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# Qualitative Analysis on Layout Flexibility of Machine Layout Configurations

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***Abstract:*** *Manufacturing flexibility is one of the key parameters that determine the organizational success in today's volatile market. Layout flexibility as a subcategory of manufacturing flexibility plays a major role in handling dynamic demand patterns with shorter lead times, variable product mix and product volumes. Qualitative analysis of the layout flexibility of selected layout configurations is conducted with respect to four parameters. Physical configuration of the product, process, cellular, fractal, holographic, distributed, virtual cell and hybrid layouts is analyzed in this paper. Through the findings of this paper, it is possible to select the most appropriate layout configuration to improve manufacturing flexibility. It is vital to conduct a thorough analysis on characteristics of target market, organizational requirements and resource availability before selecting layout configuration/s for a particular industry.*
***Keywords:*** *layout flexibility, manufacturing flexibility, dynamic demand, flexible layout.*

## I. Introduction

Flexibility of a manufacturing system is one of the key parameters that determine the organizational success in present market. Due to increased number of competitors, improved manufacturing flexibility is vital to survive in today's market.

Manufacturing flexibility is further divided in to variety of subcategories. Some of the traditionally reviewed flexibility types that influence the manufacturing flexibility are product, process, mix, volume, routing, expansion, etc. Out of these, layout flexibility has a greater impact on manufacturing flexibility especially in case of frequent demand fluctuations with shorter lead-time. It is inter-related with some of the traditional types of flexibilities, which directly affect the organizational manufacturing flexibility. Therefore, layout flexibility is vital to improve the manufacturing flexibility especially in case of shorter lead times with variable product mix and volumes.

Organization of the sections in this paper is as follows. In this paper, section II briefly discuss about the literature on relationship between layout flexibility and manufacturing flexibility. In addition, section II focuses on parameters to improve layout flexibility as discussed in literature. In section III, layout flexibility of the physical configuration of selected layouts is discussed with respect to four parameters of layout flexibility. Conclusion of the quantitative analysis of layout types is presented in section IV whilst the future research directions are discussed in section V. It was observed that the majority of authors are focused on facility layouts. In this paper, the approaches for facility layout are used to analyze the flexibility of machine layouts.

## II. Literature Review

### 1.1 Role of layout flexibility in improving the manufacturing flexibility

According to Raman et al. [1], layout flexibility is defined as the "ability of a layout to effectively withstand various changes that arise from unceasing transformations in customers' requirements and the enterprises' internal disturbances in terms of cost and time."

Several authors have emphasized the need of improving layout flexibility in order to increase the manufacturing flexibility ([1], [2], [3], [4], [5]). De Carlo et al. [6] argued that the selection of flexible layout is vital to achieve a high level of manufacturing flexibility to face the today's volatile demand. Although De Carlo et al. [6] have focused on fashion market; this argument is applicable for other industries with similar demand characteristics. As per [2] and [1], the expansion, volume and routing flexibilities have direct impact on layout flexibility. Additionally, according to the flexibility hierarchy presented by Benjaafar & Ramakrishnan [7], layout flexibility and volume flexibility are directly related to the process flexibility and thus to the manufacturing system flexibility. Furthermore, the material handling flexibility is directly influenced by layout flexibility [4]. Altogether, layout flexibility can be considered as a combination of traditionally accepted flexibility types [2]. Therefore, layout flexibility is an essential feature to increase the manufacturing flexibility, which is a key requirement in present market scenario.

### 1.2 Parameters to evaluate layout flexibility

Gupta & Lambert [8] discussed about different approaches adapted by several authors to improve and evaluate layout flexibility. Majority of the authors are focused on using material handling cost minimization as a measure of evaluating the layout flexibility [9].

