Industrial Layouts Design for a SME in the Electronics Industry

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Abstract

With the ever-increasing levels of market competition, companies are continuously forced to innovate and enhance their product development to increase their performance and stay relevant in the market. In this scenario, manufacturing companies must react to this increase in production rhythm by correctly planning and constantly improving the production lines implemented on the shop floor. Additionally, to meet the customers' requirements, it is needed to produce new and quality products at reduced prices. To achieve this, lead times must be reduced, and production lines must become increasingly efficient. The Facility Layout Problem has a significant impact in several important aspects, such as manufacturing costs, work in progress, lead times, and productivity. When adding new production lines, manufacturing companies must do a more in-depth study on how to make this addition without having a negative impact on the efficiency of the already existing production lines and on production costs. In this work, a company that needed to restructure its shop floor to insert a new production line for a new product is portrait. To perceive the impact of this change, three different case studies were analyzed, and layouts were developed for three production lines applying different line balancing techniques and layout development techniques.

Keywords
Industrial Layout Design, Systematic Layout Planning, Lean Facility Layout System, Line Balancing and Linear Programming.

1. Introduction
As global markets become increasingly more competitive, the uncertainties and difficulties associated with the development of a new product increase alongside with the pressure to keep up with the demand in product innovation (Gupta and Wilemon 1990). Therefore, innovation is considered critical for a company to obtain a dominant position in the market and to gain higher profits (Cheng et al. 2010). Time management, more specifically, the reduction of lead times, will result in a competitive advantage, allowing manufacturing companies to gain an edge over the creation and production of new products (Tersine and Hummingbird 1995).

The facilities placement in the plant area, often referred to as ''Facility Layout Problem", is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity (Drira et al. 2007). A good layout contributes to the overall efficiency of operations (Drira et al. 2007), keeps costs low and reduces unnecessary material handling while maintaining the product flow through the facility (Khan and Tidke 2013). Besides this, improving the layout also increases the machine utilization that enhances the machining capacity of the shop floor (Khan and Tidke

2013). Therefore, manufacturing companies must pay special attention to this problematic, existing several reasons why a change in layout is necessary: changes in the product design; expansion of enterprise; new products added to the existing line; new departments added to the enterprise; the need to reduce the quantum of work-in-progress (WIP); the need to eliminate or minimize bottlenecks, etc.

The layout planning takes place in two decisive phases of the organizations: in the implementation phase and at moments of facility adaptation to new functions, productions or other type of challenges. The design of a layout and the decisions associated with it are of great importance for companies. Mistakes made in the initial phases of layout design and implementation have repercussions throughout the life of organizations. Several problems occur when the study and implementation of layouts is not supported by a careful planning and solid study, thus risking lowering the efficiency of the production lines.

During the last decades, several studies with different approaches to solve the facility layout problem were published. Singh and Sharma (2006) presents the current and future trends of research on facility layout problems including formulations, solutions methodologies, and developments of different software packages. Some of these methodologies are: Empirical Model, Systematic Layout Planning (SLP) and Lean Facility Layout System (LFLS). De Carlo et al. (2013) presents a case study of a small batches production line using these three approaches, where the LFLS achieved better results.

The SLP method, developed by Richard Muther (Muther 1973) is widely used in layout design in various small and medium enterprises (Ali Naqvi et al. 2016), and its application is already proven through several successful studies (Ali Naqvi et al. 2016; Eliud et al. 2018; Fahad et al. 2017; Wiyaratn et al. 2013). In the SLP, after some preliminary information, a flow analysis is combined with an activity analysis to develop a relationship chart (Sule 1991), being this the output from the first phase. These charts highlight the importance of proximity between pairs of resources belonging to the various workstations. In the second phase, a relationship diagram is elaborated, making the relationships of proximity between the various resources visually perceptible. Through the analysis of this diagram and considering the limitations that may exist in terms of space and requirements, alternative layouts are developed. In the third and last phase, the alternatives are evaluated, in order to determine which is the most suitable, or if it is necessary to make some kind of combinations of two or more alternatives to obtain the final layout.

The Lean concept is based on the waste elimination, also referred as *MUDA*, in order to obtain a continuous flow. The characteristics of the Lean Manufacturing philosophy can be applied to the Facility Layout Problem resulting in the Lean Facility Layout System. This methodology has been successfully applied in several works (Jia et al. 2013; Putri and Dona 2019). According to Khan and Tidke (2013), this method consists of four phases: Definition of the current state mapping through the Value Stream Mapping Lean Tool (As-Is Model Development); Waste elimination; To-Be Model Development; Layout Development. The facility layout obtained according to this process has properties and goals similar to the lean manufacturing ideas: it will be oriented towards a reduction of each kind of waste, such as transporting time, space and unnecessary workstations (Khan and Tidke 2013).

