Improvement in the flow of materials in the painting section of an industrial company

Luís Paulo M. Ferreirinha
ISEP - School of Engineering, Polytechnic of Porto
Department of Mechanical Engineering
4200-072 PORTO
PORTUGAL
l.ferreirinha96@gmail.com

Teresa Pereira
ISEP - School of Engineering, Polytechnic of Porto
Department of Mechanical Engineering, 4200-072 PORTO
PORTUGAL
CIDEM – Centro de Investigação e Desenvolvimento em Engenharia Mecânica, Porto, Portugal
Algoritmi Center, Minho University, Braga, Portugal
mtp@isep.ipp.pt

Luís Pinto Ferreira
ISEP - School of Engineering, Polytechnic of Porto
Department of Mechanical Engineering
4200-072 PORTO
PORTUGAL
lpf@isep.ipp.pt

Abstract
This research was undertaken in the Painting section at the company Preh Portugal, which is currently increasing its capacity. The plastic components are painted and engraved, and then supplied to internal customers so that they can then be assembled on the final line. The main purpose of the study resides in analyzing the value flow. The methodology used consisted of the case study itself, in association with the use of lean tools. The objective was to reduce the changeovers generated by activities which, in the customer's perspective, are of no added value. To this end, one studied the possibility of altering the configuration of the FIFO supermarket, as well as optimizing laser production in the section. The changes proposed resulted in gains of 74,02% and 74,4% regarding the distance of the routes covered by material and operators, respectively. Additional studies were carried out in the Painting section, more specifically in the new section of Painting. Here, one analyzed the layout projected by the company and subsequently carried out some changes which will enable gains of 48 and 43% in the distance of the routes covered by material and operators, respectively.

Keywords
Layout; Flow of material; Lean production; Optimization; Case study.

1.Introduction
This project was carried out in the scope of the Degree in Engineering and Industrial Management of the Higher Engineering Institute of Porto (ISEP), in partnership with the company Preh Portugal, Lda. The same was developed during the second semester of the academic year 2016 / 2017 and held at the company's premises, Trofa.

The company belongs to the group Preh GmbH based in Germany and manufactures mainly electronic components for the automotive industry, with its main market being the European Union.

This company has been implementing the Lean philosophy, which contributes significantly to the creation of value and the systematic elimination of waste, benefiting all those who directly or indirectly use their innovative products and services of excellence.

Faced with the growing evolution of markets and the internationalization of the economy, organizations are increasingly in need of flexibility and a strong capacity to adapt to change, so we must be aware of movements and trends. Today, it is fundamental to keep up with evolution, to innovate and improve continuously.

In a successful company, much of the driving force is found in our employees. Therefore, they must be integrated in the organization by giving them the opportunity to suggest improvements at every stage of the process, as well as to acknowledge their important contribution. In addition to interactive, improvement processes are iterative. In a first approach, it is necessary to understand, observe and investigate. Next, it is necessary to idealize solutions in agreement with the collaborators, to

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test them in an industrial environment and finally to implement them. This was, therefore, the path outlined in the elaboration of this work. This project arises from the need to improve the flow of materials in the painting section, at a time when the company is expanding. The group intends to bet on this sector of activity, where it expects a great growth, being of great importance to organize it in order to reach a service of excellence and, thus, to improve the satisfaction of its clients.

2. Methodology

In the first place, a reception and integration plan were carried out at Preh Portugal, Lda., Which allowed us to know the company's structure, its current needs, as well as an overview of the products and production processes. Then, a reception plan was carried out in the Painting section which, in more detail, allowed to observe the different processes and the tasks performed by the section operators. For the success of any project it is necessary to clearly define the objectives and their fulfillment are of high importance. In this logic, a work plan was elaborated with the tasks to be developed following a methodology based on the PDCA cycle (Plan, Do, Check, Act).

Thanks to regular monitoring of the factory floor, direct observation and dialogue with all employees, it was possible to map the initial situation, outline areas of work and make proposals to improve material flows.

The approach in the Painting section started with the mapping and the elaboration of a spaghetti diagram in order to verify the routes of the operators and the materials in question. After the analysis of the various flows and the simulation of several scenarios, it was proposed to change the layout of both the current area and the future area and the development of an optimum production plan for the laser operation, taking into account the requirements of the company and operators.