Several authors have discussed about two basic approaches to achieve the layout flexibility [4], [10], [11], [12]). One approach is by using a layout that can continuously perform near to optimum level under multiple different demand scenarios. The second approach is focused on achieving flexibility through a layout, which facilitates inexpensive and easy rearrangement of resources in response to variable demand. The first approach is known as robustness whilst the second approach is known as flexible/dynamic/ adaptable or reconfigurable.

Lahmar & Benjaafar [13] stated that the robust layouts are more popular among manufacturers than dynamic/ flexible layouts. Reason for that may be the cost of re-layout, which incur from time to time under variable customer demand. Kulturel-Konak [14] discuss extensively about the previous researches on stochastic FLP problem under three criterion flexibility, dominance and robustness. According to his research findings, 86% of researches in 21$^{st}$ century are focused on robustness whereas only 14% are on flexibility.

Kreng & Tsai [15] and Leondes [4] discussed about robustness as an approach to handle the layout problem in an uncertain environment where the exact probabilities of possible demand scenarios are unavailable in advance. Here, robustness of the layout performance under variable demand scenarios is used to define the flexibility of a particular layout. Layout that can perform near to optimum level for the highest number of different demand scenarios will be the most flexible layout. Therefore, under specific demand scenarios, higher the robustness of particular layout, higher will be the layout flexibility and vice versa.

a. Furthermore, Leondes [4] proposed four critical principles to improve the layout flexibility. They are
ii. Increasing the routing flexibility by minimizing distance variance between dissimilar departments
iii. Improving material handling flexibility (which has greater impact on layout flexibility as abovementioned)
iv. Increasing the number of duplicate departments and strategic distribution of duplicated departments throughout the facility
v. Improving the capability of expanding or contracting the layout under different scenarios; known as expansion flexibility ([2], [16])

It is possible to summarize the abovementioned factors for layout flexibility improvement as below. Layout flexibility can be improved by increasing,

i) Routing flexibility
ii) Material handling flexibility
iii) Robustness
iv) Ease of reconfigurability
v) Level of distribution of machine duplicates throughout the plant

It is recommended to refer [4], [2], [1] for further reading on layout flexibility.

## III. Qualitative Analysis On The Layout Configurations With Respect To Selected Layout Flexibility Parameters

Qualitative analysis of the abovementioned layout types will be done based on following factors.

i) Routing flexibility
ii) Robustness under variable demand scenarios
iii) Ease of reconfigurability under demand fluctuations
iv) Level of distribution of duplicated machines throughout the plant

Layout flexibility of following layout types will be discussed hereafter. Only the physical configuration of layouts is considered in this paper. It is assumed that the layouts are operating under volatile demand scenarios with high product variations, small lot sizes and shorter lead times.

a) Product/ Assembly line layout
b) Process/ Functional/ Job shop layout
c) Cellular/ Group technology layout
d) Fractal layout
e) Holonic/ Holographic/ Maximally distributed layout
f) Distributed layout
g) Virtual cell layout
h) Hybrid layout

### 3.1 Product layout/ assembly line layout

In a product layout, machines are arranged according to the operational sequence of a particular product. Product layout or assembly line layout is suitable for products with high volume and low product variety ([17], [18], [19], [20], [21]). According to [22], [23] and [19], product layout suffers from certain limitations such as; lack of flexibility, dependency of throughput time on bottleneck operation, disruption of total line output due to breakdown of a single machine.

