A Simulation Model of Horseshoe Layouts

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Abstract

With the advent of information systems and the recent developments in computing technology, traditional manufacturing systems are fast becoming obsolete. A new generation of factories is being designed with cellular or linked-cell manufacturing systems. This recent shift from traditional to cellular manufacturing system has necessitated the redesign of the factory and its layout. Traditional process and product layouts (involving straight and long assembly lines or departments) are now being replaced by horseshoe layouts which feature small, semi circular, work cells. We report on a comparison between traditional and horseshoe layouts. We shall discuss when each is the more appropriate with regard to quality and to cost.

1.0 Introduction

During the first industrial revolution basic machine tools were invented and developed. The development of machine tools led to the first levels of mechanisation and automation. During the age of automation and mechanisation factories developed along with the manufacturing processes. These early factories were located near the power source. During these early times, factories were placed near water streams, as at these times water was the chief source of power.

The production planners of the first industrial revolution saw it logical and expedient to group like machines that needed to run at about the same speed. Their logical thinking made the factories of those times laid out functionally according to the kinds of machines used. As an extension of their logical thoughts, the processes were divided according to the kinds of skills needed to operate the process.

With the advent of steam and electric engines the manufacturing system flexibility increased manifolds. However, the functional arrangements persisted and were named job shops [2].

The increase in product complexity and the increase in the size of factories led to the evolution of various functional departments for product design, accounting and sales. In the scientific era of Taylor and Gilbreth departments for production planning work scheduling and methods improvement were added [2]. Nowadays these functions compose the production system, which services the manufacturing system.

The design of manufacturing systems is undergoing significant changes. These changes are fueled by the trends like increase in variety of products demanded, increase in quality (in terms of precision and accuracy), increased variety of materials used, decrease in time between design concept and manufactured product, increase in the computing power, advent of advanced information systems and the emergence of global markets with global producers [3].

These trends require the manufacturing systems of the future to incorporate continuous redesign and improvement, produce superior quality products with lower costs and production time and be flexible and reliable.

The present era of international competition defines the success of a manufacturing company in terms of the design of its manufacturing system. In present times the manufacturing system must have functional requirements of superior quality, competitive prices and on-time delivery with attractive products. Most importantly the manufacturing system must be safe, flexible, reliable, involve employees, provide good service and is understandable [2].

The traditional kinds of manufacturing systems like job shops, flow shops, continuous process and project shops are fast becoming obsolete. Traditional manufacturing systems are making way for a new type of manufacturing system called Linked-cell manufacturing systems (L-CMS) [2]. These systems have manufacturing cells, in which processes are grouped according to the sequence of processes and operations needed to make a group or family of parts or products [5]. With the evolution of this new type of manufacturing systems the traditional layout schemes (process and product) are paving way for horseshoe layouts which feature small, semi circular, work cells.

The present paper discusses both the traditional and horseshoe layouts, draws on the comparison between the traditional, and horseshoes layouts. It also examines the applicability of each type of layout under various manufacturing scenarios. As an extension, the paper also reports on the simulation study currently undertaken by the authors on horseshoe layouts.

2.0 Layout

A layout is the physical configuration of departments, workstations, and equipment in the entire conversion process. It is the spatial arrangement of physical resources used to create the product or service [10].

The right layout for an organisation improves productivity, the quality of the product or service, and the delivery rates. The layout decision is very important strategically for any organisation to stay competitive in the present era [11].

3.0 Types of Layouts

The type of layout most suitable to any organisation is a function of the operations the organisation performs. The operations function in any organisation can be either intermittent or continuous [1].

Intermittent operations deal with made-to-order products, low product volume, general purpose equipment, labour-intensive operations, interrupted product flow, frequent schedule changes and large product mix.

Continuous operations on the other hand deal with standardised products made to store inventory, high product volume, special purpose equipment, capital-intensive operations, continuous product flow and small product mix.

Tompkins & White [10] provide three basic kinds of layouts depending on the types of workflow they entail. These three basic kind of layouts are : process-oriented, product oriented and fixed position.

Apart from the three basic kinds of layout, a recently new kind of layout is the cellular layout. Cellular layout is characterised by the arrangement of a facility so that equipment used to make similar parts or families of parts in a group called a cell [11].

4.0 Process layout

A process-oriented layout is most appropriate for intermittent operations [1]. The layout for a process consists of grouping like processes together and placing individual process departments relative to one another based on workflow between departments [10]. Process layout is suitable for operations when workflow is not consistent for all output.

Typically, there is a high degree of interdepartmental flow and little intradepartmental flow. Process layout suits well when the volume of activity for individual or groups of parts is very high and has a high degree of variations.

