CRITICAL ANALYSIS OF LAYOUT CONCEPTS: FUNCTIONAL LAYOUT, CELL LAYOUT, PRODUCT LAYOUT, MODULAR LAYOUT, FRACTAL LAYOUT, SMALL FACTORY LAYOUT.

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Canem et. al.(1996) highlight that layout planning is important because it usually represents the largest and most expensive resources of organization. Moreover, the arrangement of production equipment has a direct impact on two of the seveen wastes of production identified by Ohno (1997): excessive handling and transportation. Other waste, such as work in process, lead time and delays are also influenced by the physical arrangement of facilities. Therefore, the layout of shop floor has impact in the organization's performance. Performance indicators like flexibility, time, cost, among others, are affected by the concept of physical arrangement adopted by the factory. Designing physical layout in order to obtain an efficient process flow is a big challenge for companies that seek excellence in their production processes. To design a new layout, a project team can make use of many concepts and layout models. Among various layout concepts found in literature some are used in many companies while others are still in experimental field. Functional layout, for example, is the most traditional layout concept. A great number of companies use this concept to distribute machines and workplaces in the shop floor. Muther (1976) developed a model for designing functional layout, the SLP model (Systematic Layout Planning). Other three layout models can be classified as traditional layouts: cell layout, positional layout and product layout. Latest researches have presented some new layout concepts like: modular layout, fractal layout and small factory layout. Although new layout concepts are little known and with few real applications in factories, these new concepts appear as points to be considered when designing a physical layout. Based on this scenario, the aim of this paper is to present the new layout concepts and analyze them from the perspective of lean production philosophy. This philosophy was developed at Toyota Motor Company by Taichi Ohno and, nowadays, so

many companies have adopted its principles. The traditional and new layout concepts will be analyzed based on criteria such as continuous flow, inventory, transportation, visual management, among others. These variables are important points for the lean production system. So, based on these points, it will be defined which layouts are closest to lean production principles.

Palavras-chaves: Layout, Lean Production

1. Introduction.

The concern with the organizations layout (or physical arrangement) came up with the necessity to expand the productive capacity of industrial units. The physical layout of equipment, based mainly on the functional organization, was no longer suitable for many production environments. The pressure for cheaper products, higher quality, greater variety, punctuality of delivery, among other factors, conducted the company to a way of change, where the physical arrangement was one of the targets of these changes.

The importance of the physical arrangement has been highlighted by many authors. Muther (1976), a pioneer in the development of a methodology for layout design, said that the costs to implant a good physical arrangement or an unsuitable one would probably be the same for an organization. But once a poor physical layout is installed, the costs of fixing it is very high, and in some cases, the costs of changing this layout could make it prohibitive. Thus, once a poor arrangement is deployed, the company will have to live with this problem for a long period. In some cases, during its entire existence.

More recent authors, such as Slack et. al. (2005), argue that, if the physical arrangement is wrong, it can cause:

- Extremely long patterns of flow.
- Inventories of materials throughout the process.
- Costumers queuing throughout the operation.
- Unnecessarily long operation time.
- Inflexible operations.
- Unpredictable flows.
- High costs.

Finally, Gonçalves Filho (2005) points out that an efficient manufacturing system can be obtained by combining four variables: updated manufacturing technology, a facility layout optimized, a trained and motivated workforce, and a proper management. As it can be seen, the physical arrangement is very important to the organization, impacting on factors like flexibility, punctuality, inventories, etc.

Based on the importance of the organization goals and the changes in the industrial scenery, resulted from pressures exerted by market changes, some concepts of the physical arrangement emerged, creating some types of layouts. The concepts and types of layouts are presented below.

