Chapter Five

PROCESS SELECTION AND FACILITY LAYOUT

Process Selection

Process selection refers to deciding on the way production of goods or services will be organized. It has major implications for capacity planning, layout of facilities, equipment, and design of work systems.

Process selection and capacity planning influence system design.

Processes convert inputs into outputs; they are at the core of operations management. But the impact of process selection goes beyond operations management: It affects the entire organization and its ability to achieve its mission, and it affects the organization’s supply chain. So process selection choices very often have strategic significance. Different process types have different capacity ranges, and once a process type is functioning, changing it can be difficult, time consuming, and costly. Obviously, long-term forecasts as well as an organization’s mission and goals are important in developing a process strategy.

Process selection has operational and supply chain implications. Operational implications include equipment and labor requirements, operations costs, and both the ability to meet demand and the ability to respond to variations in demand. Supply chain implications
relate to the volume and variety of inputs and outputs and the degree of flexibility that is
required.

Technology is often a factor in process selection and layout. Three aspects of technology
can be factors: product technology, processing technology, and information technology.

There are following types of manufacturing process technologies:

1. **Project technology:**
   - No movement of products
   - Products cannot be standardized and moved from one place to another
   - They require special technology, highly skilled manpower and procedure
   - Examples are bridges, dams, roads, Building etc.

2. **Job shop technology:**
   - Various small batches products produced, may be in process. Low volume of products
   - It is difficult to predict materials requirements
   - Objective is to meet customers immediate demand
   - No specification, low quality, No standardization of products, process, raw materials etc.

3. **Batch Technology:**
   - Suitable when there is stable line of standardized products
   - Production in periodic batches
   - Production is in periodic batches either to the customers orders or for stock
   - It is more flexible because it can produce low volume and high variety of products
   - Planning, scheduling and controlling of activities possible

4. **Assembly line Technology:**
   - Stable products with narrow range and standardized products
   - Limited products
   - High volume
   - Sophisticated technology, specialized equipments, skilled manpower and management system are used
   - Electronic appliances such as TV, DVD, Computers are assembled by using this type of technology

5. **Continuous Flow Technology:**
   - Highly standardized, large volume products having stable demand, produced for stock
   - Capital-intensive automation, standardized materials, machine and equipments are used
   - It is an inflexible technology
There are following types of Service process technologies:

Service process technologies are determined based on the customer’s contact and labour versus capital intensiveness. There are following types of Service process technologies:

1. **Quasi-manufacturing:**
   - Low customer contact, high capital intensity. It offers rigid standardized services with reliable delivery services. E.g. Post office, tele-banking, cheque processing, automatic banking etc.

2. **Custom shop:**
   - Facility based and Capital intensive, high professional staff e.g hospitals, telecommunication, banks etc.

3. **Mass service:**
   - Labour intensive which provides standardized services to customers. HR is well trained and properly scheduled for providing services to customers. E.g. teaching, live TV programs etc.

4. **Professional services:**
   - Provides customerized services through intensive interactions between customers and professionals e.g. legal services, Counseling, Medical diagnosis, Auditing etc.

**Flexible Manufacturing Systems (FMS)**

A flexible manufacturing system (FMS) is a type of automation system that combines the flexibility of intermittent operations with the efficiency of repetitive operations. As you can see by the definition, this is a system of automated machines, not just a single machine. An FMS consists of groups of computer-controlled machines and/or robots, automated handling devices for moving, loading, and unloading, and a computer-control center. Based on the instructions from the computer-control center, parts and materials are automatically moved to appropriate machines or robots. The machines perform their tasks and then the parts are moved to the next set of machines, where the parts automatically are loaded and unloaded. The routes taken by each product are determined with the goal of maximizing the efficiency of the operation. Also, the FMS “knows” when one machine is down due to maintenance or if there is a backlog of work on a machine, and it will automatically route the materials to an available machine.

**Layout Decision**

Simply layout means the physical arrangement of industrial facilities. It is concerned with the dispositions of various parts and components of plants along with all equipments used. It is the next problem of any organization after selection of proper location. It is the method for allocating machines and equipments to various production process.

In manufacturing process, facility layout consists of configuring the plant site with lines, buildings, major facilities, work areas and other pertinent features such as department boundaries. Because of its relative permanence, facility layout probably is one of the most crucial elements affecting the efficiency of organization. An efficient layout can reduce unnecessary material handling, help to keep costs low, and maintain product flow through the facility. The layout is the major consideration in Operations management because a poor layout does not contribute for overall efficiency and productivity of organization. In order to increase the efficiency
of organization, there must be a proper arrangement of facilities in available space, which is called as layout. It means layout should be optimized and optimum layout contains:

- Proper arrangement of departments within the site or venues.
- Proper arrangement of equipments within the departments.
- Proper arrangement of manpower within the equipments or work-centers.

Finally, layout is the physical arrangement of plant or facility in selected location. Layout encompasses disposition of department upon a site and also location of equipments within departments. Hence, layout concerns the configuration of departments, work centers, and equipment with particular emphasis on movement of work (customers or materials) through the system. The layout is affected with introduction or change of a new product or service or a new location is established. Also, the capacity change directly affects the layout. The layout decision is important for three basic reasons:

a) It requires substantial investment of both money and effort.

b) It involves long-term commitment, which makes mistakes difficult to overcome.

c) It has a significant impact on the cost and efficiency of short-term operations.