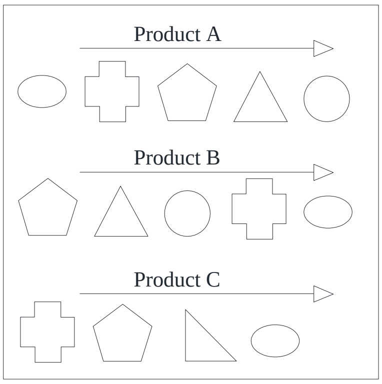



Figure 1: Typical product layout with multiple assembly lines

Major problem in product layout is the need of minor to major rearrangement of machines in the presence of volatile demand scenarios. As a result, layout flexibility especially in terms of robustness is low in product layout. Variations in demand quantities will result in expansion or contraction of product layout and thereby increase the re-layout cost. For extreme variations in product mix, product layout should be completely rearranged. Associated re-layout cost will be steadily increased in such situations. Therefore, in terms of robustness and the ease of reconfigurability, the product layout can be considered as unsuitable for dynamic demand patterns. Furthermore, routing flexibility in product layout is limited due to specialization of assembly lines for pre-determined product design. Therefore, it is impossible to assign the subsequent operations for other lines especially in case of machine breakdowns. This will increase the throughput time and the manufacturing lead time. As a result, the plant availability for upcoming orders will be significantly hindered. Ultimate result will be the reduction of manufacturing flexibility, which is unfavorable.

When considering the individual machines in a product layout, it may possible to observe a high level of machine distribution throughout plant floor. However, it does not help to increase the layout flexibility due to specialization of machines for particular products.Altogether, the flexibility of conventional product layout seems to be unacceptable for volatile demand scenarios.

### 3.2 Process layout/ Job shop/ Functional layout

According to [24], [19], [17], [22], [18] and [25], process layout consists of machines with similar functionality are grouped together at one location. In order to complete a particular product, the required parts should follow a specific path, which connects the different machine groups. Malakooti [17], Dwijayanti et.al. [20], Kumar & Suresh [22] and Sly [26] have suggested that the process layout is suitable for products with high variety and low volume. Limitations of process layout are; increased material handling cost, routing complexity especially in case of products with multiple processing steps, longer throughput times, increased setup cost in product changeovers, high WIP (Work In Process) between operations, etc ([22], [25], [24]).

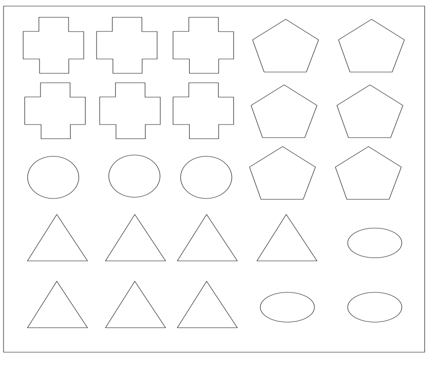


Figure 2: Process layout

As in Fig. 2, the level of distribution of machine duplicates in plant floor is low in process layout. Therefore, in order to complete an order, the parts should follow particular routes throughout the plant. Higher the number of processing steps, higher will be the material handling and routing complexity. Modrak & Paandian [24] stated that the increased routing flexibility as one of the major advantages of process layout. However, the effect of associated routing complexity will be severe in case of frequent demand variations. In case of labor-intensive industries, high level of routing complexity will give rise to human errors. Therefore, the true advantage of increased routing flexibility in process layout will be absent in such situation.

Process layouts can be considered as robust for multiple demand scenarios. Number of setups will be reduced in process layout but with an increase of material handling. Additionally, the routing flexibility of a process layout is comparatively higher than the product and cellular layouts. Products can be manufactured using multiple routes due to the physical configuration of process layout. However, as abovementioned, the routing complexity will diminish the true advantage of robustness and routing flexibility.

Level of distribution of machine duplicates throughout the plant floor is extremely low in process layouts. Therefore, material handling cost is steadily increased especially in case of multiple processing requirements. In addition, the prolonged throughput times and high WIP accumulation in process layout will increase the production lead-time. This will ultimately reduce the manufacturing flexibility of the plant/ company.

**3.3 Cellular layout/ Group Technology layout**

The cellular layouts are generated based on lean manufacturing concept. The conventional approach of cell formation is done by generating part families based on Group Technology principles. Each cell is responsible to complete the assigned part family. When considering a particular part family, the setup time/cost is reduced due to dedicated cell configurations ([27], [22], [24], [23]).

