ASSEMBLY LINE DEVELOPMENT UNDER LEAN LINE DESIGN PARADIGM

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Abstract. *Markets' demand has grown not only at the level of quality but also in terms of variety of products, pushing costs up. To keep competitiveness, companies must be prepared to adapt themselves readily to the different market solicitations. The Lean Line Design theory (LLD) helps to design sequential assembly envisaging waste elimination and ensuring flexibility. This theory can be applied both to an existing assembly line and to the design of a new one. The theory pleads that its application provides great advantages to assembly work not only for the use of smaller movements of workers without adding value to the product, but also by the placement of automatic machines out of assembly lines. As the lines flexibility is conditioned by the level of automation, there is an inverse relationship between both. Moreover, the "island" elimination and the creation of a more efficient layout, also allows the worker to carry out additional tasks in the post that is laying at his back, which leads to a more efficient work distribution closer to the Target Cycle Time(TCT). There are also ergonomic advantages, related with the worker rotational movements, with work standardization and worker suppression in tasks were no worker movements are performed. Also, losses in existing lines, due to delays in certain positions, can bereduced by the use of stock control and its distribution along the assembly line. In this paper the application of the LLD in a Portuguese factory of a multinational company in the sector of car components assembly is analyzed and presented. The results may be considered for the extrapolation of this approach to other companies of the same kind.*

Keywords*:* Lean Line Design; Assembly Lines; Target Cycle Time

1. INTRODUCTION

One of the main objectives of production systems is the reduction of anything that may be considered waste. Any activity that consumes resources and does not aggregate value is considered waste. Therefore, the theories concerning waste minimization are becoming very important tools to help companies' survival. When waste is reduced, not only direct economical advantages are obtained because of unnecessary costs elimination, but also by reducing non-adding value operations, productivity increase is expected. This way larger profit became possible

The lean theory is based in the elimination of wastes to reduce production costs, to maximize the customer's satisfaction; tat is, to maximize added value "Elias et al., (2004)".

Several changes are happening in production systems that are resulting in an increase of the number and variety of products, and a decrease of the batch size as the diversity increases. Also, costs related with materials, including transportation and energy, a substantial component of the total cost of the products, are increasing. The pressure to reduce the product's design and production time due to the permanent market changes; the increasing demand for more exigent tolerances requests for smaller (more accuracy and precision producing better quality) "Tompkins et al., (1996)"

To be able to satisfy this trend in demand, production system should be:

- capable of making superior quality products, at lower unitary cost, and delivery hem in shorter period, in order to o satisfy the customers;
- designed to be flexible and comprehensible (simpler and focused), and also more reliable.

These items constitute the objective of this work. To have an effective layout can make the difference between the success and the failure of the product. The waste that happens in a non-optimized layout conditions the whole process, increasing the cost of the product and making it to acceptability in the market.

Layout design is one outstanding activity concerning a production system, when regarding production, defined as the set of activities involved manufacture departments localization, production lines definition, working posts, machines and ancillary functions (maintenance) and in the definition of adequate means and handling routes for products transportation "Menipaz (1984)".

Concerning production resources, they are of vital importance for the organization since usually a great number is needed and because their cost is significant. One of the reasons to study layout efficiency is the interest in reducing the movement costs. According to Canen and Williamon "the best material movement is not to move" "Canen (1998).

Not infrequently when analyzing a production system, one verifies that the company's responsible is not really aware about existing waste sources, because these are not easy to perceive. However in companies several wastes exist such as "Scribd (2009)": stock excess; stopped machines; workers staring to working machines; unnecessary transportations; machines failure; materials waste; defects and re-work; bureaucracy; waiting times; tools seeking times.

The present paper is structured as follows: section 2 briefly exposes Lean Manufacturing principles; in section 3, the present layout in use at the factory is characterized; in section 4 the conception of a new layout based on the Lean Theory is presented; finally, in section 5, some considerations about the implications of LLD implementation are made.

