LECTURE NOTES
ON
Production Operation Management
2018 – 2019
IV B. Tech I Semester (JNTUA-R15)
Mr. G Parosh, Assistant Professor

CHADALAWADA RAMANAMMA ENGINEERING COLLEGE
(AUTONOMOUS)
Chadalawada Nagar, Renigunta Road, Tirupati – 517 506
Department of Mechanical Engineering
UNIT – I

INTRODUCTION

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

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

Production/operations management is the process, which combines and transforms various resources used in the production/operations subsystem of the organization into value added product/services in a controlled manner as per the policies of the organization. Therefore, it is that part of an organization, which is concerned with the transformation of a range of inputs into the required (products/services) having the requisite quality level.

The set of interrelated management activities, which are involved in manufacturing certain products, is called as production management. If the same concept is extended to services management, then the corresponding set of management activities is called as operations management.

Production function is that part of an organization, which is concerned with the transformation of a range of inputs into the required outputs (products) having the requisite quality level. Production is defined as “the step-by-step conversion of one form of material into another form through chemical or mechanical process to create or enhance the utility of the product to the user.” Thus production is a value addition process. At each stage of processing, there will be value addition.

Edwood Buffa defines production as ‘a process by which goods and services are created.’ Some examples of production are: manufacturing custom-made products like, boilers with a specific capacity, constructing flats, some structural fabrication works for selected customers, etc., and manufacturing standardized products like, car, bus, motor cycle, radio, television, etc.

The production system of an organization is that part, which produces products of an organization. It is that activity whereby resources, flowing within a defined system, are combined and transformed in a controlled manner to add value in accordance with the policies communicated by management.

The production system has the following characteristics:

1. Production is an organized activity, so every production system has an objective.
2. The system transforms the various inputs to useful outputs.
3. It does not operate in isolation from the other organization system.
4. There exists a feedback about the activities, which is essential to control and improve system performance.

Components of a system: The input, processing, output and control of a system are called the components of a system

Control: There are two types of control, namely Proactive Control and Reactive Control.

There are three types of feedback mechanisms such as feed forward control, feedback control and concurrent control

1.2 What is Production and operations management?
In any manufacturing system, the job of a Production Manager is to manage the process of converting inputs into the desired outputs.

It is concerned with the production of goods and services, and involves the responsibility of ensuring that business operations are efficient and effective.

It is also the management of resources, the distribution of goods and services to customers.

Therefore, Production Management can be defined as the management of the conversion process, which converts land, labor, capital, and management inputs into desired outputs of goods and services. It is also concerned with the design and the operation of systems for manufacture, transport, supply or service.

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

   If it is a product centric that is known as production,

   If it is a service centric then that is known as operation

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

1.4.1 Components of a production system:

There are two components for a production system such as:

1. Facilities – the factory and equipment in the facility and the way the facility is organized (plant layout)

2. Manufacturing support systems – the set of procedures used by a company to manage production and to solve technical and logistics problems in ordering materials, moving work through the factory, and ensuring that products meet quality standards
1.8 Classification of production system

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

Type of production – Job shop production, Batch production, Mass production

Size of the plant – Large size plant (eg. Oil refinery), Medium size plant, Small size plant (eg. Printing press)

Type of product- Complex to manufacture (Aircraft) and simple to manufacture

Physical flow of material – Automated flow, Semi-automated flow and Manual flow

Nature of order/demand pattern – Stable demand, unstable demand

Variety of jobs – More variety (eg. Automobiles/electronic goods), One variety (eg. Oil refinery)

1.8.1 Job shop production

Characterized by make-to-order strategy

There are three possible situations for production quantity

Product is manufactured only once

Small quantities of product are repeated at irregular time intervals

Small quantities of product are repeated at regular time intervals

In Job shop production, first and second situations are common.

End product is most of the time as per the customer need.

No standard methods and time standards can be developed as the job is not regularly produced.

Machines and resources must be of general purpose and flexible.
Highly skilled workforce is needed to work on product variety.

In-process inventory is high.

Machines are grouped as per their functional capabilities.

System is flexible

Planning and control is very difficult.

Job-shops are typically inefficient and have long lead times, large work-in-process inventory and high costs.

Example: Commercial printer, Boiler manufacture, tailoring shop

1.8.2 Batch production

Batch of identical articles are manufactured

The demand rate is lesser than the rate of production and hence batch production method is traditionally adopted

There is a built-up of inventory in batch production

There are three possible situations

A batch is manufactured only once (make-to-order)

Batch is repeated at irregular time intervals (make-to-order)

Batch is repeated at regular time intervals (make-to-stock)

Final product is usually standard. The basic design is same.

Such production of standardized items on a continuous basis is called repetitive production.

Customer may be external or internal. For example, in an automobile plant, the engine assembly plant will be an internal customer for gear assembly plant)

Machines and resources must be of general purpose or semi-automated.

Skilled workforce is needed to work on product variety.

Less supervision is need in comparison with job-shop

Less flexible than job-shop

Machines are grouped as per their functional capabilities.

1.8.3 Mass production

The demand rate is more than the rate of production.

Similar product is manufactured and hence, standard method and time standard is to be analyzed.

Most of the machines used in mass production are special purpose.
The equipment is dedicated to the manufacture of a single product type such as light bulbs, medicines etc.

The system is capital intensive and a long term planning needed before the investment.

Semi-skilled labour is only needed as the product design is similar mostly.

This system is a rigid production system.

**Figure 1.5 Process flexibility Vs. Product variety**

1.9 Product design

Product design is the process of deciding on the unique characteristics and features of the company’s product. Process selection is the development of the process necessary to produce the designed product. Product design and process selection are typically made together. Product design must support product manufacturability (the ease with which a product can be made). Product design defines a product’s characteristics of appearance, materials, dimensions, tolerances, and performance standards.
Service design is unique in that the service and entire service concept are being designed. When a service is designed, the designer must define both the service and service concept.

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

1.9.1 Phases of product development

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

Phase 0: Planning

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

Phase 1: Concept Development

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

Phase 2: System-Level design

System level design includes product architecture and decomposition of products into sub-systems and components.
- Final assembly of the product is decided
- Geometric layout of the product
- Functional specification of each of the layout sub-system
- Preliminary process flow diagram for final assembly process

Phase 3: Design Detail

Complete specification of the geometry, materials, and tolerances of all the unique parts in the product.
- Identification of standard parts
- Tooling is designed

Phase 4: Testing and Refinement

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

- Will product work?
- Whether product satisfies customer needs

Phase 5: Production Ramp-up

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

1.10 Economic analysis of product development

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

Operational design and development decisions – should we outsource to save time? Should we launch the product in four months at a unit cost of 10000 INR or wait for six months, when we can reduce to 8500 INR?

Go/no-go milestones – should we try to develop a product to address market opportunity? Should we proceed? Should we launch?

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

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

1.10.1 Break-even analysis

Break-even analysis is a technique widely used in production management. It is based on categorizing production costs between those which are "variable" (costs that change when the production output changes) and those that are "fixed"
The variable and fixed costs are compared with sales revenue in order to determine the level of sales volume, sales value or production at which the business makes neither a profit nor a loss (the "break-even point").

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

Figure 1.7a Break-even chart

The point at which neither profit nor loss is made is known as the "break-even point (BEP)" and is represented on the break-even chart by the intersection of the lines representing total cost and total revenue.

As output increases, variable costs incurred increases, meaning that total costs (fixed + variable) also increase. At low levels of output, costs are greater than revenue or income. At the point of intersection, BEP, total costs are exactly equal to total revenue or income, and hence neither profit nor loss is made.

Examples of fixed costs:
- Rent and rates
- Depreciation
- Research and development
- Marketing costs (non-revenue related)
- Administration costs

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

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

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

Computation of Break-even point:
BEP is the quantity of goods; the company needs to sell to cover its costs.

Where, \( Q_{BE} \) – Break even quantity

\( F \) – Fixed costs

\( SP \) – selling price/unit

\( VC \) – Variable cost

Break-even analysis also includes calculating

Total cost = sum of fixed cost and variable cost

Total cost (\( TC \)) = \( F + (VC) \times Q \)

Revenue – amount of money brought in from sales

Revenue (\( TR \)) = \( SP \times Q \)

\( Q \) = number of units sold

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

It is a very comprehensive concept, both in its aim and also in its operational content. It is a matter of common knowledge that higher productivity leads to a reduction in cost of production, reduces the sales price of an item, expands markets, and enables the goods to compete effectively in the world market. In fact the strength of a country, prosperity of its economy, standard of living of the people and the wealth of the nation are very largely determined by the extent and measure of its production and productivity. By enabling an increase in the output of goods or services for existing resources, productivity decreases the cost of goods per unit, and makes it possible to sell them at lower prices, thus benefiting the consumers while at the same time leaving a margin for increase in the wages of the workers. Productivity can be defined in many ways. Some of them are as follows:

Productivity is nothing but the reduction in wastage of resources such as labour, machines, materials, power, space, time, capital, etc.

