Research Paper

PLANT LAYOUTS' ANALYSIS AND DESIGN

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ABSTRACT

The paper provided a detailed definition of plant layout; and listed efficient labour utilization, manufacturing and maintenance ease, enhanced productivity, manufacturing flexibility, effective utilization of staff, machines, materials, and equipment, as well as reduction of accidents, hazards, and inventory handling cost as some of the benefits of a well-designed plant layout. The numerous factors that determine the designing of a plant layout were also discussed in full, after which the various types of plant layout were analysed. The plant layout design, its major objectives, and the equations for analytical calculations of work in progress and efficiency in plant layout design were also discussed, before the paper concluded on the need for manufacturers to have a well-designed functional plant layout that will be able to switch from one line of product to another without major alterations.

KEYWORDS: work in progress, inventory, throughput, product, process, plant layout design, flexibility, manufacturing, production.

I. INTRODUCTION

Little adjustments in the position of machines and equipment in a manufacturing plant can greatly alter the easy flow of materials; this also affects the production costs and efficiency of the entire manufacturing process. The inability to get manufacturing processes right leads to delays, inflexibility, inefficiency, excess inventory, high costs, low product quality, and unhappy customers. Modifying an ineffective layout is quite expensive; hence the need to design a functional plant layout right from the onset.

Designing and operating an effective plant layout that can promptly and efficiently adjust to the requirements of ever-changing technology and customer demands is becoming increasingly vital to the success of manufacturing companies. With the realities of reduced product life cycle and lead times, as well as increased variety of products and random customer demands, manufacturers are realizing that operating a single line of product can no longer be profitable. This is because production efficiency entails that plant layout should quickly adapt from a product line to another without equipment replacement, extensive retooling, and re-arrangement of resources.

To manufacture high quality products that will meet the customer demands, it is pertinent to concurrently produce several products, to enable low volume products to be produced alongside others, thereby easily accommodate volume and product mix variations. Today's manufacturing layouts must demonstrate adequate robustness and flexibility regardless of constant changes in operating requirements. This explains why proper plant layout design has turned out to be an essential basis of current industrial facilities, thereby enhancing the efficiency of product outputs.

Plant layout is the systematic arrangement of a firm's physical facilities to enhance the efficient use of machines, material, equipment, energy, and the workers. It can also be defined as the plan or act of planning an ideal facility arrangement, which include equipment, storage space, workers, machines, inventory flow, and other services that enhance production, alongside the design of an efficient structure to accommodate the facilities.

According to Kumar (2013), plant layout is "a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling, equipment, and all other supporting services along with the design of best structure to contain all the facilities." He explained that it involves proper space allocation, as well as the arrangement of equipment to ensure that the overall operating costs are minimized.

In his work Singh (2012), explained that Plant layout "decisions entail determining the placement of departments, work groups within the departments, workstations, machines, and stock-holding points within a production facility." He pointed out that the objective include the arrangement of these elements in a manner that ensures a smooth work flow in a manufacturing unit or a particular traffic pattern in a service organization.

A good plant layout is designed to offer competitive advantage to manufacturers by enhancing the flow processes of inventory and information, thereby leading to reduction in manufacturing cost and improved productivity. Thinklink (2014), observed that "The production efficiency of a manufacturing unit depends on how well various machines, flow paths, storage facilities, and employee amenities are located in the plant." They observed that a systematically designed plant layout will guarantee a smooth and rapid movement of material from the raw material stage to the end product stage.

2. BENEFITS OF WELL DESIGNED PLANT LAYOUTS

A properly designed plant layout provides an ideal synergy among raw materials, manufacturing processes, available space, and the output. It ensures the efficient utilization of all available space and flexibility of arrangements and manufacturing operations, streamline the movement of inventory in the entire manufacturing plant without hitches or unnecessary delays, maintains adequate turnover of materials, reduces lead time and cost of material handling, and also ensure the workers safety, comfort and convenience.

