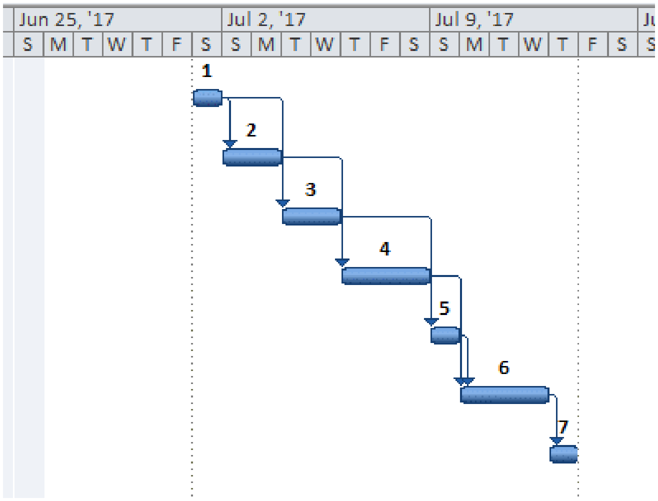
Activity	Duration (days)	Successors	No. of units of Resource required
1	1	2,3	1
2	2	4	1
3	2	5	2
4	3	6	2
5	1	6	1
6	3	7	2
7	1		2

Above table indicates the Duration, Resource requirements for each activity and the activity dependencies. By scheduling this project using MS-Project software, the following Gantt chart is obtained without putting any resource constraints (Assuming unlimited resources). As seen from the schedule obtained, without any resource constraints, the project can be completed in 10 days.



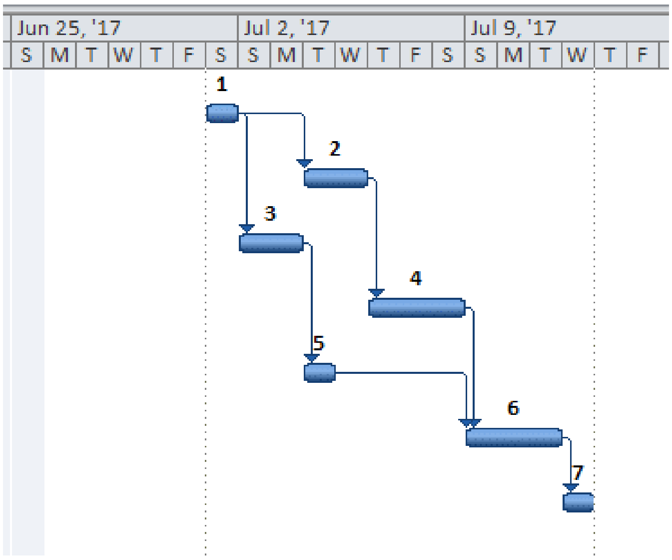
Schedule without Resource constraints

However, once the resource constraint of only 2 units of resource available per day is introduced and the project is rescheduled in MS-Project, the schedule changes as below making the project duration as 13 days.



Schedule with Resource constraints

But, tweaking the schedule generated by MS-Project by rescheduling activity 3 to start before activity 2, the total project duration becomes 12 days, with the same resource constraint.



Modified Schedule with Resource constraint

As observed above, a small change in the resource allocation has reduced the total project time from 13 to 12 days without change in the resource constraint.

This illustration should hint at the level of complexity that occurs as many more different types of resource constraints are introduced. For example, in many domains, such as aircraft assembly there can be multiple resources per task. In many cases physical space becomes a limited resource, i.e., only so many workers will fit in a given area, and some actions may permanently eliminate possible workspace, thus physical space becomes an important resource that needs to be managed.

Many works have been published including the main research on RCPSP and great advances have been made in the solving procedures which take into account two different approaches: optimal and heuristic. The optimal approach includes methods such as dynamic programming and implicit enumeration with branch and bound. Nevertheless, the NP-hard nature of the problem makes it difficult to solve realistic sized projects, in such a way that, in practice, the use of heuristics is necessary. Therefore, besides exact algorithms many authors have developed Heuristics for the RCPSP as the only feasible method of handling practical resource constrained project scheduling problems.

4.12 Dynamic Scheduling

Dynamic scheduling is proactive, with the schedule being adjusted to maximize production. A dynamic scheduling system should adjust production to minimize resource (machine breakdown, tool failures, QC issues) or job-related (rush jobs, cancellations, or ECO's) issues and ensure optimal use of shop floor resources. A variety of approaches have been developed to solve the problem of dynamic scheduling. Dynamic scheduling could be classified into four categories, completely reactive scheduling, predictive-reactive scheduling, robust predictive-reactive scheduling, and robust pro-active scheduling. It is better to combine together different techniques such as operational research and artificial intelligence to overcome dynamic scheduling problems.

<u>Some of the approaches that can be used for Dynamic Scheduling are</u>: Heuristics - Knowledge based- Multi-Agent systems (e.g., AARIA)

<u>Capabilities:</u> Decentralization – Integration – Robustness -Flexibility

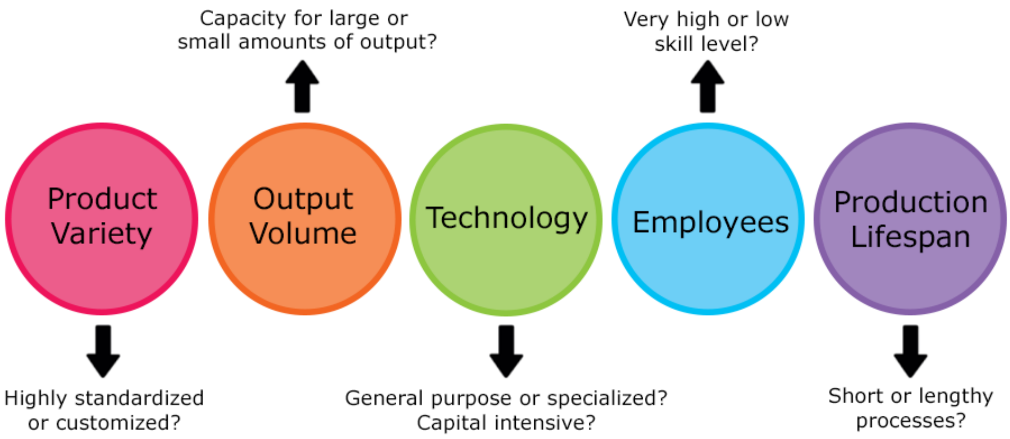
Chapter 5

Designing Manufacturing Processes

5.1 Introduction

Every firm that produces a good or a service will do so by the use of a process. This process will use the firm's resources in order to transform the primary inputs into some type of output. In designing the actual process, particularly the number and sequence of steps, several important factors need to be considered.

1. Product variety – Is the product highly standardized, or is the product highly customized?
2. Volume of output – Is the business created to produce large volumes or a small amount of output?
3. Is the technology to be used general purpose or specialized? Is it capital intensive?
4. The skill level of employees, it is very high or low?
5. What is the expected duration?



Three generic planning premises are in use in operations management: make to stock, make to order, and assemble to order.

5.2 Generic Planning Premises

5.2.1 Make to Order (MTO)

In a **make-to-order** business, the customer's order is not manufactured until the order is received. This allows customization to the exact specifications that the customer requires. It may also be referred to as build-to-order. This type of production is considered a pull type system. The work is "pulled" through the process when customer demand is present.

The disadvantage of this type of system is that it takes time for the firm to acquire any materials and needed components, and then to schedule and produce the customers order. Goods are made in small amounts, and may be more expensive.

The advantage of this type of process is that inventory is lower than in a typical make-to-stock system. There is not any uncertainty about what the customer desires and there is no obsolete stock to be disposed of. Dell Computer has utilized this type of system to produce personal computers very successfully.

5.2.2 Make to Stock (MTS)

In a **make-to-stock** process, goods are produced in anticipation of customer demand, usually from a sales forecast. These products are generally made in larger amounts and put into storage to wait for customer orders. Although the unit cost may be lower due to large production volumes, there may be losses due to forecast error, excess inventory, obsolescence and theft. Lead times however are short because goods are available when the customer places the order. These goods are not customized, but standardized.

5.2.3 Assemble to Order (ATO)

When variety is not very high, as in the case of a jumbled flow process, it is possible to work with a planning methodology that is intermediate to MTS and MTO. This approach to planning is known as assemble to order (ATO). The ATO planning framework incorporates some of the features of MTS into the MTO planning methodology to create a hybrid version. In this approach, the system utilizes MTS for the early stages of the manufacturing process. At the later and final stages of the manufacturing system, the planning changes to that of MTO. The basic assumption behind ATO is that while at the component and sub-assembly level there is a high degree of commonality, related variety problems manifest only at the final assembly stage. Therefore, MTO can be postponed up to the point of product differentiation.

5.3 Process Types

5.3.1 Project

A one-time event, such as construction of an apartment building, implementation of a new ERP system, or writing a book, would all be considered a project type of process. Each of these projects have a high degree of customization, substantial use of resources, and a complex set of related activities. There is only a single output at the end of the project.

5.3.2 Job Shop

Many businesses have a job shop type of process. This is most commonly used when the product being produced is unique for each customer. It is a make-to-order type of business where production is intermittent (i.e. rather than one entire product being completed at a time, work will continue on multiple products as time permits). Often the product has unique characteristics for each customer. The workers in this type of business are very highly skilled in their craft or trade. Often they are referred to as craftsmen or makers. The volume of output is low in a job shop. The equipment used is quite general purpose. Examples include a small bakery that produces beautiful custom wedding cakes, or a business that makes custom guitars or bicycles based on the customers measurements and preferences of materials and components.

5.3.3 Batch

Some businesses are in the situation where they make groups of identical products on a regular basis. These groups are referred to as a batch. The batch will progress through a set of steps to be completed from the start to the end. An organization may have multiple batches at different stages coming through the process. This type of processing is also intermittent. (start, stop, start) There is less variety in this type of business (compared to a job shop) and the equipment used will be relatively general purpose and suited to the industry that they are in. Employees need to be skilled and experienced at operating that equipment and producing these products. Examples of products made using batch production are baked goods, aircraft parts, clothing, and vaccines. An important decision by these firms is how big the batch should be.

5.3.4 Repetitive

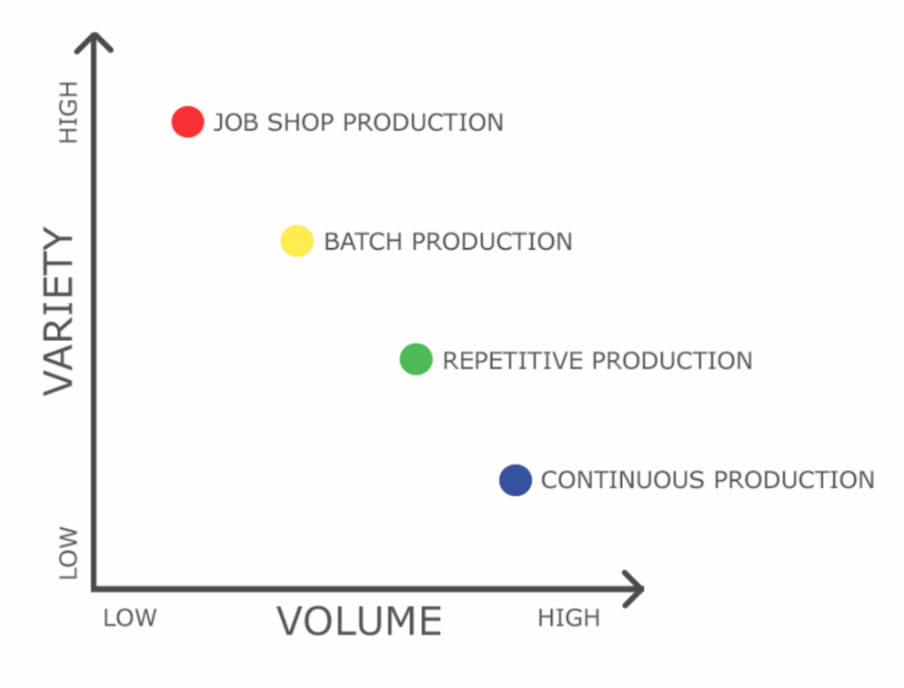
This type of business produces products that are more standardized in nature. Usually the output is high. Since the goods are quite standardized, the equipment used tends to be quite specialized and often highly customized for that process. The skill level of the employees is usually low because the steps are highly standardized. Although these types of jobs may not require a trade or extensive experience, they often do require skills such as multi-tasking, concentration, problem solving, and teamwork. Often, these processes use flexible automation that allows for customization such as the addition of upgraded features. Examples of a repetitive process include assembly lines such as assembling automobiles or electronics, a carwash, or a cafeteria line.

5.3.5 Continuous

A continuous process is when a very high volume of standardized product is produced. The type of product being made is described as non-discrete. This means that these businesses do not produce individual products, rather a product that is often a liquid or a product such as sugar, gasoline, or steel. An example of this type of process is an oil refinery. There are not separate individual workstations, rather the product flows from one step to the next within the system. The equipment in this type of process is highly complex and designed solely for that product at that facility. There are very few workers except for those that are responsible for process monitoring, maintenance, and cleaning.

5.3.6 Hybrids

There are many firms using mixtures of process types. One such common exception is the **Mass Customization** model of production. In mass customization, a company combines low-cost high volume of output, but each and every customer order is customized to the customers specifications. Usually the use of computer-aided manufacturing systems is what permits this customization. Examples include furniture makers who wait to produce the exact model of sofa based on the customers dimensions and fabric choice, or the vehicle manufacturer that has dozens of customization packages and paint options such that each vehicle is custom for the purchaser. A key requirement for successful mass customization is a modular design to allow fast seamless change from each product to the next.



5.4 Facility Layout

Layout refers to the way in which organizations position their equipment, departments, or work centres. Having an effective layout can streamline production activities, eliminate wasted or redundant movement and improve safety. The general types of layouts are: a fixed position layout, a process layout (functional), a product (line) layout, and a cellular layout, which is considered a hybrid. Other common layouts include office layouts, retail layouts, and warehouse layout.

5.4.1 Fixed Position Layout

When producing a product that is not easily able to be moved, it may require that the worker, their tools and equipment are brought to the site where the production is taking place. This is a common layout in manufacturing a building, a ship or performing repairs to major equipment.

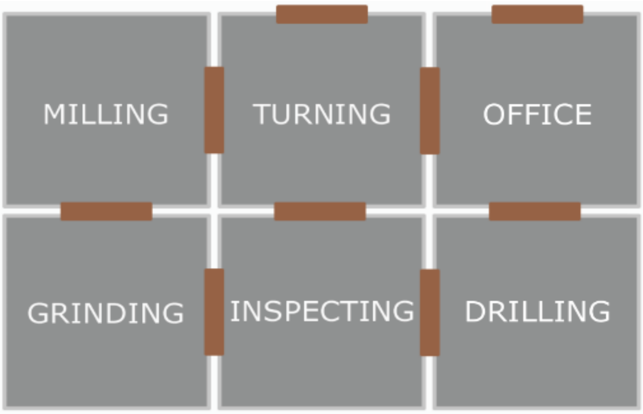
5.4.2 Process Layout

A process layout is a layout in which departments, equipment, or workcentres are arranged according to their function. In a manufacturing environment, all of the milling machines may be in one area or “department,” the lathes may be in another area, and the drilling machines all in another area. This layout is also common in services. In a department store, similar goods are arranged together such as footwear, jewelry, and housewares. At a hospital, cardiology is in one area, maternity in another location, and pediatrics elsewhere. The specific dedicated equipment and skilled practitioners work in each of these areas.

An advantage to a process layout is that equipment tends to be quite general-purpose. If one particular piece of equipment breaks down, it will not halt the entire process. This type of process gives flexibility to handle a variety of products or customers. It is ideal for job shops or small batch manufacturing.