### Considering Factors in Layout Design

Following factors are taken in consideration in layout design:

- Higher utilization of space, equipment and human resources.
- Better movement of information, material and people
- Improve employee morale and safer working condition
- Improve customer and chief interaction
- More flexibility

### Objectives of Layout

The fundamental objective of layout is to arrange all physical facilities in such manner that ensures a smooth flow of work in a factory or service organization. But some general objectives are given as follows:

- Efficient utilization of floor space
- Efficient material handling system.
- Provide adequate safety of work
- Minimize production time and cost.
- Motivation for employee etc.
- Facilitate the manufacturing process
- Maintain high turnover of in process inventory
- Flexibility of manufacturing operations and arrangements
- Provide for employee convenience, safety and comfort

### The Importance of Layout

The importance of a layout would be better appreciated if one understands the influence of an efficient layout on the manufacturing function. Proper layout makes manufacturing function smooth and efficient. The importance or advantages of an ideal layout are outlined in the paragraphs that follow.

(i) **Effective Use of Available Area:** Every inch of the plant area is valuable, especially in urban areas. Efforts should therefore be made to make use of the available area by planning the layout properly. Some steps for achieving this end are: location of equipment and services in order that they may perform multiple functions; development of up-to-date work areas and operator job assignments for a full utilization of the labor force.
Minimization of Production Delays: Repeat orders and new customers will be the result of prompt execution of orders. Every management should try to keep to the delivery schedules. Often, the deadline dates for delivery of production orders are a bug-a-boo to the management. Plant layout is a significant factor in the timely execution of orders. An ideal layout eliminates such causes of delays as shortage of space, long-distance movements of materials, spoiled work and thus contributes to the speedy execution of orders.

Improved Quality Control: Timely execution of orders will be meaningful when the quality of the output is not below expectations. To ensure quality, inspection should be conducted at different stages of manufacture. An ideal layout provides for inspection to ensure better quality control.

Minimum Equipment Investment: Investment on equipment can be minimized by planned machine balance and location, minimum handling distances, by the installation of general purpose machines and by planned machine loading. A good plant layout provides all these advantages.

Avoidance of Bottlenecks: Bottlenecks refer to any place in a production process where materials tend to pile up or are produced at a speed, less rapid than the previous or subsequent operations. Bottlenecks are caused by inadequate machine capacity, inadequate storage space or low speed on part of the operators. The results of bottlenecks are delays in productions schedules, congestion, accidents and wastage of floor area. All these may be overcome with an efficient layout.

Better Production Control: Production Control is concerned with the production of the product of the right type, at the right time and at a reasonable cost. A good plant layout is a requisite for good production control and provides the production control officers with a systematic basis upon which to build organization and procedures.

Better Supervision: A good plant layout ensures better supervision in terms of determining the number of workers to be handled by a supervisor and enabling the supervisor to get a full view of the entire plant at one glance.

Improved Utilization of Labor: Labor is paid for every hour it spends in the factory. The efficiency of a management lies in utilizing the time for productive purpose. A good plant layout is one of the factors in effective utilization of labor. It makes possible individual operations, the process and flow of materials handling in such a way that the time of each worker is effectively spent on productive operations.

Improved Employee Morale: Employee morale is achieved when workers are cheerful and confident. This state of mental condition is vital to the success of any organization and it depends upon better working condition, better employee facilities, reduced number of accidents and increased earnings. Plant layout has a bearing on all these.

Avoidance of Unnecessary and Costly Changes: A planned layout avoids frequent changes which are difficult and costly. The incorporation of flexibility elements in the layout would help in the avoidance of revisions.

Factors Influencing Plant Layout

Some of major factors influencing plant layout are:

1. Material factor: This includes design, variety, material, quality, necessary operations of production system.
2. Machinery factor: This includes equipment, tools and their utilization.
3. Main factor: This includes human resources, and supervision
4. Movement factor: This includes inter intra departmental movement of man and material and machinery
5. Waiting factor: This includes permanent and temporary storage of finished, semi- finished or raw material
6. **Service factor:** This includes maintenance, inspection, waste, scheduling, and dispatching.
7. **Building factors:** This includes outside and inside building features.
8. **Change factors:** This includes versatility, flexibility, and expansion.

### Basic Facilities Layout / Types of Layout

Basic facilities layout determines the format of work of any organization. The same format of work or layout may not be suitable in each type of organization. Layout depends upon many factors like types of production system, volume of output nature of production or service, product mix, building configuration, space availability etc. Any one out of following 5 types of basic layouts can be considered by an organization. They are:

(a) **Process layout/Functional layout:**

Under this layout, machine and equipments performing same type of operations are installed at one place according to their functions. This type of layout is suitable when the volume of output is unknown and do not require a great enough specialized production facilities to produce. It means same facility can produce a wide variety of products. Process layouts are found primarily in job shops or firms that produce customized, low-volume products that may require different processing requirements and sequences of operations.

Process layouts are facility configurations in which operations of a similar nature or function are grouped together. As such, they occasionally are referred to as functional layouts. Their purpose is to process goods or provide services that involve a variety of processing requirements. A manufacturing example would be a machine shop. A machine shop generally has separate departments where general-purpose machines are grouped together by function (e.g., milling, grinding, drilling, hydraulic presses, and lathes). Therefore, facilities that are configured according to individual functions or processes have a process layout. This type of layout gives the firm the flexibility needed to handle a variety of routes and process requirements. Basically this type of layout is mostly used on garments, printing press, hospitals, banks, auto repairs, libraries, and universities.