Productivity can also be defined as human endeavor (effort) to produce more and more with less and less inputs of resources so that the products can be purchased by a large number of people at affordable price.

Productivity implies development of an attitude of mind and a constant urge to find better, cheaper, easier, quicker, and safer means of doing a job, manufacturing a product and providing service.

Productivity aims at the maximum utilization of resources for yielding as many goods and services as possible, of the kinds most wanted by consumers at lowest possible cost.
Productivity processes more efficient works involving less fatigue to workers due to improvements in the layout of plant and work, better working conditions and simplification of work. In a wider sense productivity may be taken to constitute the ratio of all available goods and services to the potential resources of the group.

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

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

This productivity measurement technique is used when the firm is interested to know the productivity of a group of input factors but not all input factors.

1.9 SCOPE OF PRODUCTION AND OPERATIONS MANAGEMENT

Production and operations management concern with the conversion of inputs into outputs, using physical resources, so as to provide the desired utilities to the customer while meeting the other organizational objectives of effectiveness, efficiency and adoptability. It distinguishes itself from other functions such as personnel, marketing, finance, etc., by its primary concern for ‘conversion by using physical resources.’ Following are the activities which are listed under production and operations management functions:

1. Location of facilities
2. Plant layouts and material handling
3. Product design
4. Process design
5. Production and planning control
6. Quality control
7. Materials management
8. Maintenance management.

PRODUCT DESIGN

Product design deals with conversion of ideas into reality. Every business organization has to design, develop and introduce new products as a survival and growth strategy. Developing the new products and launching them in the market is the biggest challenge faced by the organizations.
The entire process of need identification to physical manufacture of product involves three functions: marketing, product development, and manufacturing. Product development translates the needs of customers given by marketing into technical specifications and designing the various features into the product to these specifications. Manufacturing has the responsibility of selecting the processes by which the product can be manufactured. Product design and development provides link between marketing, customer needs and expectations and the activities required to manufacture the product.

**PROCESS DESIGN**

Process design is a macroscopic decision-making of an overall process route for converting the raw material into finished goods. These decisions encompass the selection of a process, choice of technology, process flow analysis and layout of the facilities. Hence, the important decisions in process design are to analyze the workflow for converting raw material into finished product and to select the workstation for each included in the workflow.

**PRODUCTION PLANNING AND CONTROL**

Production planning and control can be defined as the process of planning the production in advance, setting the exact route of each item, fixing the starting and finishing dates for each item, to give production orders to shops and to follow up the progress of products according to orders.

The principle of production planning and control lies in the statement ‘First Plan Your Work and then Work on Your Plan’. Main functions of production planning and control includes planning, routing, scheduling, dispatching and follow-up.

Planning is deciding in advance what to do, how to do it, when to do it and who is to do it. Planning bridges the gap from where we are, to where we want to go. It makes it possible for things to occur which would not otherwise happen.
Routing may be defined as the selection of path which each part of the product will follow, which being transformed from raw material to finished products. Routing determines the most advantageous path to be followed from department to department and machine to machine till raw material gets its final shape.

Scheduling determines the programme for the operations. Scheduling may be defined as the fixation of time and date for each operation as well as it determines the sequence of operations to be followed.

Dispatching is concerned with the starting the processes. It gives necessary authority so as to start a particular work, which has already been planned under ‘Routing’ and ‘Scheduling. Therefore, dispatching is ‘release of orders and instruction for the starting of production for any item in acceptance with the route sheet and schedule chart.

AGGREGATE PLANNING

Aggregate planning is intermediate-range capacity planning used to establish employment levels, output rates, inventory levels, subcontracting, and backorders for products that are aggregated, i.e., grouped or brought together. It does not specifically focus on individual products but deals with the products in the aggregate.

For example, imagine a paint company that produces blue, brown, and pink paints; the aggregate plan in this case would be expressed as the total amount of the paint without specifying how much of it would be blue, brown or pink. Such an aggregate plan may dictate, for example, the production of 100,000 gallons of paint during an intermediate-range planning horizon, say during the whole year. The plan can later be disaggregated as to how much blue, brown, or pink paint to produce every specific time period, say every month.

Achieving a balance of expected supply and demand is the goal of aggregate planning. Informal graphical techniques, as well as mathematical techniques are used by decision makers to handle aggregate planning.

Informal Techniques

Planners often use graphs or tables to compare current capacity with projected demand requirements. The informal techniques provide some general information and insight but not the specific aggregate production details. The graphs below depict aggregate planning using Level and Chase Strategies.

In case of Level Strategy, production is uniform whereas in case of Chase Strategy, production chases the demand by fluctuating the work-force or work-force utilization. Organizations must compare work-force fluctuation costs with inventory costs to decide which strategy to use. Level Strategy is used when inventory costs are low as compared to the costs of fluctuating the work force and when efficient production is the primary goal. When inventory costs are high as compared to work force fluctuation costs, Chase Strategy is used, although it is less efficient for production.

Aggregate Planning Strategies

Apart form the production strategies such as Level and Chase Strategies, we also have planning strategies.

There are three major strategies associated with aggregate planning:

1) Product variations due to hiring, firing, overtime, or under time,

2) Permitting inventory levels to vary, and

3) Subcontracting
An example depicting these strategies is presented below along with some sample computations of the costs associated with these strategies:

Level production is 300. Backorders are permitted. Initial Inventory is 70 units. 200 units are to be subcontracted for Period 6. Costs are as follows:

<table>
<thead>
<tr>
<th>Product Variations</th>
<th>Inventory</th>
<th>Subcontracting</th>
<th>Shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$20/unit</td>
<td>$3/unit/period</td>
<td>$25/unit</td>
<td>$7/unit/period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>DEMAND</th>
<th>REGULAR</th>
<th>OVER</th>
<th>UNDER</th>
<th>BEGIN</th>
<th>END</th>
<th>AVG</th>
<th>SUBCONTRACT</th>
<th>SHORTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350</td>
<td>200</td>
<td>-</td>
<td>100</td>
<td>70</td>
<td>0</td>
<td>35</td>
<td>-</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>250</td>
<td>-</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
<td>250</td>
<td>-</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>130</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>400</td>
<td>100</td>
<td>-</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>350</td>
<td>150</td>
<td>-</td>
<td>150</td>
<td>20</td>
<td>0</td>
<td>10</td>
<td>-</td>
<td>180</td>
</tr>
<tr>
<td>6</td>
<td>300</td>
<td>350</td>
<td>50</td>
<td>-</td>
<td>0</td>
<td>70</td>
<td>35</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

**Costs For The Above Plan:**

Product Variations . . . . . . . 500 x $20 = $10,000

Inventory . . . . . . . . . . . . 90 x $3 = $ 270

Subcontracting . . . . . . . . 200 x $25 = $ 5,000

Shortage . . . . . . . . . . . . . 520 x $7 = $ 3,640

Total . . . . . . . . . . . . . . . $18,91
Rough-cut Capacity Planning

Aggregate planning is based on a general production plan that deals with how much capacity will be available and how it will be allocated. A rough-cut capacity plan can be developed to evaluate the work load that a production plan imposes on work centers.

Although a trial production plan is often used for rough-cut capacity planning, a trial master production schedule can be used too. The example below shows the application of rough-cut capacity planning based on a trial master schedule.

**MASTER PRODUCTION SCHEDULE**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>PRODUCT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>180</td>
<td>240</td>
<td>300</td>
<td>420</td>
<td>350</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>210</td>
<td>220</td>
<td>240</td>
<td>230</td>
<td>220</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>500</td>
<td>480</td>
<td>450</td>
<td>440</td>
<td>420</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>310</td>
<td>330</td>
<td>380</td>
<td>410</td>
<td>480</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Below is a bill of labor which lists the hours required in each department to make one unit of product.

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>DEPARTMENT</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>0.4</td>
<td>0.2</td>
<td>0.7</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.1</td>
<td>0.6</td>
<td>0.4</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>1.1</td>
<td>0.3</td>
<td>0.7</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
Develop capacity requirements for the following combinations:

<table>
<thead>
<tr>
<th>Sl.no</th>
<th>MONTH</th>
<th>DEPARTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>22</td>
</tr>
</tbody>
</table>

The solution is outlined below:

\[
\begin{align*}
\text{a. } & 240(1.1) + 220(0.3) + 480(0.7) + 330(0.6) = 864 \text{ hours} \\
\text{b. } & 420(0.4) + 230(0.2) + 440(0.7) + 410(0.5) = 727 \text{ hours} \\
\text{c. } & 260(0.5) + 200(0.0) + 400(0.4) + 500(0.6) = 590 \text{ hours} \\
\text{d. } & 300(0.1) + 240(0.6) + 450(0.4) + 380(0.9) = 696 \text{ hours} \\
\end{align*}
\]

For example, we must have at least 864 hours available in Department 33 for Month 2 to meet capacity requirements. Suppose that we only have 640 man hours available in Department 33 in Month 2. Then, we can use aggregate planning strategies such as hiring, overtime, etc. to bring the capacity up to the required amount of 864 man or machine hours in order to comply with master production schedule. Note that this 864 hours is greater than the actual number of hours in a month (24 hours /day x 30 days / month = 720 hours / month). We may encounter this situation often because we are talking about the man or machine hours. For example, in case of a one 8-hour shift, 20 working days per month, and 10 workers, the man hours = 8 x 20 x 10 = 1,600

**FORECASTING MODELS**

Production and Inventory control activities:

A few years ago, a small test equipment manufacturer in Bombay received a corporation directive to improve their business operations.

