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Optimized Manufacturing Layout and Operational Balancing - A Case Study in an Electronic Line from the Industrial Pole of Manaus/AM, to increase productivity

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***Abstract*— In the face of an extremely complicated phase for the national and international market, the factories are seeking ways to survive this turbulent moment for the economy, pursuing alternatives in order to make their processes more sustainable. So, in this way this can be possible to remain in the midst of increasingly difficult challenges and goals, it is understood the great importance of seeking the optimization of its manufacturing processes through their layouts in order to be economically stronger. Based on this, a case study was recommended to carry out an experiment, whose main objective is to optimize the layout as well as every part that makes up its production processes, proposing the unification of two production lines installed in the PIM (Manaus Industrial Pole) of the Electronics sector. With information of the production process through the collected data, was identified in the first layout the excesses in two production lines under study, which had the two identical processes in common, as well as the duplication of stations, tests and the unbalance of operational activities in oversized stream. The update of Takt time was also necessary given the opportunities found specifically in the packing area, with overproduction waste in certain stations. Searching for more productivity and improvements at a low cost, was determinate to choose the study to optimize the layout and improvements in the flow with a reduction in the operational cost through low-cost means. The entire experiment was accomplished with tools and programs in free versions available on the internet and already widely used in the industrial factory and environments, such as Sketchup, GBO (Operational Balance Chart) and Kinovea video editing program.*

I. INTRODUCTION

An optimization of the factory *layout* or its administration, typically remains under the responsibility of the Industrial Engineering area or the Process Engineering of the factory, seeking to obtain the autonomy to study and transform the current process by proposing new and more productive processes. The study of this process gives to the factory the flexibility to make decisions regarding the adaptation to new technologies such as new machines or new production methods that take up less space than manual processes, replacing those that depends on more people or large occupation of the factory area. Each production process has its particularity, and having a detailed layout in your hands is knowing exactly what you can and cannot do, in other words, it means perhaps being one step ahead in a market that is always very competitive, making possible to be ready for a quick and strategic change in the factory layout, with a short-term financial return and implementation of low-cost projects.

According to [1], the *layout* is the arrangement of men, machines and materials, which allows integrating the flow of materials and the handling of needed equipment, yield and movement, so that the storage takes place within the standard of economy and efficiency. Along these lines, the correct positioning of machines, inputs, products and equipment contribute to minimizing waste, both those related to movement, production such as stock and waiting [2].

The proper sizing of the *layout* provides to the organizations an efficient communication progress, between units, in which the company's available area makes the workflow more efficient [3]. This way, one of the major obstacles faced by industrial companies, regardless of the size of the factory, is the adaptation or redesign of the *layout* according to growth, in view of the need to produce new products or, in other words, to comply with the constant demand of the customer. Therefore, more and more the market demands that companies be ready to adapt their processes, enabling new ways to produce, optimizing their physical arrangement, and increasing their productivity.

Productivity is the real usage of all and any available resource, it is often confused exclusively with production and just to produce not always mean to have productivity, usually the productivity does not appear with a set of improvements which can make the productivity to be always and constantly in a production process if this process is controlled and mapped frequently. Thus, the elimination of downtime is an important action to obtain and to produce more with less cost, where the same hours lost during the production process can be transformed into productivity.

Regarding productivity, according to [4] time management is a contribution to personal life planning. Facing this competitive scenario in the industrial market, many factories focus on mapping and studying different ways in order to have in hands solutions that show the best usage of their industrial structure as a whole, as well as their machines, raw material, labor and its capital altogether. The choice of tool will depend on some factors, for example: type of *layout* intended, amount of information available or designer's preference [5]. The way the design of a physical arrangement or *layout* is designed directly reflects on the productivity of a production line installed in a factory that depends on various processes to be efficient in its output, considering all the points described above and highlighted by its importance in designing a *layout* to become efficiently productive.

This study describes the transformation of a factory layout comparing its current and future process after improvements made through flow and balancing studies that led to a new process design, as a condition to prove the improvements made, pursuing more productivity and optimization in two lines of production through possible eliminated waste, followed by presentation and detailing with data and the result obtained with the help of specific literature on factory *layout* design and lean production, making possible to achieve the objective of this case study, in this way obtaining more productivity through optimized factory layout and balancing the operational process.