### PROCESS LAYOUT

<table>
<thead>
<tr>
<th>Store Room</th>
<th>Inspection Department</th>
<th>Broaching Section</th>
<th>Miling Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lathe (cut) section</td>
<td><strong>SHAPER SECTION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drill Section</td>
<td></td>
<td><strong>STOCK SECTION</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Advantages (Pros)**

- Flexible in nature
- No interruption in production due to breakdown of machine in another process.
- Efficient supervision.
- Increases the scope of expansion.
- Suitable for batch production.
- System protection: Since there are multiple machines available, process layouts are not particularly vulnerable to equipment failures.

**Disadvantages (Cons)**

- High work-in-progress inventories.
• Difficulties to plan and control the production system, because of frequently changes in production nature and type.
• Requires highly skilled manpower.
• Not suitable for continuous production system

(b) Product layout / Assembly line layout:
Under this, Equipments machines and other facilities are arranged in the same sequence as the operating required for manufacturing products. Each work centers must employ machine and equipments of equal capacity. Product layouts are found in flow shops. Flow shops produce high-volume, highly standardized products that require highly standardized, repetitive processes. It is useful for those organizations where volume of output is large and for that type of product which has stable demand like salt, sugar, textile, cigarettes etc. From one side input is introduced and from another side output is produced. It is inflexible in nature and applied for continuous production system.

In a product layout, resources are arranged sequentially, based on the routing of the products. In theory, this sequential layout allows the entire process to be laid out in a straight line, which at times may be totally dedicated to the production of only one product or product version. The flow of the line can then be subdivided so that labor and equipment are utilized smoothly throughout the operation.

Two types of lines are used in product layouts: paced and un-paced. Paced lines can use some sort of conveyor that moves output along at a continuous rate so that workers can perform operations on the product as it goes by. It is used for bulky production. For longer operating times, the worker may have to walk alongside the work as it moves until he/she is finished and can walk back to the workstation to begin working on another part (this essentially is how automobile manufacturing works).

On an un-paced line, workers build up queues between workstations to allow a variable work pace. However, this type of line does not work well with large, bulky products because too much storage space may be required. Also, it is difficult to balance an extreme variety of output rates without significant idle time. A technique known as assembly-line balancing can be used to group the individual tasks performed into workstations so that there will be a reasonable balance of work among the workstations.

Product layout efficiency is often enhanced through the use of line balancing. Line balancing is the assignment of tasks to workstations in such a way that workstations have approximately equal time requirements. This minimizes the amount of time that some workstations are idle, due to waiting on parts from an upstream process or to avoid building up an inventory queue in front of a downstream process.

Advantages (Pros)
- Better Utilization of space area
- High degree of labor and equipment utilization
- Reduce wastage due to continue production
- Increase efficiency due to regular production.
- Better control and economies in transaction.

Dis-Advantages (Cons)
- High capital investment
- Inflexible in nature
- Whole production system is interrupted, if one machine is breakdown.
- The system is at risk from equipment breakdown, absenteeism, and downtime due to preventive maintenance.
- Unfavorable for batch production.

Some Examples of Product layout / Assembly Line Layout
(a) Straight Line Layout
Note: It is suitable for those organization which requires minimum work centers.

(b) **Serpentine Layout:**

Note: It is suitable for those organization which requires maximum work centers and where floor space is minimum.

(3) **L - Shaped Layout**

Note:- The selection of L - Shaped layout depends upon the availability of floor space and nature of task.

(4) **U - Shaped Layout:**

Note:- The selection of U - Shaped layout depends upon the availability of floor space and nature of task.
(c) **Fixed position layout / constant layout:**
The layout which is used for fixed production is called fixed position layout. It means, production itself does not move. Instead of product, the process and material should be brought to the final production area or site. In other words, materials, labors and machines are moved to a place, where all manufacturing activities are to be done. This type of layout is useful due to following two major reasons:

(i) Products are extremely large and heavy
(ii) Product volume is extremely low.

A fixed-position layout is appropriate for a product that is too large or too heavy to move. For example, battleships are not produced on an assembly line. For services, other reasons may dictate the fixed position (e.g., a hospital operating room where doctors, nurses, and medical equipment are brought to the patient). Other fixed-position layout examples include construction (e.g., buildings, dams, and electric or nuclear power plants), shipbuilding, aircraft, aerospace, farming, drilling for oil, home repair, and automated car washes. Due to the nature of the product, the user has little choice in the use of a fixed-position layout.

For this type of layout, it requires specialized production facilities of construction as well as manpower. Therefore, fixed position layout is generally followed different construction companies to construct buildings, bridges, dams, ships etc.

**Advantages (Pros)**
- Simple and capable to adjust changes in both product and process.
- Labors or workers can be busy throughout the project duration.
- Economies in labor cost because daily base workers work in this layout generally.
- Much more workers can get employment during the project duration.

**Disadvantages (Cons)**
- Complexity in nature.
- Much more facilities are required to produce only one product.
- Require high investment.
- Seasonal job opportunity to workers.

(d) **Combination of layout / mixed layout:**
Many situations call for a mixture of the three main layout types. These mixtures are commonly called mixed or hybrid layouts. For example, one firm may utilize a process layout for the majority of its process along with an assembly in one area. Alternatively, a firm may utilize a fixed-position layout for the assembly of its final product, but use assembly lines to produce the components and subassemblies that make up the final product (e.g., aircraft). It is the mostly used layout.