2. LEAN THEORY

Lean theory then became an important tool for the survival of the companies, because it has as objective to minimize waste. When waste is reduced, besides the direct financial advantages obtained by the elimination of unnecessary costs, also results a reduction in terms of non-adding value traveled distances and so productivity increases, providing larger indirect profit. Taiichi Ohno identified a series of wastes in the productive sector of Toyota's mass production system, with the objective of elimination them, and devised a method nowadays popularized as Lean Manufacturing. According to Hines and Taylor (2000), the Lean Manufacturing principles developed by Ohno are:

- to Specify what generates value and what does not, under the customer's perspective.
- to *Promote* actions with the objective of creating a continuous flow of value, without interruptions or waiting times;
- to *Produce* only the amounts requested by the consumer;
- to *Make* an effort to maintain a continuous improvement, seeking the removal of losses and wastes.

Unlike the traditional practice, one should not evaluate the situation under the company or its department's perspective, but on contrary, in the perspective of the costumer.

Lean Line Design theory (LLD) has the objective of optimizing sequential assembly production lines, through a series of variables that allow waste reduction. This theory is based on the operators, materials and information flows in a work system. This allows the achievement of several improvements in the production lines, if their concepts are efficiently applied. Besides the reduction, or elimination of wastes, flexibility also presents great importance as far as this theory is concerned.

Some other aspects to take in account are:

- the reduction of workers' displacement, by designing the layout after work distribution, and by putting automatic machines out of the production lines;
- reduction of time losses by limiting the stock per worker to a minimum, so avoiding losses ahead due to delays of a previous worker;
- islands elimination, by linking all the processes, making possible a more efficient work distribution without losing workers' by workstation isolation;
- ergonomic advantages are also expected under this theory, since each worker will be able to perform operations at least in two posts, entirely eliminating the occurrence of static work.

3. PRESENT LAYOUT CHARACTERIZATION

Figure 1 depicts the case study being treated in this paper. It corresponds to the actual situation of a production line of a multinational corporation that manufactures electronic appliances.

For a better understanding of the line under study, a brief description of the production process will be made. The assembly line begins by the placement of components such as condensers, heat dissipaters and lateral walls in a printed circuit board (PCB), which is set up in another section of the company. After this assembly is made, the board is automatically sent to a wave-welding machine. Then, electrical and visual tests are accomplished, the following phase consisting in the board programming, which is done by means of an automatic equipment. Until this phase, the PCB board still keeps a small outline, since it is useful for automatic conveyer transportation system. In the following phase, this outline is milled, and then a tuning to the board is done. After, the assembly of a front panel and other components of the appliance chassis is made. The flow of the front panel is opposed to the flow of the other components, in order that they join each other in the shorter distance possible. Afterwards the apparatus is subjected to new visual tests. Then the apparatus is controlled again, this time to check characteristics such as signal quality/noise relationship and power consumption. In addition, a new visual control is made to make sure that the product meets the best conditions. After these controls, each apparatus is labeled and packed.

The manner how the present layout is designed makes it narrow, although long (9 x 45 m). This configuration allows that all the supplying ramps are in the corridor side, which allows a simple and easy supplying operation.

However, this configuration presents some drawbacks. The different assembly phases are not completely linked, which forces the existence of islands. An island is a place whose workers are not able to perform other tasks due to physical separation, or to the big distance between workplaces. This factor severely conditions distribution, since a worker in an island may have a working time much inferior to Target Cycle Time (TCT), so lowering work contribution to the company.

Another characteristic of this layout is the workstations alignment: they are located in row, in front of the workers, placed side by side, with no posts in their back. This distribution of working posts is not good, since the amount of neighboring post positions surrounding a particular workstation is small, decreasing the probability of guarantying the work time close to TCT. On the other hand, when the customer's demand decreases so reducing the number of workers, forces each worker to walk longer distances to return to his initial position after concluding a cycle, without adding value in the way.