A disadvantage of a process layout is that a particular product will likely have to travel from department to department to get the set of processes completed. This often leads to lots of material handling and movement of goods throughout the facility. A flexible material-handling system is needed such as forklifts. Inventory will sit in each area waiting for its turn to be processed. This waiting inventory is referred to as **queue.** When examining the total throughput time of jobs through the system, it is often discovered that each order spends much more time waiting in queue than it does actually being processed. For that reason, this type of layout is generally very inefficient. A major consideration in a process layout is to ensure that departments with a large amount of interaction are located nearby one another.

Below is an example of a machinery plant with a process layout:



5.4.3 Product (Line) Layout

These are used in businesses that use assembly lines or production lines. If the product has high volume an assembly line might be the best option. The equipment in these types of layouts are often very capital intensive and are laid out according to the progressive steps of the process. Each work station is located along the line and may consist of a worker with equipment, or robots. Often each work station is adding components (assembly line) or modifying a product (production line). It is important to note that it is not necessarily a straight line, often assembly lines zig zag or are in a shape to use the maximum amount of space available. Some services may use a line layout, such as preparing hospital meals, or a cafeteria line. Due to considerable cost involved with setting up an assembly line, a large volume of product needs to be produced. Demand that is steady and consistent is ideal.

The goods produced in a line layout are generally very standardized, and the work processes are also highly standardized. Each product follows the same set of steps so that a fixed path material handling system is used such as a conveyor belt. This conveyor belt may be manual or automatic. It may operate at a pre determined speed, or it may be worker paced. It may run continuously or pulsed. The speed of the conveyor will determine the amount of product that will be produced per shift.

In contrast to a process layout a product layout is very efficient**.** There are a number of reasons for this.

1. Because of the division of labour and the repetition, there is less variability in the work performed
2. There is no build up of inventory, and no waiting. When completed at one work station, the job automatically moves to the next workstation. Only the inventory that is in process is in the system. Goods tend to be shipped when they are completed.
3. Due to the material handling system, goods move quickly and not very far.
4. Changeovers are not necessary so very little time is lost in changing between products.

It is important that assembly lines are balanced**.** The amount of time required at a preceding work station should be relatively similar to the amount of time required at the following work station.

Challenges in a product (line) layout include:

1. The fact that the line may be susceptible to shut downs if there are equipment malfunctions so preventative maintenance is critical. Preventative maintenance involves the inspection and replacement of any parts that have a high probability of failures, as well as holding ample spare parts in stock and having a detailed maintenance schedule for each piece of equipment.
2. Training and job rotation are critical activities to make sure employees are capable of completing the work tasks and that there are multiple people that can work at each individual job
3. With repetitive standardized jobs, it is critical that good ergonomic job design is performed. Organizations that ensure the health, safety and comfort of their employees reap rewards in terms of the quality of work they receive from employees.

Here is a fun video; see Rick Mercer on the Assembly line in GM Oshawa:

5.4.4 Cellular Layout

Cellular layouts are considered a “hybrid” type of layout because it includes characteristics of both a Process layout and a product (line) layout. It is very common that a business may have multiple product lines, with far too much variety in order to take advantage of one assembly line. Often these businesses may have been using a process layout, with all of the associated product movement and waiting times. An alternative that became popular beginning in the late 1980s is the Cellular layout type. This type of production layout is still heavily utilized today.

This type of layout begins with the company performing a thorough analysis of their products and deciding which products are similar to one another and often share common geometry and processing requirements in terms of equipment, machinery, technology and employee skills. These products are grouped together and manufactured in a work cell. This is referred to as group technology.

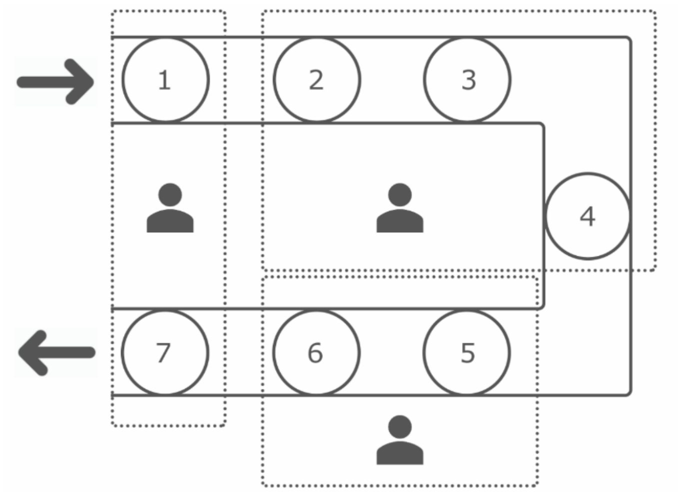
Each work cell will contain a unique set of equipment to manufacture this family of parts in an assembly line type of layout. The equipment is laid out in a U shape with equipment located close together so jobs do not have to move very far.

Advantages of a cellular layout include:

1. Reduced set up times for each piece of equipment because each machine is making products that are very similar, often set-ups are very fast or non-existent.
2. Speed is greatly enhanced because batches can now be small and goods that enter the system will continue until they are complete. Small batches means fast run times and short wait times.
3. Inventory investment is now reduced due to small batch sizes enabled because of the low set up times required.

4. Quality is enhanced because employees work only within that cell on a narrow range of products. Cross training of employees ensures good and thorough knowledge of the entire production process.
5. Employee morale is improved due to working as part of a team that has responsibility for the throughput and quality of the cell. The U-shaped design heightens collaboration among workers.
6. Less floor space is required due to machines being placed close together and less movement of product.

An example of a U-shaped layout can be found below:



5.5 Basics for Analyzing Processes

Takt Time - In Lean, Takt time is the rate at which a finished product needs to be completed in order to meet customer demand.

- For example, a factory operates 1,000 minutes per day. Customer demand is 500 units per day.
  Takt time = *1,000 / 500 = 2 minutes*

Cycle Time - Cycle Time is the total elapsed time to move a unit of work from the beginning to the end of a physical process.

Throughput - User-measured processing speed of a machine expressed as total output in a unit period under normal operating conditions.

WIP - The amount of work that has entered the process but has not been completed.

Process mapping, is a tool to understand the various steps involved in performing a business process. The basic premise behind process mapping is that in every organization there are several business processes and these processes consume resources and time, finally driving the cost. Therefore, improvements in cost, lead time and resource utilization essentially boil down to understanding how processes are performed and identifying unnecessary steps in the process for possible elimination.

Process mapping is the starting point for any improvement effort in an organization as it equips the improvement team with a wealth of data. While it details how the process is currently performed, it does not indicate whether the various steps are required. Therefore, the next step in the process is to categorize the various activities into alternative heads and analyse their relevance.

Value-added (VA) Activities

An activity is classified as value-added as long as the customer is willing to pay for that activity. In a manufacturing system, carrying inventory is not value-added as it does not concern the customer if the organization carries inventory or not. On the other hand, activities pertaining to the core manufacturing process are considered as value-added. Similarly, having an inspection department check the incoming or outgoing quality level is a non-value-added activity from a customer's perspective.

Non-value-added (NVA) Activities

All those activities for which the customer may not want to pay are classified as non-value-added activities. These include having a poor plant layout resulting in large distances to be travelled by the production items; increasing the WIP inventory; having an army of progress chasers, production planning, and control personnel; having a large number of indirect labourers; expensive follow up of suppliers; frequent breakdowns of machines; defects; and rework. All these activities invariably add cost and time to the products and services offered, but no value. Having poorly designed processes requiring excessive approvals, Clarification and multiple visits to several sections of the service delivery system will eventually lead to delays, excessive waiting times and poor resource productivity. These are typical examples of non-value added activities in service systems.

Essential but Non-value-added (NNVA) Activities

Defining non-value-added and value-added activities is a difficult task in reality. Several activities are non-value-added but appear to be value-adding on account of the quality of management practices in an organization. For example, inspection of quality is a non-value added process in a strictly theoretical sense. However, if an organization does not have a robust quality assurance system, it is highly risky to eliminate the inspection activity. Therefore, in several such cases, it is better to classify them as necessary but not value-adding. The motivation for making an NNVA classification is that it highlights a set of activities that are to be eventually eliminated as and when better systems are developed in an organization.

Chapter 6

Supply Chain Concepts

6.1 Introduction

Supply Chain refers to the group of organizations that are linked together by their participation in order to fulfill a customer order from the sourcing of raw materials through the production of goods to distribution and sale. Each organization has a role to play in adding value for the final customer. The organizations that participate in a supply chain include suppliers, manufacturers, transporters (also known as carriers), distribution centres, wholesalers, retailers and end-consumers.

Every link in this chain of supply is very important. As they say, "a chain is only as strong as its weakest link." This has implications for the supply chain management in a sense that it is not enough for the companies just to focus on their own internal operations. They need to regularly check with their supply chain members to make sure that everybody is performing at their best. One weak member in any supply chain will impact everybody else.

For example, if a retail store is not doing a good job at replenishing their inventory on time, the product will not be available to some end-consumers when needed, and as a result, lost sales happen and that supply chain will be affected financially. Let's think about it for a second: fewer products had got ordered from the manufacturer, and thus, fewer raw materials were ordered (by the manufacturer) from higher tiered suppliers. This way, everybody in the supply chain sold less than what they could if the retailer had ordered the right quantity at the right time.

6.2 Managing Main Flows in the Supply Chain

There are three types of main flows that happen in any supply chains: flow of materials/goods, flow of money/cash, and flow of information. There is a forward flow of materials/goods for the regular flow that happens all the way from higher tier suppliers (upstream) to the end-consumer (downstream). In addition, if there is any returns for any reason, there will be a reverse flow of materials/goods in the opposite direction to the forward flow.

Flow of money (cash flow) happens from downstream to upstream. For example, the retailer needs to pay the distributor for the goods they have received from them.

Flow of information happens both ways in the supply chain since organizations will need to share different type of information with each other so that the whole supply chain can make better decisions to improve overall performance.

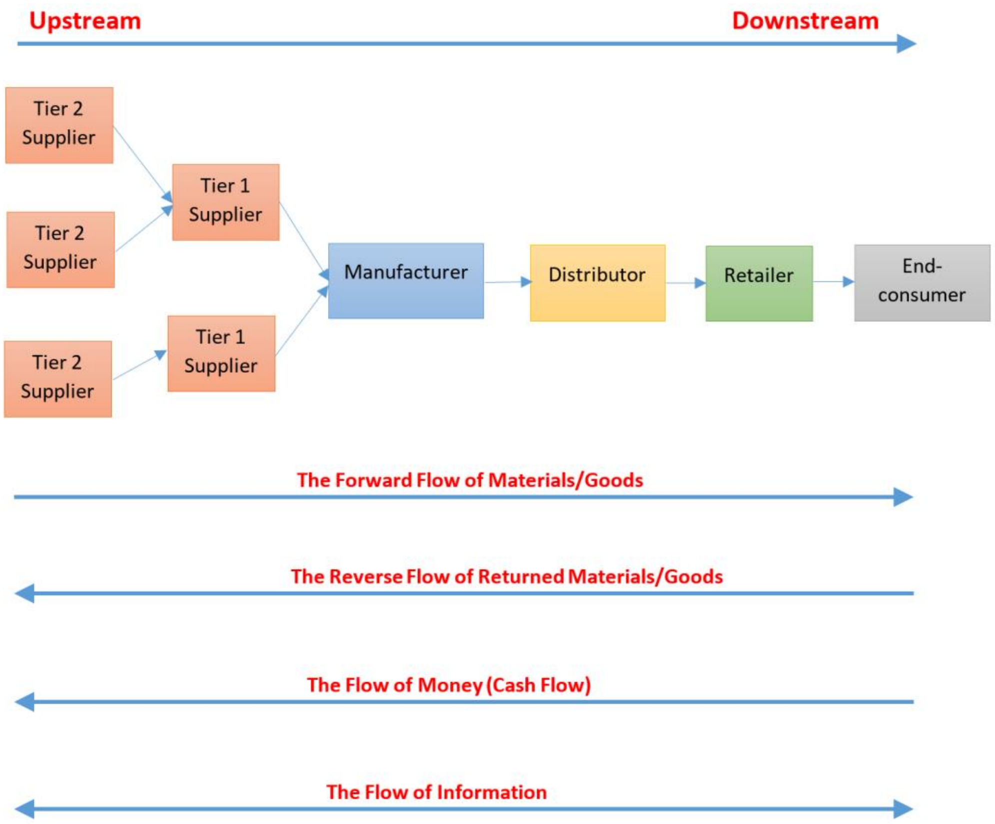


Figure : Upstream and downstream of a supply chain and its flows.

6.3 Foundational Elements of Supply Chain Management

Each organization in a supply chain needs to manage four key elements. These include supply management, managing the internal operations, distribution management, and managing the integration of all of these so that all parts of the supply chain are working with each other in harmony. The following sections will cover some of the things that are done in relation to each one of these elements. Figure depicts the foundational elements.

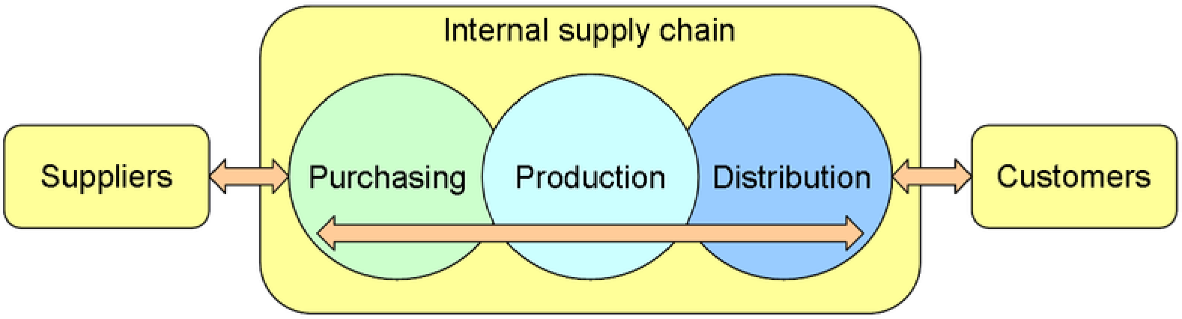


Figure: Example of a company's supply chain

Supply Management includes purchasing and managing the suppliers and the relationships with them. **Internal Operations** is consisted of managing whatever the company does to add value. For example, a manufacturer does "Production", along with managing inventory of raw materials and finished goods, human resources, etc. **Distribution Management** deals with managing the customers and the relationships with them. In order to do this, the organization needs to have a deep understanding of its customers and their needs to be able to deliver the right product/service to the right customer at the right time. **Integration Management** uses several technologies such as ERP systems to make the collaboration among the different elements easier and more accurate.

6.4 Supply Chain Design

Supply Chain Design is a strategic decision which determines who needs to take on what role or responsibility in the supply chain and where they should be located. Different companies choose different design or structure for their supply chains. For example, Walmart has always used traditional brick and mortar stores to serve its customers, while Amazon has been using an online platform to get customers' orders and then, ship them directly from their distribution centres.

When designing a supply chain, two main things to consider are Efficiency (cost reductions) and Responsiveness. The balance between these two could be different for different companies. That is, depending on the customers' preferences, the company decides to have a certain structure for their supply chain. For example, if the customers for a particular company are willing to wait for 5-7 days to get their ordered products online, the company can store its inventory in fewer locations and use the longer time of transportation to serve its customers. However, if the customers want to have their products right away, the company may need to open quite a few stores and keep enough inventory in each one to be able to respond faster to its customers' needs.

A company may decide to use other companies for parts of their supply chain or to have their own entities. This includes Vertical and/or Horizontal integration. Vertical integration is a term that is used when a firm owns more than one portion of its supply chain. For example, for a manufacturer company, they may have their own distributors or even retail stores to sell their products to the end-consumers (forward integration) or they may choose to own one or more of the suppliers that provide the company with certain materials or components (backwards integration).

Horizontal Integration is a situation where a business chooses to increase their holdings by acquiring or merging with another firm in the same market. An example of this was the 2015 merger of Kraft foods and Heinz, or Marriott International's purchase of Starwood hotels in 2016.

6.5 The Role of Inventory in the Supply Chain

Managing inventory is one of the most important activities in a supply chain. Materials/goods are needed to provide manufacturers with the exact items that they need, in the right order, the right quality, delivered to the right location, and at the right time. Without all of this happening, it will be impossible to produce high quality goods and meet commitments to our customers. In addition, when goods are ready for shipment, the outbound supply chain needs to be organized in such a way that customers receive their requested orders in a cost-efficient manner.