Singh (2012), observed that a good plant layout design "facilitates the production process, minimizes material handling, time and cost, and allows flexibility of operations, easy production flow, makes economic use of the building, promotes effective utilization of manpower, and provides for employee's convenience, safety, comfort at work, maximum exposure to natural light and ventilation." He

concluded that it is also important as it affects material flow and processes, labour efficiency, supervision and control, use of space and the possibilities of expansion.

According to Strategosinc (2014), like other engineering design, plant layout "proceeds through a logical sequence of steps. At each step, the designers make compromises between conflicting requirements or technical limitations, doing it well require a deep and profound knowledge of the elements, their functions, and their interactions." A good designed plant layout offers competitive advantage to a manufacturing company, as it has the ability to operate at low cost, reduce lead time, facilitate frequent new products, and also ensure the manufacturing of high quality products.

Other benefits of a well-designed plant layout as shown in figure 1 include: efficient labour utilization, inventory handling cost reduction, manufacturing and maintenance ease, accidents and hazards reduction, enhanced productivity, manufacturing flexibility, as well as effective utilization of staff, machines, materials, and equipment.

Figure 1: Benefits of a well-designed Plant Layout. Source: Singh (2012)

3. FACTORS THAT DETERMINE THE DESIGNING OF PLANT LAYOUT

Some of the goals of designing plant layouts are to achieve a minimum amount of materials handling, reduce bottlenecks, minimize machine interference, and also enhance flexibility, throughput, safety, and employee's morale. To achieve optimum layout effectiveness when designing a plant layout, many factors of operation need to be seriously considered. This principle includes the following:

- Room for future adjustments and expansion – at the onset, plant layouts should be designed to be easily changed or expanded in line with ever-changing needs of manufacturing. This will ensure that flexibility is attained in the facility in order to reduce the set up time required in the manufacturing of different products, and also attain the required throughput.
- Maximum flexibility - good plant layout should be easily modified in order to meet up with the ever-changing demands of the customer and market.
- Throughput – plant layouts should be designed to assist the business to attain its production output at the shortest possible time, in order to ensure repeat patronage and customer satisfaction.
- Efficient utilization of space – this entails the provision of sufficient space around the machines and the traffic lanes, as well as ensuring that adequate spaces are made available for storage points within the facility.
- Ease of Communication – plant layouts should be designed to enhance communication and easy flow of information among the various departments/units, as well as the customers.
- Promotional value – a well-designed layout enhances the image and reputation of a company, thereby serving as a good promotional factor.
- Safety – as the importance of safety in all human endeavors should not be over-emphasized, a good plant layout should be designed to function efficiently and ensure that accidents and its causes are reduced to the barest minimum.
- Maximum accessibility: the repairs and maintenance sections should be made readily accessible. This implies that equipment and machines must not be placed against the walls in order to ensure that maintenance and servicing operations are easily undertaken.

4. TYPES OF PLANT LAYOUT

The modern manufacturing factories are designed to have advanced and sophisticated plant layouts. The three basic types of layouts by which production sections are organized in a plant, which are defined by the type of workflow are process layout, product layout, fixed-position layout. The fourth type of plant layout which has gained wide acceptance and often regarded as a hybrid layout is called cellular layout. However, some manufacturing companies have a combination of more than one type of layouts; like setting out the area of production by cellular layout, while another section or department will be laid out by process.

Process Layout

Also referred to as functional layout, process layouts are very suitable for applications where the products that are gotten from raw materials and work-in-progress entails high variations while processing the individual operations. The layout which is designed to engender the processing of activities that need many value additions is widely adopted, if the operation's system require large amount of products in small volumes. It is very useful in situations where the production process is structured in batches as the different product are organized to move from an area to another, based on the succession of operations earlier established.

Small Business (2013), explained that process layout "groups workstations together according to the activities being performed, regardless of which products each workstation is working on." Here the machines and workers needed to perform similar function are assigned in the same place, also the distance between sections should be very close to

reducing the waste of movements and materials handling.