This document is divided into five chapters. In the first one, a brief presentation of the company as well as the contextualization of the project is made. In chapter 2, the methodology adopted, and the structure are described. In Chapter 3, subjects relevant to the project were discussed in an analysis of the Literature Review, which support the decisions taken. Chapter 4, characterizes the current state of the paint section, exposes the problems encountered, the proposed solutions and the gains obtained. Finally, in the fifth chapter, 5, the final considerations are drawn on the work as well as the perspectives of future work.

3. Literature Review

The process of globalization of the current economy has given rise to new organizational techniques, which seek a scenario of constant changes, direct companies to a high degree of competitiveness and ensure their survival in the current market i.e., the concept of Lean Thinking (Amasaka, 2007).

Based in Japan, in particular Toyota's Toyota Production System (TPS) at Toyota, the lean philosophy aims to adapt companies to the constant fluctuations of markets, making them more efficient, more agile and more competitive (Pinto, 2009). Womack and Jones (2003) also add that the lean system allows to produce more with less resources, be they material, physical, temporal or human, approaching more and more the organization to customers.

The main objective of lean production is to increase production efficiency through the constant elimination of waste (Ohno, 1997). In today's industry, it is increasingly important to meet customer requirements, so organizations must offer differentiated products that meet the requirements of each. In order to meet this new business context, there is a need to use lean tools, but more importantly, to apply its fundamental principles.
According to Womack and Jones (2003), the foundation of lean philosophy consists of specification of value, identification of value flow, implementation of a continuous flow, adoption of a pull system and, ultimately, continuous search for perfection.

3.1. Spaghetti Diagram

The spaghetti diagram is a lean tool that corresponds to an aerial view of the factory layout with the representation of the path that the operator, or material, performs in the execution of his tasks by means of lines. In an initial phase, by observation of the work, the displacements of the operator are defined, being able to calculate the time and the distances traveled. It is a good tool for the determination of waste, since it makes it possible to observe changes in the time spent in dislocations, refluxes, or distances traveled, for example (Townsend, 2012).

3.2. Value Stream Mapping

The value stream map (VSM) is a visual representation tool, very useful for the identification of actions that add value to the flow, and especially for the identification of sources of waste. Some reasons that justify the use of this tool include: providing a common language to communicate about productive processes, helping to visualize the sources of waste, providing a basis for implementing a lean plan, revealing the link between information and material flows and connect many of the lean concepts and tools. In this way, the value stream map is a very useful qualitative tool to describe in detail how the factory should function to create a continuous flow (Rother & Shook, 1999).

3.3. Value Stream Design

Value Stream Design (VSD) is a drawing that represents the view of the future state of the value stream after a value stream map of the current state has been taken. This map represents the improvement opportunities identified on the current state map so that the company can begin to act in the supply chain with a view to achieving a higher level of performance in the future (Coimbra, 2013)

4. Characterization of the Initial Situation in the Painting Section

The painting section is responsible for the painting of the plastic components from the injection section, as well as the laser engraving of the same if required by the material. In this section, the materials can be divided into four distinct process families, which will be described below. There are materials that only need an application of paint, finishing, soon, its transformation process, Paint-Inspection (PI) family. Others, need two applications of paint, before proceeding for inspection (PPI). Another family is one in which the materials undergo the application of the primer and are laser-etched before awaiting inspection (PLI). Finally, the last family represents materials with primary application, laser engraved and with high gloss application., thus ending their transformation process (PLPI). For a better analysis of the flows existing in the section, the references were grouped by the process families already described so as not to analyze them individually.

4.1. Storage of Painted Material That Awaits Laser in the Current Section

Throughout the development of this project it was observed that a stock surplus of material that needed to be engraved and of high brightness was created daily. This observation allowed to conclude that the main problems resided in PLPI families since the laser could not respond in a quickly and effectively way, to the quantities of existing primary material, thus it was found the bottleneck section.

The material, after the primary, awaits engraving in the supermarket of trolleys, in turn each cart supports a certain number of pieces depending on the reference in question. The components requiring high brightness while there was space were placed in an area near the entrance of the painting machine (Venjakob), represented in Figure 1 by A. However, the space intended for this material was shared with materials awaiting inspection and quality aprovement. That said, the area available to allocate materials from the PLPI family was dependent on the amount of material that existed for inspection or quality approval. When the capacity of this space was reached, the engraved material was reallocated in the FIFO supermarket of trolleys. Such storage, besides creating a dispersion in the location of the materials, implied a displacement of both the operators and the materials, too high. The flows of both situations described are shown in figure 1, and the average distances traveled by operators and materials are shown in table 1.