Efficient production is not only due to an effective layout, but also depends on the good balancing of the production lines. Production activities in manufacturing industry are closely related to the assembly line balancing (Syahputri et al. 2018). The line balancing consists of distributing evenly the workload needed to produce each unit among the workstations. This assignment of tasks must be efficient since it will determine the productivity of the entire production system. To achieve better results , the combination of layout design with line balancing techniques has already proven to be quite advantageous (Buchari et al. 2018; Syahputri et al. 2018). Therefore, a virtuous layout can be designed, and productivity can be increased through an appropriate assembly line balancing (Yemane et al. 2017). The assembly line balancing problem consists in assigning tasks to an ordered sequence of workstations such that the precedence relations among the tasks are satisfied and some performance measure is optimized (Erel and Sarin 1998). Each workstation is expected to have the same cycle time, though with different capacities, so that no idle time and bottlenecks occur (Syahputri et al. 2018). In this context, the Simple Assembly Line Balancing Problem (SALBP) arises. This problem consists of assigning a set of tasks to a set of workstations, intending to minimize the number of workstations or the cycle time of the production line.

Different methods and approaches can be applied for solving SALBP, from exact methods, like branch-and-bound (Ege et al. 2009) to heuristic methods. These last ones can be from simple heuristics to meta-heuristic approaches. Using different preference criteria to assign tasks to the workstations, also results in different heuristics. For example, some simple heuristic refers to sorting the tasks in descending order (MaxTime Heuristic) or ascending order (MinTime Heuristic) of their processing time. After this ordering, the tasks are assigned to the workstations according to the established order, considering that the defined cycle time cannot be exceeded. There are other heuristics, for example: when the assignment of tasks to workstations is carried out in decreasing order of each task processing time divided by the upper bound (MaxG – G being for greatest); when the allocation is made by prioritizing the tasks with the greatest number of successors (MaxS); when the assignment of tasks is made in descending order of the ranked positional weight of each task (MaxRPW).

1.1 Motivation and objectives

This work was developed in a Portuguese SME belonging to a group in the electronic industry. This group develop and produce efficient, sustainable, and suitable solutions for the Smart Cities/Utilities, Smart Buildings/Installations, and Smart Homes/Appliances. The company is dedicated to the production of Induction Cooking Plates (ICP), LED Lights and, more recently, a new product, that for the sake of disclosure, will be referenced throughout this paper as MWMs.

Due to the development of the new product, the need to insert a new production line on the shop floor arose. Taking advantage of this need, the company wanted to completely redesign the layout of its shop floor to increase the efficiency of each production line.

2. Methodology

As mentioned before, the manufacturing company under study wants to produce three products brands, and for that three production lines must be installed on its shop floor (two existing production lines – LED Lights and ICP production lines – and a new production line – MWM production line). To this end, three production lines were studied, thus resulting in three different case studies, where the layout of each production line is developed in each one. The work developed in each of the case studies resulted in the development and publication of three different scientific papers.

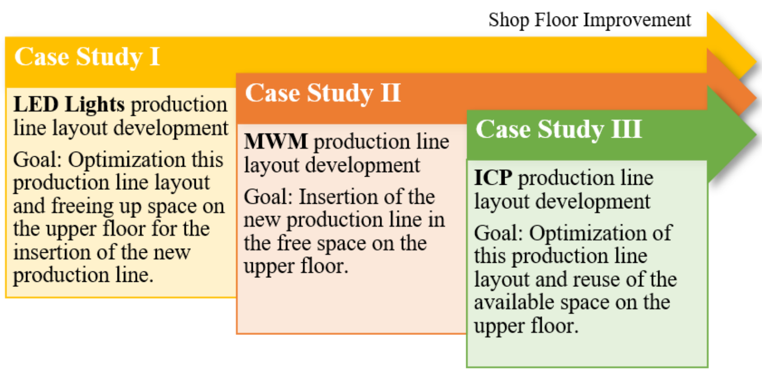

Figure 1. Methodology division into case studies.

The company's shop floor is divided between two floors. At the company's request, the new production line would have to be installed on the upper floor, however, for this to happen, it is necessary to free up space on that same floor. Analyzing the processes of the production line installed on the upper floor (LED Light production line) it was readily apparent that there would be advantages in installing it on the lower. Those advantages were related not only to the existence of high amount of waste related to the workers and unfinished/finished products movements, but also to the existence of a high number of products damage due to the movements between floors when the products were poorly packaged.