The machine shop is a good example of a process layout, as it has different departments for boring, milling, pressing, and milling operations, which ensure that imbalances present in one section is not allowed to interfere in other sections, thereby achieving better utilization of the available machines and equipment. Figure 2 shows a pictorial representation of process layout.

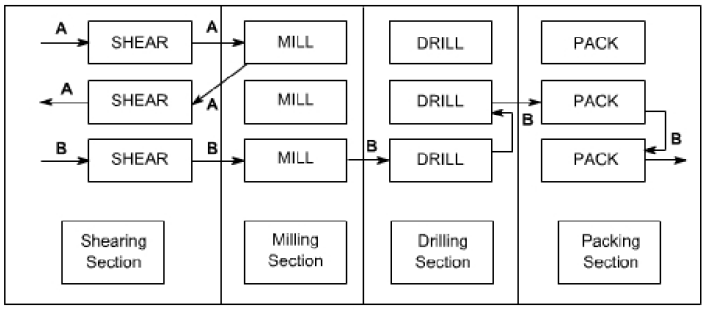

Figure 2: A Pictorial Representation of Process Layout
Source: (Nptel)

The characteristics of process layout include rapid change-over, delayed lead time, high rate of work in progress inventory, flexibility of material handling equipment, requirement of highly skilled workers, technical supervision, and general purpose equipment. To design a functional process layout the following are required: the need for the closeness of the work centers or sections, the required area for the different sections, the limitations of the sections, as well as the flow direction between the sections.

The numerous advantages and disadvantages of process layout are tabulated in Table 1 below.

Table 1: the advantages and disadvantages of process layout

Advantages	Disadvantages
Reduced overhead cost	High work-in-progress inventory
Increased utilization of machine	Low operations and expensive material handling compared to the product layout
Encourages efficient supervision	Requires constant inspection
High products' variety	High production gap
Enhanced flexibility	Requires highly skilled operators
Reduced initial capital investment	Requires expensive machines

The process layout is mostly suited for production processes where: equipment and machines are very costly, the products are not standardized, products are produced in batches, lower production volumes are required, and also frequent alterations of style and product's design.

Product Layout

Also referred to as line layouts, product layouts which has small cycle of manufacturing with reduced material handling is a type of plant layout where machines, equipment, and workers are organized in a line based on the operation's progression needed for a product. Here machines and equipment are grouped together, thereby enabling inventories to flow successively in a clear and easy to control manner from one machine to another as values are being added on them.

A good example of product layout is the vehicle assembly line which entails the movement of nearly all types of similar models in the same operation sequences. The decisions to be made before designing a product layout include the amount of the required cycle time, the number and the arrangement of the various manufacturing processes, how to tackle the time variations for the different processes, and the need to effectively balance the layout.

Here the cycle time is calculated as

$$\frac{\text{available time}}{\text{number of products to be processed}}$$

A pictorial representation of a product layout is depicted in Figure 3.

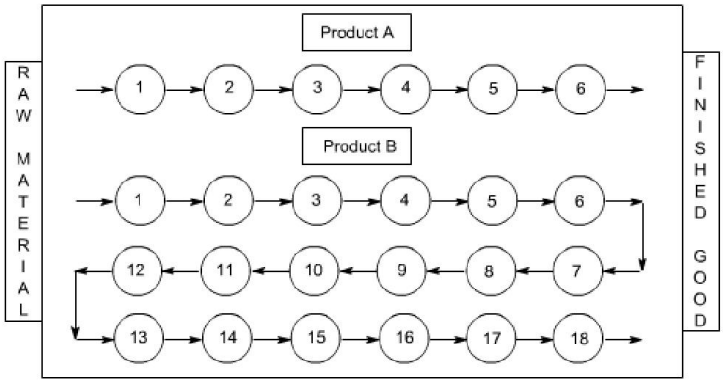

Figure 3: A Pictorial Representation of Product Layout
Source (Nptel)