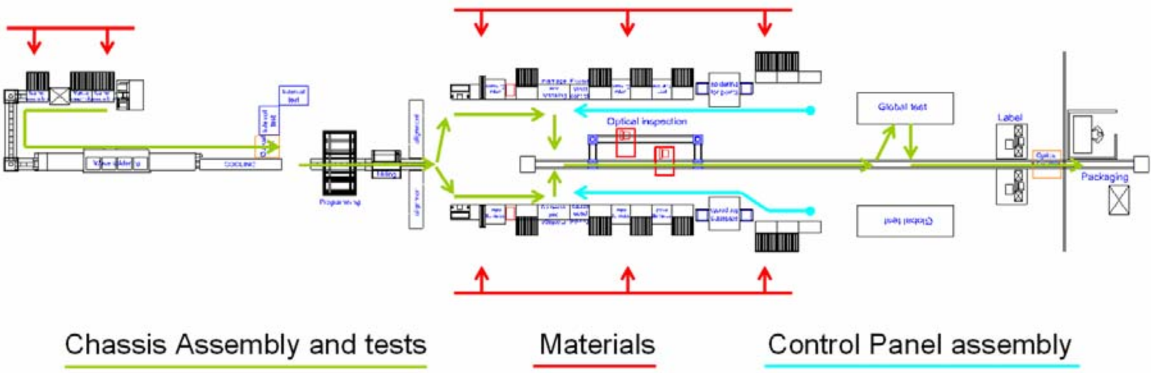

Figure 1- Production line, assembly flow and materials supply.

Flexibility is a very important aspect in a production line. More and more production lines must be flexible. The permanent change of customer's demand, forces companies to adapt themselves to maintain their viability. When demand decreases, a production line that is prepared for a certain amount of production, will support heavier losses if it is maintained unchanged, so presenting a very low flexibility. The whole supporting infrastructure, like cabling, piping that are difficult to rearrange, so imposing severe restrictions to line redesign.

Another aspect to take in account results from the line path branching in two different lines after welding, where visual and electrical tests are done. The existence of two branches in the line is justified by the possibility of keeping the main line working when a failure occurs in one of the branches. No any else advantage is identified.

After the characterization of the line in study, by presenting its strong and weak points, the characteristics intended to the new line design will be described.

4. CONCEPTION OF THE NEW LINE LAYOUT

An efficient layout will certainly satisfy directly the workers, as well as indirectly the clients that will benefit of lower costs due to higher efficiency. However when designing a layout not only the productive aspects should be taken into consideration, but also the aspects related with the workers' safety should be considered. If the production lines are observed in detail, several wastes are noticed, and their elimination should be an objective. The objectives may be set in quantitative or qualitative manner. In the case of qualitative objectives, production processes and logistic support must be considered such as operator displacement, parts flow, manufacture and logistics separation and standardization, worker and production lines flexibility in agreement with the demand.

The following quantitative objectives must be established: low processing time in each post position to avoid static workers; high flexibility to adjust work done with demand weekly, making daily production amount equal each week; high and constant productivity of the operator; reduction of area occupied.

The operator used to define the process and to create the flow before lean thinking, both in manual and semi-manual systems. Demand variations could be matched by the adjustment of the number of workers with the work volume. Figure 2 presents the steps from the analysis of the demand to the resulting operator's flow.

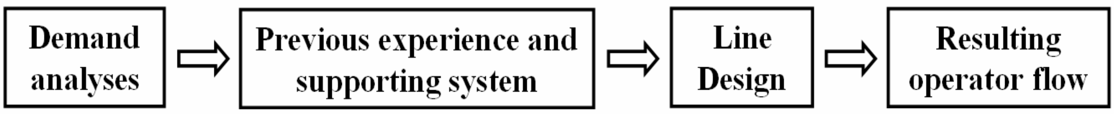

Figure 2 -Outline analysis of the layout design before lean thinking.

The layout is built prior knowing which will be the operator's flow. Sometimes, due to space issues or to relations with other entities (maintenance for instance), it is not possible to set a certain equipment in the intended position. This will become very problematic if one do not know which will be the flow made by the operator. This way a worker may need to do a long path to accomplish his work or else work distribution will not be adequate.

In terms of lean line design, the first aspect to take in account is the operator's flow. The layout arrangement must be considered later. Figure 3 shows the steps to follow from demand analysis to ancillary production systems design.