Types of Inventory in the Supply Chain:

- Finished goods
- Raw materials
- Purchased components and operating supplies
- Work-in-process

Reasons for holding inventories:

Many reasons exist for keeping stocks of inventory. Some of the most common include:

- Manufacturers often build up inventories throughout the year because of seasonal demand.
  - An example is a Chocolate manufacturer who does not have the capacity to produce all the product that is needed for Christmas. They may begin building inventory in late spring in order to have enough on hand for orders in November and December.
- At the same time, a manufacturer may carry large amounts of inventory if they have some uncertainty or risk in their supply base**.** If suppliers have some risk of shortages, work stoppages, poor quality or late deliveries then more stock may be carried.
- Firms may be tempted by extra discounts often provided by purchasing large order sizes. Perhaps they may want to minimize transportation costs. There may also be some worry about future price increases that can cause organizations to build up their inventories.
- Retailers carry inventory to ensure that they do not run out of what they anticipate their customers may want. Distributors and retailers may try and balance the cost of keeping large inventories on hand with providing excellent customer service with few or no disappointed customers. However, it is often a challenge to anticipate exact customer behaviour.
- It is a challenge to synchronize incoming flow of materials and goods in order to meet production schedules and ship to customers as promised. As a result,

inventory may be stored at many locations along the supply chain. This causes extra cost and inefficiencies for each organization.

6.6 Logistics

Logistics refers to the activities of coordinating and moving resources, particularly inputs into the transformation process, and finished goods out to customers. Originally, the term logistics was from the military and referred to moving troops, equipment and supplies. Managing logistics involves making decisions such as the following:

- Choosing to operate and manage the firm's own transportation, or whether to outsource this activity
- Selecting suppliers that have the capability to ship goods safely and securely within the required time frame
- Choosing the correct mode of transportation and the most effective route
- Negotiating the shipping rate

6.7 Modes of Transportation

There are several modes of transportation available to companies. We discuss them in the following:

6. 7.1 Trucking

The majority of goods are shipped by truck completely or at some point during the shipping. Trucking is the most flexible of all modes of transportation. Trucking is categorized by "truck-load" (TL) when the entire truck is hired and delivered directly, or "less-than-truckload" (LTL) which generally includes using several orders to increase the utilization of the truck. A serious issue facing Canada at this time is the expected shortage of qualified drivers. Demand for drivers continues to increase every year, and the average age of drivers is increasing. The trucking industry will face challenges to make driving more attractive to entice new workers into trucking jobs.[3]

6.7.2 Railroads

Rail can be a very cost effective means of transporting goods that need to travel long distances. Goods in containers, or products that are bulky and heavy are ideal for train transport. Canadian rail ships products including cars, fertilizer, food and beverages, forest products, grain, metals and minerals and petroleum products. Often, large manufacturers locate themselves near rail lines to make for easy shipment of raw material into, and finished goods out of their facilities. Compared to trucking, shipping by rail is very energy efficient, and removes many trucks from congested highways. Canada has a very old and well-established rail system.[4]

6.7.3 Airfreight

For goods that are expensive, small and light, air shipping may be a good choice. Air carriers charge by a combination of the weight and size of the shipment. This mode of transport is generally used when speed is more important than cost. Shipping by air is very reliable. Firms may want to consider the environmental impact of regular use of air shipping.

6.7.4 Waterway

This is a very common way of shipping goods. The goods that travel by water include chemicals, stone, cement, sugar, coal and other heavy commodities. Millions of containers travel by ship each year. The cost for shipping by waterways is inexpensive. Most low-cost products are shipped by waterways.

6.7.5 Pipelines

Crude oil, natural gas and other petroleum products are shipped by pipelines. Once the pipelines are built, the cost per kilometre for shipping is very inexpensive. There is a lot of opposition and concern over new pipelines because of worry over spills and leaks that may contaminate land and waterways.

6.7.6 Multimodal/Intermodal shipping

This refers to the use of a combination of different types of transportation to move goods from origin to destination. A common example is a combination of truck/ship/train. The goal is to ship the goods as efficiently as possible. The goods are shipped under a single contract with a carrier, and can be easily tracked. It also uses several modes of transportation but also uses a container so that freight does not have to be handled each time it changes modes. Each mode will have a carrier responsible for the shipment. The use of containers increases the security, reduces loss and damage and increases the speed of shipment.

6.8 Supply Chain Collaboration

6.8.1 Vendor Managed Inventory (VMI)

Vendor Managed Inventory (VMI) is an advanced supply chain relationship whereby a vendor (often a manufacturer) has access to their customer's inventory information and the vendor takes the responsibility for maintaining an agreed-upon level of product at the customers location. This arrangement can be used with manufacturers, distributors and retailers.

VMI has numerous benefits for both the supplier (vendor) and the customer. The vendor has strong motivation to ensure that shelves are fully stocked, any slow-moving stock is discontinued and that employees have full understanding of the product offerings. The customer benefits from these VMI relationships because less work is involved on the buyers' end. Due to EDI, there are few errors and goods flow quickly. Point-of-sale data updates the inventory and determines what items are needed. Salespeople from the vendor often provide assistance by training sales staff and assisting customers when possible.

6.8.2 Collaborative Planning, Forecasting and Replenishment (CPFR)

Collaborative Planning, Forecasting and Replenishment (CPFR) is an arrangement where two trading partners in a supply chain collaborate to agree on forecasts and orders between the manufacturer and distributor/retailer. The distributor/retailer will have collected POS data and added any additional information, such as promotion plans, inventory status or forecasts. That information gets shared with manufacturers who will then compare it with their own forecasts and capacity. Both teams can collaborate to solve any discrepancies, eliminate gaps and agree on a final set of numbers. Collaborating in this way will enable both firms to reduce inventory as well as reducing problems such as shortages and capacity problems.

6.9 Measuring Supply Chain Performance

6.9.1 Inventory Turnover

Key Performance Indicators are measurements used to evaluate supply chain performance. One of the ways to evaluate the supply chain performance is to calculate **inventory turnover** (inventory turns):

$$\text{Inventory Turnover} = \frac{\text{Cost of goods sold}}{\text{Average Aggregate Inventory Value}}$$

"Average aggregate inventory value" is a term used to describe all of the inventory held in stock, which includes raw materials, work in process and finished goods, all valued at cost.

Inventory turnover is an indicator of the policies and practices of an organization. It represents their ability to purchase materials, produce and sell their products in a timely manner. A higher value for the inventory turnover means that the organization has been capable of replenishing and selling its inventory more number of times in any particular amount of time, and as a result, have a better cash flow.

It is important to keep in mind that high or low value of inventory turnover for each company is relative to its own industry. For example, dairy (milk) manufacturing has an annual inventory turnover of around 23, while this number is 14.7 for the grocery supermarkets, and 4.8 for the automotive industry. Industries with higher volume, but lower margin, usually have the highest inventory turnovers.

Example

XYZ Ltd is a supplier to restaurants and institutions for frozen foods fresh fruits and vegetables. Here is an analysis from the past two years regarding their inventory management. In which year was their supply chain performance better?

	Last year	Two years ago
Cost of goods sold	17,550,000	16,255,000
Average aggregate inventory value	$1,650,000	$1,763,350

Solution

Inventory turns for last year = 17,550,000 / 1,650,000 = 10.64 turns

Inventory turns for two years ago = 16,255,000 / 1,763,350 = 9.22 turns

Last year, their inventory turnover was faster. If customer service was equivalent in both years, then their performance was better last year than it was two years ago. This may have resulted in customers receiving fresher foods as well.

6.9.2 Days of Supply

Another related performance measure is **days of supply**:

$$\text{Days of Supply} = \frac{\text{Average Aggregate Inventory Value}}{\text{Annual Cost of Goods Sold}} \times 365 \text{ days}$$

Days of supply formula (average aggregate inventory value divided by annual cost of goods sold, the sum of which is multiplied by 365 [days]).

Example

J’s Custom Automotive Finishing has calculated that his annual cost of goods sold at 45,000,000. His average inventory value in 2019 is:

Production components	2,350,000
Production supplies	450,000
Finished goods	225,600
Total aggregate inventory value:	**3,025,600**

Solution

Days of supply = (3,025,600 / 45,000,000) x 365 = 24.54

This measure can be thought of as how much inventory is sitting in the building at any one time. In terms of measuring the efficiency of the inventory, a lower number is better. It would imply that goods are purchased more frequently and spend less time in the facility before being converted into sales.

There are other ways to measure supply chain performance as well. In a warehouse or distribution setting, **fill rate** is an important measure. It is the percentage of customer orders that are filled from on-hand stock. In a manufacturing setting, a measure such as the **percentage of orders delivered on time** is an important indicator of customer service level.

Chapter 7

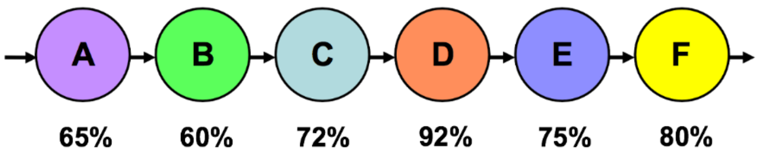
Constraints Management

7.1 Introduction

Before getting in to details of Constraints Management, let us try to understand this concept by doing a simple exercise given below:

Exercise

Imagine you are responsible for managing the below process flow. Each letter represents a different sub-process such as sales, design, operations stage 1, operations stage 2, customer invoicing, payment collection, etc. Take a moment to visualize a simple sequential process that you are familiar with, perhaps in manufacturing or services, or even a government process such as issuing driver's licenses.



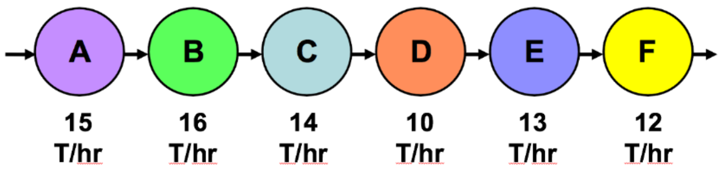
You are given the above report detailing the overall efficiency of each sub-process.

1. Where will you FOCUS most of your attention?
2. Where will you avoid putting ANY attention?

Which sub-process did you choose...?

Did you have any questions or information that you felt might be missing?

Just after you decided where to focus your attention, you receive a report containing the maximum capacity of each sub-process:



Substitute any measurement of capacity that suits your chosen process. For example, tons per hour.

1. Were you focusing in the right place? Most people focus on Process B, even though process D is actually the constraint
2. What are the necessary consequences if you focus primarily on optimizing process B?
3. The efficiency report remains equally accurate before and after receiving the capacity report. What changed?
4. What would you expect the maximum possible output from such a system to be?

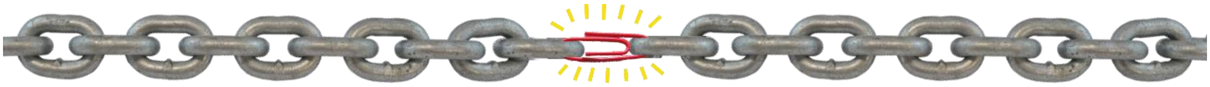
The Theory of Constraints is an approach to improving organizational performance created by Dr. Eli Goldratt and is explained in his book, The Goal. The thought behind Theory of Constraints is that in every organizational system, there is one constraint that limits the flow of value. This methodology emphasizes the importance of identifying the "**system constraint**" or bottleneck. By leveraging this constraint, organizations can achieve their financial goals while delivering on-time to customers, avoiding stock-outs in the supply chain, reducing lead time, etc.

Other common benefits of implementing the Theory of Constraints include better control over operations, less inventory, reduced conflicts between team member and drastically reduced firefighting. Often, additional capacity gets exposed without further capital investment or hiring additional workers.

The **Core** Idea – Every system has a limiting factor or constraint. Focusing improvement efforts to better utilize this constraint is normally the fastest and most effective way to improve profitability.

7.2 Constraints - The Chain Analogy

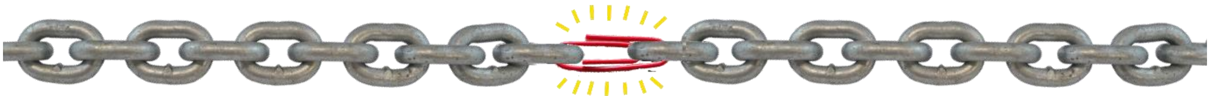
No chain can ever be stronger than it's weakest link. Similarly, every system must have a **constraint** that limits it's output. We know this because no system has infinite output... for example, you will never find any company with infinite sales or profit!



Note that every chain will have ONE (and only one) weakest link. Strengthening the other links can never increase the overall strength of the chain, because they are not the weakest. In fact, strengthening a non-weakest link will probably DECREASE the overall strength of the chain due to the added weight:

Similarly, attempts to optimize each individual process and function tend to ignore the impact on the constraint, thereby causing a variety of unforeseen problems that reduce the overall performance and effectiveness of the organization. For example, if sales orders are the constraint, optimizing production output can result in overproduction. Such large quantities of excess finished goods inventory will in turn incur hefty carrying charges and cost of capital. A resulting cash crunch might also delay payments to vendors, thereby triggering supply problems which delay orders, tarnish the reputation with customers and reduce future sales.

What if we made efforts to utilize the weakest link more fully? We could exploit it more by minimizing idle time of the chain, or subordinate everything else to it by avoiding sudden jerks that add additional stress when it is fully loaded. Once we have mastered how to utilize the chain well, we might begin searching for ways of strengthening the weakest link itself. Even a small increase in the strength of the weakest link could have a rather large impact on the overall strength of the chain:



A constraint limits the output of every system, whether we acknowledge it or not. When properly identified and managed, **constraints provide the fastest route to significant improvement** and form the bedrock for continuous growth. When ignored, the constraint may lie idle, squandering system capacity. An out-of-control constraint may also wreck havoc on delivery schedules and cause unpredictable delays. It is therefore crucial for any manager to make the most of their constraint and learn to manage it well.

TOC shifts the focus of management from optimizing separate assets, functions and resources to increasing the flow of throughput generated by the entire system. TOC's key processes are focused on removing barriers that prevent each part from working together as an integrated whole.

TOC explains why local optimization doesn't help and that we need to use systems thinking. Similar to the weakest link in a chain, improvements to the rest of the chain don't make it stronger. Only by improving that weakest link can we improve the strength of the chain.

7.3 Five Focussing Steps of TOC

Theory of Constraints uses what Dr. Goldratt refers to as the Five Focusing Steps for optimizing systems. This approach allows you to address constraints is the simplest way possible.

Step 0: Define the Goal

Each system has a goal. What is it you want to achieve and how will you know when you've reached the goal? To determine the goal, need to understand who uses the output of the System and what's valuable to them. After you understand that, find metrics to measure the throughput, or amount of value produced by the system.
Understanding the goal is often the most difficult step in the process. Finding the right goal and the right metrics to measure progress toward that goal will be critical to your success.

Step 1: Identify the Bottleneck

Each system has one constraint that determines the throughput of the entire system. The constraint can be a person, a team, a physical machine, one organizational rule, or anything else that limits the speed at which value flows through the system. The constraint is often called a bottleneck.

At its core, the Theory of Constraints provides an approach to finding the bottleneck and taking action to improve throughput of the system as a whole.

As mentioned earlier, making improvements anywhere but the bottleneck will not improve the throughput of the system and it can even have a negative effect.
How do you recognize a bottleneck? If the bottleneck is a person, team, department, or piece of equipment, work piles up in front of them and people downstream of the bottleneck are idle some of the time.

To help identify the bottleneck, you can use tools like flow charts, swim lane diagrams, root cause analysis, Pareto charts, or queuing models. Remember that a system can only have one constraint at a time.

It's important to understand that being a bottleneck doesn't mean a person or team is bad at what they do or that they're doing anything wrong. Being the bottleneck is neither good nor bad; it's just a fact of the system. There's always one constraint.
Now that we've identified the bottleneck, what can we do to improve throughput?