With the help of a consultant, they decided to discard their manual production control system and undertake a five-phase program to gain better control of their costs. Here’s what happened.

- The material requirements, estimated costs and inventory records were computerized within four months, they began to check actual inventories against the computerized data base and analyze any variances.
- The general ledger and financial data were integrated into the system a month later.
- Ten months after that, the payroll and labor distribution information was transferred from their bank to the system;
• It was automatically interfaced to the job costing system. Finally, the order entry information and invoicing was incorporated.

The manufacturing control system took about two years to implement and saved the firm Rs. 152000/- in the first year of operations.

In the second chapter we had discussed on the operations strategy, which is embodied in the long range operations/production plan.

While all elements of operations management are important, I view forecasting as one of the key elements in the operations structure. In this chapter, helps us to recognize the models and when to use for our needs.
Forecast of a product is an estimate of its future demand. However, it is not a prediction. A forecast is however based upon scientific analysis of past data, if available and by other techniques.

Once these are in place, the fundamental structure of the operation function is established.

Before, resources can be planned but, it is critical to estimate or forecast long-range and short-range demand for products and services.

These forecasts guide the strategic allocation of resources. Based on the expected levels of demand, decisions are made concerning product, process and service designs, facility capacity, location and layout, operations technologies and allocation of operations resources. Other issues involving the strategic allocation of resources include managing quality, planning service operations and managing projects.

Forecasting meals on airline flights

Providing in-flight meals to the airline passengers is big business.

Few companies’ which have business are listed below

Northwest airlines and continental’s food budget per year: $300 million dollars

Delta serves about 135,000 meals per day

American airlines spends around $800 million each ear on food with each meals cost is $8.20

With this huge expense, the airlines are interested in accurately forecasting the number of meals that will be needed in each flight.

Factors that make airline meal forecasting:

Passengers purchasing tickets just before a flight

Cancelled flights

Passengers no-shows

Complicate matters

Some passengers decide not to have meals,

Children can request a kid’ meals

Some passengers request special-diet meals,

First class passengers receive different meals than economy class passengers and may have two or more choices of meals.

Some flights may have 60% full and while others may be 100%
If an airline orders too many meals for a flight, extra meals must be thrown away, although some items such as boxes of cereal might be given to charity.

If it does not order enough meals, then hungry passengers may be upset and may not fly on that airline in the future.

**Shortages of meals statics:**

Last year: 1% shortage Continental had average meal shortage : 0.6% Excess meal : 3.5% At Home base: 5%

To satisfy the customers of first class passengers the airline orders 125 percent instead of 100 percent. Accurate demand forecasting is critical to providing good customer service in a cost-efficient manner. Forecasting enables his company to respond more quickly and accurately to market changes. How does forecasting relate to the management processes of planning, organizing and controlling? These processes are not independent processes. They interrelate and overlap.

If operations have been properly planned and organized, control is easier and smoother. These were forecasting comes in. Operating cost can be reduced and accurately goods and services can be estimated and this in turn improves operating efficiently increases. The figure below explains the relationships of P O C and the forecasting plan.

Fig: 2 operations and production management activities

Operations managers need long range forecasts to make strategic decisions about products, processes and facilities. They also need short-range forecasts to assist them in making decisions about operations issues that span for few days or weeks. The following table 1 shows summarizes some of the reasons why operations managers must develop forecasts.

**Some Reason Why Forecasting Is Essential in Operations Management**

New facility planning. It can take as long as five years to design and build a new factory or design and implement a new production process. Such strategic activities in POM require

Long –range forecasts of demand for existing and new products so that operation managers can have the necessary lead time to build factories and install process to produce the products and services when needed.

Production Planning. Demand for products and services vary from month to month. Production and services rates must be scaled up or down to meet these demands. It can take several months to change the capacities of production
processes. Operation managers need medium-range forecasts so that they can have the lead time necessary to provide the production capacity to produce these variable monthly demands.

Workforce scheduling. Demands for products and services vary from week to week. The workforce must be scaled up or down to meet these demands by using reassignment, overtime, layoffs, or hiring. Operations managers need short-range forecasts so that they can have the lead time necessary to provide workforce change to provide the weekly demands.

In the table 2 shows examples of things that are commonly forecasted.

Forecasting is an integral part of business planning. The inputs are processed through forecasting models or method to develop demand estimates.

Theses demand estimates are not the sales forecasts; rather, they are the starting point for management teams to develop sales forecasts.

The sales forecasts become inputs to both business strategy and production resource forecasts.

Fig: 3 Forecasting as an Integral Part of Business Planning

Forecasting is the basis of planning ahead. It involves estimating the future and the expected demand of the company’s product.

Forecasts of future demand is the company’s expectation with the outside environment that permits planning functions to commence activities.

While forecasting is not exactly planning it just puts planning action into motion.

Forecasts are estimates of the occurrence, timing, or magnitude of future events.

They give operations managers a rational basis for planning and scheduling activities, even though actual demand is quite uncertain.

WHY DO FIRMS FORECAST?
Forecasting of independent demands, item by item, is required to maintain the supply of materials for production in anticipation of future demand.

Forecast is important in case of advance commitment to procure or to produce. From forecast of demands optional plans are adapted.

Accurate projections of future activity levels can minimize short term fluctuations in production and help balance workloads.

This lessens hiring, firing, and overtime activities and helps maintain good labor relations.

Good forecasts also help managers to have appropriate levels of materials available when needed.

Forecast enable managers to make better use of facilities and give improved services to customers.

Benefits from forecasts
1. Improved employee relations
2. Improved Materials management
3. Better use of capital and facilities
4. Improved customer service

COST OF FORECASTING

As forecasting activities increases the data requirements also increases, hence increasing the cost of data collection and analysis.

The system for reporting and control must also be expanded resulting in increased cost.

On the other hand if forecasting is not done it might lead to reduced activities and result in loses in terms of unplanned labor, material, capital costs, expediting costs, and ultimately lead to lost revenues.

To gain an appreciation of the value of forecasting and an understanding of some of the more widely used techniques, we discuss the following methods of forecasting.

1. Judgmental
2. Time series
3. Exponential smoothing
4. Regression methods

FORECASTING VARIABLES

Forecasting activities are a function of the following
1. Type of forecast
2. Time horizon being forecast
3. Database available
4. Methodology employed

**Types of forecast:**

Most of the items produced in a firm do not need forecast in a formal way, because they are components, subassemblies or required services that are part of a finished product.

Forecasts should be used for end items and services that have uncertain demand. Other types of forecasts

**Purpose:**

The purpose of forecasting activities is to make the best use of the present information to guide decisions toward the objectives of the organization.

Managers should continually make decisions about:

1. Purchasing new equipment
2. Setting employment levels
3. Carrying inventories
4. Scheduling production ...etc.

There are two types of variables being forecast:

1. Controllable
2. Uncontrollable

Example: Sales of a firm is a function of both controllable variables such as advertising efforts and inventory levels where as the uncontrollable variables are competition in the market and raw-material cost.

Forecasting methodology help by providing information about the uncontrollable variables.

**Accuracy:**

Forecasts tend to be more accurate when the uncontrollable variables of a variable can be identified and isolated.

In general the more the random effects can be isolated, the better the forecast will be.

Whereas individual forecasts are susceptible to error due to spontaneous random effects (which cannot be anticipated), when several projects are aggregated together, the error effect is dissipated throughout the group, and compensating effects occur.

One product's demand may exceed the forecast, while another's might fail to meet it.

But as a whole, the aggregate forecast generally tends to be more accurate than individual product forecast.
Types of forecast:

- Example: the manager who must decide whether to invest in a computer system this year (or wait till next year) faces a different problem from the one who must decide how much inventory to place in stock. Here the former must grapple with the pace of technology whereas the latter must project future demand.

Manager must select or develop those types of forecasts that will be most useful to them in their specific area of concern.

Forecasts of demand are specifically important to operations managers because they guide the firm’s scheduling and production control activities.

Reliable forecasts enable managers to formulate material and capacity plan directing how their system will respond.

Technological forecasts are concerned with the pace of new developments in technology, such as developments in storage devices that will increase the capacity and decrease the cost of computers.