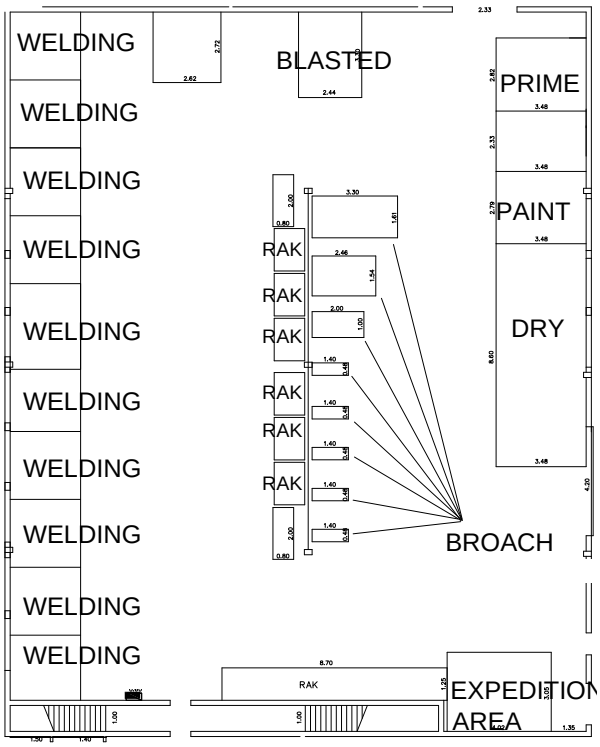
2. Concepts and types of physical arrangement.

The first layout concept is the organization of productive resources based on function. The concept and the type of layout are presented below.

2.1 Functional Layout.

The most common concept used in the physical arrangement is the organization based on the function performed by the equipment or, when it comes to office layout, based on the tasks performed by people.

The type of physical arrangement based on this concept is called a functional layout by process. According to Corrêa and Corrêa (2004) the challenge in the decisions on the physical functional arrangement consists in arranging the relative position of each sector in order to place the sectors that have flow among them close together, avoiding unnecessary travel among them. The aim is to position the sectors taking into account a number of constraints. These constraints can be technological or of other nature. The following picture represents the layout of a metalworking industry, where the equipment is arranged in a functional way.



Picture 1 – Functional layout example in a metalworking industry

Font: Silva (2009)

As shown in Picture 1, the equipment is distributed according to the function it performs. Welding stations were allocated in the same area, as well as drills, the raks for storage of parts, etc. This physical arrangement is found in most small and medium Brazilian companies.

2.2 Product layout or line layout.

Many companies produce a range of products that have a similarity in the sequence of manufacturing. Based on this characteristic, arised the concept of positioning the productive resources in accordance with the sequence of manufacturing. The typical physical arrangement of

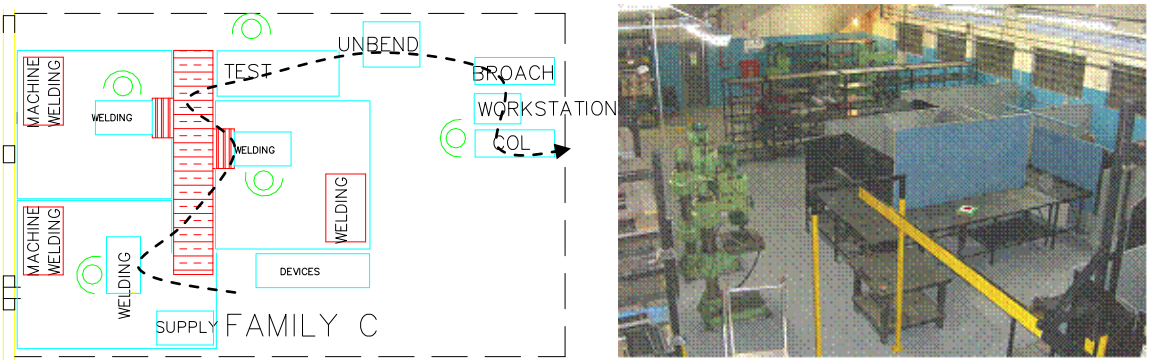
this concept is the product or line arrangement. This type of layout was widely publicized through the production line built by Ford for the assembly of the Model T.

According to Corrêa and Corrêa (2004) it is recommended to only get the resources arranged according to the sequence of process steps if it is covered by a large volume of flow. In other words, this layout is more suitable for operations that process large volumes of flow, which go through a very similar sequence. For example, firms that produce one or a few products in large volumes, or that attend to a large volume of customers who go through a common sequence of steps.