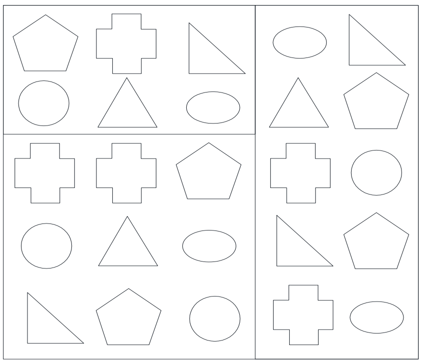


Figure 3: Cellular layout [4]

Cellular layouts are inflexible for the introduction of completely new product mix ([24], [27]). In such situation, the excessive rearrangement of machines results in an increased setup time/cost. Furthermore, it increases the inter-cell movement of resources whilst reducing equipment under variable volume. Marsh & McCutcheon [27] argued that cellular layouts are with low routing flexibility, which directly influences the layout flexibility [2]. Further, in terms of robustness, it can be argued that cellular layouts are inflexible since the manufacturing cells should be rearranged from time to time under variable product mix.

When considering products with high variety and low volumes, Goldengorin, Krushinsky & Pardalos [28] argued that the functional layout would be better than cellular layout. Additionally, Benjaafar, Heragu & Irani [29], argued that the product, process and cellular layouts do not sufficiently address the issues raised due to volatile demands patterns. Reason for that is the above three types of layout are designed by assuming the product mix and volumes remain stable for multiple planning horizons. Altogether, it is possible to conclude that the traditional product, process and cellular layouts will not be a solution to increase layout flexibility to match with today's dynamic demand patterns.

**3.4 Fractal layout**

Fractal layouts are generated by grouping multiple different machines into fractal cells. Depending on the machine grouping, fractal cells are more or less identical. Each fractal cell is capable of producing almost every product type manufactured within the company ([24], [30]). In terms of material handling efficiency, some fractal cells are more suitable than others for manufacturing a particular product mix ([28]). Shih & Gonçalves Filho [31], discussed about different approaches on fractal cell formation with more focus on similarity-based methodology. They have developed a mathematical model to generate fractal layout by adapting two criteria as; minimum material handling distances (intercellular and/or intracellular) and highest similarity of fractal cells. Similarly, a number of other authors have presented different approaches for designing fractal layouts.

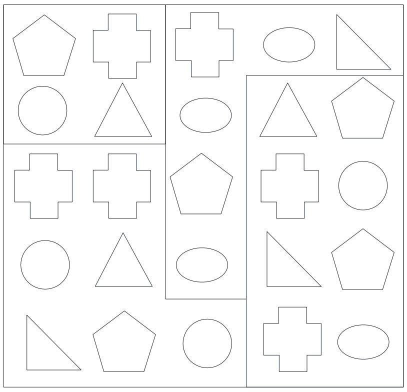


Figure 4: Fractal layout [4]

Limitations of fractal layout are discussed by several authors. Goldengorin, Krushinsky & Pardalos [28] argued that the fractal layout is somewhat unsuitable for manufacturing processes with unique machines. Jaramillo [30], argued the requirement of multiple identical machines as the main disadvantage of fractal layouts. In addition, the scheduling complexity is another drawback [5]. According to Silva & Cardoza [19], fractal layouts possess several other limitations as listed below.

- Facilitate batch production not the continuous flow
- Difficulty in visual management due to absence of standard layout within fractal cells
- Use of specialized workforce

As stated by Silva & Cardoza [19], the main advantage of fractal layout is its volume flexibility, which directly influences the layout flexibility as aforementioned. In addition, fractal cells are capable of handling variations in product mix [24]. Routing flexibility may be increased in fractal layout due to the presence of more or less identical cells. Furthermore, fractal cell is robust for multiple demand scenarios [32]. Altogether, the fractal layout can be considered as a flexible layout for volatile demand scenarios.