This study was divided in three case studies (Figure 1). In the Case Study I, the layout of the LED Lights on the lower floor was performed. This first development led to a space release on the upper floor. In the Case Study II, the layout design for the MWM production line to be inserted on the upper floor free space was studied. Finally, in the Case Study III, taking advantage of an area available on the upper floor, and at the company's request, a layout for the final encapsulation processes of the ICP production line was studied.

With these three case studies, all production lines available on the shop floor were design, and the layout of the entire shop floor was optimized.

3. Structure and main results

The dissertation was structured into **three parts**, in which were included 5 chapters (Figure 2). **Part 1** portrays the introductory chapter, which includes the global problem introduction, the study objectives and its methodology, the case studies introduction, more specifically, presents the company structure, its evolution in the company group goals and the evolution of its production. In this dissertation there was no initial chapter with literature review, being this done at the beginning of each chapter, having all the related subjects covered in it. **Part 2** includes Chapter 2 to Chapter 4, where each chapter presents the work resulted from the three scientific papers developed. The three papers have already been published in two different International Conference on Industrial Engineering and Operations Managements (IEOM) and in the International Conference on Operations Research and Enterprise Systems (ICORES). Finally, in the **Part 3** is included the Chapter 5, where the final conclusions resulted from the three previous chapter are presented, and where some suggestions for future work were also made.

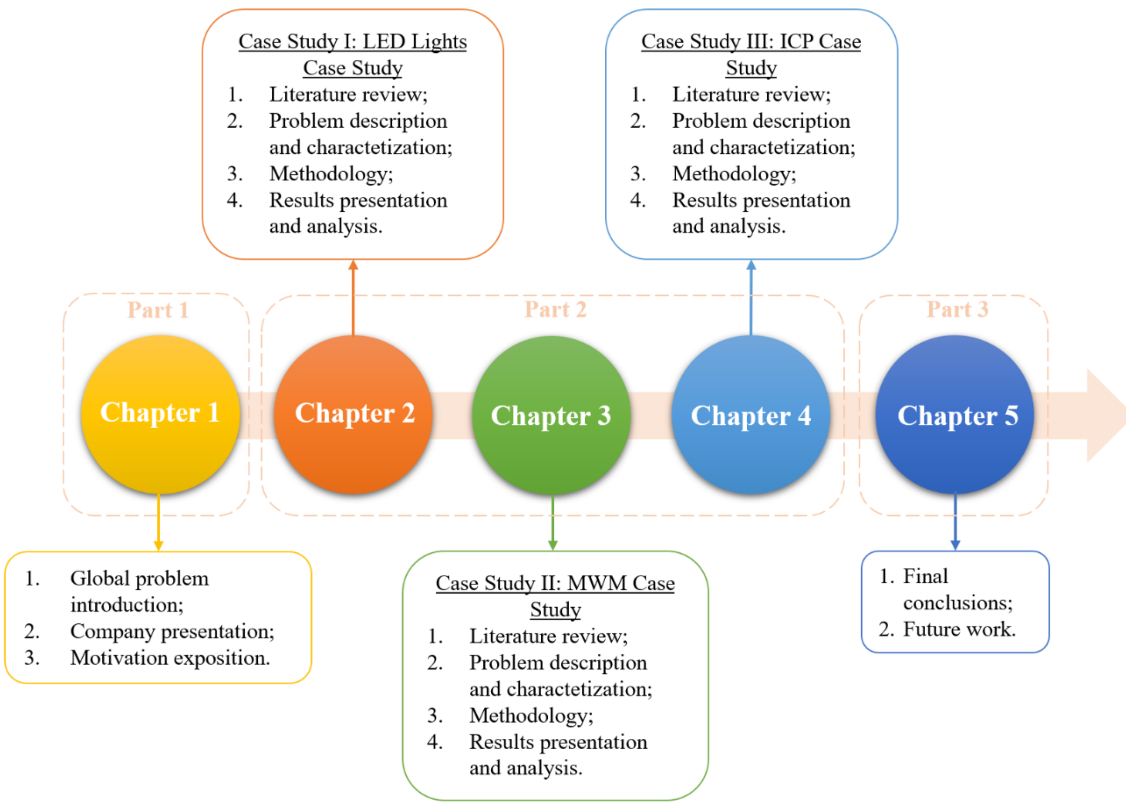

Figure 2. Dissertation division into chapters.