![Diagram showing combinations of layout types](image)

Where,
- \(C_1\) – Combination of layout between product and process layout
- \(C_2\) – Combination of layout between product and fixed position layout
- \(C_3\) – Combination of layout between process and fixed position layout
- \(C_4\) – Combination of layout among product, process and fixed position layout

(e) **Cellular layout / Group Technology layout:** Under this, various cells or work centers are formed to produce products having similar shape and nature. It is focused on group technology
and groups are designed to perform a specific set of process. These groups are called cells. Therefore, a cellular layout is an equipment layout configured to support cellular manufacturing. Cellular manufacturing is a type of layout where machines are grouped according to the process requirements for a set of similar items that require similar processing. It is similar to product layout on which various cells (groups) are dedicated to limited range of products. It is widely used layout in Japan, so it is also known as Japanese layout. Workers in cellular layouts are cross-trained so that they can operate all the equipment within the cell and take responsibility for its output. Sometimes the cells feed into an assembly line that produces the final product. In some cases a cell is formed by dedicating certain equipment to the production of a family of parts without actually moving the equipment into a physical cell (these are called virtual or nominal cells). In this way, the firm avoids the burden of rearranging its current layout. However, physical cells are more common.

### Designing Product Layout – Line Balancing

The goal of a product layout is to arrange workers or machines in the sequence that operations need to be performed. The sequence is referred to as a production line or an assembly line. These lines range from fairly short, with just a few operations, to long lines that have a large number of operations. Automobile assembly lines are examples of long lines. At the assembly line for Ford Mustangs, a Mustang travels about nine miles from start to finish! Because it is difficult and costly to change a product layout that is inefficient, design is a critical issue. Many of the benefits of a product layout relate to the ability to divide required work into a series of elemental tasks (e.g., “assemble parts C and D”) that can be performed quickly and routinely by low-skilled workers or specialized equipment. The durations of these elemental tasks typically range from a few seconds to 15 minutes or more. Most time requirements are so brief that it would be impractical to assign only one task to each worker. For one thing, most workers would quickly become bored by the limited job scope. For another, the number of workers required to complete even a simple product or service would be enormous. Instead, tasks are usually grouped into manageable bundles and assigned to workstations staffed by one or two operators.

The process of deciding how to assign tasks to workstations is referred to as line balancing. The goal of line balancing is to obtain task groupings that represent approximately equal time requirements. This minimizes the idle time along the line and results in a high utilization of labor and equipment. Idle time occurs if task times are not equal among workstations; some stations are capable of producing at higher rates than others. These “fast” stations will experience periodic waits for the output from slower stations or else be forced into idleness to avoid buildups of work between stations. Unbalanced lines are undesirable in terms of inefficient utilization of labor and equipment and because they may create morale problems at the slower stations for workers who must work continuously. Lines that are perfectly balanced will have a smooth flow of work as activities along the line are synchronized to achieve maximum utilization of labor and equipment. The major obstacle to attaining a perfectly balanced line is the difficulty of forming task bundles that have the same duration. One cause of this is that it may not be feasible to combine certain activities into the same bundle, either because of differences in equipment requirements or because the activities are not compatible (e.g., risk of contamination of paint from sanding). Another cause of difficulty is that differences among elemental task lengths cannot always be overcome by grouping tasks. A third cause of an inability to perfectly balance a line is that a required technological sequence may prohibit otherwise desirable task combinations. Consider a series of three operations that have durations of two minutes, four minutes, and two minutes, as shown in the following diagram. Ideally, the first and third operations could be combined at one workstation and have a total time equal to that of the second operation. However, it may not be possible to combine the first and third operations. In the
case of an automatic car wash, scrubbing and drying operations could not realistically be combined at the same workstation due to the need to rinse cars between the two operations.

Line balancing involves assigning tasks to workstations. Usually, each workstation has one worker who handles all of the tasks at that station, although an option is to have several workers at a single workstation. For purposes of illustration, however, all of the examples and problems in this chapter have workstations with one worker. A manager could decide to use anywhere from one to five workstations to handle five tasks. With one workstation, all tasks would be done at that station; with five stations, for example, one task would be assigned to each station. If two, three, or four workstations are used, some or all of the stations will have multiple tasks assigned to them. How does a manager decide how many stations to use?

The primary determinant is what the line’s cycle time will be. The cycle time is the maximum time allowed at each workstation to perform assigned tasks before the work moves on. The cycle time also establishes the output rate of a line. For instance, if the cycle time is two minutes, units will come off the end of the line at the rate of one every two minutes. Hence, the line’s capacity is a function of its cycle time.

We can gain some insight into task groupings and cycle time by considering a simple example.

Suppose that the work required to fabricate a certain product can be divided up into five elemental tasks, with the task times and precedence relationships as shown in the following diagram:

The task times govern the range of possible cycle times. The minimum cycle time is equal to the longest task time (1.0 minute), and the maximum cycle time is equal to the sum of the task times (0.1+0.7+1.0+0.5+0.2=2.5 minutes). The minimum cycle time would apply if there were five workstations. The maximum cycle time would apply if all tasks were performed at a single workstation. The minimum and maximum cycle times are important because they establish the potential range of output for the line, which we can compute using the following formula:

Output rate = Operating time per day / Cycle time ……………(1)

Assume that the line will operate for eight hours per day (480 minutes). With a cycle time of 1.0 minute, output would be

480 minutes per day / 1.0 minute per unit = 480 units per day

With a cycle time of 2.5 minutes, the output would be

480 minutes per day / 2.5 minutes per unit = 192 units per day

Assuming that no parallel activities are to be employed (e.g., two lines), the output selected for the line must fall in the range of 192 units per day to 480 units per day. As a general rule, the cycle time is determined by the desired output; that is, a desired out-put rate is selected, and the cycle time is computed. If the cycle time does not fall between the maximum and minimum
bounds, the desired output rate must be revised. We can compute the cycle time using this equation:

\[
\text{Cycle time} = \frac{\text{Operating time per day}}{\text{Desired output rate}} \quad \text{...........} \quad (2)
\]

For example, suppose that the desired output rate is 480 units. Using Formula 2, the necessary cycle time is 480 minutes per day / 480 units per day = 1.0 minute per unit.