Step 2: Exploit the Bottleneck

The first way to try to address the bottleneck is to "exploit" it. Exploiting the bottleneck isn't what it sounds like. "Exploiting" means that we're ensuring that the bottleneck isn't distracted by non-throughput producing work.
If you think about it, the flow of value through the system is determined by a single constraint. Therefore, any work done by the bottleneck that doesn't contribute toward the goal is waste and results in less throughput.

You can exploit the bottleneck by ensuring that the bottleneck always works on the highest priority, highest value work that contributes to the goal. You can also:

- Make sure the bottleneck works on only one thing at a time. We want to get to done; stop starting and start finishing.

- Remove any non-throughput producing work from the bottleneck.
- Shield the bottleneck from interruptions and quickly remove impediments, but don't shield them from important information like customer input and feedback.
- Make sure that the bottleneck is never idle or waiting for information, equipment, or materials. This type of waste reduces the value producing work that the bottleneck can do.

You may want to use techniques such as brainstorming to identify possible experiments you can try to exploit the bottleneck and improve the system. After you implement the exploit experiment, measure the impact to see if it made a positive change.

Make sure you only change one thing at a time. If you make multiple changes, you can't tell if some changes had a positive effect and some had a negative effect.
After each change, you'll also want to go back to the beginning to make sure the goal hasn't changed. You'll also need to make sure that the bottleneck hasn't moved.

Through your improvements, it's quite possible that the original constraint is no longer the system constraint. You may have improved the bottleneck to a point where they're no longer the constraint and any additional improvements to the original bottleneck won't improve the system. That's why you go back to the first step after each change.

Start by exploiting the bottleneck because it requires the lowest investment. It only affects the single bottleneck and it doesn't require additional time or money, but results in higher throughput.

Step 3: Subordinate Decisions to the Bottleneck

After you've exhausted what you can do through exploiting the bottleneck, the next step is to subordinate decisions to the bottleneck. Subordinating decisions means the rest of the system works to help the bottleneck produce maximum value.

That's because people other than the bottleneck have some slack. If everyone is working toward the same goal, anyone working beyond the pace of the bottleneck is not increasing the throughput of the system.

Instead of working at what they do faster, they can work to the pace of the bottleneck and use their extra capacity to support the bottleneck.
Some approaches you can use are:

- Ensure that the work, information, and materials received by the bottleneck as an input to their work is of the highest quality.
- Have everyone work to the pace of the bottleneck (no faster or slower).
- Someone else may be able to take some non-specialized tasks from the bottleneck. At this stage, only have someone take on tasks if it doesn't require a large investment in time or money.

Subordinating decisions to the bottleneck is done after the exploit step because there's a slightly higher investment needed, but it's still relatively easy. Subordination only impacts a few resources and requires little investment.
As with the exploit step, find a subordination experiment, implement it, and measure the result. Afterwards, go back to the beginning. Has the goal changed? Has the bottleneck changed?
If not and after you exhausted what you can do to subordinate decisions to the bottleneck, the next step is to elevate the bottleneck.

Step 4: Elevate the Bottleneck

After doing what you can to exploit and subordinate, you can elevate the performance of the bottleneck. Elevating the bottleneck requires time and money, so it's done only after exploiting and subordinating.
You can elevate the bottleneck and improve performance by:

- Get more people that can do the same work as the bottleneck.
- Buy more or faster machines
- Give people training and better tools
- Coach for individual improvement
- Improve the workspace

- Change organizational policies

Often we jump right directly to elevating by adding people, getting training, buying equipment and tools. These changes can be expensive and it takes time to get a positive impact on throughput. They could even have a negative effect in the short term.

Elevate as a last resort when you can’t find any more ways to exploit or subordinate.

Step 5: Repeat

Every time you find a potential improvement, implement it, measure the results and go back to the beginning. Make sure the goal is still valid and see if the constraint has moved.

The key is to see the system as a whole, understand what’s valuable, and recognize the constraint. After that, make small changes one at a time starting with the easiest and cheapest to implement and measure the results.

Chapter 8

Lean Management

8.1 Introduction

Lean management is an approach to managing an organization that supports the concept of continuous improvement; a long-term approach to work that systematically seeks to achieve small, incremental changes in processes in order to improve efficiency and quality. Lean management is a total business approach designed to identify and eliminate all forms of waste in the process of producing goods, services, or combinations of both.

The primary purpose of lean management is to produce value for the customer through the optimization of resources and create a steady workflow based on real customer demands. It seeks to eliminate any waste of time, effort or money by identifying each step in a business process and then revising or cutting out steps that do not create value. The philosophy has its roots in manufacturing.

Lean management focuses on:

- Defining value from the standpoint of the end customer.
- Eliminating all waste in the business processes.
- Continuously improving all work processes, purposes and people.

Lean management facilitates shared leadership and responsibility; continuous improvement ensures that every employee contributes to the improvement process. The management method acts as a guide to building a successful and solid organization that is constantly progressing, identifying real problems and resolving them.

Lean management is based on the Toyota production system which was established in the late 1940s. Toyota put into practice the five principles of lean management with the goal being to decrease the amount of processes that were not producing value; this became known as the Toyota Way. By implementing the five principles, they found that significant improvements were made in efficiency, productivity, cost efficiency and cycle time.

8.2 Principles of Lean Management

Lean management incorporates five guiding principles that are used by managers within an organization as the guidelines to the lean methodology. The five principles are:

1. Identify value
2. Value stream mapping
3. Create a continuous workflow
4. Establish a pull system
5. Facilitate continuous improvement

Identifying value, the first step in lean management, means finding the problem that the customer needs solved and making the product the solution. Specifically, the product must be the part of the solution that the customer will readily pay for. Any process or activity that does not add value -- meaning it does not add usefulness, importance or worth -- to the final product is considered waste and should be eliminated.

Value stream mapping refers to the process of mapping out the company's workflow, including all actions and people who contribute to the process of creating and delivering the end product to the consumer. Value stream mapping helps managers visualize which processes are led by what teams and identify the people responsible for measuring, evaluating and improving the process. This visualization helps managers determine which parts of the system do not bring value to the workflow.

Creating a continuous workflow means ensuring each team's workflow progresses smoothly and preventing any interruptions or bottlenecks that may occur with cross-functional teamwork. Kanban, a lean management technique that utilizes a visual cue to trigger action, is used to enable easy communication between teams so they can address what needs to be done and when it needs to be done by. Breaking the total work process into a collection of smaller parts and visualizing the workflow in this regard facilitates the feasible removal of process interruptions and roadblocks.

Developing a pull system ensures that the continuous workflow remains stable and guarantees that the teams deliver work assignments faster and with less effort. A pull system is a specific lean technique that decreases the waste of any production process. It ensure that new work is only started if there is a demand for it, thus providing the advantage of minimizing overhead and optimizing storage costs.

These four principles build the lean management system. However, the last principle -- continuous improvement -- is the most important step in the lean management method.

Facilitating continuous improvement refers to a variety of techniques that are used to identify what an organization has done, what it needs to do, any possible obstacles that may arise and how all members of the organization can make their work processes better. The lean management system is neither isolated nor unchanging and, therefore, issues may occur within any of the other four steps. Ensuring all employees contribute to the continuous improvement of the workflow protects the organization whenever problems emerge.

Examples of lean management

The lean management principles can be used as a universal management tool to improve companies' overall performance.

Some examples of specific business and production processes that are based on the lean management concept include:

- Lean manufacturing
- Lean software development
- Lean six sigma
- Lean startup

- Value-based healthcare

8.3 Benefits of Lean Management

Lean management benefits organizations by focusing on improving all parts of the work process throughout every level of the company's hierarchy. Specifically, managers benefit from advantages such as:

- A more intelligent business process - The pull system ensures work is only carried out when there is an actual demand and need for it.
- Improved use of resources - The pull system also ensures the organization is only using resources when they are needed since it operates based on real customer demand.
- Improved focus - Lean management decreases the amount of wasteful activities, therefore allowing the workforce to increase their focus on tasks that produce value.
- Enhanced productivity and efficiency - Improved focus leads to a more productive and efficient workforce since attention is not given to unnecessary activities.

These major benefits work together to create a company that is more flexible and has the ability to address customer requirements in an improved and faster manner. Overall, the lean management system creates a solid production system that has a higher chance of improving a company's total performance.

8.4 Discussions on Waste

Waste is any activity that adds cost/time without value to the service we offer to our customers. It means any activity for which a customer will not pay. For example, if we offer car with attractive packing and we charge for packing, then customer will not agree to pay so packing a car is a waste full activity in this case.

Waste can also be defined as any resource which do not add value to the product being manufactured. There are three important activities

- Value added (VA),

- Non-value-added (NVA), and
- Necessary but non-value-added (NNVA) activities

Value-Added Activities: These are those activities for which the customer is willing to pay for.

Non-Value-Added Activities: These are those activities for which the customer is not willing to pay for. They only add to cost and time. Non-value-added activities are also called "wastes," as delved in the last article. The focus should be to eliminate these non-value-added activities. Examples of non-value-added activities include all the eight wastes of Lean.

Necessary but non value added activities or Business Value-Added Activities: These are those activities for which the customer is not willing to pay for but needs there for running of processes and the business. For example inspection is a non-value added activity but it is required to ensure the quality of output. These business value-added activities could include work done on audits, control, reduce risk, for regulation or to support value added work. aichi Ohno called all these non-value-added activities muda ("waste" in Japanese). Business value-added activities are called Type-1 muda while non-value-added activities are called Type-2 muda.

Aim of Lean Management is to reduce NVA.

There are mainly following seven types of wastes:

- Motion : Moving without working
- Delays : Waiting for anything
- Transporting : Moving products between work centres
- Defects : Not working right first time
- Over-processing : Doing work that beyond what is needed
- Over production : producing more than required
- Inventory : Keeping products waiting

Wasteful motion is all the motion, whether by a person or a machine, that could be minimized. If excess motion is used to add value that could have been added by less, than that margin of motion is wasted. Motion could refer to anything from a worker bending over to pick something up on the factory floor to additional wear and tear on machines, resulting in capital depreciation that must be replaced.

Delay or waiting for anything refers to wasted time because of slowed or halted production in one step of the production chain while a previous step is completed.

The most serious of the wastes, **overproduction** can cause all other types of wastes and results in excess inventory. Stocking too much of a product that goes unused has obvious costs: storage, wasted materials, and excessive capital tied up in useless inventory.

Transport is moving materials from one position to another. The transport itself adds no value to the product, so minimizing these costs is essential. This means having one plant closer to another in the production chain, or minimizing the costs of transportation using more efficient methods. Resources and time are used in handling material, employing staff to operate transportation, training, implement safety precautions, and using extra space. Transport can also cause the waste of waiting, as one part of the production chain must wait for material to arrive.

Defects refer to a product deviating from the standards of its design or from the customer’s expectation. Defective products must be replaced; they require paperwork and human labor to process it; they might potentially lose customers; the resources put into the defective product are wasted because the product is not used.

Over-processing refers to any component of the process of manufacture that is unnecessary. Painting an area that will never be seen or adding features that will not be used are examples of over-processing. Essentially, it refers to adding more value than the customer requires.

Inventory waste refers to the waste produced by unprocessed inventory. This includes the waste of storage, the waste of capital tied up in unprocessed inventory, the waste of transporting the inventory, the containers used to hold inventory, the lighting of the storage space, etc. Moreover, having excess inventory can hide the original wastes of producing said inventory.

8.5 Creating a Lean Enterprise

To create lean enterprise following two philosophies are followed simultaneously with a common aim of reducing or eliminating the waste:

- Just-in-time manufacturing (JIT)
- Total quality management (TQM).

JIT is used in an organization-wide to exposing problems related to wasteful activities. TQM is to solve the problems. Hence, these two are the basic enabling mechanisms of lean management system. Just-in-time, or JIT, is an inventory management method in which goods are received from suppliers only as they are needed. The main objective of this method is to reduce inventory holding costs and increase inventory turnover.

In JIT , changes are made to properly organize the resources and reschedule. Lot size reduction, set up time reduction, using simplified operational control (KANBAN) and using pull system are the important steps. Using pull system and the production is taken up only on getting the order from the customer.

TQM is used to reduce the waste on daily or regular basis by using the tools like continuous improvement, quality circles, Kaizen, process mapping etc. Total Quality Management (TQM) is a management framework based on the belief that an organization can build long-term success by having all its members, from low-level workers to its highest ranking executives, focus on improving quality and, thus, delivering customer satisfaction.

The basic enablers of lean enterprises are JIT and TQM as shown in fig. 3. The tools and techniques used for these are shown in the fig.3.

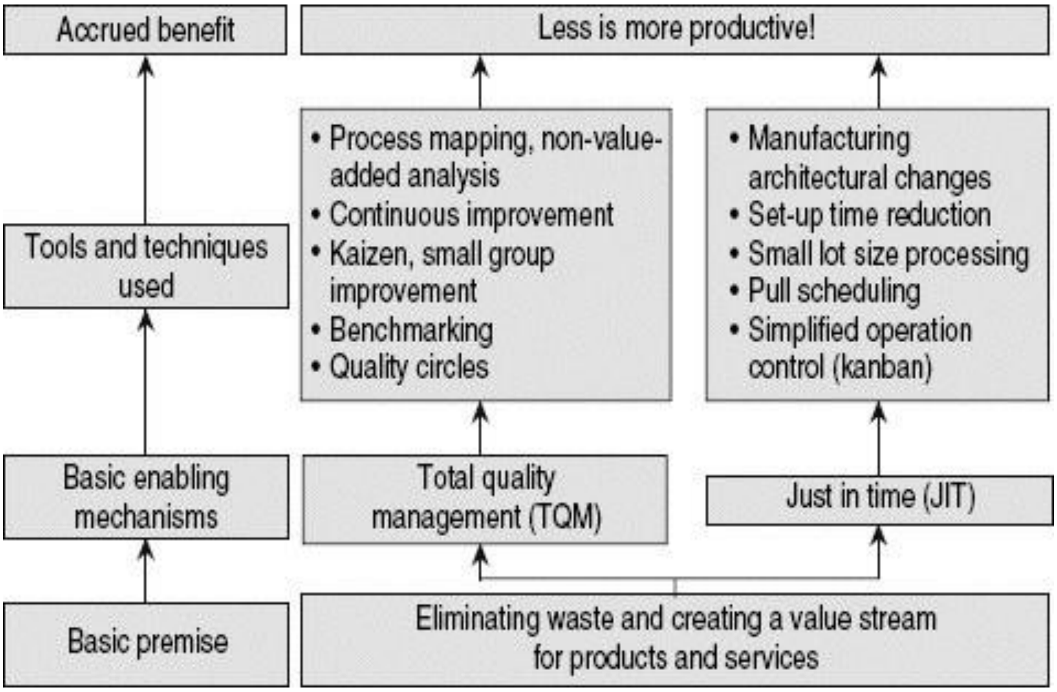


Fig : Creating Lean Enterprise (Ref : Operations Management: theory and Practice 3rd Edition edited by B. Mahadevan)

8.6 JIT and Water flow analogy

Water flow analogy is used to identify the problem in production where high inventory hides the problems. Excess inventory generally means an organization is struggling to turn over inventory and make sales. It also leads to significant costs, lengthened lead times & inventory management requirements that have disadvantages of its own.

Inventory is a symptom of managing production and logistics by “push” which means making or moving goods and services without a clear signal from the customer or downstream process. Therefore, lowering metaphorical water (inventory) helps the organizations to make the problems visible and allows addressing the problems which in turn helps the organization to design a streamlined & responsive production and logistics system that is based on a pull.

8.7 Lean Tools and Techniques

There are various tools and techniques used in lean management. Important Lean tools and techniques are summarized in the fig 6. Important tools and techniques are explained in the following paragraphs.

8.7.1 5 S

5S or good housekeeping involves the principle of waste elimination through workplace organization. 5S was derived from the Japanese words seiri, seiton, seiso, seiketsu, and shitsuke. The cornerstone of 5S is that untidy, cluttered work areas are not productive. As well as the physical implications of junk getting in everybody's way and dirt compromising quality, we all are happier in a clean, tidy environment and hence more inclined to work hard with due care and attention. 5S and good housekeeping are core elements of lean thinking and a visual workplace and are a fundamental platform for world-class manufacturing.