3.1 Chapter 2 – Case Study I: Led Lights Case Study

The Chapter 2 presents all the work developed to the LED Lights production line. To start the production of MWMs, the company faces the problem of lack of free space to accommodate this new production line. Simultaneously, there is another problem, related to the LED Lights existing production line, whose efficiency has been decreasing. So, the need of free space for a new production line caused a change in the layout of the factory floor. This was an excellent opportunity to study in detail the LED Lights production line and, improve its performance. In Phase 1 (Figure 3), the LED Lights production line was observed, and it was characterized through the elaboration of operative flowcharts. Besides this, to characterize the current layout it was also elaborated spaghetti diagrams and Ishikawa diagrams. Through its analysis, it was evident that there were several flaws that culminated in the significant problem currently felt – the production efficiency decreasing. This can cause a weakness in the capacity to meet the customers' requests. This case study considers the production line of three families of LED Lights that, for sake of disclosure, were mentioned as IE, Ic and L. These products share the same production line, being this the production line that presented a noticeable decrease in production efficiency.

In Phase 2, the study and development of the layout was carried out using three different methods. The first was an Empirical Model (EM) based on observation and the other two were methodologies that include engineering and optimization techniques - Systematic Layout Planning (SLP) and Lean Facility Layout System (LFLS). Finally, in Phase 3, to select the layout to be implemented, the three layouts' results were compared using the following KPIs: the production lead time, the workers' movement time, and the workers' movement distance.

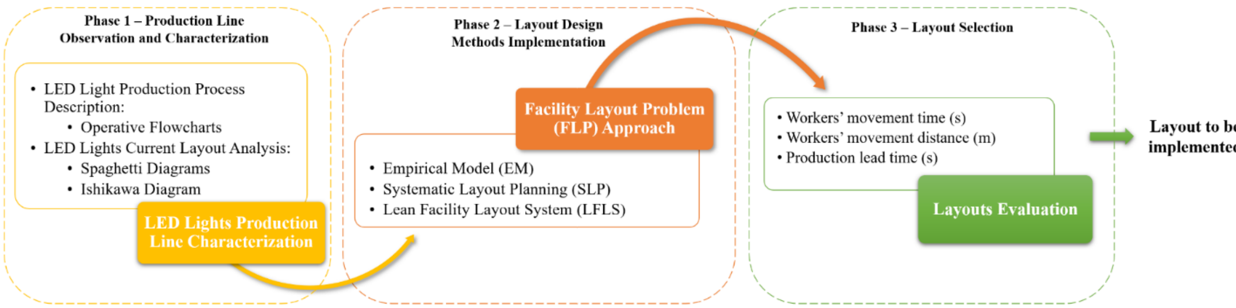

Figure 3. LED Lights case study methodology.

Table 1 shows the improvements achieved by the three methods when compared to the real situation. These improvements are given in terms of percentage, for all KPIs considered. The highlighted values refer to the best results among the three approaches.

Table 1. Improvements obtained for each family through the implementation of each methodology.

LED Light Family	**IE**			**I**			**L**		
KPI\Method	**Emp. (%)**	**SLP (%)**	**LFLS (%)**	**Emp. (%)**	**SLP (%)**	**LFLS (%)**	**Emp. (%)**	**SLP (%)**	**LFLS (%)**
P. L. T.	-0,02	-0,03	**-0,04**	-0,03	**-0,04**	**-0,04**	-0,06	-0,05	**-0,07**
Workers' moving time	-20,2	-25,8	**-27,0**	-21,3	-25,1	**-25,3**	-22,0	-30,0	**-31,0**
Workers' mov. distance	-19,6	-25,1	**-26,3**	-20,2	-23,9	**-24,0**	-21,0	-29,0	**-30,0**

Comparing with the reality, regarding the production lead time of each product family, the improvement was not significant. This was due to the processing times being much higher that the transportation times. So, the processing times have a more significant contribution to the products production lead time. Regarding the workers' movement distance and time, when directly compared, it was noticeable that there was a substantial improvement, which can reach up to 30%. Besides these improvements, the proposed layout is to be fully implemented on the same floor, unlike the current production line. Thus, since the movement of unfinished products between floors was considered one of the main causes related to non-conformities, in itself, the fact of moving the entire production line to a single floor already allows for an improvement in product quality. Overall, and making a comparison between the three approaches, the Lean Facility Layout System achieves a greater layout (Figure 4) improvement over the other approaches, and this was the layout suggested to the company' Executive Direction to be put into practice.

The work developed and presented in this chapter was submitted to the 4th European International Conference on Industrial Engineering and Operations Management (IEOM2021 – Rome) (Brás and Moura, 2021b), and it was already been presented and published.