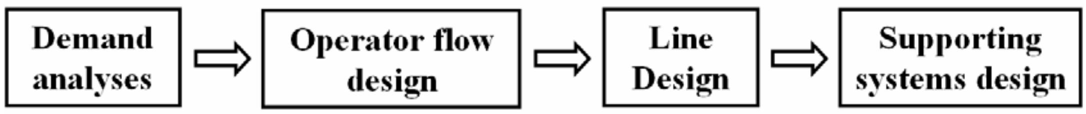

Figure 3 - Outline analysis of the layout design after lean thinking.

Assuming the inconveniences above referred (space and maintenance), equipments may be reorganized in a simpler manner, since each operator's flow is known before the layout design, and the equipments may be reorganized to each operator's flow, these may lay lightly apart each other whenever the worker has to execute a different operation. The resulting free space has not to be considered waste, since it may be used to store intermediate stock.

4.1. Steps to obtain a lean layout

When a lean layout is pretended, a conceptual sequence of steps should be followed to guarantee the expected results. Firstly, a simple sketch of the workstations should be made. This sketch should be a straight line, and the layout should be drawn as if a single worker should perform all the operations to make the product. In this phase, there is no need to respect scale; it is enough that each simple box represents a different workstation. In a subsequent phase details of the machine are necessary to determine the optimal operator’s flow, and the following indications should be made in the stations: Work in progress (WIP) points to indicate where the parts are in the machine and how operators should move; auto-eject (AE); number of cavities to put products (x C).

Automatic stations should be represented with entrance and exit arrows.

Parts transport, between uncoupled posts, should be represented by a horizontal arrow.

Next, the cycle time for operators should be written above each station. This time must be, if possible, inferior to 40% of the target cycle time, to grant larger flexibility in work distribution. Then, each worker may always deal at least with two posts, resulting that the static work is eliminated. The list of needed parts and the automatic processes cycle times should be put below each workstation. Figure 4 presents the aspect that a line should have.

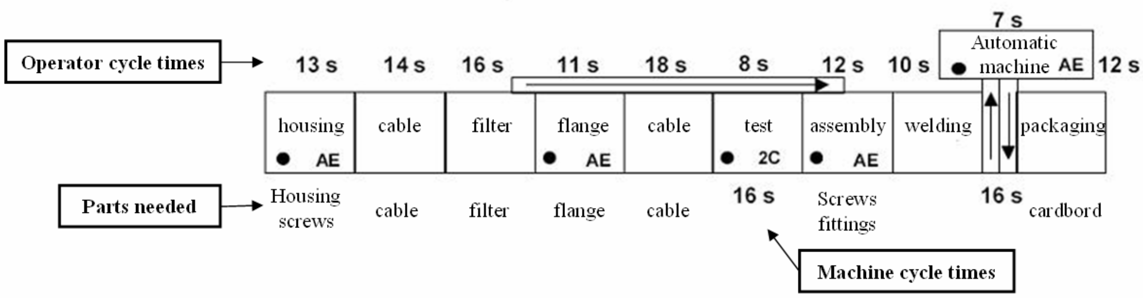

Figure 4 - Illustrative outline of the construction of a LLD.

After this phase, knowing the operator's flow, the materials needed, the reference times and a first line layout, the layout can be detailed drawn to the scale. A mock-up should be made, using paper contour models of the machines and the workstations drawn to the scale to propose and discuss layout solutions. The machines, if possible, should be placed with their narrowest side to the worker's flow to reduce displacements. The layout should continue to be improved, through the analysis of the solutions found, always in the base of a single worker's flow. Only after this phase the number of needed workers and their work distribution should be calculated

4.2. Relationship between automation level, flexibility and LLD

Production lines tend frequently to become more automated, the automation level being linked to a greater productivity, smaller number of workers needed, larger production cadence, smaller number of defective parts and larger repeatability in comparison with the manual work. However too much automation also brings inconveniences such as: larger number of failures, smaller flexibility and larger implementation costs. Figure 5 presents the relationship between flexibility and the type of system applied, with larger or smaller automation level.

When a larger flexibility is pretended, automation becomes an obstacle, since there is an inversely proportional relationship with the automation level. The extent that automation can be increased guaranteeing flexibility may also be seen in Figure 5.

Through Figure 6, one may verify that automation level may be increased until having the machine process and unload automatic, so maintaining flexibility and compatibility with LLD theory.