II. MATERIAL AND METHODS

As reference was used a company from the PIM (Industrial Pole of Manaus) in the Electronics sector for process mapping and *layout* design adopting 3D Sketchup software, version 2017 with a CAD (DWG) file, for the floor plan purpose, in which the area measured was described with characteristics of little space between operators, with stations operating in counter-flow making it difficult for the continuous process that should be working without interruptions.

For the job balancing the use of Lean GBO tool (Operational Balancing Chart), presents the optimization of the operational production process, proposing a new Takt in a shorter time than the current process, in which it had bottlenecks proving the unbalance of the activities.As an analysis, the illustration was made through the ***Yamazumi graph*** (a graph that shows the cycle time of each task), which in Japanese has the meaning of “stacking” the data. According with the process information, the Kinovea software was used for analysis through video, where the data is read in numbers. Considering that the tools used in this article are available in the industrial environment, or in other words, in the Production Engineering for the purpose of aiding in the study of processes with mapping or ergonomic evaluation for data collection, are an excellent support to the engineering engineer to the professional and the production in the industrial area.

Thus, this research is classified as descriptive [6] in detailing a specific production process and explanatory in identifying and understanding the cause and effects of a production process with quantitative data comparing before and after. This is a case study that reports the important benefits of an optimized factory layout, showing that the continuous study of the production process in greater detail makes it possible to produce more with less.The data collection was carried out in a production area with two assembly lines containing 30 workstations each, with a total of 60 operators.

The entire production process was filmed stand-by-stand, the images are used for studies in the image editor program called ***Kinovea***, *a program of French origin proposed by Calmet in 2012*, facilitating the chronoanalysis, recording of times and detailing of the assembly in angles, in such a way it was possible to carry out a detailed study at each workstation where the images generate data on the operational cycle of each operator (Figure 1).

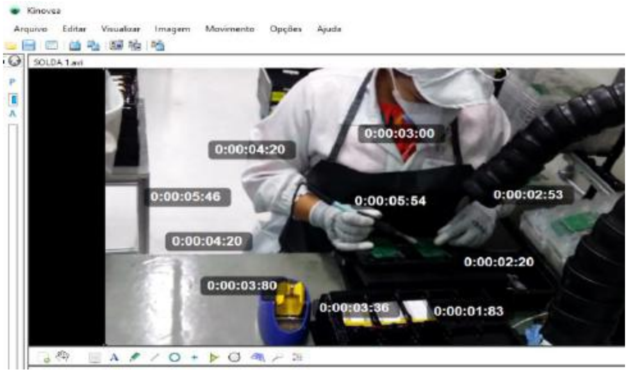

Fig.1. software ***Kinovea*** *timing on video.*

Subsequently, the data will be presented in a balancing graph for process optimization analysis. Each movement is registered and quantified forming operational cycles and based on their time averages that will feed the graphics which will represent this process. It is important to be aware of situations or movements that can break the sequence of the activity, this can occur in cyclical or no cyclical situations, which can be repetitive movements or with variation at the end of the activity. This video editor program called Kinovea, was an important tool used in data collecting for this experiment. Throughout, it is also possible to observe whether the operator is making adequate movements in carrying out the activities, whether the filming was well done, valuing the views during the video recording, and it is also necessary to identify whether the trained performer or operator is performing their activities according to the standards established through industrial engineering. It is possible for the operator to deviate from the standard method. In this video analysis model, it is possible to land the image or even slow down, zoom, so in this way details that would go unnoticed at normal speed can be identified. As well as inappropriate ergonomic movements that can cause discomfort to the operator and impact the time available to perform the activity or even each assembly cycle.

Before any filming in the process, it is important to guide the person who will be filming so as not to lose any detail of the editing process, everything is important.

Collecting data from the manufacturing area, the measurement was performed using a measuring tape and later all the measurement data were added to the free version drawing modeling software 3D ***SketChup***, owned by ***Google***, which is a program that offers numerous tools to transform the process in images, making possible to offer the future vision of a proposed *layout* and its possible impacts (Figure 2).