Environmental forecasts are concerned with the social, political, and economic state of the environment.

Econometric forecasts provide forecasts of the gross national product, consumer prices, unemployment, housing starts or other economic variables of particular interest to the firm.

Forecasting and operations subsystems:

In the production units – number for televisions in a plant, the number of patients fed in a hospital, the number of books circulated in a library, or the number of lots of common stock sold in a brokerage house – the resource forecasts are used to plan and control operation subsystems, as shown in figure 4. Information on most recent demand and production

Demand forecast for operations

Output of goods and services

Planning (designing) the system:

Managers need to forecast aggregate demands so they can design or redesign processes necessary to meet demand.

The degree of automation for example: Depends a great deal upon future product demand.

- Automated
- Continuous flows facilitate high production volumes
- Manual or semi automated
- Intermittent flows (batching)
The demand forecast is critical to this design decision. Once process design, product design and equipment investment decision have been made for an anticipated volume, managers are locked into a facility of specified capacity.

There may be wide variations between anticipated demand and actual demand can result in excessive production and operating cost.

Capacity planning that makes use of long-run forecasts is one of the areas in production/operations that is both critical and not well understood or developed. In the steel, power generation and other basic industries, Ex: jet aircraft, McDonnell Douglas and Airbus, facilities becomes idle some time.

Scheduling the system:
When deciding how best to use the existing conversion system, accurate demand forecasts are very important.
Managers need intermediate-run demand forecasts for three months, six months and a year into the future.
Forecast must be established from the current and future workforce levels and production rates. Job scheduling in intermittent and continuous operations is more stable if demand forecasts are accurate.

Controlling the system:
Managers need forecasts of demand to make decisions about controlling inventory, production, labor and overall costs.
Accurate forecasts are needed for the immediate future – hours, days and weeks ahead.

The demand patterns are shown in the following figures

![Graph: Steady Demands](image)

Fig: 5.1 Steady Demands
To describe the points clustered about a pattern, we use the term NOISE. We have two types of NOISE:

**LOW NOISE:** Means all or most of the points lie very close to the pattern.

**HIGH NOISE:** Means many of the points lie relatively far away from the pattern.

In decision making, we deal with devising future plans. The data describing the decision situation must thus be representative of what occurs in the future.

For example:

- An inventory control, we base our decisions on the nature of demand for the controlled item during a specified planning horizon.

- In financial planning, we need to predict the pattern of cash flow overtime.

We know forecasts are of kinds:

- Long range
- Short range

The long range is making forecasts on capacity, location, and layout. The short range makes forecasts on the individual items. The following figure shows different types of planning decisions depend on different types of information, which in turn depend on what are called the forecasting time horizons, of the future times to which the forecasting points.
Let us differentiate between Forecast and Prediction:

<table>
<thead>
<tr>
<th>Forecast</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A forecast is an estimate of a future event achieved by systematically</td>
<td>A predication is an estimate achieved through</td>
</tr>
<tr>
<td>combining and casting forward in a predetermined way data about the past.</td>
<td>consideration other than just this subjective</td>
</tr>
<tr>
<td></td>
<td>consideration.</td>
</tr>
</tbody>
</table>

EX: for Forecasting

A TV manufacturer, for example can use past data to forecast the number of picture screens required for next week’s TV assembly schedule.

A fast food restaurant can use past data to forecast the number of hamburger buns required for this weekend’s operations.

EX: for Prediction:

Suppose the manufacturer offers a new TV model or the restaurant decides to offer a new item.

Since, no past data exist to estimate first year sales of the new product, prediction, not forecasting is required.

For predicting good subjective estimates can be based on the manager’s skill, experience and judgment; but, forecasting requires statistical and management science techniques.

TIME HORIZON

Forecasts are often classified according the time period.

Short – range----up to 1 year (typically 0-3 months); these forecasts serve primarily as guides for current operation.

Medium – Range----1 to 3 years;

Long – range----5 years or more; Medium and longer range forecasts are often of more comprehensive or aggregated nature.

A 3-5 year forecast may be necessary to support plant capacity decisions, whereas product- line and plant location decisions may require longer forecasts.

Product life and seasonal factors affect the length of forecasts.

Products in their earlier stage of development will require longer forecasts than those in the declining stage.
The forecasts are needed for planning different employment and inventory levels as the product phases through the various stages of growth and maturity.

DATABASE: QUANTITATIVE AND QUALITATIVE

- Most forecasting relies on quantitative data—it is the basis for scientific decision making. It enhances the objective of the model and forces precision.

- Some variables cannot be quantified, or the quantification process itself is biased.

- In some cases, the models that a firm designs (or can afford) cannot accommodate the variable that the firm might like to include. Some judgmental allowance must be made for the models inadequacy.

- Even the most sophisticated models used need the balance of a good judgment.

- Testing the model on past data or simulated data can be an effect check of its adequacy.

In the modern forecasting techniques, the techniques have been grouped into qualitative models, time series models and causal models.

The most frequently used techniques in operations management are the qualitative and time series models.

The casual models are often more costly to implement and do not offer the increased accuracy for short-term forecasting typically needed by the production/operations manager.

The table shows the representative forecasting techniques:

<table>
<thead>
<tr>
<th>Model type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative models</td>
<td></td>
</tr>
<tr>
<td>Delphi method</td>
<td>Questions panel of experts for opinions</td>
</tr>
<tr>
<td>Historical data</td>
<td>Makes analogies to the past in a judgmental manner</td>
</tr>
<tr>
<td>Nominal group technique</td>
<td>Group process allowing participation with forced voting.</td>
</tr>
<tr>
<td>Time Series (Quantitative Models)</td>
<td></td>
</tr>
<tr>
<td>Simple average</td>
<td>Averages past data to predict the future based on that average</td>
</tr>
<tr>
<td>Exponential smoothing</td>
<td>Weights old forecasts and most recent demand</td>
</tr>
<tr>
<td>Causal Quantitative Models</td>
<td></td>
</tr>
<tr>
<td>Regression analysis</td>
<td>Depicts a functional relationship among variables</td>
</tr>
<tr>
<td>Economic modeling</td>
<td>Provides an overall forecast for a variable such as gross national product (GNP)</td>
</tr>
</tbody>
</table>
1. Delphi Technique: A qualitative forecasting technique in which a panel of experts working separately and not meeting arrive at a consensus through the summarizing of ideas by a skilled coordinator.

The procedure works as follows:

- A coordinator poses a question, in writing; to each expert on a panel. Each expert writes a brief prediction.
- The coordinator brings the written predictions together, edits them and summarizes them.
- On the basis of the summary, the coordinator writes a new set of questions and gives them to the experts. These are answered in writing.
- Again, the coordinator edits and summarizes the answers, repeating the process until the coordinator is satisfied with the overall prediction synthesized from the experts.

The key to the Delphi technique lies in the coordinator and experts. The experts frequently have diverse backgrounds; two physicists, a chemist, an electrical engineer, and an economist might make up a panel.

The coordinator must be talented enough to synthesize diverse and wide-ranging statements and arrive at both a structured set of questions and a forecast.

2. Historical data

It is based on the past data with informed judgment.

3. Nominal group technique: a qualitative forecasting technique in which a panel of experts working together in a meeting arrive at a consensus through discussion and ranking of ideas.

The process works like this. Seven to ten experts are asked to sit around a table in full view of one another, but they are asked not to speak to one another.

A group facilitator hands out copies of the question needing a forecast. Each expert is asked to write down a list of ideas about the question.

After a few minutes, the group facilitator asks each expert in turn to share one idea from his or her list.

A recorder writes each idea on a flip chart so that everyone can see it.

The experts continue to give their ideas in a round-robin manner until all the ideas have been written on the flip chart.

When all the discussion has ended, the experts are asked to rank the ideas, in writing, according to priority. Quantitative Models:

Many models use historical data to calculate an average of past demand. There are several ways of calculating an average.

Simple average: a simple average (SA) is the average of the demands occurring in all previous periods. The demands of all periods are equally weighted:
Sum of demands for all periods

\[ SA = \frac{\sum D_i}{n} \]

where, \( n \) = the number of periods

\( D_i \) = the demand in the \( i \)th period

Example: at weld supplies, demand for a new welding rod was 50 dozen in the first quarter, 60, dozen in the second, and 40 dozen in the third. The average demand has been:

\[ \frac{D_1 + D_2 + D_3}{3} \]

\[ SA = \frac{50 + 60 + 40}{3} \]

\[ = \frac{150}{3} \]

\[ = 50 \]

A forecast for all future quarters could be based on this simple average and would be 50 dozen welding rods per quarter.

Simple Moving Average:

A simple moving average (MA) combines the demand data from several of the most recent periods, their average being the forecast for the next period. Once the number of past periods to be used in the calculations has been selected, it is held constant. We may use a 3-period moving period or 20 moving period moving average.