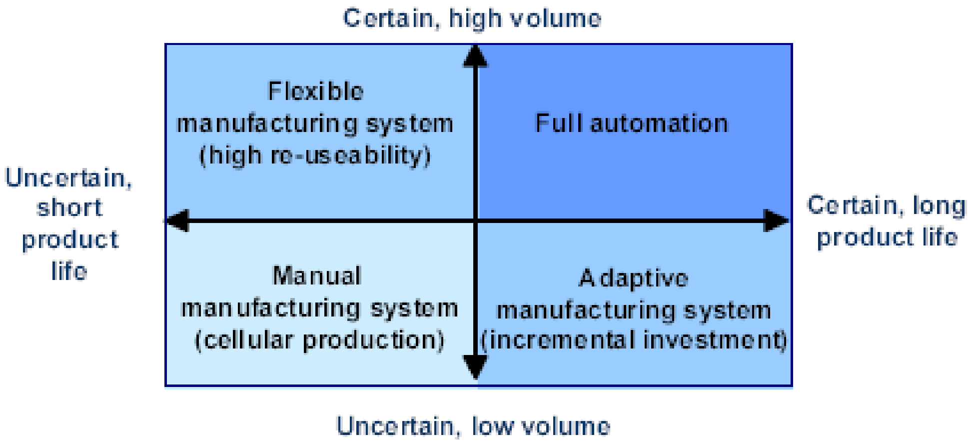

Figure 5 - Relationship between automation level and flexibility.

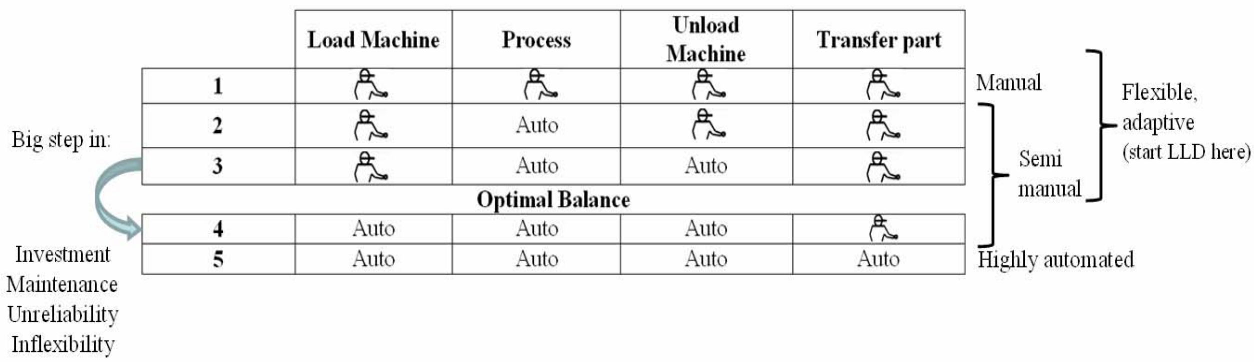

Figure 6 - Relationship between the automation level and the LLD theory.

4.3. Automatic machines

Automatic equipments are sometimes the place where several losses occur, depending on the equipment dimensions. Until a certain dimension, it is acceptable that a worker executes both the equipment loading and unloading, even if losses exist due to non-adding value displacements.

When machine dimensions are considerable, it is not at all convenient that an operator executes both the machine load and unload, since the traveled path will be large, and the resulting non-adding value return to the workstation will also be large. To overcome this problem, the solution is to make a work distribution in that the worker making the machine load and the worker making the machine unload are different. However, this solution brings another problem, for it makes the work distribution more complex, since a kind of island develops. In the present layout, in the absence of posts in the workers back, it may happen that the worker has a work time much inferior to TCT.

So, to solve this problem, automatic machines should be positioned out of the assembly flow, that is, out of the production line. Then, these should be provided of a system capable to take the product to the equipment and to bring it back to production line after processing. Then the equipment must be equipped with a “self-eject-system.” This system will provide a post for placement a product to be processed to the worker and afterwards a position to remove it when processed. In Figure 7 is presented an equipment without a self-eject-system, which only allows to input a product after removing the one previously processed; Figure 8, presents an equipment with a self-eject-system, in two different configurations.