The number of workstations that will be needed is a function of both the desired output rate and our ability to combine elemental tasks into workstations. We can determine the theoretical minimum number of stations necessary to provide a specified rate of output as follows:

\[
N_{\text{min}} = \frac{\Sigma t}{\text{Cycle time}}
\]

Where, \(N_{\text{min}}\) is theoretical minimum number of stations

\(\Sigma t = \text{Sum of task times}\)

Suppose the desired rate of output is the maximum of 480 units per day. (This will require a cycle time of 1.0 minute.) The minimum number of stations required to achieve this goal is

\[
N_{\text{min}} = 2.5 \text{ minutes per unit} / 1 \text{ minute per unit per station} = 2.5 \text{ stations.}
\]

Because 2.5 stations is not feasible, it is necessary to round up (because 2.5 is the minimum) to three stations. Thus, the actual number of stations used will equal or exceed three, depending on how successfully the tasks can be grouped into work stations.

A very useful tool in line balancing is a precedence diagram. Figure 1 illustrates a simple precedence diagram. It visually portrays the tasks that are to be performed along with the sequential requirements, that is, the order in which tasks must be performed. The diagram is read from left to right, so the initial task(s) are on the left and the final task is on the right.

In terms of precedence requirements, we can see from the diagram, for example, that the only requirement to begin task \(b\) is that task \(a\) must be finished. However, in order to begin task \(d\), tasks \(b\) and \(c\) must both be finished. Note that the elemental tasks are the same ones that we have been using.
Now let’s see how a line is balanced. This involves assigning tasks to workstations. Generally, no techniques are available that guarantee an optimal set of assignments. Instead, managers employ heuristic (intuitive) rules, which provide good and sometimes optimal sets of assignments. A number of line-balancing heuristics are in use, two of which are described here for purposes of illustration:

1. Assign tasks in order of most following tasks.
2. Assign tasks in order of greatest positional weight. Positional weight is the sum of each task’s time and the times of all following tasks.

Arrange the tasks shown in Figure 1 into three workstations. Use a cycle time of 1.0 minute.

Assign tasks in order of the most number of followers.

1. Begin with task a; it has the most following tasks. Assign it to workstation 1.
2. Next, tasks b and c each have two following tasks, but only task c will fit in the time remaining at workstation 1, so assign task c to workstation 1.
3. Task b now has the most followers, but it will not fit at workstation 1, so assign it to workstation 2.
4. There is no time left at workstation 2, so we move on to workstation 3, assigning task d and then task e to that workstation.

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Time Remaining</th>
<th>Eligible</th>
<th>Assign Task</th>
<th>Revised Time Remaining</th>
<th>Time</th>
<th>Station Idle Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>a</td>
<td>a</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>b, c</td>
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<tr>
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<td>1.0</td>
<td>b</td>
<td>b</td>
<td>0.0</td>
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</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>d</td>
<td>d</td>
<td>0.5</td>
<td></td>
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<tr>
<td></td>
<td>0.5</td>
<td>e</td>
<td>e</td>
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<td>0.3</td>
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</tbody>
</table>

The initial “time remaining” for each workstation is equal to the cycle time. For a task to be eligible, tasks preceding it must have been assigned, and the task’s time must not exceed the station’s remaining time.
Example 1 is purposely simple; it is designed to illustrate the basic procedure. Later examples will illustrate tiebreaking, constructing precedence diagrams, and the positional weight method. Before considering those examples, let us first consider some measures of effectiveness that can be used for evaluating a given set of assignments.

Two widely used measures of effectiveness are

1. The percentage of idle time of the line. This is sometimes referred to as the balance delay. It can be computed as follows:

   \[
   \text{Percentage of idle time} = \frac{\text{Idle time per cycle}}{(N \text{ actual} - \text{Cycle time}) \times 100} \quad \ldots \ldots \quad (4)
   \]

   Where \( N = \text{actual number of stations} \)

   For the preceding example, the value is

   \[
   \text{Percentage of idle time} = \frac{.5}{(3 \times 1.0)} \times 100 = 16.7\%
   \]

   In effect, this is the average idle time divided by the cycle time, multiplied by 100. Note that cycle time refers to the actual cycle time that is achieved.

2. The efficiency of the line. This is computed as follows:

   \[
   \text{Efficiency} = 100\% - \text{percent idle time} \quad \ldots \ldots \quad (5a)
   \]

   Here, \( \text{Efficiency} = 100\% - 16.7\% = 83.3\% \). Alternatively, efficiency could be computed using Formula 5b:

   \[
   \text{Efficiency} = \frac{N \text{ actual} \times \text{Cycle time} - \text{Idle time}}{N \text{ actual} \times \text{Cycle time}} \times 100 \quad \ldots \ldots \quad (5b)
   \]

   Now let’s consider the question of whether the selected level of output should equal the maximum output possible. The minimum number of workstations needed is a function of the desired output rate and, therefore, the cycle time. Thus, a lower rate of output (hence, a longer cycle time) may result in a need for fewer stations. Hence, the manager must consider whether the potential savings realized by having fewer workstations would be greater than the decrease in profit resulting from producing fewer units.