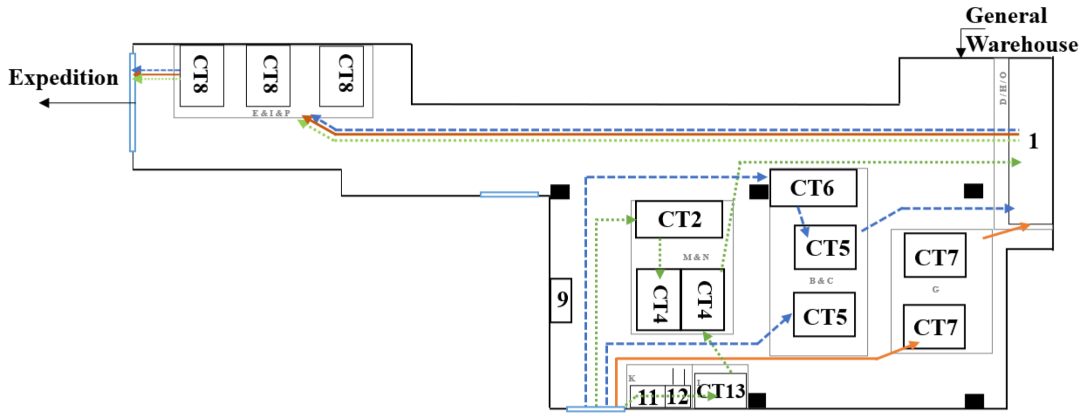

Figure 4. Sections and workflows in the layout resulting from the Lean method. The dashed blue line represents the IE, the filled orange the Ic and the dotted green the L family workflows.

3.2 Chapter 3 – Case Study II: MWM Case Study

The development process of the MWM production line layout was presented in Chapter 3. In Phase 1 (Figure 5), to characterize the MWM production process, being this a new product, there was the need to collect some relevant information, besides the one provided in the MWM product design. With this information, the MWM operative flowchart and precedence diagram were elaborated. Besides this, some of the resources needed to carry out each task and related processing times were also measured during the final product tests. Considering the costumers' demand, the company aims to produce 920 units/week, which implies a cycle time of 158,2 seconds/unit. This means that each workstation will have a cycle time of 158,2 seconds in which all the tasks assigned to it must be carried out. In Phase 2 and 3, the layout solutions were achieved using two different methodologies.

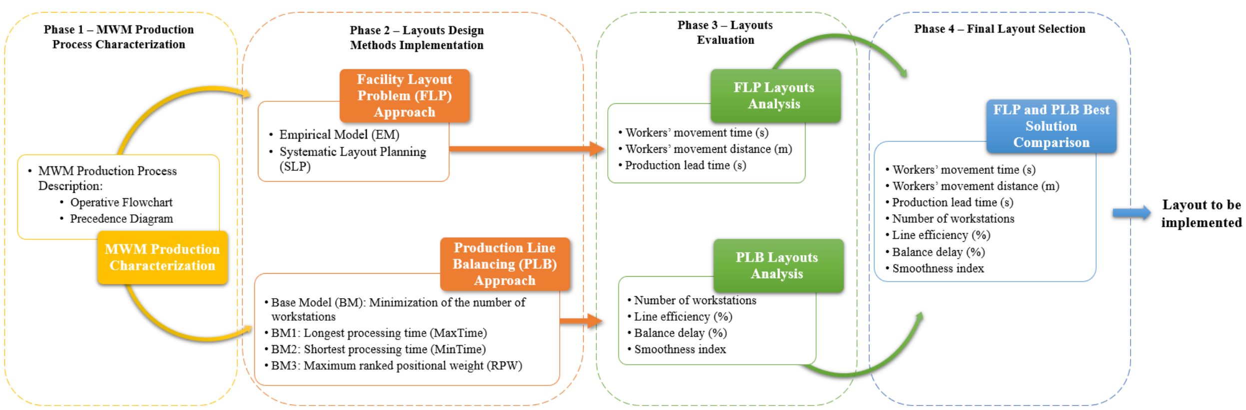

Figure 5. MWM case study methodology.

The first methodology was based in the Facility Layout Problem (FLP), where two layout solutions were obtained through the application of two different approaches: Empirical Model (EM) and Systematic Layout Planning (SLP). The first two layouts were compared considering some KPIs recommended by the company. Those KPIs are related to the production time being them the workers' movement time, the workers' movement distance, and the production lead time. The second methodology was based on the resolution of an Assembly Line Balancing Problem (ALBP), using a linear programming model, that from now on will be referred as Production Line Balancing (PLB) approach. The facility layout of industrial manufacturing plants is concerned with finding the most efficient arrangement of *n* indivisible facilities in *n* locations. Minimizing the material handling cost by reducing material (or workers) movement, is the most considered objective since it decreases the work-in-progress levels and throughput time, reduces product damage, simplifies the material control, and reduces the overall congestion. Besides the minimization of the material handling cost, there are other objectives that should also be considered when planning a new production line. The objective of the PLB approach to design the third layout, like in any ALBP, is the minimization of the number of workstations. It was also tested several versions of the PLB approach, using different criteria: longer processing time (BM1), shorter processing time (BM2) and higher rated positional weight (RPW) (BM3). Four different balancing solutions were obtained. To evaluate the four versions of the PLB approach performance, it was used as KPIs the number of workstations, the line efficiency, the balance delay, and the smoothness index. Once the best solution has been chosen, the layout was designed considering the balancing solution, the upper floor available space, the workstation occupation areas, and the production workflow. In this layout design, special attention was paid to the distances between the resources used in consecutive tasks, and these were reduced as much as possible. Finally, in the Phase 4, to choose the final layout, the best ones of each methodology were compared using all the KPIs established for the two problems.