This type of layout is appropriate for diversified products using common operations, varying volumes and varying rate of output [10]. It is suitable for operations with variable workflow where each product may require unique sequence of operations.

4.1 Advantages of Process Layout

Since the layout deals with varied workflow, it increases machine utilisation. The break down of departments according to the processes they perform requires only general-purpose equipment [10]. This type of layout is highly flexible in allocating personnel and equipment. Process layout reduces material handling requirements. Because of the variety of processes to perform there is a diversity of tasks for personnel. The personnel working in this type of layout perform tasks of scheduling, materials handling and production and inventory control.

4.2 Limitations of Process Layout

Due to the variation in workflow, process layout often produces duplicated handling [10]. There is a low turnover of raw material and work-in-progress inventories and there is a high raw material inventories. As far as space utilisation is concerned there is small output per unit space and there is a large work-in-progress requirement [1]. Process layout results in long production lines. Though it requires low fixed costs, yet it requires high unit costs for direct labour, materials and materials handling [1].

5.0 Product layout

A product-oriented layout is most appropriate for continuous operations [1]. A product layout is an arrangement of a facility so that work centres or equipment is in line to afford a specialised sequence of tasks [10].

Product layout is appropriate in producing standardised product in large volume [1]. Typically material flows directly from one workstation to the adjacent one in a well-planned way which results in high volume environment.

In a product layout, each unit of output requires the same sequence of operations from the beginning to the end [10]. Each work centre performs one highly specialised part of the total product build-up sequence.

5.1 Advantages of Process Layout

Product layout produces smooth, simple, logical and direct workflow lines. As the layout is appropriate for standardised production in large volume, it results in stable rate of output [10]. The presence of smooth workflow lines between different departments reduces the work-in-progress inventories. The layout reduces the total production time per unit. Material handling is often predictable, systemised and automated. There is a high turnover of raw material and work-in-process inventories. Because of smooth workflow, simple production control is possible. As the layout produces large output per unit space, the space is efficiently utilised [1]. Due to the large volume of production, the layout results in low unit costs for direct labour and materials. The personnel working in this type of layout perform highly specialised repetitive tasks at fixed pace.

5.2 Limitations of Product Layout

The smooth and sequential workflow between the various machines in product layout is susceptible to any machine failure, which stops the entire line [10]. Any change in product design makes the layout obsolete. The slowest station in the production line governs the speed of production in product layout [1]. These types of layout require a large number of support staff that schedules materials and people and monitor and maintain work. The layout requires large investment in specialised equipment and process. The product layout is characterised by relatively high-fixed costs [1,9].

6.0 Fixed-position Layout

A fixed-position layout is appropriate when, because of size, shape or any other characteristic, it is not possible to move the product [1]. A fixed-position layout is the arrangement of facility so that that product stays in one location and tools, equipment and workers are brought to it as required.

The layout for a fixed material location department differs in concept from the other layout [10]. Aircraft assembly, shipbuilding and most construction projects use fixed-product layout. Fixed-product layout involves the sequencing and placement of workstations around the product.

The fixed-product layout involves made-to-order products and low volume production. It involves little or no workflow. It requires great flexibility where work assignments and locations vary a lot [1].

Material handling in fixed-product layout is often variable and low. It generally requires heavy-duty, general-purpose handling equipment. The inventories are often variable in fixed-product layout and the tie-ups are frequent due to the long production cycle.

6.1 Advantages of Fixed-product Layout

As the product stays at one place, the material movement is minimal in fixed-product layout [10]. Since majority of fixed-product layout use team approach there is a continuity of operations and responsibility among personnel. The made-to-order characteristics of the product in this type of layout result in more job enrichment opportunities for the personnel. The layout promotes pride and quality as an individual can complete the "entire job." [9,1,2] Due to the non-movement of product the layout is highly flexible and can accommodate changes in product design, product mix and production volume. Fixed-position layout requires low fixed costs and high unit labour and materials costs [1].

6.2 Limitations of Fixed-product Layout

Due to the fixed product, the personnel and equipment movement is very high in the fixed-product layout. The fixed-product layout results in duplication of equipment

[10]. Since many processes are performed on a fixed product, fixed-product layout requires greater skill for personnel. The fixed-product layout results in increased space and greater work-in-progress [1,9]. Fixed-product layout requires close control and co-ordination in scheduling production. Since the product manufactured is generally very big in size, there is small output per unit space[1].

7.0 Cellular Layout

Cellular layout consists of an arrangement of a facility so that equipment used to make similar parts or families of parts is grouped together [11]. The cell configuration is often U-shaped, enabling personnel to move from machine to machine, loading and unloading parts [2]. The machines in the cell are usually all single cycle automatics so they can complete the machining cycle unattended. The cell usually includes all the processing needed for a complete part or subassembly [2].