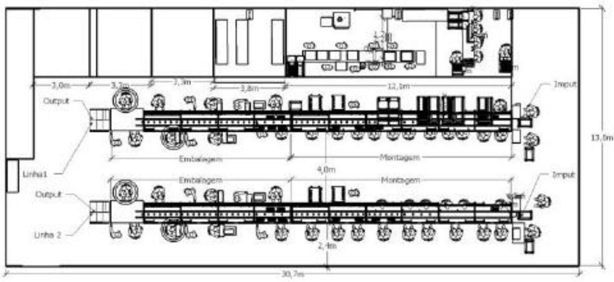

Fig.2. Construction of the current layout with the averages collected in the available area.

The figure 2 illustrates the measures added in the software this way generating the current *layout*, as main information a large area of 423.66m² was identified, but poorly distributed with two identical production lines capable of producing the same product models. The location of each process was measured in relation to the current *layout,* in the total space available, having as characteristics the distance between the two production lines measuring 4 meters between them, and 20 meters in length from beginning to the end, with side aisles measuring 2.4 meters illustrated via 2D drawing, enabling the study for new opportunities of improvement. With this software it was possible to design machines, assembly devices, its line structure and all the jobs evaluated in this experiment.

It is important to emphasize that since the identification of each object part of the production, from the detailing of each workstation, to the profile used on the treadmill, it was designed with this software called ***SketChup.*** An ally for engineering in 2D and 3D designs and helps in mapping any production process, whereas understanding the current process and proposing a future process is easier, considering that with more detail in the layout higher are the chances of transforming the process safely and have less risk of errors in project execution. With good planning it is possible to avoid unnecessary expenses with errors in the project. This way a 2D *layout* with a top view is born, in technical drawing designing the entire process and following rules through standards established with the Brazilian Association of Technical Standards (ABNT), rich in metric details characterizing the input and output that represents the production flow of this production process described here for this experiment.

The 3D image generated by the Sketchup software simplifies the study of the entire production area visually, making it easier to see the entire process and develop solutions for a new flow in a future vision, based on the changes made for the development of the *layout* (Figure 3).

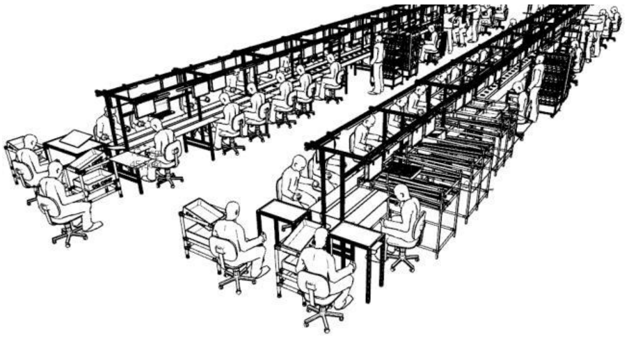

Fig.3. Current 3D layout with two production lines.

One of the main benefits of working with 3D layouts is the immediate identification of possible impacts on the movement of machines or workstations, which can bring negative results, impacting in productivity. The space available for each workstation with the exact dimensioning measurement is easily projected in this program, detailing everything, even all the material needed for assembly per workstation.

In 3D are also developed drawings of new devices that help in the assembly to facilitate the installation in a shorter time, they can be projected in the future state, enabling a dimensional analysis of how much space they will occupy in the future layout. These devices eliminate many manual processes that make assembly difficult. 3D drawing also facilitates understanding in management presentations where technical reading becomes an attachment to projected images, leaving lines in a superior 2D view, to three-dimensional images with rich details, facilitating the decision making regarding all changes made in the experiment involving the production process.

Then, in the development of the technical drawing, the main orthogonal views are projected as: A. Front; B. Higher; C. Side.

III. RESULTS AND DISCUSSIONS

Analyzing all the information on the production process of this factory located in the Industrial Pole of Manaus (PIM), considering the total area distributed to the two production lines with their layouts, plus the chronoanalysis data obtained from the study of the workplaces, a proposal for a new layout and operational balance was reached.