Regarding the FLP approach, through a quick analysis to the KPIs results, the most suitable layout was achieved by the SLP method. Compared with the empirical approach, this solution has an improvement of 30% when considering the workers' moving distances/time, and 17% when considering the production lead time.

In the PLB approach, all models (versions: BM1, BM2 and BM3) reached the optimal solution of 3 workstations, which means that they have the same value for line efficiency and balance delay. Since a smaller balance delay means that the production line has a shorter idle time, it could be stated that in all the approaches, the tasks are equally divided by all the workstations and, that for a real case study results in a line efficiency relatively good. A smaller smoothness index means that the production line is closer to a perfect balance. Therefore, through the results analysis, it was possible to conclude that the best solution is achieved when considering only the simple objective function, i.e., considering only the minimization of the number of workstations (BM). That said, in the Phase 4, the layout resulting from the SLP method (From Table 2) and the PLB-BM were compared.

Table 2. Layout's performance comparison.

KPI \ Approach	**SLP**	**PLB - BM**
Workers' moving distance (m)	246,8	206,2
Workers' moving time (s)	327,3	279,4
Production lead time (s)	668,1	619,4
No. of workstations	4	3
Line efficiency (%)	53,8	71,8
Balance delay (%)	46,2	28,2
Smoothness Index	103,5	41,6

In terms of PLB KPIs, the PLB-BM approach has better results than the SPL approach: 25,1% in relation to the line efficiency, 39% in relation to the balance delay and 59,8% in relation to the smoothness index. The reduction of the number of workstations shows that the production line with 3 workstations is more efficient and the balance delay becomes smaller. This could lead to a decreasing in the possibility of bottlenecks occurrences. The reduction of smoothness index shows that the quality of the line balancing increased. The layout achieved with the PLB-BM (Figure 6) is also better in terms of workers moving distances and time. Besides that, it also outperforms the SLP approach when comparing the lead time, having a reduction of, approximately, 7,3%. Having this in mind, the layout from the PLB-BM approach was the one suggested to the company' Executive Direction.

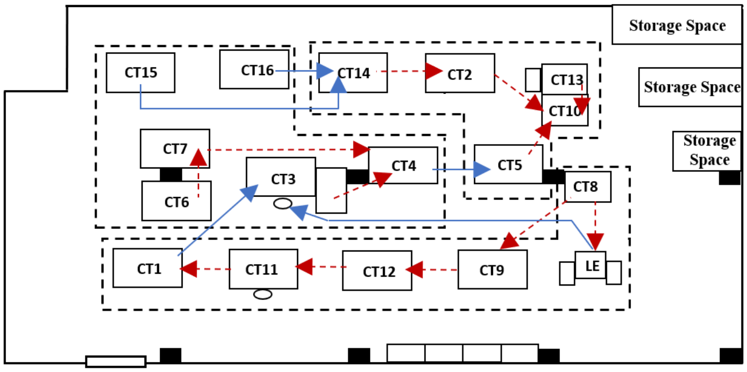

Figure 6. Layout and workflows resulting from the line balancing approach. The filled blue line represents the workflows between workstations and the dashed red line represents the workflow within the same workstations.

The work developed and presented in this chapter was submitted to the 6th North American International Conference on Industrial Engineering and Operations Management Conference (IEOM2021 – Monterrey) (Brás and Moura, 2021a), and it was accepted to publication.

3.3 Chapter 4 – Case Study III: ICP Case Study

With the insertion of the MWM production line on the upper floor, there was a reorganization of the remaining space available on the same floor. With this reorganization, the opportunity to separate the processes of automatic insertion of electronic components from the processes of manual insertion of electronic components and ICP encapsulation arose. Therefore, at the company's request, the space available on the upper floor was studied, to insert the final processes of manual insertion of components and encapsulation of the ICP production line.