According to the methodology, the path to optimal workplace organization lies in the five steps that should be done in a particular order. 5S, also known as Five S, is an acronym for five Japanese words:

- Seiri (organize)
- Seiton (orderliness)
- Seiso (cleanliness)
- Seiketsu (standardize)
- Shitsuke (discipline)

In English, the 5S terms have been adapted to:

- Sort
- Set in Order/Straighten
- Shine
- Standardize
- Sustain

Sort (Seiri)

The “sort” phase of the 5S methodology involves sorting through all tools, furniture, equipment, materials, resources, etc. in the work area to determine what is needed and what can be eliminated. Some common questions are asked during this phase, such as:

- What is this item’s purpose?
- How is it used?
- How frequently is it used?
- Who uses it?
- Is it really needed?

The involvement of staff is required to answer some of these questions. Items deemed unnecessary to the workspace are removed.

Set in Order/Straighten (Seiton)

With the clutter removed, the remaining items can then be organized. Common item grouping systems include:

- Who uses the item
- Where the item is used
- When the item is used
- Item type

With items appropriately grouped, they’re then arranged neatly in a way that is most logical to the identified workflow.

Shine (Seiso)

In the Shine phase, the workplace is thoroughly cleaned. This includes basic cleaning, such as dusting, sweeping, tidying, and mopping, as well as performing regular maintenance on equipment and machinery. The goal of this step is to keep the workspace in order and identify any equipment breakdown that would slow down progress. And it isn’t just the janitorial staff expected to keep the area clean.

Employees are encouraged to maintain their workspace, giving them a sense of ownership meant to further their investment in their role.

Standardize (Seiketsu)

The standardization step is designed to prevent a company from slipping back into old ways after the progress of the first three steps. Organizing and cleaning aren't an every-now-and-then practice in a 5S workplace. By standardizing the principles, regular tasks are assigned, schedules are made, and instructions are given to ensure these activities become habit or standard operating procedures. Visual cues, such as posters and labels, help to ingrain practices into the work culture.

Sustain (Shitsuke)

To sustain 5S lean methodology, it must be consistent across all workers. Managers should participate, as well as every employee type in each department. Sustaining 5S is a team effort. It should also be part of training for new employees. With everyone on board, 5S becomes a long-term effort.

8.7.2 Lot-size Reduction and One piece flow

Usually, large lot size are kept due to high set up time to produce new item. But this results in increased inventory. By reducing lot size, the items are made as per customer demand with less inventory. However, set up time reduction is required to reduce the lot size. Lot size reduction leads to one piece flow concept of lean. One can reduce lead time by reducing the lot size. However, this is most useful for make-to-stock production. In make-to-stock production, the lot size influences the inventory one needs to cover the time until the part can be produced again.

One-piece flow, also called continuous flow, refers to the way products move from one step in the process to the next—moving them efficiently by planning workflow based on the product and its needs, instead of the organization or equipment. In one piece flow, small batch of the work piece is moved from one work station to other.

If there is any defect only a few items are get rejected or reworked. In process inventory is reduced. Continuous flow helps reduce waste, specifically waiting, processing, and overproduction. Waiting waste is removed from the system because there is rhythm and balance between each step of the process. This allows each team member to be able to add value instead of creating waste. Processing waste is reduced because there is inherently less rework (or over-processing), only the amount of effort that the customer is willing to pay for is being accomplished (less under-processing), and there is one agreed-upon way to do the work (no bad processing).

8.7.3 Visual Controls

These Controls enable the work place to be self –explaining, self-regulating and self –controlling. Visual aids like signs, labels, coloured markings, alarms etc are used so that anyone can understand what is going wrong and what is out of place**.** The status of practically every process should be visible in lean management. Visual controls and the processes surrounding them represent the nervous system in lean management. Visual controls bring focus to the process and drive improvements.

The purpose for visual controls in lean management is to focus on the process and make it easy to compare expected vs. actual performance. These comparisons highlight when the process is not performing as expected and where improvement might be needed. Examples of visual control are :

- Colour Coded pipes and wires
- Painted floor areas for goods stock, scrap, etc.
- Shadow boards for parts and tools
- Indicator lights, hooters
- Work group display boards with charts, matrices, procedure, etc.

Visual management can be sued in the following areas : Man, Machine, Material, Methods, Key performance indicators, delivery, quality and cost.

8.7.4 Cellular Manufacturing

Companies continually seek ways to become more efficient and productive. Lean production helps make that happen. Lean production continually strives for improved efficiency and customer satisfaction. cellular manufacturing aims to move products through the manufacturing process one-piece at a time, at a rate determined by customers' needs. Cellular manufacturing can also provide companies with the flexibility to vary product type or features on the production line in response to specific customer demands. The approach seeks to minimize the time it takes for a single product to flow through the entire production process. In cellular manufacturing, production work stations and equipment are arranged in a sequence that supports a smooth flow of materials and components through the production process with minimal transport or delay. This arrangement is called cell layout. Cellular layout refers to the way specific departments within a company are organized. An efficient layout plan, can improve a company’s performance and help to eliminate waste.

A cellular layout is the physical organization within a company that improves workflow, efficiency, and production. This structure entails the creation of work cells, which are micro units of 3-12 workers. Each unit contains a certain number of machines and supplies. The goal is to have workers be able to access machinery and supplies on demand so that they don’t have to waste time sourcing the equipment or supplies they need to carry out their jobs. Depending on the size and needs of the company, a department can have as few as three employees and one machine, or up to a dozen employees and a half-dozen machines or more. A set up of cellular manufacturing is shown in fig 12. Cell can have many types like I cell, U – cell, T-cell depends on the type of products and machines.

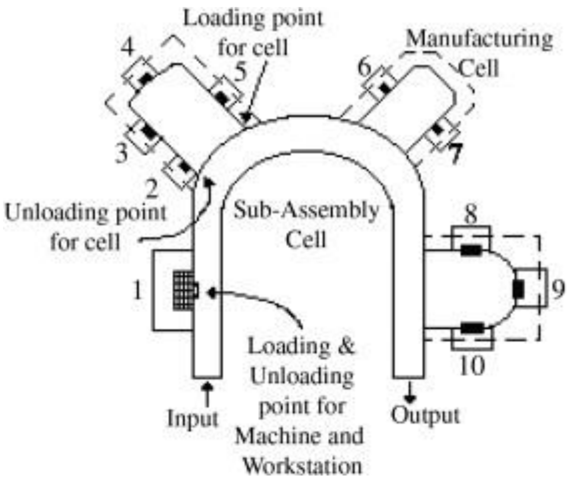


Fig: Cellular Manufacturing

(ref: https://www.sciencedirect.com/science/ article/abs/pii/S027861251000021X)

8.7.5 Kanban

Kanban is a Japanese noun, meaning “visible record”. This is one form of JIT system. Kanban is a scheduling system for lean manufacturing. Taiichi Ohno, an industrial engineer at Toyota, developed kanban to improve manufacturing efficiency. This represents a family of different production & inventory control systems and methods which signal (communicate) some or all of the following:

- what parts to manufacture,
- when to start manufacturing,
- when to stop manufacturing,
- how many to manufacture, and
- where to deliver them to.

Kanban works in line with replenishment of the items in supermarket.

Production control is achieved by passing information usually authorization of work, regarding production to the respective work centres. Kanban provides the production, pickup, and transport quantity required in any production planning control function. A pre-determined quantity of items is to be stacked between every pair of succeeding and preceding processes. As operator pulls out his requirement, the signal travels along the chain and each link in the chain schedules production only to the extent of refilling the stocking points. The signaling from the operator down to the raw material stores is done through kanban. Kanban could be a card, an electrical signal, or a message flashed through the Web. A Kanban board is shown in fig.13.

Kanban boards are a shared space where teams and organizations can visually manage their work. harnessing our brains' innate preference for consuming visual information, Kanban boards help teams:

- See work in progress
- Streamline their processes
- Keep work flowing from “To Do” to “Done”

When assembly job is taken up in final assembly area , the components are drawn from Kanban stock point and then signal pass on to machining area to take up for the machining of the component. Thus it works on pull system.

8.7.6 Total Productive Maintenance

Total productive maintenance (TPM) is the systematic execution of maintenance by all employees through small group activities. The dual goals of TPM are zero breakdowns and zero defects.

TPM stands for Total Productive Maintenance. TPM Development was first published in Japan in 1982. Since then new concepts and refinements have been added to the basic program. TPM first took root in the automotive industry. More recently it has been introduced in consumer goods, electronics, plastics and many others. Administrative and support departments such as product development and sales also use TPM. Production output and rate, quality, safety, and the environment depend almost entirely on the state of equipment. TPM is a method for continuously improving the effectiveness of production equipment and processes.

Why TPM

It is claimed that most companies can realise a 15-25 percent increase in equipment operation rates within three years of adopting TPM. Following benefits are inivsaged for TPM

- Guarantees Significant Tangible Results - Results achieved include – reduction in equipment breakdowns, lower quality defects and claims, higher productivity, shrinking inventory, lower number of accidents.
- Net productivity goes up by 2x
- Process defect rate comes down 90%
- Production costs comes down 30%
- Production and work in process inventories comes down to half.
- Accidents come to zero.
- Improvement suggestions go up by 10x
- It transforms the Plant Environment – a rusty plant can be reborn as a pleasant, safe working environment.
- It transforms the Employees - As concrete results are achieved, workers become motivated. Associates begin to think of TPM as part of their job.

Conducting TPM

In TPM, each employee takes the role of maintenance man also. Machine Operators are trained to do much of the maintenance operations, and it's part of their Standard Work. On daily basis he checks the machine and carries out basics maintenance jobs. TPM is also conducted for a machine in form of a Kaizen event where a machine with the problem is taken and the problem is resolved and TPM boards for daily and preventive maintenance are made which is to be followed by the operator.

8.7.7 Set Up Reduction and Single Minute Exchange of Die (SMED)

Set-up time is the time required to set up a process (or a machine) before it can be used for production. Before start of the machine usually raw material or semi finished part is loaded with tools. Jigs, fixtures and cutting tools are set up. This takes time and if it takes lot of time , operator hesitates to change set up very often. Setup reduction and fast, predictable setups enable lean manufacturing. Setup reduction reduces setup cost, allows small lot production and smoothes the low.

There are two types of setup time:

Internal Set-up or internal operations :

Those activities that must be performed while the machine is shut down. (Work content done in addition to Machine Time). Example of this is removing dies and tooling from the machine bed.

External Set-up or exetrna operations :

Those activities that are performed while the machine is operating. For example, Preparing tooling outside of the machine for the next set-up is external set up.

SMED is a systematic method by which internal operations are progressively converted into external operations. This happens in stages by studying the operations and identifying the set up which can be done externally. SMED was developed by Shigeo Shingo, a Japanese industrial engineer who was extraordinarily successful in helping companies dramatically reduce their changeover times. His pioneering work led to documented reductions in changeover times averaging 94% (e.g., from 90 minutes to less than 5 minutes)

A successful SMED program will have the following benefits:

- Less adjustments means less chance for errors
- Elimination of trial processing reduces material waste
- Increases scheduling flexibility/capacity
- Reduces need for on-hand inventory
- Improved service levels for customers
- Smaller runs means less likelihood of large scale defect problems in inventory

- Uncovering large amounts of wasted capacity and making the system flexible and responsive to changes

8.7.8 Poka Yoke

Poka Yoke is one of the most valuable takeaways of lean management. It has become one of the most powerful work standardization techniques and can be applied to any manufacturing or service industry. Poka Yoke is a Japanese term which means mistake proofing. A Poka Yoke device is one that prevents incorrect parts from being made or assembled, easily identifies a flaw or error. It is from the word yokeru means to avoid and poka means inadvertent errors. It is the first step in truly error proofing a system.

Error proofing is done by designing manufacturing process, equipment and tools so that an operation literally cannot be performed incorrectly. Its idea to prevent errors and defects from appearing in the first place is universally applicable and has proven to be a true efficiency booster.

Poka-Yoke technique could be used whenever a mistake could occur, or something could be done wrong – meaning everywhere. It can be successfully applied to any type of process in the manufacturing or services industry, preventing all kinds of errors:

- **Processing error:** Process operation missed or not performed per the standard operating procedure.
- **Setup error:** Using the wrong tooling or setting machine adjustments incorrectly.
- **Missing part:** Not all parts are included in the assembly, welding, or other processes.
- **Improper part/item:** Wrong part used in the process.
- **Operations error:** Carrying out an operation incorrectly; having the incorrect version of the specification.
- **Measurement error:** Errors in machine adjustment, test measurement, or dimensions of a part coming in from a supplier.

Poka-Yoke is easy to implement because of its universal and rational nature. one can follow this step by step process to apply it:

1. Identify the operation or process.
2. Analyze the 5-whys and the ways a process can fail.
3. Choose the right Poka-Yoke approach, such as using a ***shutout type*** (preventing an error being made) or an ***attention type*** (highlighting that an error has been made).
4. Take a comprehensive approach instead of thinking of Poka Yokes just as limit switches or automatic shutoff.
5. Determine whether a ***contact*** (use of shape, size, or other physical attributes for detection), ***constant number*** (error triggered if a certain number of actions are not made), or a ***sequencing method*** (use of a checklist to ensure completing all process steps) is most appropriate.
6. Test the method and see if it works.
7. Train the operator, review performance, and measure success.

One of the most common is when a car driver with a manual gearbox must press on the clutch pedal (a process step – Poka-Yoke) before starting the engine. The interlock prevents an unintended movement of the car. Another example is a car with an automatic transmission, which has a switch that requires the vehicle to be in “Park” or “Neutral” before it can be started.

These serve as behavior-shaping constraints as there are actions that must be performed before the car is allowed to start. This way, over time, the driver’s behavior is adjusted to the requirements by repetition and habit. Some other examples of mistake proofing in the automotive industry are :

- Radar and video cameras
- Automatic breaking system
- Lane-keeping assist
- Electronic stability control
- Cross-traffic alerts
- Adaptive headlights
- Airbags

- Seat belt pre-tensioners
- Blind spot assist
- Electronic Braking System (EBS)
- Brakes

8.7.9 Kaizen Event

Kaizen is Japanese word which means orderly and continuous improvement. Masaaki Imai (lean's founding father) has brought out Kaizen - "a means of continuing improvements in personal life, home life, social life, and working life".

- Kai - to modify or change
- Zen - to think about making good or better

At workplace, managers and workers work together to make improvements with low capital investments

There are two types of kaizens:

i) Point Kaizen : operating in a cell or operation

ii) Flow Kaizen : operating in the whole company

The main purpose of the event is to remove waste viz., materials, cycle time, movements, delays, transportation, process improvement, tooling improvement, quality improvement, reduction of rejections, reduction of down time breakdown of plant & machinery, housekeeping 5S etc. Usually large financial outlays, increase of manpower are not admissible as action points of Kaizen vent.

Kaizen can be broken down into two categories: short-term (daily) use and long-term use. Continuous process improvement should always be at the forefront of actions at work, especially in regard to sustaining improvements that have already been implemented. This is where short-term or daily Kaizen events come in to play. You may have heard of the term "Kaizen culture" within a company. This refers to employees always making continuous improvement part of their job.

Some changes require a more long-term and focused approach. A properly executed Kaizen event requires a significant investment in employee time. Kaizen events are focused three- to five-day breakthrough events focusing on a targeted problem in a process. Long-term Kaizen events include the following activities:

- Training
- Defining the problem/goals
- Documenting the current state
- Brainstorming and developing a future state
- Implementation
- Developing a follow-up plan
- Presenting results
- Celebrating successes

Kaizen events are often planned using value stream mapping to target the right areas for improvement. What follows is a list of some of the problems that can be solved using kaizen events:

- Decreasing changeover time on a piece of equipment or process. Using kaizen, a team can improve upon the time to change over equipment using the SMED system,
- Organizing the workplace using 5-S.
- Creating a one-piece-flow work cell.
- Developing a pull system.
- Improving equipment reliability through TPM (Total Productive Maintenance).
- Improving the manufacturability of a product design.
- Improving a product development process.
- Improving other administrative processes such as order processing, procurement, engineering change processing and other paperwork/information processing activities.