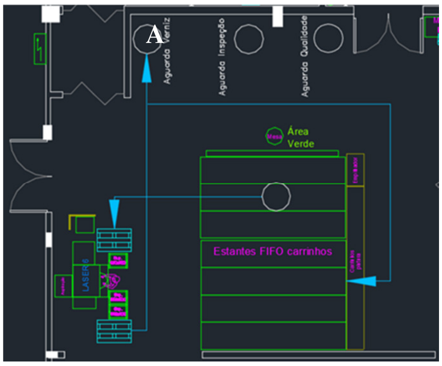

Figure 1. Material flow waiting for high gloss.

Table 1. Distances covered in the current layout, per cart.

	Venjakob entrance (A)	Supermarket
Material	13,29 m	27,79 m
Laser operator	*65,63 m	*112,2 m

As it can be concluded from table 1, the maximum distance that the operator traverses happen when the same has to store the engraved material that is waiting for high gloss in the supermarket. Laser operation itself takes a long time processing materials and with operators spending their time traveling these distances throughout the day, prevents the daily capacity of the laser to be used at 100%.

In order to minimize the distances traveled throughout the day, a layout change was proposed regarding supermarket, which was to make it flexible in the direction of the entrance of the materials. That is, it was intended that instead of the supermarket having only one entrance side of trolleys, as shown in figure 2 on the left, it will have two entrances, as shown in figure 2 on the right. To adopt such a scenario, a change of the slope of the supermarket's upper rugs to the opposite direction was necessary.

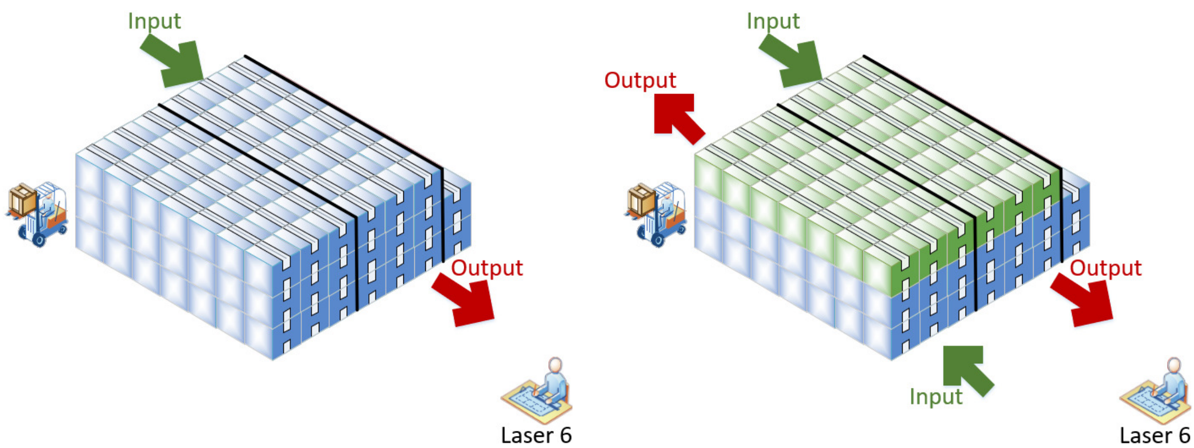

Figure 2. Layout of the current supermarket on the left / layout of the proposed supermarket, on the right.

The flow foreseen for this change can be visualized in figure 3, and the distance traveled of both the materials and the operators in this new layout is in table 2.

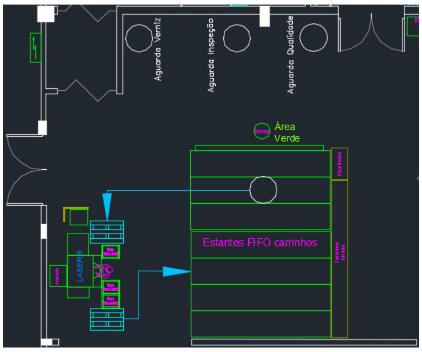

Figure 3. Flow foreseen for the proposed solution.