The layout design methodology was divided into four phases (Figure 7). In Phase 1, to characterize the ICP production process, the production line was analyzed, and a study was made on the resources needed to carry out each task and the tasks processing times were measured. Through this information, the ICP operative flowchart and the precedence diagram were elaborated. In Phase 2, it was solved an Assembly Line Balancing Problem, using a linear programming model. Based on this mathematical model, 5 variants were used and tested, using different optimization criteria to assign tasks to the workstations: shortest Processing Time (MinTime); longest Processing Time (MaxTime); Greatest RPW (RPW); Greatest G (MaxG) (maximum processing time divided by the upper bound); Greatest S (MaxS) (Greatest number of successors). The line balancing results were compared using the standard KPIs: number of workstations, line efficiency, balance delay and smoothness index. In Phase 3, using the best solution found in the previous phase, the Facility Layout Problem (FLP) was solved using the Systematic Layout Planning (SLP) approach. In the last phase – Phase 4 – occurs the layout evaluation using the standard KPIs related to production time - workers' movement time, workers' movement distance, and production lead time - and the standard balancing KPIs, already calculated.

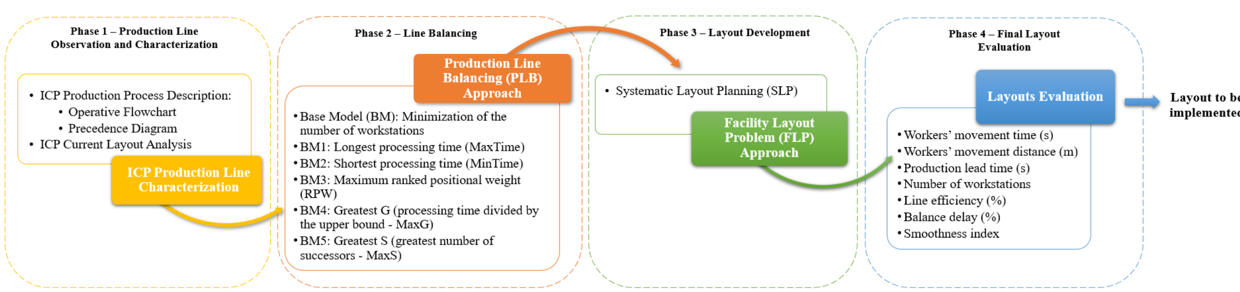

Figure 7. ICP case study methodology.

In Phase 2, six models were developed, one of them called the basic model (BM) whose objective is to minimize the number of workstations and 5 other variants (from BM1 to BM5). Each variant has a combined objective function, where it is not only intended to minimize the number of workstations, but also taking into consideration each of the following criteria: longest processing time (BM1), shortest processing time (BM2), maximum ranked positional weight (BM3), greatest G (BM4) and greatest S (BM5). All the six models achieved the optimal solution of 8 workstations, being this translated in the same efficiency and balance delay. According to the cycle time and the sum of the tasks processing time, the theoretical minimum number of workstations is 7 (workstations lower bound). However, this value does not consider all the constraints of the problem (duplicated workstations and task-related or zone constraints), and in this case the constraints are quite a few. So, it could be stated that in all the approaches, the tasks are equally divided by all the workstations and can also be considered that for this case study, the line efficiency is relatively good. The minimum value of the smoothness index is 0 which indicates a perfect balance, i.e., a smaller smoothness index indicates a production line closer to a perfect balance. Therefore, through the balancing results analysis, it was possible to conclude that the best solution is achieved when considering the mono-objective model, i.e., considering only the minimization of the number of workstations (BM) or when considering the bi-objective model, more specifically the minimization of the number of workstations while prioritizing tasks with bigger RPW (BM3).

Considering the BM/BM3 results (Table 3), the layout present in Figure 8 was develop through the application of the SLP method. The orange line represents the workflow into the same workstation, and the green line represents the workflow between workstations. The KPIs related to production time are also considered satisfactory, since the percentage of workers' movement time is insignificant compared to the production lead time. Therefore, the layout obtained can be considered efficient both in terms of resource/space optimization and production line optimization.

The work developed and presented in this chapter was submitted, and accepted, in a scientific paper to the International Conference on Operations Research and Enterprise Systems 2022 (ICORES 2022).

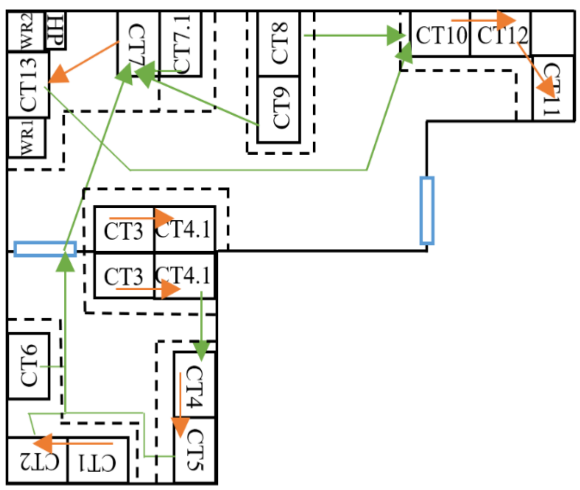

Figure 8. ICP production line final layout.