Chapter 9

Maintenance Management

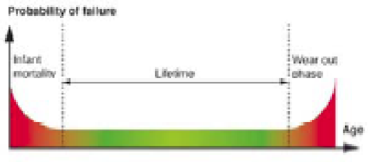
9.1 Introduction

MIL Standard 3034 defined maintenance as the action of performing pre-defined tasks on assets at pre-determined intervals to ensure that all relevant and required functions of the asset are available till next scheduled maintenance intervention. Moubray simplified this, and defined maintenance as activities that ensure that the assets continue to do what they are intended to do as per the expectation of their users. He also provided an organised structure, which depicted the evolution of maintenance through three generations. Later, Dunn, S and Manickam, L.R.A added that maintenance practices have been continuously changing, and the current phase of the evolution is slightly different from the third generation of Moubray. Thus, the fourth generation of maintenance came into the picture.

9.2 Moubray's three generations of maintenance

Table 9.1 provides a comparison between the three generations of the maintenance proposed by Moubray J. From this table, it is clear that Maintenance has evolved from mere supporting function to an important function that determines the pace of the growth of an organisation. Over these three generations maintenance techniques have been modified to cope up with the increasing expectations. The focus on reliability has increased many folds, and maintenance goal has been changed from correcting the failures to avoiding them.

Table 9.1 Moubray's Three Generation of Maintenance

Generations → Attributes ↓	First Generation	Second Generation	Third Generation
Period	**1930-1940**	**1940-1975**	**1975-Onwards**
Expectations from Maintenance	**Fix It When It Broke**	• **Higher Plant Availability** • **Longer Equipment Life** • **Lower Costs**	• **Higher Plant Availability** • **Greater Safety** • **Better Product Quality** • **No Damage To The Environment** • **Longer Equipment Life** • **Greater Cost Effectiveness**
Views on Equipment Failure			
Maintenance Techniques	**Fix It When It Broke**	• **Scheduled Overhaul.** • **Systems for Planning and Controlling Work.** • **Big, Slow Computers.**	• **Condition Monitoring.** • **Design for Reliability and Maintainability.** • **Hazard Studies.** • **Small, Fast Computers.** • **Failure Modes and Effects Analyses.** • **Expert Systems** • **Multi-skilling and Teamwork.**

9.3 The Fourth Generation of Maintenance

Even though, the current generation of the maintenance follows most of the themes as presented in the Moubray's third generation of the maintenance; it can be considered as an entirely new generation on following accounts, as expressed by Dunn, S and Manickam L.R.A:

1.) In addition to the expectations outlined in the Table , the fourth generation of maintenance has been exposed to another serious expectation in the recent past, which is risk management. There has been a significant increase in the focus on determining and controlling prospective high consequence low probability events, particularly in industries operating in high-risk environment.
2.) The fourth generation of maintenance can be characterised by the focus on successfully reducing the number of maintenance activities that result in failure pattern F type probability distributions (Refer Figure).
3.) The fourth generation of maintenance has significant number of new tools for maintenance management, such as Lean Maintenance, Total Quality Maintenance, Total Productive Maintenance, Spare Parts Optimisation Models, Reliability Modelling and Outsourcing.
4.) The fourth generation of maintenance is proactive rather than predictive or reactive.
5.) Integration of IT with the maintenance management system is another distinguishing feature of this generation.
6.) The focus of maintenance has been changed from the maintenance cost to the Life Cycle Cost of the assets.

Refer Figure 9.1, wherein various failure patterns are shown. It is clearer from the image that the relationship between the age of the machine and the failure is applicable for only 11% cases. Most of the assets have a constant or very slowly increasing failure probabilities. Fourth generation maintenance has accepted this fact, and the maintenance efforts are more pro-active than the reactive.

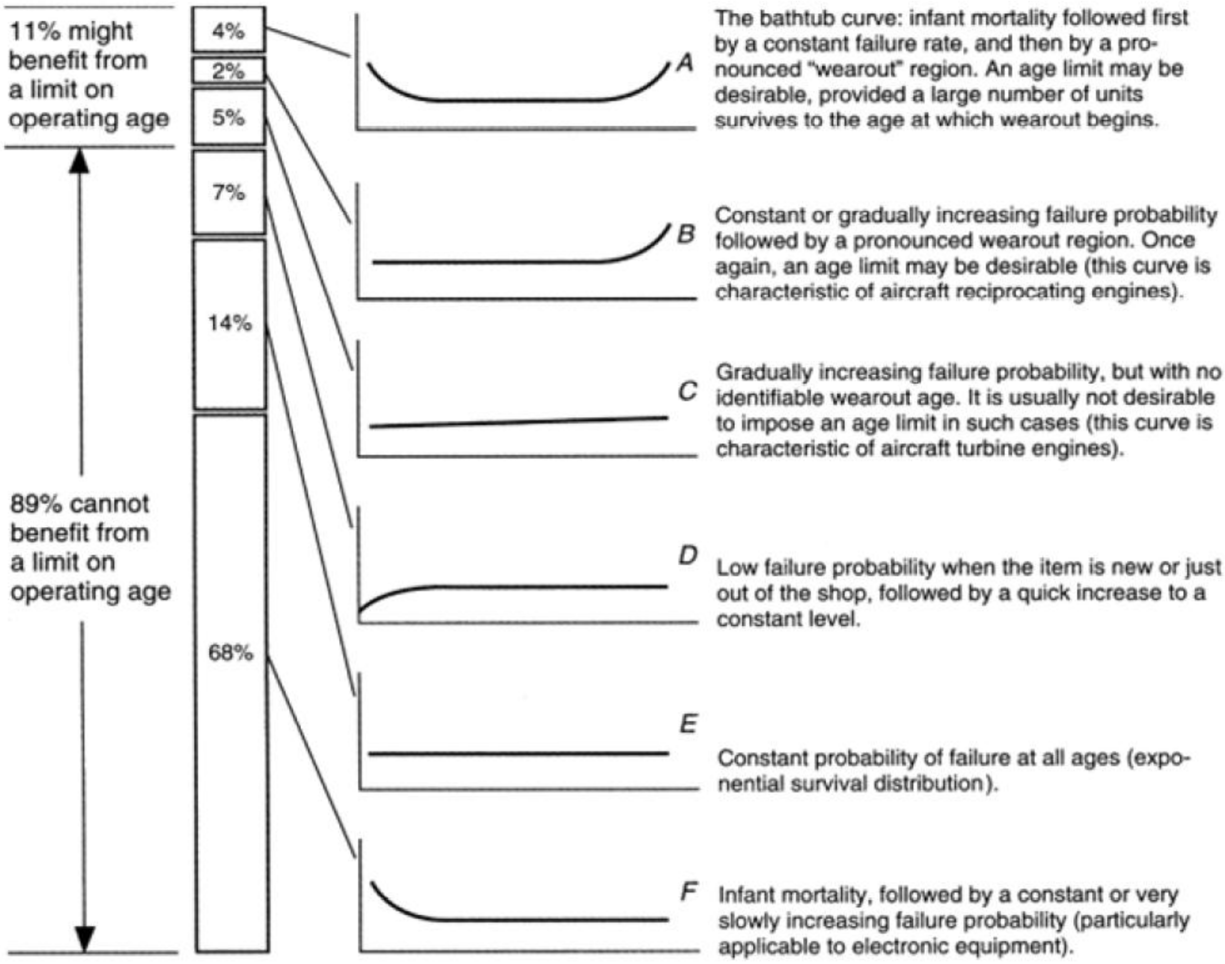


Figure 9.1 Nowlan and Heap's failure Patterns

9.4 Maintenance Management

JSP 886 Vol 7 Part 8.03 C defined maintenance management as the activities involved in deciding when and where actual maintenance should be done. Dhillon, B.S identified six critical maintenance management practices that can make a maintenance department more productive and successful, if applied on regular basis (Figure 9.2). These are: -

a) Maximum Productivity: - Maximum Productivity results when each involved person in an organisation has a defined task to perform in a definitive way within a defined time.
b) Schedule for Control: - Control points should be effectively scheduled. The intervals should be such that the problems are detected in time so that the scheduled completion of the job is not delayed.
c) Measurement: - Measurement comes before control. Normal values of all parameters should be measured to have an effective control.

d) The customer service relationship: - Relationship is the basis of an effective maintenance organisation. Relations inside maintenance team as well as relations between maintenance and user teams should be improved.

e) Job control: - Job control can be achieved by definite and individual responsibility for each activity during the life span of a work order.

f) Optimal Crew Size: - The optimal crew size is the minimum number that can perform an assigned task effectively.

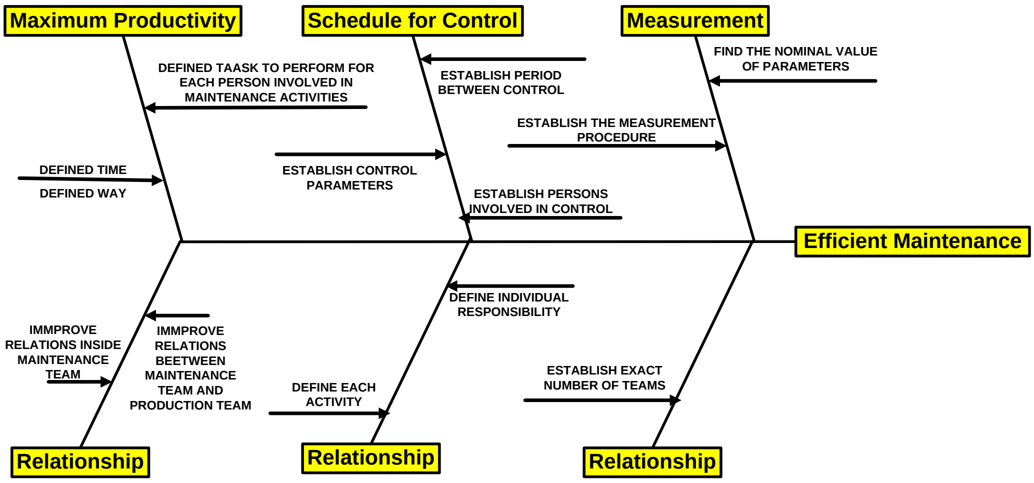


Figure 9.2 Maintenance Management Principles

9.5 Maintenance Management Framework

There are no specific methods or frameworks for maintenance management, which are equally applicable and effective in all situations. Maintenance management framework or style changes from organisation to organisation. However, in general the maintenance management framework consists of steps as shown in Figure 9.3.

Marquez, A.C. et al presented a typical model for the maintenance management framework, which consisted of eight management building blocks (Refer Figure). The first three building blocks of this model decide the maintenance effectiveness; the next two blocks ensure maintenance efficiency; subsequent two blocks provide an idea of maintenance cost/asset life-cycle cost assessment, and the last block ensures continuous improvement.

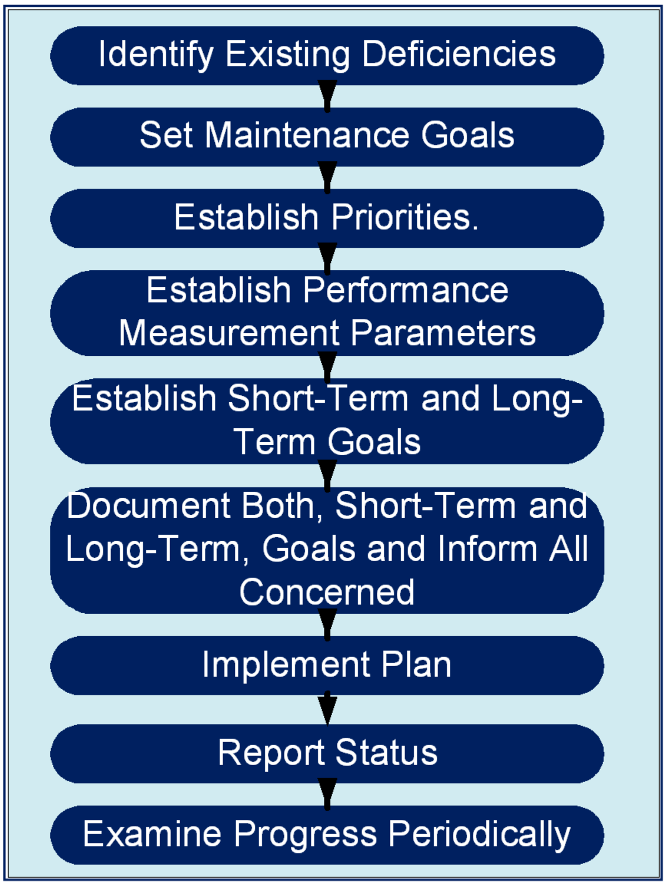


Figure 9.3 Maintenance Management Framework

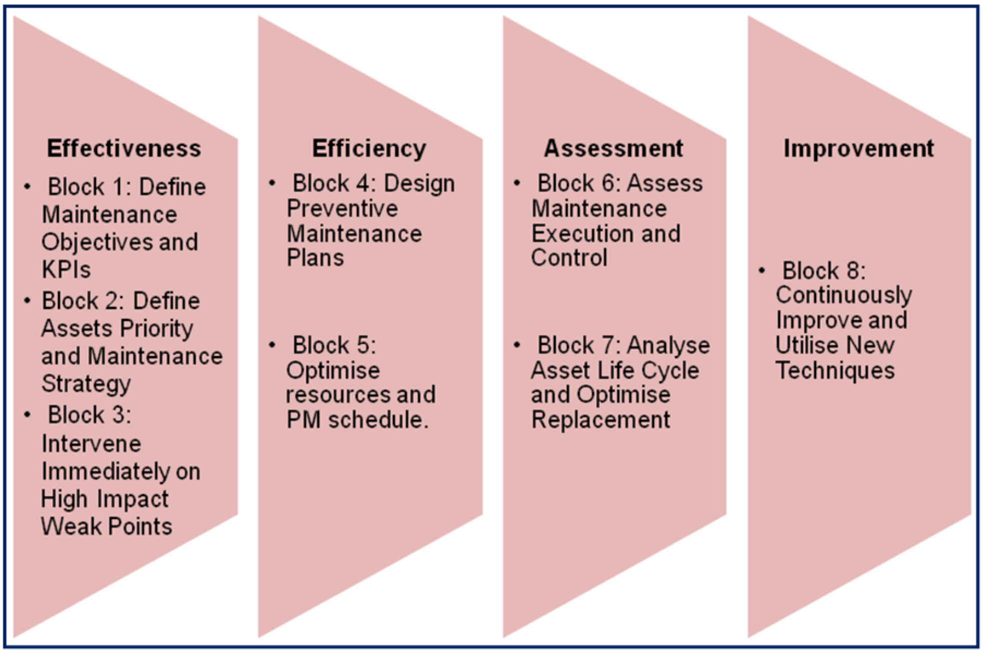


Figure 9.4 Building Blocks of Maintenance Management

9.6 Maintenance management strategies

Patton, J.D presented the concept of five-finger approach to maintenance. This approach emphasised on minimising, if not complete elimination, of maintenance need to the maximum possible extent, checking and spotting failures prior to their start, mending defects, monitoring of conditions and failure modes, and fixing the asset on a predetermined interval basis only if no better means exist. This five-finger approach suggests that improvement maintenance is like the thumb; corrective maintenance is like the little finger, and on-condition, Condition-based and scheduled maintenance are the other three fingers of the hand. Figure 9.5Figure shows various types of maintenance.