Product layouts are employed to attain a faultless and constant flow of large quantity of raw materials or work in progress through the plant; it achieves an increased volume utilization of equipment and labour. Here continuous flow is achieved as the entire production process is formed to reduce the problems that are associated with unpleasant bottlenecks. Transtutors (2015), listed the following as some of the benefits of product layout: "less work in process (WIP) inventory as the flow of material is continuous

along a line, compared to process layout, it requires less space for same volume of production, conveyorized material handling or automation in the material handling is cost effective as the flow of material is well known."

More advantages and limitations of product layout are shown in Table 2.

Table 2: The advantages and limitations of product layout

Advantages	Limitations
Reduced material handling cost, activities, and throughput time.	Expensive investments in machines and equipment
Efficient floor space usage	Breakdown of any machine will lead to serious bottlenecks
Continuous and little amount of work in progress	Little or no flexibility in manufacturing processes
Reduced manufacturing cost	Expensive overhead cost
Can be easily learnt and managed by unskilled operators	Monotonous and boring operations
Simplified sequence of operations	Changes in product design requires major layout alterations

The continuous flow of inventory which entails little amount of work in progress, fixed equipment for material handling, expensive and delayed changeovers, little or no direct inspection, requirement of general purpose machines and equipment, and lead time reduction are some of the characteristics of Product type of layout. It is recommended for repetitive and simple production processes, products with very high demands, and mass production of products.

Fixed Position Layout

Fixed position layout is not applicable for small projects or products as it is the plant layout type where the machines, equipment, and workforce are transported to the site of the major product to be produced. It is used in the construction of bulky or fragile projects like bridges, space rockets, ships, aircrafts, dams, flyovers, road construction, and buildings. Figure 4 depicts a representation of a fixed position layout, while the advantages and limitations are shown in Figure 4.

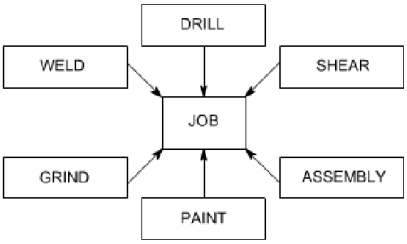

Figure 4: A Pictorial Representation of Fixed Location Layout Source (Nptel)

Figure 3: Advantages and limitations of Fixed Position Plant Layout

Advantages	Limitations
Very flexible and can accommodate changes in design and production processes	Very expensive capital investment
Saves cost and time involved in incessant movement of work from one location to another	Requires large amount of space for the warehouse close to the plant.
It is very economical as jobs at different levels of completion can be produced concurrently	Lengthy production period

Cellular Plant Layout

Cellular plant layout can be defined as a layout type where machines and equipment are properly arranged in order to enhance the steady and uninterrupted movement of materials and tools, through the process of production without stoppages and time wastage. Levinson and Rerick (2002) observed that it is "only by relating each machine with the others in such a way that production will follow in straight lines without confusion, can the highest economy operation be attained." As depicted in figure 5, Cellular Layout does not allow easy accumulation of inventory as materials are immediately processed one after the other.