The first step was to detail the process in the current layout, observing the entire manufacturing area described, this way, presenting more possibilities to produce more with less space.(Table 1).

Table 1. Improvement opportunities in the current state.

Opportunities for improvements in the current layout	
Layout / equipment	Assembly activities
Duplicate line layout	Out of the pattern
Duplication of posts	Very low uptime
Counter flow	
Super sizing	Duplication of activities
Excess material	No Golden Zone

The points raised were seen as opportunities for improvement with a low investment cost, since it was a process with characteristics of operational unbalance, disposal of materials beyond the reach of operators, without (Golden Zone), bottlenecks in the process, overproduction in stations, non-standard production processes in a specific layout with opportunity for improvement, dealing with two identical lines in their production processes. Then, raise the opportunities in operational balance analyzing the current state.

Taking into account that each line produced the same product model as the other, and that its machines and testing equipment had the same quantity in both lines, adding to the information obtained in the current GBO graph (Operational Balancing Graph) which the packing stations located at the end of the process are faster in their cycles activities, so they can deliver their respective assemblies in a shorter time than the initial part of the station line, showing the unbalance of activities in the same production line in layout format “I”.

For a better analysis, the production lines were divided into two parts: assembly and packaging. This way the process became clearer, where the use of design software for the visual of the current process became more evident and clearer.

As one of the first information obtained from the study, the chronoanalysis made evident in numbers that there were processes with greater production capacity, as well as the packaging that had manyoperators being part of this process, in the production line, which could be better distributed.(Table 2).

Table 2. Opportunities for improvement in the future state.

Proposed opportunities in the future state	
Layout / equipment	Assembly activities
Unified layout	Standardized work instruction
Unification of workstation posts	Operative balancing
Uninterrupted flow correction	Job optimisation
Layout optimization	Delete duplicate activity
Adequacy to material flow	Implement Golden Zone
Optimization of tests and equipment	Develop mounting devices

The opportunities highlighted in the study of the current layout resulted in the unification of the processes for their similarities supporting this proposal, eliminating the duplication of workstations that were repeated when the processes were analyzed together. Has been observed the opportunity to optimize the space available to produce, the arrangement of materials in the workstation resulted in the elimination of unnecessary movements with the application of the Golden Zone, which means the best arrangement of materials in the operator's gold zone. A better detailing in the work instruction avoided deviation from the established assembly standard. With the chronoanalysis and the balancing of activities, it was possible to optimize workstations. The development of devices that assist in production, streamline the process and ensure standardization of the assembly cycle, making the operating sequence more robust, without suffering sudden variations in the established takt, because without a well-detailed work instruction and with clearer information, it is difficult ensure standard production (Figure 4).

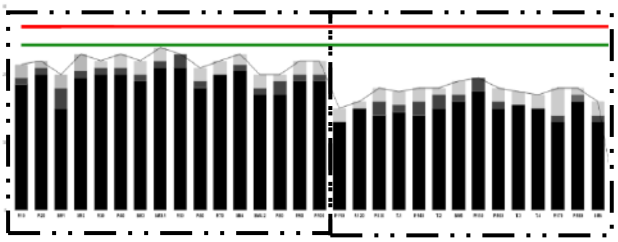

Fig.4. Current GBO Chart (Operational Balance Chart).

The GBO chart above was built using the times of activities collected by workplace that make up the information of the assembly process. The green parts are the activities that add value directly to the product, the activities in yellow are, for example, necessary movements in a manual process, in this way, they do not add value, but it is essential in this production model, and the activities in red color are unnecessary movements or activities that will make time available to produce more. These data prove the operational imbalance and the identification of the production line process with the highest production capacity.

Evaluating the result above, there are two production lines that before the experiment used to produce individually at a takt of 12,8 seconds 281 pieces per hour, and had a shift capacity of 2.306 per shift with the quantity of 30 operators per production line.(Table 3).

Table 3. Results by production line.