2.3 Cellular layout.

With the arise of group technology concept a new physical arrangement was proposed, the cellular layout. This type of layout is based on the concept of forming groups of parts and products based on the similarity of processes, or form, or volume, among other criteria. This new concept originated a cellular manufacturing.

Al-Mubarak (2003) points out that manufacturing cells is a form of organizing the layout of the ground-floor seeking to achieve efficiency and flexibility. Cell manufacturing is a philosophy that seeks to explore and use the similarity between components. The components are grouped into families based on similarities of shape, production process or both. The machines are then grouped into cells to produce these components. Martins and Laugeni (2006) point out that the manufacturing cell consists in allocating in the same place (the cell) different machines that can manufacture the entire product. Picture 2 below shows an example of layout cell in a metalworking company.



Picture 2 – Cellular layout example in a metalworking industry

Font: (Silva, 2009)

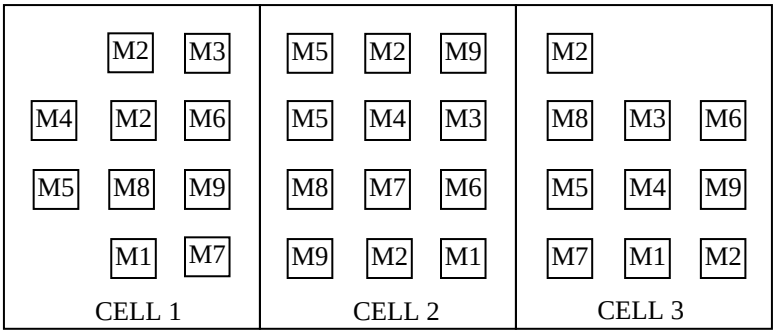
As it can be seen the equipment necessary to manufacture a particular family of products is allocated according to the sequence of manufacturing.

Inside the cell, the flow is unidirectional and the parts are manufactured in flow, with no stock points and waiting. The balance of activities is essential to create a continuous and smooth flow inside the cell.

2.4 Fractal layout.

Another concept related to the organization of productive resources is the distribution of equipment groups, where each one has the ability of processing, if not all, but the vast majority of products manufactured by the company. The type of physical arrangement arising from this concept is called the fractal physical arrangement. The groups of productive resources are called fractal cells.

Picture 3 shows a theoretical example of a fractal cell.



Picture 3 – Fractal layout example

Font: (Venkatadri et al., 1999)

In Picture 3, it is possible to observe that the fractal cells 1, 2 and 3 have a very similar capacity, when compared in terms of production resources.

2.5 Modular layout.

According to Gonçalves Filho (2005) a module of a modular layout is defined as a small group of machines that has the characteristics and flow pattern of a specific type of physical arrangement. Irani and Huang (1998) reveal that the modules can be of several types:

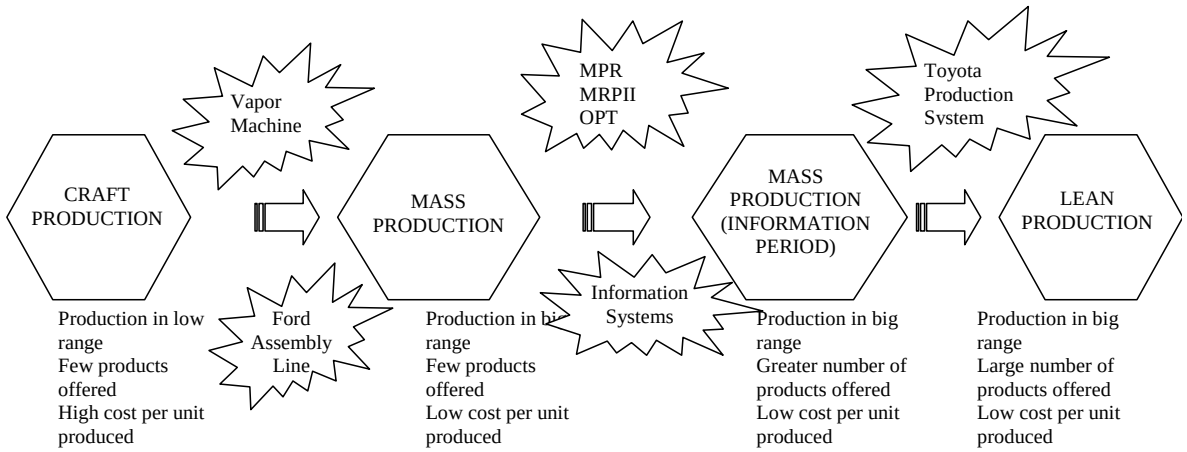
- Flow line module.
- Flow line branch module.
- Cell module.
- Machining center module.
- Functional module.