A simple moving average is calculated as follows:

Sum of demands for periods

\[ MA = \frac{\sum D_i}{N} \]

where \( D_i \) = the demand in the \( i \)th period

\( N \) = chosen number of periods
The average effectively smooths out fluctuations while preserving the general data.

The adaptability of the moving average is the source of major disadvantages; however, there is no equation for forecasting.

In place of equation we use the latest moving-average value as the forecast for the next period. In the process of averaging gives equal importance to the most recent demand.

It ignores any trend in the period over which the data is averaged. However, we can assign weights to components of the moving average before averaging them

\[ \sum (wt) \times MA_{wt} = \text{--------} \]

\[ \sum wt \]

or

Forecast for the next period is given by \( E = w_1 D_1 + w_2 D_2 + w_3 D_3 + \ldots \ldots + w_k D_k \) Where: \( D_i \) = demand for \( i \) periods back

\( w_i \) = weight to be assigned to demand \( D_i \)

\( k \) = number of periods

FORECASTING METHODOLOGY

- The complexity of forecasting methodology sometimes tends to correspond to the event to which future events are evaluated in an objective or professional manner.

- As the amount of uncertainties of future events increases, firms tend to rely more upon inferences and correlations based upon the present.

- When these inferences in turn come from the analysis of the data, the methodology becomes more objective but also more complexes. Complexity does not guarantee accuracy.

- Some techniques are best suited to long-range or new-product forecasts, whereas others are more appropriate for production and inventory control.

- Opinion methods although subjective, are widely used, especially by small firms.

- To Large extent they rely upon personal insights, imagination, or perhaps even guesswork. The cost is low but the accuracy is too.

- Judgments are an improvement over pure opinion in that they call on past experience, consensus with others, or perhaps knowledge of historically analogous situations.

- Time series methods which capitalize upon the identification of trend and seasonal effects are data-based and are likely to be more accurate than opinion methods.
• The basic assumption is that history follows a pattern that will continue.

• Exponential smoothing methods are of this same type, for they are trajectory, or trend-based. They are however, readily adaptive to current levels of activity and have become increasingly popular in production and inventory control applications.

• Regression and correlation methods are associative in nature and depend upon the casual relationship or interaction of two or more variables.

• Box-Jenkins is a combination time series-regression approach that incorporates some advantages of both methods.

TIME SERIES METHODS

• A time series is a set of observations of some variable over time. The series is usually tabulated or graphed in a manner that readily conveys the behavior of the subject variable.

• Components of a series:
  1. Trend (T)
  2. Cyclical (C)
  3. Seasonal (S)
  4. Random (R) or irregular

• In the classical model of time series analysis, the forecast (Y) is a multiplicative function of these components:
  \[ Y = TCSR \]

• The trend represents a long-term secular movement, characteristic of many economic series.

• Cyclical factors are long-term swings about the trend line and are usually associated with business cycles.

• Seasonal effects are similar patterns occurring during corresponding months of successive years.

• Random or irregular components are sporadic effects due to chance and usually occurrences.

FORECASTING PROCEDURE:

1. Plot historical data to confirm the type of relationship (for example linear, quadratic..)

2. Develop a trend equation to describe the data

3. Develop a seasonal index

4. Project the trend into the future

5. Multiply the monthly trend values by the seasonal index

6. Modify the projected values by a knowledge of:
a) Cyclical business conditions (C)
b) Anticipated irregular effects (R)

Methods of estimating trend

Freehand:
- A freehand Curve drawn smoothly through the data points is often an easy and perhaps adequate representation of the data but this method suffers from subjectivity.

Moving Average:
- A moving average is obtained by summing and averaging the values from a given number of periods repetitively, each time deleting the oldest value and adding a new value.

\[ MA = \frac{\sum X}{\text{Number of periods}} \]

Where one X value is exchanged each period.

---

**LEAN SYSTEMS**

The recent globalization of businesses has resulted in highly demanding customers. This has created intense pressure on companies to meet and exceed customers’ expectations more effectively and efficiently than their competitors, and still remain profitable to survive and grow. We know that profit is a sales price minus cost. If companies believe that the sales price of their product/service is broadly determined by the customers (or market), then the only option to make profit is to reduce costs. However, the key ingredients of cost such as labor, material, etc. are roughly comparable among all the competitors aiming for a market. Hence, the excess cost that sabotages the prospects of a company amidst competitors is due to the production method employed.
8.1 The Two Types of Production Systems:

1. Push production system – The system is based on sales forecasts. It relies upon batch production and holds finished goods inventory to respond to customers' needs. This system consumes a lot of space, involves high costs of overheads and wastes, and invites risks of obsolescence.

   - Demand forecasts are prepared using past data and available information about the future, and a multi-period schedule of sales forecast/plan is prepared. These forecasts are compared with finished goods inventory available and a Master Production Schedule (MPS) is developed. An MPS, and the outputs of MRP and CRP, provide the basis for detailed schedules for all work-stations (to procure raw materials or make items).

   - Each work-station produces as per MPS. Queues and in-process/finished goods inventory are a part of the system. MPS pushes forward the product through subsequent stages of manufacture and assembly regardless of sales. Hence the name PUSH system

   - A lot of planning is required in a push system to coordinate production of a large number of parts (say, as in an automobile). Traditionally, large inventories of parts are maintained at all these stages to safeguard against the lapses in coordination (Just In Case system)

   - This approach involves guessing customer demand, duration for completing the job, etc. which, if goes wrong, results in excess or shortage of inventory. If the quality of forecasts is good, Push system produces just right quantities of products at right time

2. Pull production system - produces and moves one piece at a time, with production volume, pace mix derived from customer demand. This system aims for total elimination of different wastes and full utilization of material, labour and equipment, thus leading to lower production cost. This system is popular as Toyota Production System (TPS)
• Pull system works opposite to that of Push system. In Push system, the MPS pushes the product down the production line (regardless of sales). In Pull system, the customer demand pulls the product from upstream production line.

**'HOUSE'**

• This is what the Toyota Production System (TPS) has demonstrated to the world. The system was earlier referred to as JIT system. Of late, together with many more improvements, it is known as Lean system.

8.2 Toyota Production System:

![Toyota Production System Diagram]

- **Goal:** Highest Quality, Lowest cost, Shortest lead time
- **Just-In-Time:**
  - Continuous flow
  - Takt time
  - Pull System
- **Jidoka:**
  - Stop and notify abnormalities
  - Separate manual work & machine’s work
- **Heijunka:**
- **Standardized work:**
- **Kaizen:**
- **Stability**
The primary goal of TPS house is the Simultaneous achievement of highest quality (perfection..!), lowest cost and shortest lead time. All issues relating to Quality, Cost and Lead time are addressed through two powerful weapons namely JIT and Jidoka. They are also called as two pillars of TPS House.

- **JIT** consists of three main parts. They are known as JIT purchasing, JIT manufacturing and JIT delivery. The aim of JIT is to produce and deliver finished goods just in time to be sold, sub-assemblies just in time to be assembled into finished goods, fabricated parts just in time to go into final assemblies, and purchase materials just in time to be transformed into fabricated parts.

Each company has its own level of JIT, which also undergoes improvement over time (monthly, weekly, daily or even hourly). Tighter JIT system spawns plenty of benefits to the company. JIT approach creates a pull system, and **kanban** (signboard, card, chit, e-signal, message, etc.) constitutes an essential element in maintaining this pull system.

- **Jidoka** or Autonomation (Intelligent Automation) aims to prevent defective items being passed onto next workstation. Humans make mistakes. But machines can be designed to eliminate many of them. Devices namely Poka yoke (fool-proofing) are mounted on machines for automatic shut-off and to notify the supervisor when either the machine has completed its task or something abnormal (breakdown, defect production, tool ware-out, etc.) has happened in the production process. With this system, in a single worker can supervise as many as 20-30 machines simultaneously. These devices are used both in component production as well as in automated assembly lines.

In manual assembly (the most common mode) lines, every worker has the right (and also obligation) to stop the production line when a problem is identified or even suspected at his workstation. This helps fixing the problem at the source before a defective is produced. Visual controls aid Jidoka (Target v/s actual production, Yellow light to call for help, and Red light for line stop).

Foundation of TPS House is built with Heijunka, Standardization of components and work methods, and Kaizen.
• Heijunka - Consistency in volume, variety and sequence of items produced in a given time period (say, daily). In other words, a leveled production schedule for a mix of products so that each product is available in some quantity all the time

• Standardization of components and methods - Use of value analysis, method study and work measurement help to arrive at best design of products and work procedures which are standardized, so that every workers’ job is done in a consistent and repeatable manner, and in tune with takt time

• Kaizen implies Continuous improvement effort. Everyone in the company constantly strives to improve the system through his/her effort to eliminate Muri (anything excess than necessary), Muda (any type of waste) and Mura (any unevenness). Muda (non-value added) exists everywhere and the customer is not willing to pay for it. Kaizen aims to eliminate all types of wastes (eg. transport, inventory, motion, waiting, overproduction, over processing and defects, etc.). This calls for questioning all the assumptions behind the present way of processing and striving to perfect them.