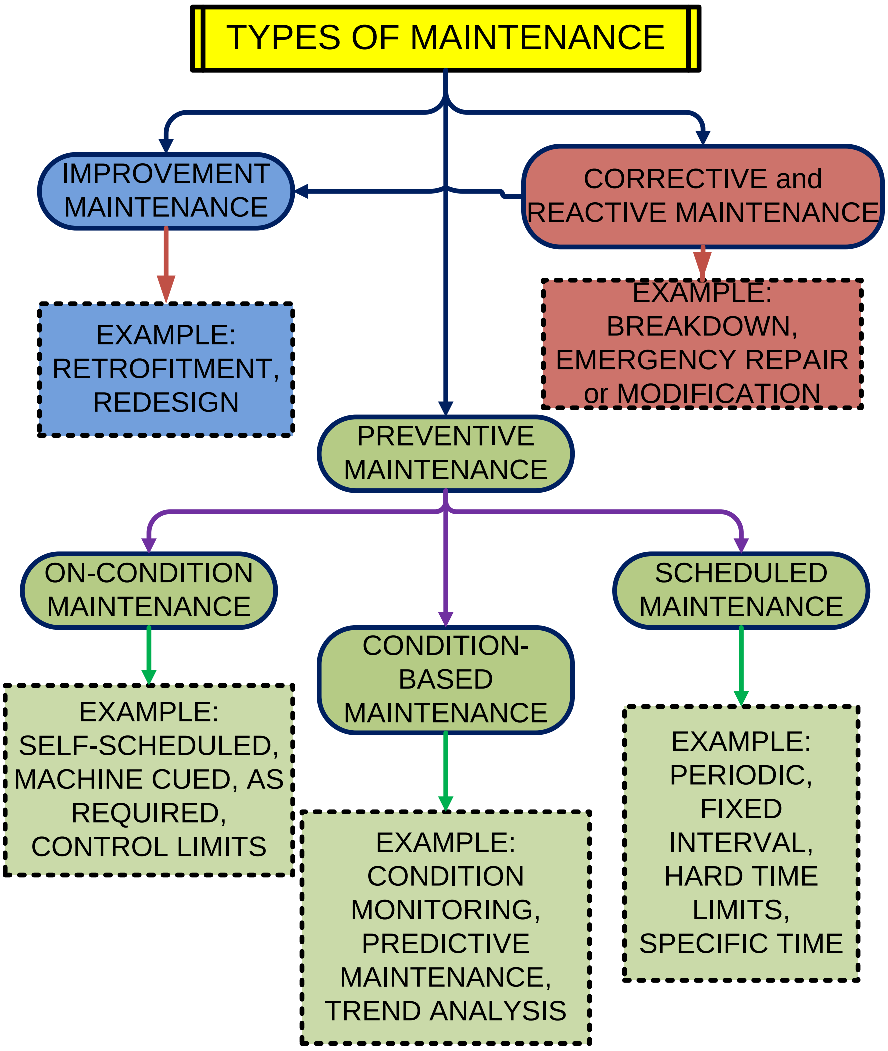


Figure 9.5 Various Maintenance Management Strategies

Based on the organisation, type of assets in the organisation, criticality of the assets and the production load; one or combination of two or more maintenance types may be suitable. For putting efforts in making the maintenance management effective; one should, first, decide the maintenance strategy. Lately, many maintenance management strategies such as TPM, RCM and CBM have been proven successful in varied contexts.

9.6.1 Corrective Maintenance

Corrective maintenance or Improvement Maintenance, also known as reactive maintenance in some specific contexts, is performed anytime a problem is identified. Many times, corrective maintenance is done after a failure has occurred, but not always. Corrective maintenance can also be completed after a problem has been noted, even if that problem has not yet created a failure.

The principal concept of corrective maintenance is that proper, complete repairs of all incipient problems are made on an as-needed basis. Basically, it involves correction of faults as and when identified or presumed to happen. Example – Cleaning the dust off the guideways, Tightening the guideway gibs, Marking the levels in the Old Oil Level Indicator, Tightening loose fasteners etc

This can also be used as a method to increase the MTBF (Mean Time Between Failure) by improving the reliability of equipment/machines through improvising, retro-fitment or redesign. For example, in a press work, the parts being cold pressed, need to have a continuous flow of the forming oil over the parts. In order to ensure this, the operator may have to go back or side of the press to see whether the forming oil level is adequate. A corrective maintenance approach may then suggest to provide another oil level indicator in front of the press control, and the suitable improvisation is done.

9.6.2 Breakdown Maintenance

Taking the corrective action only when the system/sub-system/components have failed completely, is termed as Breakdown Maintenance. It normally requires the replacement of the failed parts. The main theme of the Breakdown maintenance is “Don’t fix it if it isn't broken”.

This is also known as “Run to Failure” strategy. This is predominantly used as Maintenance Strategy in following cases: -

a) where the failure does not affect the production schedule or availability of the assets significantly or
b) where the Redundancy is available.

Breakdown Maintenance is also known as reactive maintenance when the maintenance actions are initiated after the complete failure of the parts or the components. The major difference between the “Corrective Maintenance” and the “Breakdown Maintenance” is that the corrective maintenance involves correction of the identified faults, and in some cases, it involves the complete failure and then the replacement of the part; whereas the breakdown Maintenance is applicable only when the failure has happened.

Example: - STP treated water discharge pumps. This always come as a set of two to provide redundancy to the system. So instead of planning a PM or spending money on condition monitoring like in the case of the Hydraulic Pumps, the pumps can be run on alternate basis and when one fails the other will take care of the operation till the time the failed pump is repaired or replaced.

9.6.3 Preventive Maintenance

Maintenance Management strategy in which the maintenance activities are carried out in a planned and scheduled way so that the faults/failures do not occur at all, is known as Preventive Maintenance (PM). The planning and scheduling of PM can either be based on the presence of any special conditions or on a fixed periodicity based on the OEM recommendations or the past experience.

On-Condition PM is carried out when any specific pre-set conditions appear. For example, the control charts indicate that the machine is not performing as intended and if corrective action not taken, the failure rate of the production may increase. On-Condition PM evolved, and later became Condition-Based-maintenance (CBM), where the machine health is monitored continuously. As the On-Condition PM maintenance is aimed at preventing the future faults, this is mainly considered under Corrective/Improvement Maintenance.

On-Schedule PM is largely accepted everywhere as the Preventive Maintenance, and it is also known as Planned Preventive Maintenance. It is a method for preventing damage to equipment by periodically replacing parts based on time of use and carrying out minor maintenance and inspections on a pre-determined schedule.

For effective prevention of the failure, the four basic maintenance activities (CLIT – Clean, Lubricate, Tighten and Inspect) are required to be planned and then scheduled on a fixed periodicity. Hence, this is also known as Time Based Maintenance, Planned Maintenance or Planned Preventive Maintenance.

The major difference between the “Corrective Maintenance” and the “Preventive Maintenance” is that the corrective maintenance involves actions carried out post-facto (i.e., after noticing the abnormalities or after the failure has already happened); whereas Preventive Maintenance involves the activities carried out in a planned and scheduled way so that the faults/failures do not occur at all.

9.6.4 Condition-Based-maintenance

Condition-based maintenance (CBM) is a maintenance strategy that monitors the actual condition of an asset to decide what maintenance needs to be done. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure. Checking a machine for these indicators may include non-invasive measurements, visual inspection, performance data and scheduled tests. Condition data can then be gathered at certain intervals, or continuously (as is done when a machine has internal sensors). Condition-based maintenance can be applied to mission critical and non-mission critical assets.

Unlike in planned maintenance (PM), where maintenance is performed based upon predefined scheduled intervals, condition-based maintenance is performed only after a decrease in the condition of the equipment has been observed. Compared with preventive maintenance, this increases the time between maintenance repairs, because maintenance is done on an as-needed basis.

The goal of condition-based maintenance is to monitor and spot upcoming equipment failure so maintenance can be proactively scheduled when it is needed – and not before. Asset conditions need to trigger maintenance within a long enough time period before failure, so work can be finished before the asset fails or performance falls below the optimal level.

There are various types of condition-based monitoring techniques. Here are a few common examples:

- Vibration analysis: Rotating equipment such as compressors, pumps and motors all exhibit a certain degree of vibration. As they degrade, or fall out of alignment, the amount of vibration increases. Vibration sensors can be used to detect when this becomes excessive.
- Infrared: IR cameras can be used to detect high-temperature conditions in energized equipment
- Ultrasonic: Detection of deep subsurface defects such as boat hull corrosion
- Acoustic: Used to detect gas, liquid or vacuum leaks
- Oil analysis: Measures the number and size of particles in a sample to determine asset wear
- Electrical: Motor current readings using clamp on ammeters
- Operational performance: Sensors throughout a system measure pressure, temperature, flow etc.

9.6.5 Predictive Maintenance

Predictive maintenance is the next level of Condition Monitoring or the Condition-based Maintenance.

It is a method for preventing damage to equipment by replacing parts based on the prediction of the remaining useful life of the parts. For effective prevention of the failure, critical performance parameters such as Vibration, temperature etc can be recorded and used to determine the remaining useful life. Then, based on the prediction of failure, arrived out of this data, parts can be replaced just before failure.

Example: - High Precision Grinding Wheel Spindle: - Replacement of the bearings on timely basis to ensure the accuracy may cause damages to the bearing housing. The number of replacements can be significantly reduced if the vibration/noise of the bearings is monitored and replaced just before failure.

Predictive Maintenance techniques detect anomalies in equipment before those turn into system-critical failures, allowing maintenance to be scheduled before the equipment actually breaks down. This increases equipment uptime, reduces overall maintenance costs and allows optimization of spare part inventory by enabling preventive maintenance based on the equipment’s actual needs.

Predictive maintenance builds off the strengths of both preventive and condition-based strategies. With this type of maintenance, a computerized system predicts when maintenance will be needed using historical data and sensor measurements such as temperature, vibration and noise. The benefit of predictive maintenance is that maintenance work can be scheduled in advance while maximizing the life of assets. The downside is that predictive technology can be costly up front.

The major difference between the “Predictive Maintenance” and the “Preventive Maintenance” is that in the Preventive Maintenance, maintenance tasks such as replacement of the parts are carried out on a fixed pre-determine schedule irrespective of the usage of the parts/ balance useful life. Whereas, in the predictive maintenance, the balance useful life is predicted through vibration or temperature monitoring techniques, and the parts are replaced just in time.

The difference between Predictive maintenance and CBM is that the Predictive Maintenance uses sensor data to anticipate when maintenance is needed; whereas CBM only gives alerts when equipment begins to display problems. In other words, the data generated by CBM when analysed to provide the details on the prediction of failure, it becomes Predictive Maintenance.

9.6.6 Reliability Centred Maintenance (RCM)

RCM was developed in aircraft industry. Its history traces back to the development of PM programme for jumbo jet 747 by United Airlines in 1968, in the form of MSG-1 (Maintenance Steering Group-1) PM document. Stanley

Nowlan, Horward Heap, Bill Mentzer and Tom Matteson were the leaders and pioneers of the MSG-1 document. Success of MSG-1 paved the way of MSG-2 and MSG-3. Later US Department of Defence (DOD) commissioned Nowlan and Heap to produce a detailed report of MSG concept, which became the first published document that recognised RCM as a logical discipline for the development of scheduled preventive maintenance programme.

Nowlan and Heap's RCM report (1978) is considered as the RCM bible. Later, Smith, M.A and Hinchcliffe, G.R. and Moubray, J, through various publications, asserted that RCM can be applied for industries other than aircraft industry. Thus, a new era of RCM started. Under the guidance of RCM book series from John Moubray, as well as from Anthony M. Smith, and Military Standards such as MIL standards 1629A, 2173AS and 3034; many process industries, gas & oil industries and steel plants successfully implemented RCM.

Smith, M.A. and Hinchcliffe, G.R. defined RCM as a maintenance analysis process that must have all features mentioned below:

- Preserve functions
- Identify failure modes that can defeat the functions
- Prioritise function need
- Select applicable and effective PM tasks for the high priority failure modes.

Figure 9.6 shows a simple line diagram for the RCM process proposed by Nowlan, F.S. and Heap, H.F. and Moubray, J.

RCM Programme acknowledges three types of maintenance tasks; these are shown in Table 9.2

Table 9.2 Maintenance Tasks

Time-directed tasks (Preventive Maintenance)	scheduled when appropriate
Condition-directed or Predictive Testing & inspection directed tasks	performed when conditions indicate they are needed
Failure finding tasks (Pro-active maintenance)	detect hidden functions that have failed without giving evidence of failure, and these are normally time directed

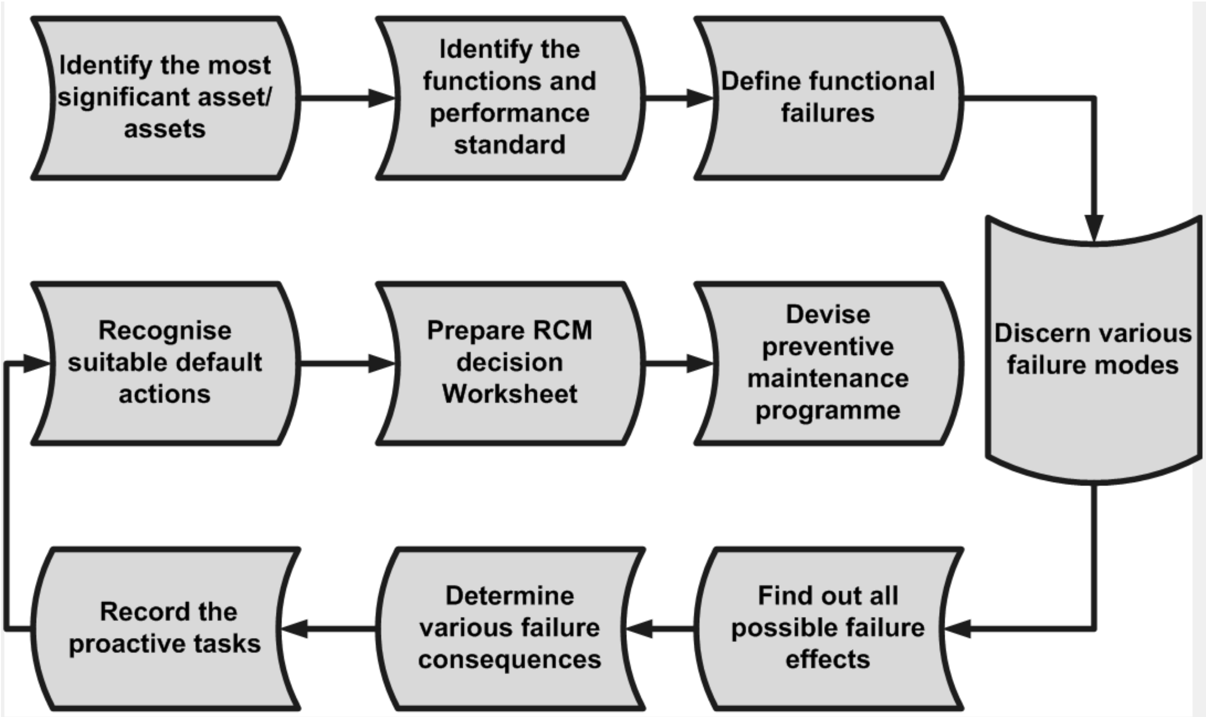


Figure 9.6 RCM Process

PM task selection in the RCM process requires that each task should be applicable and effective. MIL Standard 3034 explains that applicable tasks will prevent or extenuate failure, notice onset of failure, or discover a hidden failure; whereas, effective tasks are the most economical options among the available ones. If no applicable task exists, then the only alternative is Run-To-Failure (RTF). Likewise, if the cost of an applicable PM task surpasses the cumulative costs involved with the failure, then the effective task option will be RTF. The exception to this rule would be safety-related failure mode, where a design modification may be mandatory.

MIL-STD-2173-AS has given a great detail of the RCM tasks, and it has classified maintenance tasks in following categories:

a) Servicing/Lubrication
b) On-condition tasks
c) Hard Time tasks (Rework or Discard)
d) Combination of on-condition and hard time tasks
e) Failure finding tasks.

Thus, RCM provides a complete strategy to decide what should be done, and when, why and how it should be done.

9.6.7 Total Productive Maintenance (TPM)

The concept of plant maintenance with total participation, TPM, was originated in 1971 by the plant maintenance committee of the Japan Management Association, which in 1981 became the Japan Institute of Plant Maintenance (JIPM). TPM was conceptualised in Japan to support the Lean manufacturing practices. According to Nakajima, the founder father of the TPM concept, TPM is a combination of the American Preventive Maintenance and the Japanese Total Quality Management concepts.