Result per production line	
Before Experiment	After the experience
Takt time= 12,8	Takt time= 11,8
P/h=281	P/h=305
Capacity per shift: 2.306,25	Capacity per shift: 2.501,69
Number of operators: 30	Number of operators: 26

After the experiment, the takt was reduced to 11,8 seconds, managing to produce 281 pieces per hour and the shift capacity was now 2.500 pieces per shift. Proving that with the improvements made after the implementation of the new layout unifying the production lines, there was an increase of 24 pieces per hour, and 195 pieces per shift with 24 people, resulting in an increase in productivity of 8,46% with optimization of 8 operators in the future state.

The table 4 informs that the takt of 5,8s defined for the unified packing in the future state, has a production capacity of 620 pieces per hour, multiplying by 8,2 hours worked, the production capacity is 5.089 pieces per shift and the previous layout produced with the two lines with separate packings were only 4.612 pieces per shift, showing that the unification of identical processes can provide an optimization of operators through operational balancing and the elimination of duplicated processes, making it more productive and at the same time lean.(Table 4).

Table 4. Final result of the experimente, analysing the layoutvariables.

Result with the Packing Union of Production Lines		
Takt time= 5,8s		
P/h=620,6		
Capacity per shift: 5.089,6		
number of operators : 48		
products /hour	4.600	60 operators
products /hour	5.089	52 operators
Optimization of 8 operators		

With the optimized production flow, the result generated more productivity in a process that produced with more people in an optimized layout, making the area available for other production processes. There was also a considerable gain with the reduction of people in this process (Figure 5).

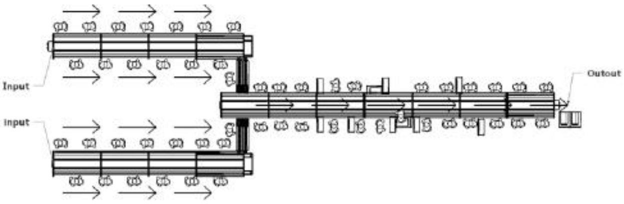

Fig.5. Future layout with Y-shaped production flow.

The Y layout was an option found for joining the lines only in the packing part, where the number of duplicated stations and tests made possible to streamline the assembly process by reducing takt and this way increasing production output and reducing labor at a area from 143 m² to 91.42 m² for the usage of small processes such as sub-assemblies that help the line with more manual processes area 143 m² to 91.42 m².

The process became a leaner and efficient without variations in productivity, before the unbalance of operational activities prevented production from maintaining constant numbers in the total daily productions, with improvements such as optimization in layout and in the productive operational process, this experiment proved to guarantee a better process through low-cost implementations proving that it is possible to produce more with less.

The choice of tool will depend on some factors, for example: type of layout intended, amount of available information or the designer's preference [5].

The measurement of possible gains in the study of the flow is one of the main objectives of this experiment, which results in an increase in productivity and, consequently, a reduction in labor costs. The profit can only be obtained by reducing costs [7].

Productivity is related to better or worse use of resources. It is the science of any business in an industry productivity and is directly linked to the production efficiency [8].

The current global scenario of crisis that companies are experiencing makes them study new proposals and re-read their production methods, their equipment and their global science in relation to their productivity [9].

IV. CONCLUSION

With the application of the layout tool as a condition for improving productivity and minimizing waste, several gains were analyzed such as: Lean production, producing more with fewer people, reduction of production operational costs, producing only what is necessary and a layout making this way an available area for other production processes that can help in more productivity.

The main wastes observed were overprocessing, defects, unnecessary movement, waiting, counter-flow and operational unbalance, have been minimized in quantity after the improvements realized in the scenario where two production lines are drawn in the layout.

The layout, through the movement of the process, presented numerous improvements, regarding the reduction of overproduction and improvements in counter-flow. Mainly maximizing the company's productivity and reducing the expenses, such as labor, which did not add financial gains.

In this experiment it was only possible to obtain this result because both production lines under analysis are identical, in other words, they have duplicated processes. The unification of the final packaging processes of the production lines was the great point seen as an opportunity to transform the layout into a 'Y' format, a point where the optimization of operators was made possible, because the packing had oversized positions when evaluated in two processes that produced the same product and obtained the same production capacity. This was the main characteristic of this production process that enabled the entire transformation, obtaining the reduction of labor at a low cost in the experiment, thus proving an excellent result.

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