The automatic equipment (AOI) can be placed closer to the load or to the unload, relatively to the self-eject-system of the Figure 8. The closer to the load the equipment is, as in the Figure 8 (right side), the larger will be the benefits, since more quickly the product will be processed, and greater will be the space for processed products.

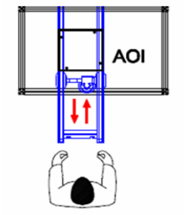

Figure 7 – Equipment without self-eject-system.

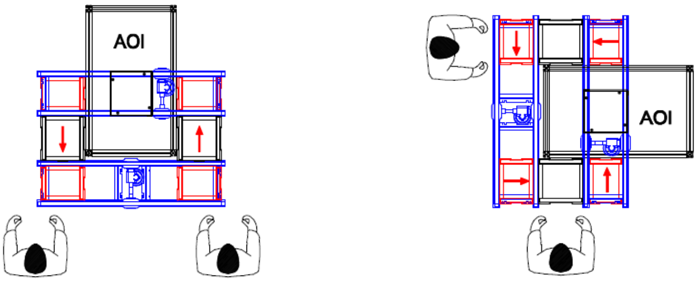

Figure 8 - Equipment with self-eject-system.

On the other hand, the amount of cavities for possible load is also an important point. Knowing that in a production line delays happen, in the case of a screwing robot, sometimes the worker must wait the process to be concluded to unload then reload the machine, if the robot only possesses a screwing base. Then the upgrade from a robot with only a screwing base (Illustration 9) to a robot with more than one screwing base (Illustration 10) presents significant advantages.

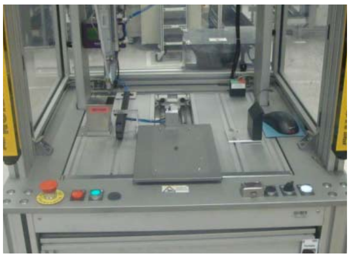

Figure 9 - Robot with only a screwing base

Figure 10 - Robot with three screwing bases.

The robots with more than one screwing base, while one works, the worker can prepare the other for process without waste of time, since the machine continues in operation. Then, the maximum time that he gains is the sum of the time of placement of the product in the base plus the time of retrieval of the product after processing, since in both cases the robot continues the screwing process. The more frequent the machine load and unload, the smaller the cycle time, the larger will be the time savings.

4.4. Post Flexibility

The design of a layout is an unavoidable problem in all the companies and the decisions relative to the positioning of the machines and equipments receive high attention in production and in the management operations. Flexibility is a factor with increasing importance nowadays. Flexible lines allow a better adaptation to the market conditions.

Recently, new technologies appeared like flexible production systems (FMS) and group technologies (GT), that have been implemented in the industry all over the world to keep competitiveness in the global market. In a FMS to establish the configuration of the machines is an important step since it affects the operational efficiency, the load capacity and the flexibility of the system "Satheesh Kumar et al, (2008)".

When flexibility is intended, conditions must be created to grant flexibility. In a sequential assembly line where t several posts exist, it is important they possess certain characteristics in order to allow position changes. Then all the positions must be movable, that is, production lines should be on wheels. Some of the work positions present no difficulties to be provided with wheels, due to their particular characteristics, and so they adjust easily to several situations. However, there are posts that, due to the equipments they include, have their movement conditioned by metallic networks. This situation can be solved easily, by replacing the metallic tubes by flexible ones. Large automatic machines that must be calibrated if moved put the most problematic case. The use of wheels is anyway a very important factor to make a line flexible. However sometimes the work done in benches demands high precision, that is not compatible with the wheels lack of stability. It is then necessary to implement a system as shown in Figure 11. The system presented makes it possible, very easy and fast, the transition from legs to wheels, that is, from flexibility to stability.

Sometimes benches provided of wheels are implemented. However, the whole cabling is fixed in fixed pipe conveyors, so limiting the flexibility of the posts, since to make any change to the line the difficulties remain. A solution may be similar to the one shown in Figure 12.