2.6 Small factory layout.

According to Camarotto (1998) the concept involved in physical arrangement of small factories is to divide the organization in small production units. These units, should have autonomy to produce all the products assigned to them. Furthermore, it should have under control operations support, such as purchasing, warehousing, human resources, etc.

A typical case of the layout of mini-factory is the Volvo plant in Udevalla presented by (Tompkins, 1996).

Parallel to changes in physical arrangements of production, production systems have also been changed accordingly by the need of market. The stages through which the production systems have passed are presented in Picture 4 below.



Picture 4 – Historical evolution of production system.

Picture 4 shows the sequence of appearance of the production systems and some of their characteristics. It should be noted that the merely emergence of a new production system has not definitely replaced the other. What happens is a better adequateness of each system in relation to certain circumstances. A brief comment on the Toyota production system (lean manufacturing system) follows.

3. O sistema *Toyota* de produção

The Toyota production system, also known as lean manufacturing system, arose from the company's need to produce a wide variety of products without increasing its cost. For some, it goes beyond the system, it is a new philosophy of production. Five principles and seven types of waste mostly form the concepts that make up this new way of producing. The principles of lean manufacturing system are:

- Identifying the customer value.
- Identifying the value stream.
- Making the stream flow.
- Establishing a pull production.

– Looking for perfection.

About the wastes, these are classified as:

– Waiting.
– Handling.
– Overproduction.
– Transport.
– Defects.
– Inventory.
– Inadequate process.

In the design of a new physical arrangement, based on the principles of lean manufacturing, it is necessary that the layout be in consonance with this production system. As follows, an analysis on the types of layouts is presented based on the concepts of lean manufacturing system.

4. Criteria for layout evaluation.

All layout models have their characteristics which put them close to or distant from the goals of the lean manufacturing system. To analyze the layouts for lean manufacturing system some criteria will be defined. These criteria have a direct impact on the performance of a plant that adopts the philosophy of lean manufacturing. The criteria are presented below.

1 – Handling and transport: handling and transport are two wastes to be eliminated from Lean Production perspective. So, the physical layout of machines must allow the minimum movement of materials and products within the plant.

2 – Continuous flow: Rother and Harris (2002) noted that the continuous flow is the main Lean Production goal. A continuous flow of parts and units depends on, among other things, production equipment proximity. So, the layout should be planned in accordance with that goal, allowing the parts and products flowing smoothly and continuously between the workstations.

3 – Visual management: Ciosak (1999) points out that the production visual management are all mechanisms used to make visible, or apparent, factors which are relevant to a proper administration of production at the operational level. The visual management has based its importance in helping to manage the activities on the ground-floor. An efficient layout, should allow the production manager have a clear vision of operators and the production system, when walking through the plant. The layout should make possible to visualize, if not the whole, at least, the complete steps of a certain process.

4 - Flexibility: seasonality and demand for customized products are some of the factors that drive companies looking for flexibility. In this sense, the layout should enable the company to change quickly and efficiently its product mix and production volume according to the demand fluctuations.

5: - Inventory: work in process is a major source of waste. The physical equipment arrangement must minimize the physical distance between the machines, trying to eliminate the need to produce in batches, consequently, generating intermediate stocks.