As mentioned by Venkatadri, Rardin & Montreuil [33], designing of fractal layout is quite challenging. In addition, the possible intra- and inter- cell movement of materials will increase the material handling. Therefore, formulation of fractal layouts in a manufacturing environment should be done after a thorough analysis to avoid possible drawbacks.

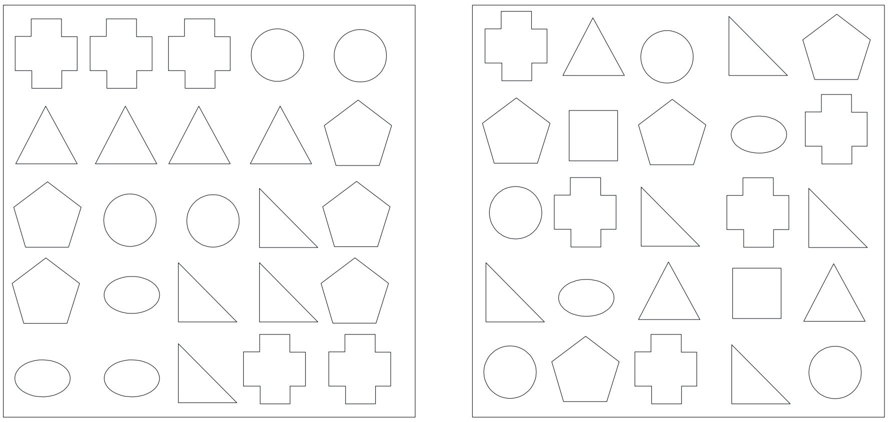
### 3.5 Holonic/ holographic/ maximally distributed layout

In a holographic layout, identical machines are maximally distributed throughout the facility as shown in Fig. 5 (b). Holographic layouts facilitate number of efficient routes for particular product ([4], [24], [29]) and thereby increase the routing flexibility. Due to maximal distribution of machines, each machine is equally accessible to production. Therefore, it is possible to follow alternative routes especially in case of machine breakdown.

Main disadvantage of holographic layout is the complexity of coordination between machines under different product demands [24]. In addition, routing complexity will be increased simultaneously with the number of process steps required for particular product. Furthermore, there can be a difficulty in visual management of the production process, especially when multiple process steps are needed. According to Nomden & Slomp [5], holographic layouts are rarely justified in practical scenarios. Therefore, the use of holographic layout especially for labor-intensive industries may lead to unnecessary complexity and will possibly act as an overburden on employees.

### 3.6 Distributed layouts

Distributed layouts are considered as a special case of holographic layouts [24] and/or functional layouts [4]. In a distributed layout, machine/department duplicates are strategically distributed throughout the plant floor ([24], [29]). Depending on the level of distribution, the layout can be either partially distributed or maximally distributed.



(a) Partially distributed layout (b) Maximally distributed layout

Figure 5: Distributed layout

Distributed layouts facilitate increased material handling flexibility under fluctuations in product mix and product volume [29]. Benjaafar, Heragu & Irani [29] and Lahmar & Benjaafar [13] argued that distributed layouts are highly desirable for frequent demand fluctuations. According to them, strategically distributed layouts can effectively remain fixed (robust) for multiple demand scenarios. Except the holographic layout, routing flexibility of a distributed layout is higher than the abovementioned layout configurations. Altogether, distributed layouts can be considered as a solution to improve layout flexibility in terms of abovementioned four indicators.

Modrak & Pandian [24] stated the "complexity of coordination" and "limited specialization of workers and machines" as major drawbacks of distributed layouts. In addition, the design and development of distributed layout possess certain challenges in order scheduling, machine scheduling, visual management, capacity planning etc. Therefore, systematic designing of distributed layouts is vital to minimize the possible shortcomings.