Table 3. KPIs summary from the ICP production line layout.

KPIs	SLP
No. of workstations	8
Line efficiency (%)	79
Balance delay (%)	21
Smoothness index	274,6
Workers' moving distance (m)	41,1
Workers' moving time (s)	88,3
Production lead time (s)	5079,2

4. Discussion and final conclusions

With the evolution of market demand and technology, the company group focus has been adjusted in order to meet the needs of its target customers. Recently, the group launched onto the market of efficient water management, which resulted in the development of a new product, the MWM. Having this in mind, the efficiency of a production line can be influenced by several parameters, being the layout of the shop floor one of the most important. The company took advantage of the need to add the MWM new production line to the shop floor, to study, not only its layout but also the layouts of other existing production lines whose efficiency has been decreasing. That said, this project was divided into three case studies, each one related to a product family production line: LED Lights Case Study, MWM Case Study and ICP Case Study.

Usually, in industry, line balancing and layout problems are often solved and addressed by the production managers, that rearrange the workstations and allocate tasks to operators following a methodology based on practical knowledge. The development of a new production line for a new product is a situation where it makes perfect sense to use the actual existing theoretical methodologies to implement an efficient production line. This last one must be, not only balanced but also, the layout should be optimized to ensure its production efficiency. That said, in the three case studies, design engineering techniques were applied to the layouts development, such as Systematic Layout Planning and Lean Facility Layout System. In addition, linear programming was used to solve the Assembly Line Balancing Problems by applying the most well-known heuristics with the aim to obtain optimized layouts, both in terms of space/resource optimization and in productivity improvement.

The first case study depicts the design of the layout of the LED Lights production line. With the layout redesign, considering the movement of workers, there was a significant improvement, reaching 30%. Although there is no significant reduction in lead time, there is a considerable improvement related to product quality, since the movement of non-finished products on the shop floor was considered one of the major causes related to non-conformities.

The layout of the new production line is developed in the second case study. Two final layout versions were achieved through two different methodologies (PLB-BM and SLP). The layout from PLB-BM methodology obtained better results both in productivity improvement and in space/resource optimization. In terms of PLB KPIs, the PLB-BM approach has better results than the SPL approach: an improvement of 25,1% in relation to the line efficiency, 39% in relation to the balance delay, and 59,8% in relation to the smoothness index were obtained. The number of workstations reduction shows that the production line with 3 workstations is more efficient, and the balance delay becomes smaller, which can be reflected in a decreasing in the possibility of bottlenecks occurrences. The layout achieved with the PLB-BM is also better in terms of workers moving distances and time, and it outperforms the SLP approach when comparing the production lead time, having a reduction of, approximately, 7,3%.

Finally, the third case study portrays the design of the ICP production line layout. In terms of the production line balancing KPIs, the layout achieved the optimal solution of 8 workstations, with an efficiency of 79% and balance delay of a 21%. Since the workstations lower bound is 7, and considering all the existing constraints, it could be stated that the production line has a relatively good efficiency. Regarding the production time KPIs, it was shown that the workers' movement time represents a small percentage of the production lead time (1,7%), which can be considered an insignificant percentage.

Consequently, it can be concluded that the layouts suggested to the company' Executive Direction are efficient both in terms of resource/space optimization and productivity improvement, due to the production line optimization.

5. Future Work

Through the implementation of the proposal layouts the space and the production lines efficiency are optimized. However, if the company culture does not emphasize the cleaning and organization, quickly the little available space ceases to exist, and consequences will be felt, again, in the productive efficiency. That said, it is necessary to review the layouts whenever possible, using different layout design methodologies to eliminate another type of waste inserted in the production line.

Since one of the case studies portrays an implementation of a new production line, it is possible that in the beginning of production, the manufacturing processes may suffer some changes, and therefore, there may be variations in the tasks processing time or addition of tasks to the productive process. In that case, to maintain or improve its efficiency, a study must be carried out again considering the existing changes.

After the implementation of the proposed layouts, a more detailed study should be carried out on the remaining problems identified in the Ishikawa diagram elaborated at the beginning of this dissertation. It is recommended an analysis of the existing non-conformities in various products, in order to identify their causes, for later elimination. This can be accomplished by applying various tools such as Pareto charts and Lean-6 Sigma techniques.

Regarding the study of line balancing, considering the type of mathematical model and its complexity, it would be interesting to study its behavior.

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