6: - Quality: layout impacts in good product quality since it enables the continuous flow. In this way, the defects are detected as soon as a part is transferred to the next process. So, there isn't a production of many defective parts. Therefore, when working in large, when a defect is detected, probably the entire lot will be defective.

7: - Utilization of multifunctional workforce: the proximity of workstations can allow an operator to work on multiple devices at the same time. The proximity is not the only reason that permits the multifunctional workforce. But, it is one of the variables to get the multifunctional workforce.

8: - Complexity level of production scheduling: the complexity level of production scheduling is correlated with the organization of process flow. The greater the randomness of flow, more difficult is to schedule production workstations. So, the greater the randomness of flows, due to the physical arrangement of equipment, the greater the index of complexity of production scheduling.

Based on the criteria pointed out, an analysis about the layout models with this criteria will be made, as follows.

5. Comparative analysis among layouts models and lean manufacturing system.

5.1 Functional Layout.

For the points mentioned above, the functional layout does not promote the continuous flow. The production is done in batches, which increases the work in process. Furthermore, visual management is compromised due to the distance between departments. As for quality factor, the production batch can cause rework or, even the loss of a whole lot, when a problem is detected.

One of the positive aspects about this layout is the flexibility. As there are not dedicated machines, both a varied quantity and a varied mix of products, can be made. As for the workforce, the functional layout still tends to use specialized and not multifunctional workforce. Finally, regarding to production scheduling, the level of complexity is high due to lack of flow pattern.

5.2 Product layout.

The product layout is better than functional layout in terms of allowing the continuous flow, has less work in process, and enables the visual management. In this case, the continuous flow helps in the improvement of quality because, if a defective part is produced it is immediately detected in the following process, thus, avoiding a whole defective lot.

One of the pitfalls of product layout is that it has low mix flexibility. Changes in the types of products cause great inconvenience because this layout works with dedicated equipment. The labor force, similar to the layout, is based in specialized workers.

As for the last aspect, the complexity of production scheduling, this is low, mainly, because the equipment is dedicated, and positioned according to product flow.

5.3 Cellular layout.

This layout model is the closest to Lean Production concepts and principles. It promotes a continuous flow, promotes the reduction in work in process level and makes the visual management possible. Like the product layout, it makes the quality control simpler and more efficient. Furthermore, the cellular layout is based on multifunctional workforce use, promoting employers' integration. Scheduling the production in cellular environment is simple, since the equipment is dedicated and positioned according to the product flow.

One problem about cellular layout is its low flexibility on fluctuations in product mix. Like product layout, the machines are dedicated, so, if it is necessary to make a new product, which has a different pattern flow, is necessary to readjust the layout. And this can be impossible for many reasons, like cost, time, etc.

Another problem, in many cases, in forming cells, is that it is necessary to duplicate machines. And this duplication can be impossible due the machinery cost.

5.4 Fractal layout.

The fractal layout does not promote the continuous flow. This is because the fractal cells have the ability to produce all products. Consequently, it is very difficult to establish a standard layout within the fractal cell that allows a continuous flow to all parts. Therefore, it is necessary to produce in batches, which raises the level of inventory between processes.

Using this layout concept is a difficulty in promoting the visual management, because the pieces do not have a specific manufacturing location. The quality is affected due to the necessity of production in batches.

As for multifunctional aspect, in this layout type there is the trend to use a specialized workforce. As there is not a pattern flow, the operators can not work with two machines, because they are separated, different in a cellular layout situation. The level of complexity of production scheduling is low due to the flexibility of production.

The biggest advantage of fractal layout is the volume product flexibility. Because the fractal cells have the ability to produce the same products, changes in demand can be easily absorbed by the fractal layout. The flexibility of product variation will depend on how different the new product pattern flow is.

5.5 Modular layout.

Because the modular layout allows flow between the modules, there is a necessity in producing in batches, without establishing a continuous flow. Consequently, the result is higher level of work in process than the cellular layout. As for the quality aspect, it has been affected because there isn't a continuous flow. The visual management is facilitated because plant is partitioned into modules. Another advantage of this layout type is the ability to absorb fluctuations in demand and mix. The multifunctional workforce will depend on how resources are arranged in the modules.