The preceding examples serve to illustrate some of the fundamental concepts of line balancing. They are rather simple; in most real-life situations, the number of branches and tasks is often much greater. Consequently, the job of line balancing can be a good deal more complex. In many instances, the number of alternatives for grouping tasks is so great that it is virtually impossible to conduct an exhaustive review of all possibilities. For this reason, many real-life problems of any magnitude are solved using heuristic approaches. The purpose of a heuristic approach is to reduce the number of alternatives that must be considered, but it does not guarantee an optimal solution.
Some Guidelines for Line Balancing

In balancing an assembly line, tasks are assigned one at a time to the line, starting at the first workstation. At each step, the unassigned tasks are checked to determine which are eligible for assignment. Next, the eligible tasks are checked to see which of them will fit in the workstation being loaded. A heuristic is used to select one of the tasks that will fit, and the task is assigned. This process is repeated until there are no eligible tasks that will fit. Then the next workstation can be loaded. This continues until all tasks are assigned. The objective is to minimize the idle time for the line subject to technological and output constraints.

Technological constraints tell us which elemental tasks are eligible to be assigned at a particular position on the line. Technological constraints can result from the precedence or ordering relationships among the tasks. The precedence relationships require that certain tasks must be performed before others (and so, must be assigned to workstations before others). Thus, in a car wash, the rinsing operation must be performed before the drying operation. The drying operation is not eligible for assignment until the rinsing operation has been assigned. Technological constraints may also result from two tasks being incompatible (e.g., space restrictions or the nature of the operations may prevent their being placed in the same work center). For example, sanding and painting operations would not be assigned to the same work center because dust particles from the sanding operation could contaminate the paint.

Output constraints, on the other hand, determine the maximum amount of work that a manager can assign to each workstation, and this determines whether an eligible task will fit at a workstation. The desired output rate determines the cycle time, and the sum of the task times assigned to any workstation must not exceed the cycle time. If a task can be assigned to a workstation without exceeding the cycle time, then the task will fit.

Once it is known which tasks are eligible and will fit, the manager can select the task to be assigned (if there is more than one to choose from). This is where the heuristic rules help us decide which task to assign from among those that are eligible and will fit.

To clarify the terminology, following tasks are all tasks that you would encounter by following all paths from the task in question through the precedence diagram. Preceding tasks are all tasks you would encounter by tracing all paths backward from the task in question. In the precedence diagram below, tasks b, d, e, and f are followers of task a. Tasks a, b, and c are preceding tasks for e.
The positional weight for a task is the sum of the task times for itself and all its following tasks.

Neither of the heuristics guarantees the best solution, or even a good solution to the line-balancing problem, but they do provide guidelines for developing a solution. It may be useful to apply several different heuristics to the same problem and pick the best (least idle time) solution out of those developed.

Using the information contained in the table shown, do each of the following:

1. Draw a precedence diagram.

2. Assuming an eight-hour workday, compute the cycle time needed to obtain an output of 400 units per day.

3. Determine the minimum number of workstations required.

4. Assign tasks to workstations using this rule: Assign tasks according to greatest number of following tasks. In case of a tie, use the tiebreaker of assigning the task with the longest processing time first.

<table>
<thead>
<tr>
<th>Task</th>
<th>Immediate Predecessor</th>
<th>Task Time (in minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>—</td>
<td>0.2</td>
</tr>
<tr>
<td>b</td>
<td>a</td>
<td>0.2</td>
</tr>
<tr>
<td>c</td>
<td>—</td>
<td>0.8</td>
</tr>
<tr>
<td>d</td>
<td>c</td>
<td>0.6</td>
</tr>
<tr>
<td>e</td>
<td>b</td>
<td>0.3</td>
</tr>
<tr>
<td>f</td>
<td>d, e</td>
<td>1.0</td>
</tr>
<tr>
<td>g</td>
<td>f</td>
<td>0.4</td>
</tr>
<tr>
<td>h</td>
<td>g</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\[ \Sigma t = 3.8 \]

5. Compute the resulting percent idle time and efficiency of the system.

Solution

1. Drawing a precedence diagram is a relatively straightforward task. Begin with activities with no predecessors. We see from the list that tasks a and c do not have predecessors. We build from here.

Step 1

- a
- c

Step 2: Task b follows a, and d follows c
Step 3: Task e follows b

Step 4: Task f follows e and d

Step 5: Task g follows f, and h follows g.

2. Cycle time = \(\frac{\text{Operating time}}{\text{Desired output rate}} = \frac{480 \text{ minutes per day}}{400 \text{ units per day}} = 1.2 \text{ minutes per cycle}\)

3. \(N_{\text{min}} = \sum t = \frac{3.8 \text{ minutes per unit}}{1.2 \text{ minutes per cycle per station}} = 3.17 \text{ Stations (round to 4)}\)

4. Beginning with station 1, make assignments following this procedure: Determine from the precedence diagram which tasks are eligible for assignment. Then determine which of the eligible tasks will fit the time remaining for the station. Use the tiebreaker if necessary. Once a task has been assigned, remove it from consideration. When a station cannot take any more assignments, go on to the next station. Continue until all tasks have been assigned.