Cellular layout involves the production of one piece at a time following the sequence and rules of the cycle time. J.T. Black [2] provides the following key points for a cellular layout:

- Machines are arranged in the process sequence.
- The cell is designed in a horseshoe shape (U-shape).
- One piece at a time is made in a cell.
- The personnel are trained to handle more than one process.
- The cycle time for the system dictates the production rate for the cell.
- The operators work standing and walking.
- Slower, dedicated machines that are smaller and less expensive are used.

Flexibility is the key design feature of Cellular layout [5]. The layout can react quickly to changes in customer demand or changes in the product design or the mix of products. The cells in the production facility link directly to the subassemblies. Cellular layout makes the production very product oriented [1].

Although cellular layout is a catchy new term, the phenomenon is not new. In the past, large job shops have grouped equipment for high volume parts or special customers. Similarly, assembly lines have group machines by type to make or modify a variety of parts that feed into the main assembly line.

7.1 Advantages of Cellular Layout

The cell makes parts one at a time in flexible design. Cell capacity (the cycle time) is quick to respond to changes in customer demand. The cycle time in a cellular layout does not depend upon the machining time [6].

Cellular layout lowers work-in-progress inventories. Cellular layout reduces material handling markedly. Cellular layout promotes faster quality responses between manufacturing and assembly operations. As the layout works on a pull system the set-up time is reduced or even eliminated [2]. The layout results in shorter flow times in production and simplified production planning.

Cellular layout greatly improves in-process monitoring, feedback and control of inventory and quality. It achieves a smoother and faster flow of products through the manufacturing operations. Cellular layout further reduces the cycle time variability and line-balancing constraints.

Overall, performance often increases by lowering production costs and improving on-time delivery [2]. Cellular layout promotes implementation of automation of manufacturing operations.

Cellular layout improves the process capability and reliability. Cellular layout makes manufacturing flexible and delivers quality products at lowest possible cost with the shortest possible delivery time.

7.2 Limitations of Cellular Layout

The major limitation of the cellular layout is the increased machine downtime since machines are dedicated to cells and may not be used all the time [1,9]. Another important limitation includes the cost of changing cells as the cells become out of date with the change in product and processes. Cellular layout requires great labour skills for team members in more than one operation [10]. The cellular layout is critically dependent on production control balancing the flows through the individual cell [2]. Cellular layout decreases the opportunity to use special-purpose equipment. In a cellular layout if flow is not balanced in each cell, buffer and work-in-progress storage are required to eliminate the need for added material handling to and from the cell [10].

8.0 Simulation Study of Horseshoe Layouts

There exists a lot in the literature that emphasises the use of horseshoe layouts in manufacturing processes to eliminate the limitations of the traditional layouts (product, process and fixed-product).

There are many solutions put forward in literature to solve the design problem of traditional layout problems [9]. Majority of the provided solutions either treats layout problem as a quadratic assignment problem or use computerised heuristic algorithms.

Many researchers have developed techniques for solving the cellular layout problems. Burbidge [4] classified the techniques in three ways : "Rule of thumb", Classification and coding and production flow analysis. King and Nakornchai [8] classified the techniques as similarity coefficient algorithms, set-theoretic algorithms and evaluation algorithms. Han and Ham [7] classify the techniques as peripatetic and ocular, PFA, classification and coding and mathematical programming technique.

An extensive analysis of various classifications provided in literature classifies the techniques in to four major categories [5]:

- Techniques that identify part families without the help of machine routing.
- Techniques that identify part families using routing.
- Techniques that identify machine groups only.
- Techniques that identify part families and machine group simultaneously.

The proposed simulation study aims to convert an existing traditional layout of manufacturing process in to cellular manufacturing system. In doing so the study will look at the quality and cost issues involved in both the traditional and cellular layouts. The proposed simulation study will use simulation software SIMPROCESS to analyse the developed models of horseshoe layouts. The proposed study will measure and compare the manufacturing parameters (like set-up time, lead time, work-in-progress, cost per unit production) on a manufacturing process under traditional and cellular layout.

Conclusion

Layout decisions are made periodically and since they have long-term consequences these decisions must be made with careful planning. The costs of producing goods and delivering services depend on the layout decisions. The paper discussed both the traditional and cellular layouts in manufacturing scenario. Traditional layouts comprise of process, product and fixed-position. The paper compared the appropriateness and the limitations of the various layouts. In the end, the paper introduces the simulation study undertaken by the authors and briefly discusses the methodology proposed in carrying out the simulation study of the horseshoe layouts.

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