About the complexity level of production scheduling that can be high or not. It will depend on, directly on, the intensity of flow among the modules. The higher the intensity of flow among the

modules and, the amount of part reflux within the module, higher the level of difficulty in scheduling.

5.6 Small factory layout.

The characteristics of this layout are quite similar to the modular layout with the main difference being that there is no flow between mini-factories, so, the moving parts tend to be lower and the production scheduling tend to be simpler.

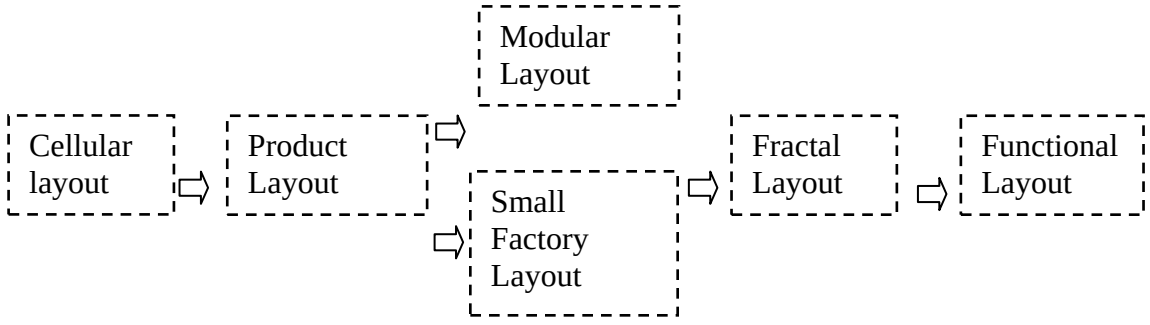
Table 1 shows a summary of layout types and its impact on the analysis criteria.

	Analysis criteria							
Layout Types	**Continuous flow**	**Inventory**	**Visual Management**	**Quality**	**Flexibility**	**Multifunctional workforce**	**scheduling complexity**	**Transport Movimentation**
Functional	low	high	low	low	high	low	high	high
Product	high	low	high	high	low	low	low	low
Cellular	high	low	high	high	low	high	low	low
Fractal	low	high	low	low	high	low	low	low
Modular	medium	medium	high	low	high	low	high	medium
Small factory	medium	medium	high	low	high	low	medium	low

Table 1 Analysis of different layouts types from lean manufacturing system perspective.

According to table 1 cell layout is the closest to Lean Production concepts, though it has some limitations. Therefore, there is not an ideal layout to be used. The particularities of each case will lead to a specific layout type. Companies that adopt the lean system, in many cases, have used a hybrid of these layouts. For certain process stages, for example, a cellular layout or even a functional layout can be used. And for other process stages a product layout is possible. This layout combination can bring many benefits, such as no need for equipment duplication.

Based on table 1 it is possible to establish a sequence of layout prioritization to be considered in a lean production system implementation. Picture 5 shows the sequence suggested by the author.



Picture 5 – Priority consideration of layout types

6. Conclusion.

As it was showed, the cell layout is the closest to lean production concepts. Whenever possible, this concept of physical arrangement should be used.

As for the deployment of physical arrangements, some factors impact on their implementation, like occupied area, equipment duplication, etc. Among these factors, the cost is the one which has a greater impact. Fractal layouts are little used because the cost of duplication makes this layout type often impractical.

The manufacturing cells also meet restrictions on costs. In many cases equipment duplications are necessary and, the costs make this layout impracticable. Product seasonality can make using and deployment of product layout also unfeasible. In environments where there are constant changes in products, the rigidity imposed by the production line can make this layout impossible to be applied. The low demand and high variety of parts and products may also be barriers in the use of product layout concept.

These are some of the difficulties in using and deploying some layout concepts. It should be noted that there is no way to define what kind of layout should be used for many different situations. It is necessary to analyze each situation and apply the layout concept that best suits to it.

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