Stability - The Philosophy (the Guiding principles) that has provided the much needed stability to TPS is two pronged.

• Continuous improvement: (i) Being aware of the challenges to realize long-term vision (ii) Kaizen through constant innovations and (iii) Going to the workplace (Genchi Genbutsu) to see the facts for oneself and make right decisions and create consensus

• Respect for people: (i) taking responsibility for other people in reaching their objectives, and to build mutual trust (ii) Develop individuals through team approach to problem solving

How pull method of material flow works?

The concepts of JIT and Jidoka developed during 1930s got dismantled due to WW-II. Demand for goods in Japan’s post-war economy were low and the concept of economies of scale through mass production (as was in the case of Ford Motors) had little relevance. Following the WW-II, Taiichi Ohno, the then Ex-VP of Toyota revived, refined and rigorously implemented the concepts of JIT and Jidoka. Ohno, having visited the American supermarkets, observed that shelves are refilled as items are withdrawn (pulled) by customers. He realized that production scheduling can be better, if done in the way as the shelves are refilled in the supermarket, especially
when overproduction was not desirable. Thus the concept of Pull came into being in production areas. In a pull system, a very small amount of inventory buffer is maintained between any two work stations for lead time usage at successor work station, or to cushion against any irregular supply. The worker at the next work station goes back to the previous station and takes only that many parts which he needs for then. The worker at the previous station now produces the exact number of parts for replenishing those that were taken away the next station’s worker. Thus the previous station’s worker produced almost Just-In-Time when the part was needed by the next workstation. If the output is not taken, the previous station’s worker simply stops producing. He does not produce unnecessarily, i.e., neither over- nor under-production. Necessary quantity’ is not defined by the MPS, but by shop-floor demands.

Conceptually, customer is linked to assembly to fabrication to suppliers with series of pull loops. As pull signals flow in one direction, product flows in the opposite direction. Each operation that uses Pull within the company becomes customer and supplier respectively to its previous and next operations.

<table>
<thead>
<tr>
<th>PUSH</th>
<th>PULL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production: Approximate</td>
<td>Production: Accurate and Precise</td>
</tr>
<tr>
<td>Anticipated Usages</td>
<td>Actual Usages</td>
</tr>
<tr>
<td>Large lots production</td>
<td>Small lot production</td>
</tr>
<tr>
<td>High inventories</td>
<td>Low inventories</td>
</tr>
<tr>
<td>Lot of waste, a lesser concern</td>
<td>Elimination of waste, a serious concern</td>
</tr>
<tr>
<td>Management by firefight</td>
<td>Management by sight</td>
</tr>
<tr>
<td>Poor communication</td>
<td>Better communication</td>
</tr>
</tbody>
</table>

To work with smaller buffer inventories, the manufacturing system must be very responsive and flexible, demand for end-products should be stabilized, concern to quality should be utmost, and suppliers’ responsiveness is a must. Japanese (to be specific, Toyota) discovered that if they wanted to make their manufacturing system responsive, they needed to cut lot sizes (relating to both production and procurement)
8.3 Small Lot Size

But cutting lot sizes call for frequent change-over of setups (or orders) and result in higher set-up (or ordering) costs. This conflict between carrying and set-up (or ordering) costs is resolved by classical Economic lot size (or EOQ) approach by the Western industry. Before Japanese (especially, Toyota) questioned, the set-up time (or ordering cost) was taken for granted as unalterable. They strived very hard to drive down the change-over (or purchase order) costs- We will discuss how Japanese did it later. This enabled a significant reduction in lot sizes, and set the JIT into motion.

When lot size drops all the way to one-piece-at-a-time (however, any reduction in lot size would be helpful) the scrap and quality improvements are maximum. If a worker makes only one part and passes it to the next worker immediately, the first worker soon hears if the part does not fit in any of the next stations. Thus defects are discovered quickly and their sources can be attacked before the next part is produced. Greater quality and less scrap or rework saves material, rework-labour and time, etc. improving productivity. If parts are made and moved in large lots, by the time the next workstation finds a defective, several defectives could already be present in the lot. Hence less quality and more scrap.

The first worker who quickly learns about the effect of his workmanship will naturally become motivated to improve. Worker's awareness of defect causation is heightened. This awareness of problems and their causes aid the workers, supervisors, engineers to generate ideas for:

- Controlling defects
- Improving JIT delivery performance (say, handling delays)
- Cutting setup time which helps reduction in lot size further
Often, even when lot size is reduced drastically, still some buffer inventory is maintained between workstations to cushion the irregularities in the part-feeder processes. Japanese do not accept the buffer principle as they think buffer inventory hides all flow- and quality-related problems. Instead of adding it at the point of irregularities, they deliberately remove it to expose the workforce to consequences. In response, workers and supervisors rally to root out the causes of irregularity at its source so that it won’t recur. Each time the cause of irregularity is corrected, the Japanese production managers remove some more buffer stock. Workers are never allowed to settle into a comfortable pattern. Rather the pattern becomes one of continually perfecting the production process. Reduction in buffer, greater awareness of problem areas and correction lead to smoother output rates.

The way MURI, MUDA and MURA (very popular in Japan for their significance and symbolic brevity) are attacked can be seen in the above JIT cause-effect chain. MURI: Means Excess (Eg. Producing in large lot -EOQ- when it can be reduced to one-piece). MUDA: Means Waste (Eg. Production of even one defective item is a waste, let alone % defectives). MURA: Means Unevenness (Eg. Buffer stock implies unevenness in production flow is accepted. The rational approach is to reduce buffer and expose the systems to variability, and then deal with it).

**Quick Setups:**

Several processes defy production in small lots. Large setups can be as long as a day or more. Hence, companies are reluctant to change setup before they produce the part in a big lot from the setup made. On the other hand, having several dedicated lines for each part may be expensive. Hence, engineers at Toyota worked to simplify and quicken the die changing process. Shigeo Shingo, a consultant hired by Ohno was able to reduce the setup time of a 1000-ton press from 6 hours to 3 minutes using the concept of SMED.

**Seven steps to SMED**

1. Observe the current method of changeover separate the INTERNAL and EXTERNAL activities: Internal activities are those that can only be performed when the process is stopped, while External activities can be done when the operation is on. For example, fetch tools for next operation before the machine stops, setup of fixture, centering dies

3. Convert (where possible) internal activities into External ones: Eg. Pre-heating of dies

4. Streamline the remaining internal activities - Simplifying/ eliminating adjustments, coding settings, standardizing tools and materials, using quick locating and clamping devices, guides/rails to move heavy dies,
simplified tools, etc. Shigeo Shingo rightly observed that it’s only the last turn of a bolt that tightens it - the rest is just movement. Apply motion and time study principles

5. Streamline the External activities, so that they are of a similar scale to the Internal ones – properly organizing work place, locating items near to the point of use, keeping machines, tools and dies in good condition

6. Document the new procedure and actions so that they are repeatable. Videotaping the process of setup with each improvement

7. Do it all again: Train the operators, add more people if needed. Practice and perfect. For each iteration of the above process, a 45% improvement in set-up times should be expected, so it may take several iterations to be less than ten minute time

The aim is for Single digit setup time (less than 10 minutes), and then One-touch setup. This can be done through better planning, process redesign, and product redesign.

To achieve smooth flow in lean system, many fundamental elements such as small lots, flexible resources (people, machinery, layout), high quality, Jidoka, kanban, standardized components and work methods, automated production must be in place.

Further to sustain the pull created in lean system, elements such as leveled production, kaizen, close supplier ties, lean culture are needed

8.5 Kanban:

The use of kanbans enables exercising greater control over the pull process in the shop floor. Kanban means ‘Card’ (signaling card). A kanban is attached to container that moves back and forth between the source and destination stations.

There is exactly one kanban per container. Containers for each specific part are standardized and they are always filled with the same (ideally, small) quantity. Kanban card contains information such as Card number, Part number, Part name, Brief description of the part, Container type and Capacity, Preceding (where it comes from) and succeeding stations (where it goes to), etc.

If the kanban is to move between supplier and customer companies, then additional information such as supplier code, supplier name, number of trips/day, dock where the goods are to be delivered, Group code, Route detail, etc, is indicated. The information on kanban does not change. Kanban does not make the
schedule of production. They only authorize the production or withdrawal of goods. Most sophisticated is Dual kanban system:

Production kanban: authorizes production of goods (container quantity) and Withdrawal kanban: authorizes withdrawal of movement of container full of goods.

Supplier kanban: The supplier brings the ordered material directly to the point of use and then picks up the empty container with kanban (if any) to fill and return later. If there are more suppliers and large number of kanbans, then kanban mailbox can also be used. The number of kanbans required to control production of an item can be calculated by:

No. of kanbans = (Ave. demand during lead time + safety stock)/ Container size

Problem 1. Masaru fills caps and labels syrup bottles. He is to process an average of 160 bottles per hour through his cell. Every container attached with a kanban holds 10 bottles. It takes 30 minutes to receive new bottles from the previous cell. The factory uses a safety stock factor of 10%. How many kanbans should circulate between these cells?