<table>
<thead>
<tr>
<th>Station</th>
<th>Time Remaining</th>
<th>Eligible</th>
<th>Will Fit</th>
<th>Assign (task time)</th>
<th>Revised Time Remaining</th>
<th>Idle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>a, c *</td>
<td>a, c *</td>
<td>a (0.2)</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>c, b **</td>
<td>c, b **</td>
<td>c (0.8)</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>b, d</td>
<td>b</td>
<td>b (0.2)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>e, d</td>
<td>None</td>
<td>---</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>e, d</td>
<td>e, d</td>
<td>d (0.6)</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>e</td>
<td>e</td>
<td>e (0.3)</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>0.3***</td>
<td>f</td>
<td>None</td>
<td>---</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>f</td>
<td>f</td>
<td>f (1.0)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>g</td>
<td>None</td>
<td>---</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>g</td>
<td>g</td>
<td>g (0.4)</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>h</td>
<td>h</td>
<td>h (0.3)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.5</td>
<td>1.0 min</td>
</tr>
</tbody>
</table>

*Neither a nor c has any predecessors, so both are eligible. Task a was assigned since it has more followers.
**Once a is assigned, b and c are now eligible. Both will fit in the time remaining of 1.0 minute. The tie cannot be broken by the "most followers" rule, so the longer task is assigned.
***Although f is eligible, this task will not fit, so station 2 is left with 0.3 minute of idle time per 1.2 minute cycle.
These assignments are shown in the following diagram. Note: One should not expect that heuristic approaches will always produce optimal solutions; they merely provide a practical way to deal with complex problems that may not lend themselves to optimizing techniques. Moreover, different heuristics often yield different answers.

5. Percent idle time = \( \frac{1.0 \text{ min}}{4 \times 1.2 \text{ min}} \times 100 = 20.83\% \)

Efficiency = 100\% - 20.83\% = 79.17\%

Other Factors

The preceding discussion on line balancing presents a relatively straightforward approach to approximating a balanced line. In practice, the ability to do this usually involves additional considerations, some of which are technical.

Technical considerations include skill requirements of different tasks. If skill requirements of tasks are quite different, it may not be feasible to place the tasks in the same workstation. Similarly, if the tasks themselves are incompatible (e.g., the use of fire and flammable liquids), it may not be feasible even to place them in stations that are near each other.

Developing a workable plan for balancing a line may also require consideration of human factors as well as equipment and space limitations. Although it is convenient to treat assembly operations as if they occur at the same rate time after time, it is more realistic to assume that whenever humans are involved, task completion times will be variable. The reasons for the variations are numerous, including fatigue, boredom, and failure to concentrate on the task at hand. Absenteeism also can affect line balance.

Minor variability can be dealt with by allowing some slack along the line. However, if more variability is inherent in even a few tasks, that will severely impact the ability to achieve a balanced line. For these reasons, lines that involve human tasks are more of an ideal than a reality. In practice, lines are rarely perfectly balanced. However, this is not entirely bad, because some unbalance means that slack exists at points along the line, which can reduce the impact of brief stoppages at some workstations. Also, workstations that have slack can be used for new workers who may not be “up to speed.”
Note: *Formula used in the line balancing:*

Desired output rate = Production plan per period / Available hours

**Cycle time:** It is the maximum time allowed for work on a unit at each station. It is the reciprocal of desired output rate.

\[ C = \frac{1}{r} \]

Where, \( C \) = cycle time in hours per unit.

\( r \) = Desired output rate in units per hour

**Theoretical minimum:** A benchmark or a goal for the smallest number of stations possible where the total time required to assemble each unit (the sum of all work element standard times) is divided by the cycle time. The theoretical minimum (TM) for the number of stations is

\[ TM = \frac{\Sigma t}{C} \]

Where,

\( \Sigma t \) = total time required to assemble each unit (the sum of all work element standard times)

\( C \) = cycle time

**Idle time, Efficiency and Balance delay:** Minimizing \( n \) automatically ensures (1) minimal idle time, (2) maximal efficiency and (3) minimal balance delay. Idle time is the total unproductive time for all stations in the assembly of each unit.

\[ \text{Idle time} = nc - \Sigma t \]

Where, \( n \) = number of stations

\( C \) = cycle time

\( \Sigma t \) = total standard time required to assemble each unit

**Efficiency** is the ratio of productive time to total time.

\[ \text{Efficiency (percent)} = \frac{\Sigma t}{nc} \times 100 \]

Balance delay is the amount by which efficiency falls sort of 100 percent.

\[ \text{Balance delay (percent)} = 100 - \text{efficiency} \]

**DESIGNING PROCESS LAYOUT**

The main issue in designing process layouts concerns the relative positioning of the departments involved. Departments must be assigned to locations. The problem is to develop a reasonably good layout; some combinations will be more desirable than others. For example, some departments may benefit from adjacent locations whereas others should be separated.

Process layout involves three basic steps for new or revised layout design.
1. **Gather information**: It covers nature of the jobs, number of workers needed, number of shifts and machines types. Space requirements by the center, available space and closeness factors.
   a. *Space requirements by center*: The layout designer must tie space requirements to capacity plans, calculate the specific equipments and space need for each center and allow circulation space such as aisle (walking space).
   b. *Available space* – Available area, block plan based on it.
   c. *Closeness factors* – The layout designer must also know which centers need to be located close to one another. Location is based on the number of trips (people movement, materials movement etc.) between centers and qualitative factors.

2. **Develop a block plan**: it is developed that best satisfies performance criteria and area requirements. For this trial and error is done. For this sometimes computer aided programs are used.

3. **Design a detailed layout**: after finding a satisfactory block plan, the layout designer translates it into a detailed representation, showing the exact size and shape of each center, the arrangement of elements (e.g. desks, machines and storage areas) and the location of aisle, stairways and other service spaces.

### EXERCISE – 3

1. What do you mean by location decision? What are the affecting factors of location decision?
2. What steps are required in planning facility location?
3. Describe the quantitative models for facility location.
4. What is layout? What are its types? Explain with suitable examples.
5. What do you mean by product layout? How it is differed from process layout?
6. Describe the relationship between capacity planning and the location planning. Consider the financial institution in explaining the relationship.
7. Write down the procedures for facility location planning.
8. Discuss various types of quantitative and qualitative techniques used in facility location decision.
9. Discuss the impact of behavioral aspect in facility location decision?