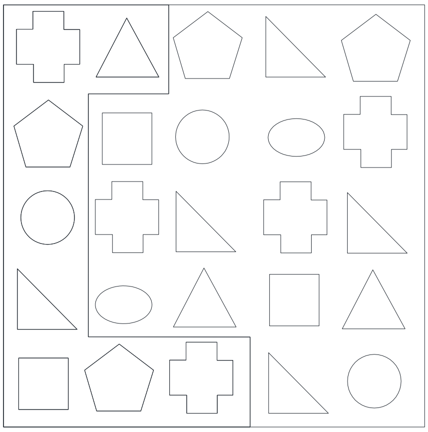


Figure 6: Virtual cell in a distributed layout

According to the analysis done by Hamedi et al. [34], virtual cell formation on distributed layout has better performance than on functional (process) layout. Several authors have argued that the virtual cell formation over distributed layouts are suitable to manufacture low volume high variety products ([34]; [29], [25]).

**3.7 Virtual cell layout**

Nomden & Slomp [5] discussed about two basic approaches in layout design as physical approach and logical approach. The physical approach focuses on topology and physical configuration whilst the logical design considers the resource flow and the logic behind dynamic flow control. According to Xambre & Vilarinho [25] and Chowdary & Praveen [35], virtual cell formation deals with logical approach whereas the conventional cellular layouts are designed based on physical approach.

Virtual cell is a logical grouping of resources dedicated to produce a particular part family. Similar to conventional cellular layouts, the part families are formed based on GT principles. The resource grouping in virtual cells is not physically reflected in the system. Once the production of part family is completed, the cell is disbanded and free to form another cell without physical rearrangement of resources ([36], [29]).

As stated by Xambre & Vilarinho [25], virtual cells are associated with high degree of flexibility under dynamic volatile environments. Strategically designed virtual cells in a distributed layout, may increase the routing flexibility and robustness. In addition, virtual cells are easily reconfigurable when compared to other types of layouts. Such layout should accompany a well-planned order scheduling method in order to reduce the complexity of coordination. In addition, high attention should be paid for visual management of the production process.

### 3.8 Hybrid layouts

All the discussed layout configurations are in theoretical extremes. It is difficult to adapt a certain layout solely in practical scenario. Majority of the firms use a combination of one or more layout types in practice. Custom-made hybrid layouts are now increasingly popular among manufacturers. Reason for that may be the capability of overcoming the limitations of particular layout types through combined effect. It is difficult to classify the hybrid layouts to above discussed layout types due to combined nature. For unique organizational manufacturing requirements, customized hybrid layouts are advisable to use in practical scenarios. Development of an effective hybrid layout should be done after a thorough analysis on organizational objectives. Likewise, the designing of hybrid layouts can be done to achieve a higher level of layout flexibility.

## IV. Conclusion

Qualitative analysis of the selected layout types is done with respect to four dimensions of layout flexibility. According to the reviewed literature the conventional process layout, product layout and cellular layout are less suitable for variable demand scenarios in today's market. In contrast, the new generation of layout types such as fractal layout, distributed layout, holonic layout and virtual cell layout seems to be more promising in terms of layout flexibility. In order to justify the above statement it is essential to do an extensive quantitative analysis of the layout configurations.

## V. Future Research Directions

Only a qualitative analysis of the physical layout configuration of selected layout types is discussed in this paper. Combined analysis of the physical configuration and production planning & scheduling methods will be more effective in terms of practical application. Therefore, it is essential to conduct a systematic quantitative analysis of layout types before practical application. The inherent characteristics of particular industry's manufacturing systems, product mix & volumes, machine requirements & capacities, etc. should be taken in to account in such analysis.

Furthermore, the level of automation, employee related factors and ergonomic conditions should be included in such analysis. Additionally, the formulation of hybrid layouts to improve layout flexibility is not discussed in this paper. Findings of this paper can be used to design customized hybrid layout after comparing the layout objectives and advantages/ disadvantages of the physical configuration of layout types.

There can be numerous customized heuristic layouts designed for individual requirements of the companies. This paper does not consider such heuristic approaches. It is advised to do case studies on different industries to observe the customized layout configurations used to improve layout flexibility.

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