Using the system of Figure 12 the line might have great post flexibility. To build it is necessary to get energy through the conveyor. The distance between sockets depends on the level of flexibility intended. Having the sockets located every 3 meters, it is necessary that the cables have the length of 1.5 meters, measured from the post summit. This flexibility carries great advantages, such as the elimination of accessibility problems for maintenance and adjustment of the layout in accord with customer's demand.

Figure 11 – Simple and rapid system to alter post positions.

Figure 12 - Example of flexible lines with wheels and pipe conveyors fixed to the ceiling.

4.5. Minimum stock per worker

The simplest way to check which post is delayed is to keep a minimum stock (about 4 units) per each worker. This minimum stock must be established by experience, for it will depend on the size of the product (space issues). The evolution of the stock in each post is then followed to verify if the amount decreases quickly, or if the worker runs out of stock space. In these cases, the work distribution should be altered in order to avoid the situations.

Of course, the objective is that each worker does standard work. In the case a worker runs out of stock, sometimes he may help the worker of the previous post. That way the work done is not standard work, and so it is difficult to evaluate the accomplishment of individual objectives. When there is a minimum stock per worker, this inconvenient is avoided. Another advantage results from producing motivation introduced by this minimum stock. When verifying that the stock for the following worker is reducing, the worker feels the obligation of restoring the stock to the acceptable level, so increasing the productivity. That also provides a simple way to measure worker's productivity. The stock available in the subsequent post allows knowing the rhythm of each worker's work, and that knowledge, along with the workers' rotation in the posts provides comparison stocks' data to check whether the problem comes from the worker or is due to the post itself. However, sometimes when work distribution is made, some factors influencing process time are not taken in due consideration. The existence of a minimum stock may induce the worker to believe to be his responsibility to inform there is a problem if he fails to keep the following position's stock after trying to do his best. This way the situation can be corrected, after a careful evaluation analysis of the responsibilities. An improvement of the production line may derive from the resulting alteration of the distribution, to which the worker contributed, and the credit must be attributed to him.

On the other hand, depending on the work distribution, the minimum intermediate stock will be in different posts. Therefore, the high flexibility of the production line referred previously has a very important role to this factor. On the other hand, as the layout is settled only after the work distribution, locations for intermediate stock placement can easily be established, preferably allowing the worker to do only short displacements.

4.6. Work Distribution

Work distribution is very dependent on the layout of the production line and of the working time for each position, as well as of coupled tasks. If the processes are linked, the work distribution will be better, since there will be no lost workers in islands. Consequently results that a better work distribution is related directly to the number of posts surrounding a particular post. That way, the larger the number of neighbor posts, the greater the probability of a work distribution closer to TCT. Then, if there are post positions in the worker's back, respecting minimum ergonomic distances for worker movement, the displacement losses being the lower possible, work distribution will become easier and more uniform for the different workers.

LLD theory states that each post position to be lean must allow the possibility to execute the task of any position immediately near itself (left, right or back). Obviously to respect this restriction over the whole production line is practically impossible, and so a lean percentage of a certain production line can be defined. To obtain the lean percentage of a line it is necessary to establish the maximum displacement for the worker, and then it is enough to analyze each position in separate and to verify that the worker can do the tasks in the positions above defined without exceeding the distance previously established.

4.7. Ergonomics

The worker's possibility to do the tasks of the post in his back brings ergonomic advantages. Depending on the work distribution, the minimum distance between back-to-back posts will have different values. When there are, at least, two workers to do back-to-back work, the minimum distance will be of 1.80 m. On the other hand, if it happens that the distribution is such there are never two workers working back to back, the minimum distance will be 1.20 m.

When the worker has to turn over to work in the post in his back, his blood circulation is improved. When the worker has not a post in his back, he will have to move sideways and that is not beneficial to his health. On the other hand, when the worker moves sideways he must travel a longer distance when returning to his initial position without adding value. This value will then be inversely proportional to the amount of products to be produced: the less the amount of products, the larger the target time cycle, and then the smaller the number of workers needed. The smaller the number of workers, the larger will be amount of work done by each worker, the larger the number of posts per worker and the larger the movements. So, the smaller the quantities, the larger displacement to the initial position without adding value, if there are no posts back to back to reduce the displacement with a good work distribution. Another ergonomic advantage results from the elimination of static work, for the worker moves at least between two posts.