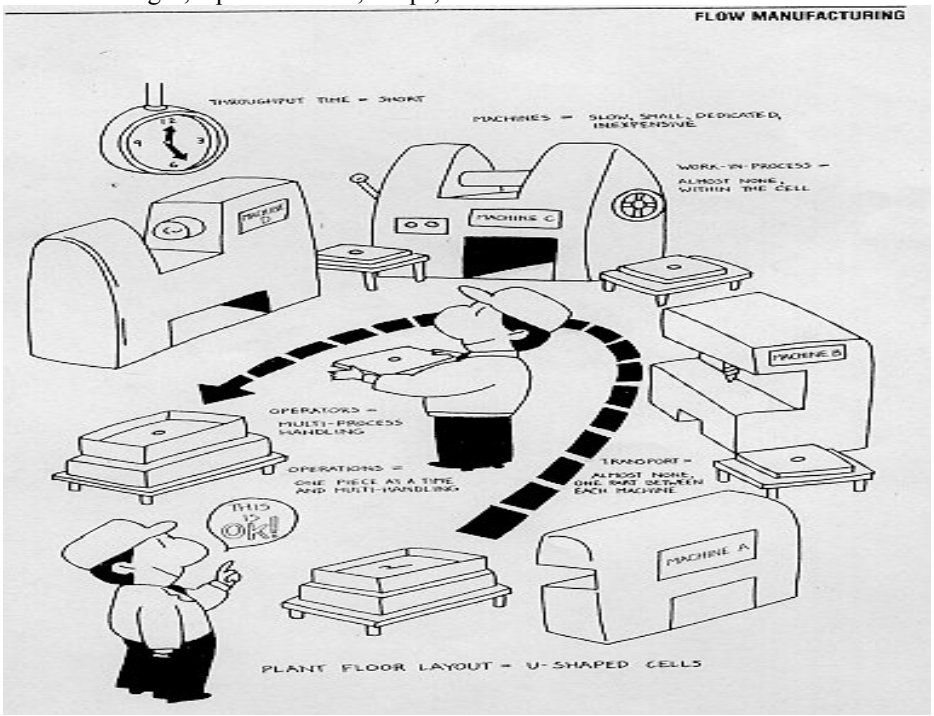

Figure 5: A Cellular plant Layout. Source: Hiroyuki (1998)

The importance of the application of Cellular layout is that it makes electronic layout less complicated, thereby allowing for cheap transporting equipment like the conveyors, unlike the functional layout that requires forklifts and very costly automation. The advantages and limitations of cellular plant layout are shown on Table 4.

Table 4: Advantages and Limitations

Advantages	Limitations
Shorter lead time	Not suitable for many variety of products
Set up time reduction	Applied for low throughput volume
Reduced work in progress inventory	Increased set up cost
Reduced inventory handling processes	Requires more machines
Reduces the wastage of shop floor space	Leads to reduced plant utilization

The main benefit of Cellular layout is that it assists organizations to reduce the overhead cost, as an individual worker can monitor and manage series of machines and equipment in a production channel. Also it encourages flexible manufacturing as well as reduces the wastage of shop floor space.

5. PLANT LAYOUT DESIGN

After selecting the type of layout that is best suited for a manufacturing company's production processes, the next plan is to choose a comprehensive design of the layout in order to ascertain the following: the plant location, machines, equipment, as well as the staff that comprise of the operation's work centre, the space to be assigned to each unit or department, and the work that will be performed by each of the units.

The major objectives of a well designed plant layout include the following:

Safety – a good plant layout must take safety very seriously in order to minimize accidents and terrible losses on the shop floor, which when not properly managed can lead to closure of facilities. Access to hazardous substances and processes should not be made possible without approval, also walk-ways and fire exits should be marked properly without inhibitions.

Conducive environment – a conducive, well lit, and properly ventilated working environment that promotes staff comfort is a hallmark of a good plant layout design.

Accessibility – all equipment, machines, and the plant should be easily accessible for servicing, maintenance, and cleaning.

Flexibility and room for expansion – the plant layout should be designed to be very flexible for easy modifications, it should also accommodate possible future expansion needs.

Length of flow – the movement of information and materials should be effectively organized by the layout in order to reduce the wasteful transport and movements in the shop floor, and also achieve the plant's objective.

Clarity of flow – sign posts should be strategically placed detailing well-specified flow direction. Also communication gadgets should be provided to enhance easy communication and supervision.

The product layout design entail the allocation of work tasks to units, as well as the arrangement of the many processes of production to be in consonance with the manufacturing cycle required for the throughput to emerge. The important information needed include the lead time, the lay out balancing, and the number of the required processing operations. Due to the complicated of work flow in a process layout, its design is often referred to as being complex. It is therefore quite difficult to achieve optimum flow in process layout as they are often designed with systematic trial and error, intuitive knowledge, and common sense.