**Numerical Problems**
1. An assembly line with 17 tasks is to be balanced. The longest task is 2.4 minutes, and the total time for all tasks is 18 minutes. The line will operate for 450 minutes per day.
   a. What are the minimum and maximum cycle times?
   b. What range of output is theoretically possible for the line?
   c. What is the minimum number of workstations needed if the maximum output rate is to be sought?
   d. What cycle time will provide an output rate of 125 units per day?
   e. What output potential will result if the cycle time is (1) 9 minutes? (2) 15 minutes?

2. A manager wants to assign tasks to workstations as efficiently as possible, and achieve an hourly output of $33\frac{1}{3}$ units. Assume the shop works a 60-minute hour. Assign the tasks shown in the accompanying precedence diagram (times are in minutes) to workstations using the following rules:
   a. In order of most following tasks. Tiebreaker: greatest positional weight.
   b. In order of greatest positional weight.
   c. What is the efficiency?

3. A manager wants to assign tasks to workstations as efficiently as possible, and achieve an hourly output of 4 units. The department uses a working time of 56 minutes per hour. Assign the tasks shown in the accompanying precedence diagram (times are in minutes) to workstations using the following rules:
   a. In order of most following tasks. Tiebreaker: greatest positional weight.
   b. In order of greatest positional weight.
   c. What is the efficiency?
4. A producer of inkjet printers is planning to add a new line of printers, and you have been asked to balance the process, given the following task times and precedence relationships. Assume that cycle time is to be the minimum possible.

<table>
<thead>
<tr>
<th>Task</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length per minutes</td>
<td>0.2</td>
<td>0.4</td>
<td>0.3</td>
<td>1.3</td>
<td>0.1</td>
<td>0.8</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Immediate Predecessor</td>
<td>-</td>
<td>A</td>
<td>-</td>
<td>B,C</td>
<td>-</td>
<td>E</td>
<td>D,F</td>
<td>G</td>
</tr>
</tbody>
</table>

I. Do each of the following:

a. Draw the precedence diagram.
b. Assign tasks to stations in order of greatest number of following tasks.
c. Determine the percentage of idle time.
d. Compute the rate of output in printers per day that could be expected for this line assuming a 420-minute working day.

II. Answer these questions:

a. What is the shortest cycle time that will permit use of only two workstations? Is this cycle time feasible? Identify the tasks you would assign to each station.
b. Determine the percentage of idle time that would result if two stations were used.
c. What is the daily output under this arrangement?
d. Determine the output rate that would be associated with the maximum cycle time.

5. As part of a major plant renovation project, the industrial engineering department has been asked to balance a revised assembly operation to achieve an output of 240 units per eight-hour day. Task times and precedence relationships are as follows:

<table>
<thead>
<tr>
<th>Task</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length per minutes</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.4</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Immediate Predecessor</td>
<td>-</td>
<td>A</td>
<td>B</td>
<td>-</td>
<td>D</td>
<td>C</td>
<td>E,F</td>
</tr>
</tbody>
</table>

Do each of the following:

a. Draw the precedence diagram.
b. Determine the minimum cycle time, the maximum cycle time, and the calculated cycle time.
c. Determine the minimum number of stations needed.
d. Assign tasks to workstations on the basis of greatest number of following tasks. Use longest processing time as a tiebreaker. If ties still exist, assume indifference in choice.
e. Compute the percentage of idle time for the assignment in part d.
6. Twelve tasks, with times and precedence requirements as shown in the following table, are to be assigned to workstations using a cycle time of 1.5 minutes. Two heuristic rules will be tried: (1) greatest positional weight, and (2) greatest number of following tasks.

In each case, the tiebreaker will be shortest task time.

<table>
<thead>
<tr>
<th>Task</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>k</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length per minutes</td>
<td>0.1</td>
<td>0.2</td>
<td>0.9</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Immediate Predecessor</td>
<td>-</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>e</td>
<td>f</td>
<td>g</td>
<td>h</td>
<td>i</td>
<td>j</td>
<td>k</td>
</tr>
</tbody>
</table>

a. Draw the precedence diagram for this line.
b. Assign tasks to stations under each of the two rules.
c. Compute the percentage of idle time for each rule.

7. For the set of tasks given below, do the following:

a. Develop the precedence diagram.
b. Determine the minimum and maximum cycle times in seconds for a desired output of 500 units in a seven-hour day. Why might a manager use a cycle time of 50 seconds?
c. Determine the minimum nos. of workstations for output of 500 units per day.
d. Balance the line using the largest positional weight heuristic. Break ties with the most following tasks heuristic. Use a cycle time of 50 seconds.
e. Calculate the percentage idle time for the line.

<table>
<thead>
<tr>
<th>Task</th>
<th>Length (minutes)</th>
<th>Immediate Predecessor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>45</td>
<td>—</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>B</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
<td>—</td>
</tr>
<tr>
<td>E</td>
<td>26</td>
<td>D</td>
</tr>
<tr>
<td>F</td>
<td>11</td>
<td>E</td>
</tr>
<tr>
<td>G</td>
<td>12</td>
<td>C</td>
</tr>
<tr>
<td>H</td>
<td>10</td>
<td>C</td>
</tr>
<tr>
<td>I</td>
<td>9</td>
<td>F, G, H</td>
</tr>
<tr>
<td>J</td>
<td>10</td>
<td>I</td>
</tr>
</tbody>
</table>

Total = 193