4.8. New Layout Design

After this study, the layout presented in the Figure 13 was obtained.

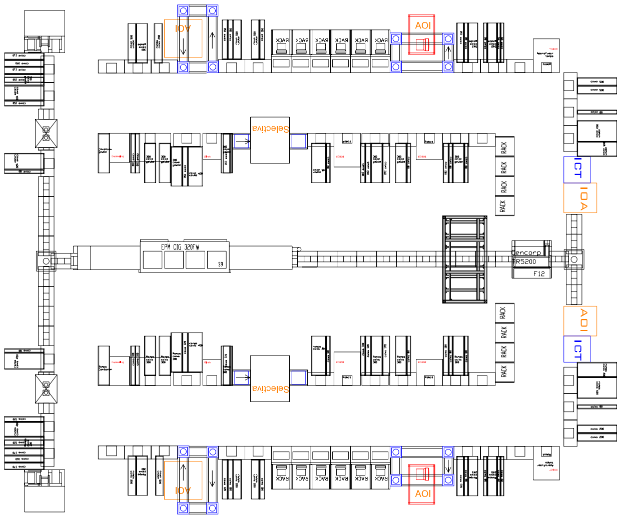

Figure 13 - Outline of the new layout.

This new layout presents several of the desired characteristics, but some inconveniences still occur:

Advantages:

- the used area with the new concept is 285 m^2 (almost square, 19 x 15 m), against the older used area of 405 m^2, occupying a narrow and long space (9 x 45 m). The new layout presents then a gain of 120 m^2. Another advantage results from the elimination of islands. All the different assembly phases are linked physically. The work distribution becomes simpler, all the workers' having the possibility to achieve work times close to TCT.
- another beneficial aspect for the uniformity of work distribution is the introduction of posts in the worker's back, so allowing better adaptation and work distribution when demand variations are imposed by the customer, since with the existence of posts in the back, because the return path (without added-value) after task conclusion is smaller.

- Another great advantage is related with the flexibility. By applying the concept above referred, using wheels in the posts, using energy sockets strategically distributed, using overhead cable conveyor with the existing layout, it is easier to add or to suppress post positions to the line.
- A very important aspect, already referred for the present layout, is the branching of the assembly line after the welding post through the testing posts. The lean line keeps the branches although extended to the entire line, from the initial assembly of components in the board. This division also carries countless advantages related with the flexibility, considering either quantities or variety of products. The same product can be manufactured in both arms, or, if necessary, different products can be manufactured taking care to use some sort of selection method prior to the milling machine, such as bar codes reading to separate the products. This method will help to adapt each line to produce the necessary quantities, so compensating other lines charge when there is a variation of customer's demand.

Disadvantages:
- Most of the supplying is made through the corridors, but some are made inside the line, forcing the passage of the supplying material through the workplace.
- In what line flexibility is concerned, the line length has a minimum length due to the welding machine dimensions, so conditioning the expected results.
- The branching in almost the entire process also has drawbacks, for the necessary investment that must be done to duplicate equipment.

5. FINAL CONSIDERATIONS

The use of lean concepts for the design of a sequential assembly line production layout leads to significant improvements obtainment. Waste reduction, productivity increase and quality recognition are among the main company objectives. Because waste elimination is one of the main objectives of the Lean mentality, the interconnection of the design of line layouts under lean theory helps the layout to be more effective. Before the introduction of lean design the line was first designed and then later the work was distributed trough the workers. With LLD, first is defined the quantity to produce, to define the number of workers needed afterwards; the work distribution is done per each worker, the workflow is established as a consequence and the layout design is done.

During the development of this study, several alternatives were considered, and comparison among them was done, taking in account the study of several characteristics expected for a layout in order to reach adequate results. Through this study, diverse improvements were made: larger flexibility concerning products variety, layout adjustment to customer's demand and post displacement to easy the maintenance. These aspects are very important nowadays, since the variety of products is increasingly larger, and so companies must be prepared adapt themselves to constant market changes.

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