Solution: N = [(160 x 0.5) + 8] / 10 = 8.8 Kanbans

Having 8 containers would result in lesser inventory at the cell and exposes problems in the cell, thus forcing the cell to improve its processes.

8.6 Standardized Components and Work methods:

Use of standardized component parts and methods of operation are encouraged. They reduce the non-value adding design elements and process elements to a minimum, and improve the consistency and efficiency in operations. The applications of value analysis and work-study techniques are widely seen in this effort.
Standardized Work: The Toyota Production System organizes all jobs around human motion and creates an efficient production sequence without any "Muda." Work organized in such a way is called standardized work. It consists of three elements:

1. Takt-Time
2. Working Sequence and
3. Standard In-Process Stock

Standardized work will define the most efficient methods to produce product using available equipment, people and materials. It depicts the key process points, operator procedures, production sequence, safety issues, and quality checks.

8.7 Automated Production:

Effective lean production systems use both manual and automated processes - the task is to determine the appropriate type of automation. The process industries are ultimate in efficiency and productivity due to the: (i) continuous flow of products (gases, liquids, paint, pallets, powder, petrochemicals, steel, etc) in the system; (ii) high degree of automation managed by a network of computers and (iii) minimum human inconsistencies.

The output in non process industries is discrete units which (unlike the stuff that flows) can be produced, prioritized, inspected, counted, stored, etc. The production and assembly system are generally labour intensive, often forced to use buffer inventory between stations, and subject to human inconsistencies, all contributing to its lesser efficiency. It is the intention of lean management approach to make discrete unit production (not only assembly stage but also all fabrication and subassembly stages) into a continuous flow production system, i.e., much like continuous processing in process industry. This, often requires the discrete unit production shops to move stage-by-stage through various plant configurations (before becoming continuous flow/repetitive production system.) These stages are (stages may also be skipped):

- Job-shop fabrication
- Dedicated production line
- Physically merged production processes
• Mixed-model processing
• Automated production lines

Automated dedicated assembly lines may be common (e.g., Automobile body welding). But, automated mixed model assembly line, automated subassembly and fabrication shops/cells are not. Japanese extensively use pseudo-robots (less flexible-pick and place type) that aid a lot when the buffer between the work stations is being reduced.

When all efficiency improvement aid are provided to the worker, but he still is unable to cope with problems, best option is to automate a part of his work. However, mixed model production calls for flexible robots which can be programme to change parameters depending upon the next model. CAD/CAM compress planning lead time so that the product quickly gets ready for manufacture. Robots and automated machine tools quickly make consistently good quality products, with no buffer or waste thus compressing manufacturing lead time. Automatic quality control (poka yoke) is an aid towards JIT system

Uniform Workstation Loads (heijunka):

The flow of production created by pull system, kanban, small lots of high quality, flexible resources and jidoka can be maintained only if the production is relatively steady. Hence, there is a need to smoothen the production requirement at the final assembly. Otherwise, kanbans of some parts will circulate very quickly at some times and very slowly at others. Variations of ± 10% is can be absorbed.

How to reduce variability?

1. More accurate forecasts to guard against unexpected
   • Sales division (e.g., Toyota) conducts a survey twice a year
   • Monthly production schedules are developed 2 months in advance
   • Review plans 1 month in advance and again 10 days in advance
   • Daily production are finalized 4 days in advance (Freeze windows) of actual production (by then orders from dealers are firm)
2. Level the demand across planning horizon:

- Demand is divided into small increments of time and spread out as evenly as possible so that same amount of each item is produced each day and
- The item production is mixed throughout the day in very small quantities. Produce roughly the same mix of products each day, using a repeating sequence
- Daily production is arranged in the same ratio as monthly demand and jobs are distributed as evenly as possible across a day’s schedule
- At least some quantity of every item is produced daily and some quantity is always available to meet variation in demand. Meet demand fluctuations through end item inventory rather than through fluctuations in production level

Problem 2. SMS automobile company makes cars, SUVs and vans on a single assembly line. December’s forecast is for 220 vehicles. SUVs sell at twice the rate of cars and thrice that of vans. Assuming 20 working days in the month, how should the vehicles be produced to have smoother production?

Solution:

Daily breakdown = 220/20 = 11 vehicles

Daily sequence (batched): S S S S S S C C C V V

Daily sequence (Mixed): S C S V S C S V S C S
8.8 Continuous Improvement (Kaizen):

Kaizen – Change for the Better or Continuous improvement. It is associated with, among others:

- Improve quality of product/service
- Eliminating waste (Muda)
- Improving process efficiency and effectiveness
- Improving morale of employees

Quality is everybody’s responsibility, not just of QC dept. Every employee at every level participates and contributes ideas to improve the processes and environment. Workers voluntarily spot quality problems, stop operation if needed, trace the source of unquality, get together to analyze processes and generate ideas for improvement and adjust their working routines (Upward communication). Kaizen can be better achieved by finding root causes of problems. To find root cause of a problem – Ask WHYs until the underlying cause is identified.

Anticipate/identify the problem, analyze the root causes, develop alternative solutions, choose the best one, measure the work content, standardize the method and monitor adherence to it. The knowledge of industrial engineering (method study, work measurement, value analysis, Quality management tools, etc) is very helpful in bringing about kaizen. Conceptually kaizen focuses on small but continuous improvements. Easy to implement, not a big change for people to resist. People enjoy the implementation as it is their ideas. Kaizen relies on the human resource rather than capital investments. Continuous improvement process will make sure the system is always getting updated.

8.9 Close Supplier Ties:

Lean Supplying: Suppliers’ support is essential for the success of lean. Suppliers need to be not just reliable, but synchronized with their customers’ requirement too. Strong long-term working relationships with a select group of suppliers located close-by to the customer would enable delivering in smaller quantities several times a day.

1. Long-term supply contracts (typically 3-5 years or life of the product): Suppliers are chosen based on their ability to meet delivery schedules with high quality and reasonable cost, and willingness to adapt to customer’s requirement.
2. Synchronized production: With longer-term contracts suppliers can focus on fewer customers. Guaranteed steady demand allows supplier’s production system to synchronize with that of customer. Customer may also provide engineering and quality management help.

3. Supplier certification: Several stages - Supplier’s products, production facilities, quality systems logistic are by the customer. Statistics of each shipment are checked. After about 6 months of no problems, the supplier is certified. Only then the goods from is considered for exemption from incoming quality inspection. However, any cost of line stop/product recall due to defective supply may also be recovered from supplier.

4. Mixed loads and frequent deliveries: Smaller quantities of variety of goods from several suppliers makeup a truck load and are delivered directly at the point of use in customer’s plant, several times a day. Several suppliers share local warehouses. Precise delivery schedules are drawn and adhered to.

5. Standardized, sequenced delivery: Using standardized containers, and exchanging filled ones with empty ones speeds up the delivery. If deliveries are made directly to the assembly line, they are sequenced in the order of assembly.
6. Locating in close proximity to the customer: For frequent deliveries, the suppliers need to be closer to the customer. If the distance prohibits daily delivery, suppliers may establish small warehouses near to the customer, which they may also share with other suppliers. These warehouses can also serve as load switching points for JIT deliveries to different customers.

7. Close relationships b/w buyers and suppliers’ QC people. Suppliers helped to meet quality requirement

Suppliers with stringent quality standards could forego incoming inspection and goods could be delivered right at the assembly line even without being counted, inspected, tagged or stacked. Suppliers encouraged to package in exact quantities. No overage or underage is acceptable. Suppliers who try to meet the increasing demands of lean customer without being themselves would have to overrun with inventory, very high production and distribution costs. Suppliers are encouraged to reduce their production lot sizes.

Lean Purchasing: Japanese JIT buyers rely more on performance specifications and less on design specifications, giving more room for supplier to innovate. Delay due to spec-clarification is avoided. Japanese JIT purchase agreements involve minimum paperwork, and may specify (in addition to price and specifications) an overall quantity to be delivered during a period of several months. Purchase agreement specifies that delivery is to be made either as per the long-term production schedule or release of kanban (which may be directly from work centre to supplier). Quantities to be delivered may vary from delivery to delivery, but fixed for whole contract term.

8.10 Preventive Maintenance and TPM:

Machines need maintenance. Maintenance is undertaken,

(i) When a machine breaks down (Breakdown maintenance): Breakdown can be very expensive due to lost production, idle workers and supervisors, damaged tools and products, missed deadlines, accidents, etc. Often, cost of up-keeping a broken down machine is much higher than preventing the breakdown.