The designer should have the knowledge of the following in order to design a process layout: the needed space for each of the work centers, the challenges of the area allotted to each of the work centers, the need for the work centers to be close to each other in order to enhance the easy flow of materials, and the rate of flow among the different work centers.

As a compromise between the product layout simplicity and the process layout flexibility, cell layout are often designed when a product that its processes can be easily forecast are to be manufactured. The design approach entails agreeing on the scope and features of the expected cells, as well as the materials to allot to them.

According to Ghosh and Dan (2012), the concepts behind the design of cell layout are to "decompose the manufacturing system into cells by recognizing and exploiting the similarities amongst components and machineries, and to design efficient inter-cell and intra-cell layout in order to smoothen the material flow on shop-floor." The comprehensive design of cell layout enhances performance and also reduces up to 46% of production.

Analytical Calculations of Work in Progress and Efficiency in Plant Layout Design

Excess work in progress inventory in the shop floor is a major waste that bedevils many manufacturing facilities; a good plant layout should ensure that it is reduced to the barest minimum in order to enhance the firm's profitability.

To achieve this the following inputs should be known at the design stage: the quantity of the expected products, the customers' demand for the products, the number of machines to be installed, the number of available space for the mounting of the machines, the distances between the machines, the speed of the transporting system (like the conveyor) in the plant, and the machines processing time for each product.

The analytical calculation of work in progress inventory is rooted on the queuing network theory. The expected work in progress in a unit or department is given as:

$$E(WIPi) - \frac{p_i(C_{ai}{}^2+C_{si}{}^2)g_i}{2(1-p_i)} + p_i \qquad \ldots\ldots \qquad (1)$$

Where: p_i is the average utilization of department 1,

$C_{ai}{}^2$ is the squared coefficient of variation of job inter-arrival,

$C_{si}{}^2$ is the squared coefficient of variation of job processing time,

g_i is the coefficient of department 1.

Also, the expected work in progress in plant conveyor is given by:

$$E(WIPt) - \frac{(C_{at}{}^2 + C_{st}{}^2)g_t}{2(1-p_t)} + p_t \qquad \ldots\ldots \qquad (2)$$

Here:

p_t is the conveyor utilization,

($C_{at}{}^2$ is the squared coefficient of variation of job inter-arrival at the conveyor,

($C_{st}{}^2$ is the squared coefficient of variation of the expected travel time per transfer of material

g_t is a conveyor coefficient.

Therefore, the expected work in progress inventory for the plant will be gotten from:

$E(WIP) = \sum E(WIPi + E(WIPt)$ ….. (3)

Also if F_{ij} is the amount of flow in loads between two departments/units i and j;

And D_{ij} is the distance in meters between two departments/units i and j; and

C_{ij} is the cost per travelled distance between two departments/sections i and j;

The efficiency of all layouts can be calculated as follows:

$Layout\ Efficiency = \sum F_{ij} D_{ij} C_{ij}$ …. (4)

6. CONCLUSION

The success of modern manufacturing facilities is tied on the capacity to efficiently design, run, and maintain plant layouts that can easily adapt to the numerous technological changes, as well as customer demands. Due to ever changing market requirements, stiff competition, more variety of products, reduced life cycle of products, and high cost of manufacturing, companies that have just one product may find it difficult to break even.

This explains the need to have a good designed functional plant layout that will be able to switch from one line of product to another without major alterations. It will also achieve fast flow of raw materials and work in progress at the lowest cost, and with the lowest amount of handling as values are being added to the product from the receipt of raw materials to the shipment of the throughput.

The paper examined in detail the various types of plant layout, their advantages and disadvantages, the design of a functional plant layout, as well as the numerous benefits of a well designed layout.

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