Ahuja, I.P.S, defined TPM as “an innovative maintenance approach that optimises equipment effectiveness, eliminates breakdown and promotes autonomous maintenance by operators through day-to-day activities involving total work force”. The three words in the term TPM suggest following:

Total = Every aspect needs to be considered, and everybody from top to the bottom need to be involved.

Productive = There should not be any interruption to the production, and things required to be done should be done in a way that it offers least troubles to the production.

Maintenance = All the equipment must be kept working autonomously with the little acceptable time for the required maintenance.

In his pioneer book, Nakajima, S, mentioned that the complete definition of the TPM includes five elements, as shown in Figure 9.7.

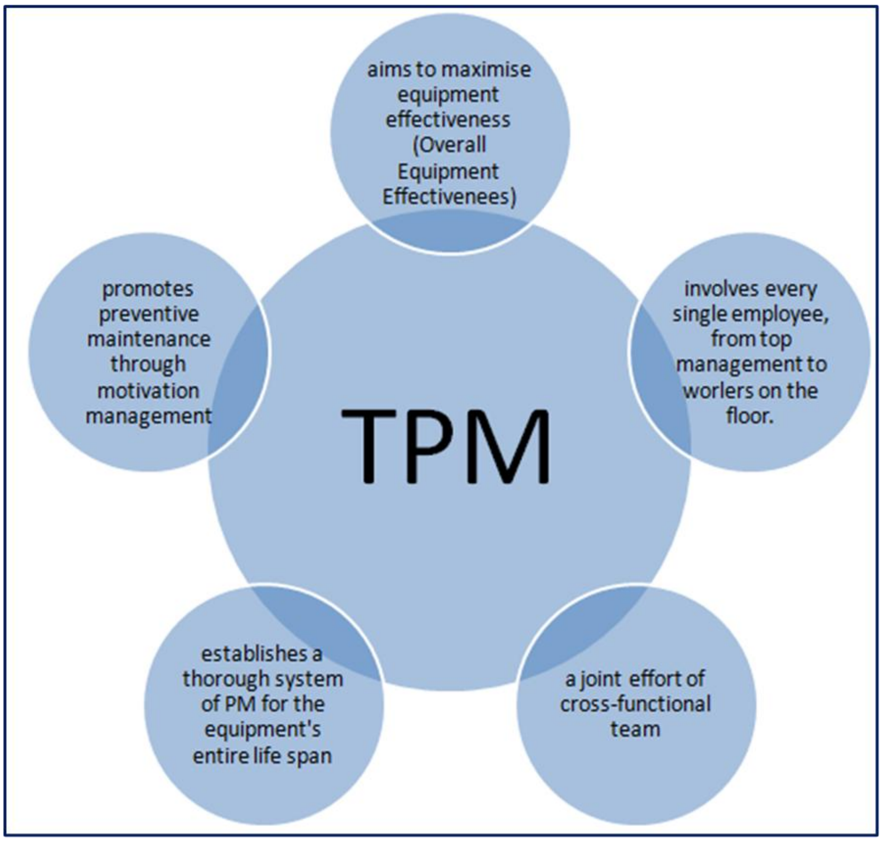


Figure 9.7 Elements of TPM Definitions

TPM model, given by JIPM, consists of 8 pillars standing on the foundation of 5-S. Figure 9.8 shows the traditional TPM model.

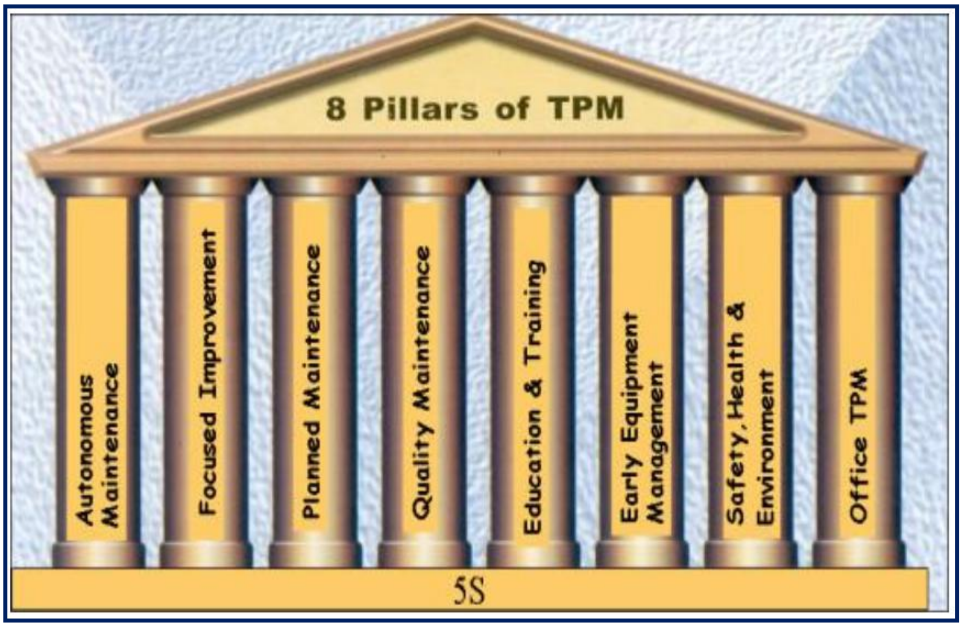


Figure 9.8 Pillars of TPM

Willmott, P, identified a nine-step plan, as shown in Figure 9.9, to bring improvement through TPM process. This improvement plan has three distinct cycles (See Table 9.2: -

Table 9.2 Cycles in TPM Process

Condition Cycle	Identifies the existing condition of the asset and looks for the areas needing improvement.
Measurement Cycle	Assesses the present effectiveness of the asset and provides a baseline for the measurement of future improvements.
Improvement Cycle	Monitors the losses and ensures that the restored condition of the assets keeps on increasing.

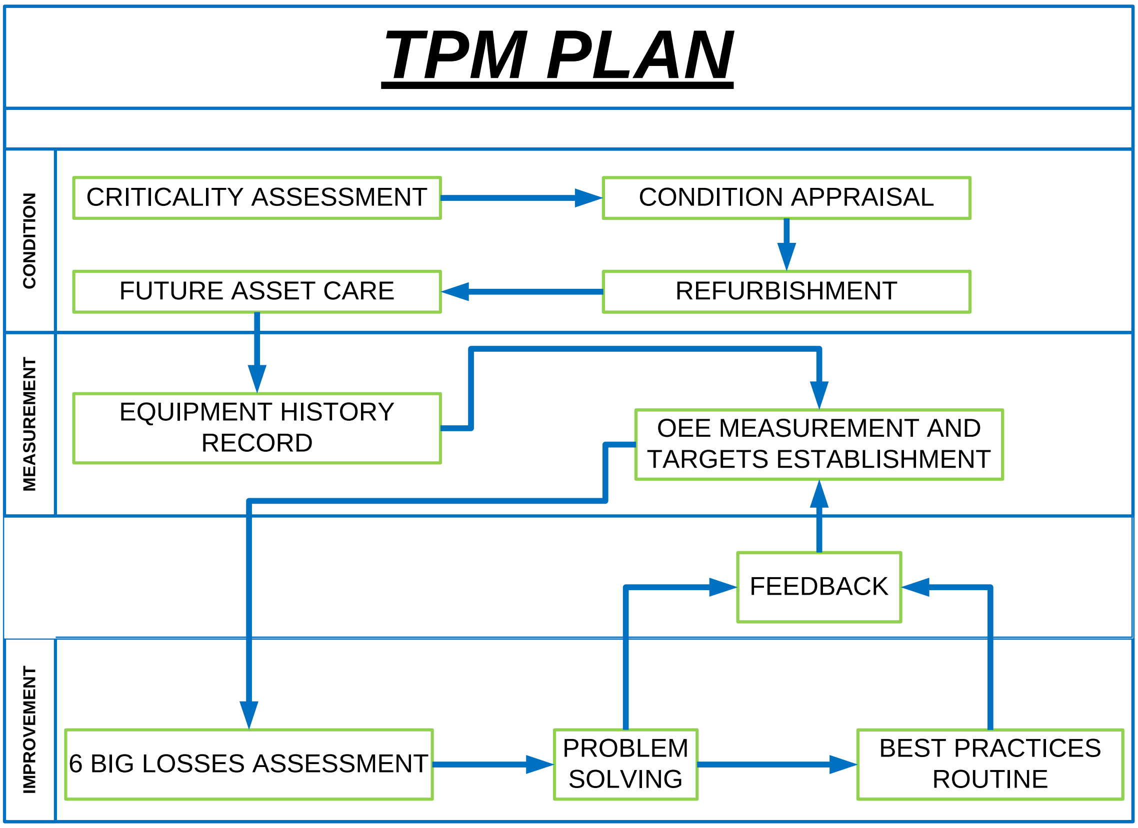


Figure 9.9 TPM Plan

Nakajima, S and Willmott, P, mentioned that the goal of TPM is to effect fundamental improvement within a company by improving men and machines' utilisation, by identifying and eliminating indirect losses, commonly known as six big losses (Table 9.3), by changing people's attitude and by increasing their skills, motivation and competency TPM maximises the equipment effectiveness and operation, and the improvement in Overall Equipment Effectiveness (OEE) directly provides a measure of the success of the TPM programme.

Table 9.3 Six Big Losses

S.No	Losses	Affected OEE factor
1	Breakdown losses	AVAILABILITY
2	Setup and adjustment losses	
3	Idling and minor stoppage losses	PERFORMANCE
4	Reduced speed losses	
5	Quality defect and rework losses	QUALITY
6	Start-up losses	

9.7 Concept of Overall Equipment Effectiveness (OEE)

OEE was launched as a quantitative metric to evaluate the performance of TPM programs, and now it has been recognized as a fundamental method for measuring the plant performance. Production losses, together with other indirect and hidden costs, constitute the majority of the production costs. Nakajima suggested that using OEE as a measure can reveal these hidden costs.

OEE is a measure of total equipment performance in terms of the degree to which the asset is doing what it is supposed to do. It is a three-dimensional analysis tool for analysing the performance of equipment based on actual availability, performance efficiency and quality of product or output.

In the simplest form, OEE of a machine can be defined as the ratio of the valuable operating time to the available operating time. Valuable operating time is the time for which a machine is engaged in producing acceptable products at the desired rate. This definition can become clearer by a close look at Figure 9.10.

OEE can be calculated using following equation: -

OEE = AVAILABILITY x PERFORMANCE x QUALITY

- Availability Factor measures productivity losses from down time (events that stop planned production for an appreciable amount of time).
- Performance factor measures losses from slow cycles (factors that cause the process to operate at less than the maximum possible speed).
- Quality factor measures losses from manufactured parts that do not meet quality requirements.

Nakajima as well as Willmott stressed that the indirect costs or lost opportunity cost of ineffective and inadequate maintenance share a significant portion in the total maintenance costs, and they are harder to measure because they are less obvious or hidden. These indirect or hidden costs include losses, which are shown in the tableThese losses are commonly known as the six big losses.

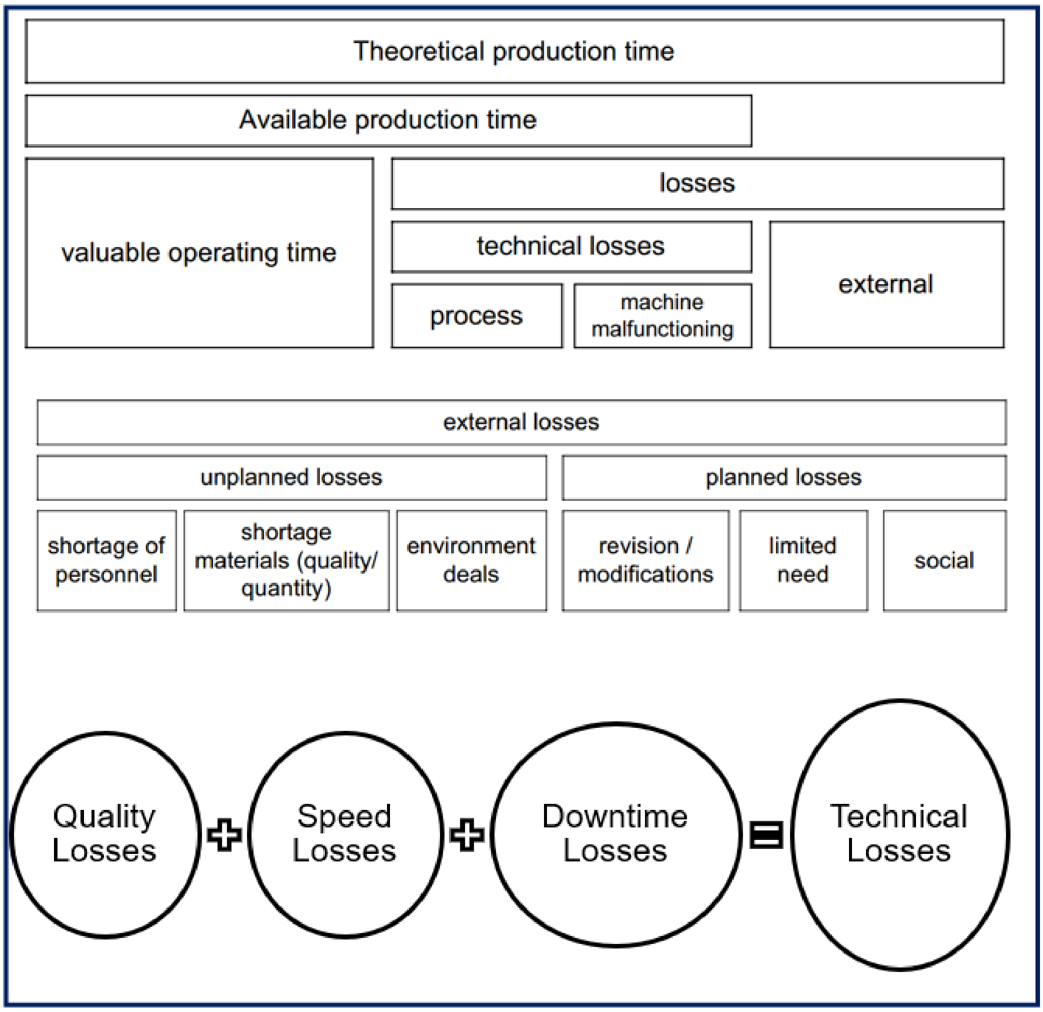


Figure 9.10 Components of OEE

9.7.1 Why OEE is preferred as a key business driver?

Griffiths and Tucker documented following reasons for choosing OEE as a key business driver:

1) It is an overall measure of how well physical assets are being used, and makes allowances for different product mixes.
2) It forces businesses to analyse and define physical capacity.
3) It is a consistent measure, and is not superseded by capital development.
4) It develops improvement programmes through reduction of six big losses, and enables areas for improvement to be targeted more effectively.
5) It promotes team-work attitudes and continuous improvement attitudes.
6) It is a proven methodology.
7) It blurs the functional boundaries between operations and maintenance.
8) It is easy to understand.

9.7.2 World class OEE figures

Nakajima suggested that the ideal conditions indicate:

Availability > 90%

Performance Efficiency > 95%

Rate of quality products > 99%

And hence **OEE > 85%**

Above mentioned figures are globally accepted benchmarks, and, hence, can safely be assumed as world class figures.

9.7.3 OEE improvement through TPM

The ultimate goal of TPM is to effect fundamental improvement within a company by improving worker and equipment utilisation. In order to eliminate the six big losses, TPM changes people’s attitude and increase their skills. Increasing their motivation and competency TPM maximises the equipment effectiveness and operation. Thus, the improvement in OEE directly provides a measure of the success of the TPM programme.

There are many case studies telling the success stories of TPM in improvement of OEE. All these case studies have a couple of common findings, which are listed below:

a) OEE can be improved through TPM only when TPM is implemented appropriately, and all the pillars' performance is ensured.

b) OEE improvement through TPM is only possible when the management commitment is ensured.

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