(ii) at predetermined times to prevent equipment from breaking down (Preventive maintenance): The history of failures of a machine (type, frequency, time b/w failures, repair time, cost, etc) can be used to mathematically workout a preventive maintenance schedule. PM includes keeping records on each machine’s usage, careful analysis to determine the frequency and schedule of PM, case reports after PM, etc. But in spite of the PM, breakdown cannot fully prevented. Hence, what Lean system needs is Total Productive Maintenance (TPM).
TPM is a combination of preventive maintenance and TQC (worker empowerment, zero defects, QC tools, etc).

TPM requires management to take a broader and strategic view of maintenance activities. Workers take daily care of their machines and the work environment. They clean, oil and grease their machines, adjust the settings, do minor repair, collect and interpret maintenance and operating data, etc. As a part of TPM, 5–S approach is also widely used.

<table>
<thead>
<tr>
<th>The S</th>
<th>Goal</th>
<th>Eliminate or Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEIRI (Sort)</td>
<td>Keep only what you need</td>
<td>Unwanted tools, inventory, supplies, parts, fixtures, displays, items blocking aisles,</td>
</tr>
<tr>
<td>SEITON (Set order)</td>
<td>A place for everything and</td>
<td>Non-availability of an item when needed, unsafe environment, pre-</td>
</tr>
<tr>
<td>SEISO (Shine)</td>
<td>Cleaning and looking for ways to keep clean</td>
<td>Floors, walls, stairs, equipment, tool trays, display boards, tools and</td>
</tr>
<tr>
<td>SEIKETSU (Standardize)</td>
<td>Maintaining and monitoring the first</td>
<td>Unavailable information, checklists, standards, prescribed limits</td>
</tr>
<tr>
<td>SHISUKE (Sustain)</td>
<td>Sticking to the rules</td>
<td>Number of workers without 5-S training, inability to locate anything within 30</td>
</tr>
</tbody>
</table>

### 8.11 The Benefits of Lean Production:

Lean provides a wide range of benefits such as:

- Reduced inventory
- Improved quality
- Lower costs
- Reduced space requirements
- Shorter lead times
- Increased productivity
- Greater flexibility
- Better relations with suppliers
- Simplified scheduling and controlling activities
• Increased capacity
• Better use of human resources
• More product variety

Limitations of Lean:

• Not appropriate for all types of organizations

• Companies with high variability of demand (takt time breaks down), large variety of low-volume products (too many kanbans) or custom-engineered products (no kanbans) find serious deficiencies in this approach.

• Lean gets derailed when unexpected changes in demand or supply occur (e.g., Fire, strike, natural calamities, etc. at supplier’s place)

• Hence, companies should assess risk and uncertainty in their businesses and adapt lean practices accordingly

-- oOo --
SCHEDULING

Scheduling can be defined as “prescribing of when and where each operation necessary to manufacture the product is to be performed.”

It is also defined as “establishing of times at which to begin and complete each event or operation comprising a procedure”. The principle aim of scheduling is to plan the sequence of work so that production can be systematically arranged towards the end of completion of all products by due date.

5.1 Principles of Scheduling

1. The principle of optimum task size: Scheduling tends to achieve maximum efficiency when the task sizes are small, and all tasks of same order of magnitude.

2. Principle of optimum production plan: The planning should be such that it imposes an equal load on all plants.

3. Principle of optimum sequence: Scheduling tends to achieve the maximum efficiency when the work is planned so that work hours are normally used in the same sequence.

5.2 Inputs to Scheduling

1. Performance standards: The information regarding the performance standards (standard times for operations) helps to know the capacity in order to assign required machine hours to the facility.

2. Units in which loading and scheduling is to be expressed.

3. Effective capacity of the work centre.

4. Demand pattern and extent of flexibility to be provided for rush orders.

5. Overlapping of operations.

6. Individual job schedules.

5.3 Scheduling Strategies

Scheduling strategies vary widely among firms and range from ‘no scheduling’ to very sophisticated approaches.

These strategies are grouped into four classes:

1. Detailed scheduling: Detailed scheduling for specific jobs that are arrived from customers is impracticable in actual manufacturing situation. Changes in orders, equipment breakdown, and unforeseen events deviate the plans.

2. Cumulative scheduling: Cumulative scheduling of total work load is useful especially for long range planning of capacity needs. This may load the current period excessively and under load future periods. It has some means to control the jobs.
3. Cumulative detailed: Cumulative detailed combination is both feasible and practical approach. If master schedule has fixed and flexible portions.

4. Priority decision rules: Priority decision rules are scheduling guides that are used independently and in conjunction with one of the above strategies, i.e., first come first serve.

These are useful in reducing Work-In-Process (WIP) inventory.

### 5.4 Types of Scheduling

Types of scheduling can be categorized as forward scheduling and backward scheduling.

#### 5.4.1 Forward scheduling
Forward scheduling is commonly used in job shops where customers place their orders on “needed as soon as possible” basis. Forward scheduling determines start and finish times of next priority job by assigning it the earliest available time slot and from that time, determines when the job will be finished in that work centre. Since the job and its components start as early as possible, they will typically be completed before they are due at the subsequent work centres in the routing. The forward method generates in the process inventory that are needed at subsequent work centres and higher inventory cost. Forward scheduling is simple to use and it gets jobs done in shorter lead times, compared to backward scheduling.

#### 5.4.2 Backward scheduling
Backward scheduling is often used in assembly type industries and commit in advance to specific delivery dates. Backward scheduling determines the start and finish times for waiting jobs by assigning them to the latest available time slot that will enable each job to be completed just when it is due, but done before. By assigning jobs as late as possible, backward scheduling minimizes inventories since a job is not completed until it must go directly to the next work centre on its routing.

### 5.5 SCHEDULING METHODOLOGY

The scheduling methodology depends upon the type of industry, organization, product, and level of sophistication required. They are:

1. Charts and boards,
2. Priority decision rules, and
3. Mathematical programming methods.

#### 5.5.1 Gantt Charts and Boards

Gantt charts and associated scheduling boards have been extensively used scheduling devices in the past, although many of the charts are now drawn by computer. Gantt charts are extremely easy to understand and can quickly reveal the current or planned situation to all concerned. They are used in several forms, namely,

(a) Scheduling or progress charts, which depict the sequential schedule;

(b) Load charts, which show the work assigned to a group of workers or machines; and

(c) Record a chart, which are used to record the actual operating times and delays of workers and machines.
5.5.2 Priority Decision Rules

Priority decision rules are simplified guidelines for determining the sequence in which jobs will be done. In some firms these rules take the place of priority planning systems such as MRP systems.

5.5.3 Mathematical Programming Methods

Scheduling is a complex resource allocation problem. Firms process capacity, labour skills, materials and they seek to allocate their use so as to maximize a profit or service objective, or perhaps meet a demand while minimizing costs.

The following are some of the models used in scheduling and production control.

(a) Linear programming model: Here all the constraints and objective functions are formulated as a linear equation and then problem is solved for optimality. Simplex method, transportation methods and assignment method are major methods used here.

(b) PERT/CPM network model: PERT/CPM network is the network showing the sequence of operations for a project and the precedence relation between the activities to be completed.

Note: Scheduling is done in all the activities of an organisation i.e., production, maintenance etc. Therefore, all the methods and techniques of scheduling is used for maintenance management

5.6 Flow shop Scheduling

In flow shop scheduling problem, there are n jobs; each requires processing on m different machines. The order in which the machines are required to process a job is called process sequence of the job. The process sequences of all the jobs are the same. But the processing times for various job on a machine may differ. If an operation is absent in a job, and then the processing time of the operation of that job is assumed as zero.

The flow-shop scheduling problem can be characterized as given below.

1. A set of multiple-operation jobs is available for processing at time zero (Each job require m operations and each operation requires a different machine).

2. Set-up times for the operations are sequence independent, and are included in processing times.

3. Job descriptors are known in advance.

4. m different machines are continuously available.

5. Each individual operation of jobs is processed till its completion without break.

The main difference of the flow shop scheduling from the basic single machine scheduling is that the inserted idle time may be advantageous in flow shop scheduling. Though the current machine is free, if the job from the previous machine is not released to the current machine we cannot start processing on that job. So, the current machine has to be idle for some time. Hence, inserted idle time on some machine would lead to optimality.
For example consider the following flow shop problem

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

If the sequence of the job is 2-1-4-3, then the corresponding makespan (total elapsed time) is computed as shown in figure below. In Figure, the makespan is 25. Also, note the inserted idle times on machine 2 are from 0 to 3, 4 to 8 and 12 to 15.

Consider another sequence say 3-4-1-2. The makespan for the schedule is 26. This problem has 4 jobs. Hence, 4! Sequences are possible. Since, n! grows exponentially with n, one needs some efficient procedure to solve the problem. For large size of n, it would be difficult to solve the problem. Under such situation we can use some efficient heuristic.

Flow shop scheduling includes

- Johnson’s rule for ‘n’ jobs on 2 machines
- ‘n’ jobs on 3 machines