Table 2. Distances covered in the proposed layout

	Supermarket
Material	7,22 m
Laser operator	28,66 m

In order to compare the current values with the proposed values, we added the distances of both in figure 4.

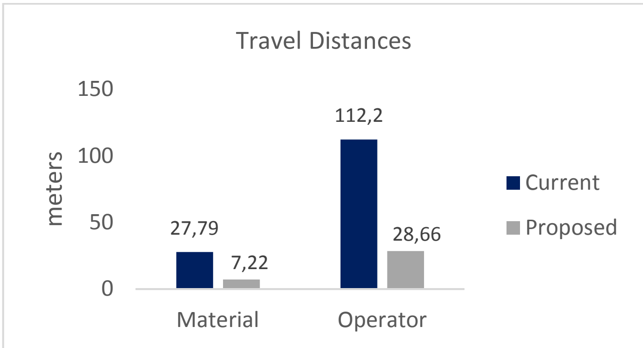

Figure 4. Distances travelled in the current layout Vs layout proposed.

Based on the worst-case scenario, it can be seen from Figure 4 that, with the adoption of this layout, it is possible to reduce the distances of material transport by 74.02% and by 74.46% the operations that do not add value, but they are necessary for the operators. Since, in this case, the distance traveled is proportional to the cost, since these are manual transports, the cost reduces the corresponding percentage.

4.2. Supermarket Capacity

It is known that the supermarket only has twenty useful queues, of seven carriages each, for the storage of the material and, with the proposed solution, it is logical that the space to store materials that await laser diminishes, because now there are positions to store recorded materials. It is also known that the supermarket operates according to the FIFO philosophy, which implies storing a single reference per row. Such a scenario complicates the proposed solution somewhat, since the lots from the primary are too large to store all the references in the supermarket.

Therefore, it was attempted to find a lot size for each reference that did not compromise the capacity of the supermarket and that justified the accomplishment of a setup of the painting machine. However, setting a demand-adjusted batch size was not sufficient to ensure that the materials could be stored in the supermarket because the laser continued as the bottleneck. However, since laser schedule was not defined, it was decided to optimize laser production in order to minimize WIP. For this, a linear programming problem was formulated, adjusted to the characteristics of the problem, and a simulator was developed to predict the behavior of the supermarket over the days. Following is the presentation of the model used, in an example, as well as the results from the same.

Model for the 1st Day-Project BMW 35UP

As stated, a batch size adjusted to either the supermarket capacity and for the demand was defined, and the results are shown in Table 3.

Table 3. Amount of material for the first painting on day 1

Primer 1st day							
Ref.	**Pieces**	**Pieces/ tray**	**Nr. trays**	**Pieces/car**	**Nr. Cars**	**Hours**	**Biweekly needs**
13061-371/0003	4 640	160	29	21 120	1	0,04	13 360
13061-367/0004	5 200	10	520	1 320	4	0,72	19 800
13061-372/0004	8 360	88	95	11 616	1	0,13	41 640
13061-366/0003	3 344	11	304	1 452	3	0,42	16 656
13061-374/0007	2 000	8	250	1 056	2	0,35	4 000
13061-499/0004	3 152	11	287	1 452	3	0,40	2 848
				Total	14	2,06	

That is, on the first day will be painted 5 200 pieces of the reference 13061-367, which originates 4 carts, which will occupy 4 positions in a row of 7, and so on. That said, the formulation of the problem for the first day is as follows:

Decision variables

$x_i = $ "*Number of trays to be engraved of material i on the first day* ", where i ϵ [1-16] and is described in table x.

Table 4. Correspondence of the decision variable

i	Reference	*i*	Reference	*i*	Reference	*i*	Reference
1	13061-379/0006	*5*	13061-394/0006	*9*	13061-386/0010	*13*	13061-497/0005
2	13061-377/0008	*6*	13061-475/0004	*10*	13061-387/0010	*14*	13061-498/0005
3	13061-378/0007	*7*	13061-476/0004	*11*	13061-388/0010	*15*	13061-517/0005
4	13061-392/0006	*8*	13061-445/0006	*12*	13061-519/0006	*16*	13061-518/0006

Objective function

$$Max\ z = \sum x_i$$

Subject to

		Availabilities	**Needs (biweekly)**	
x_1	$\leq$	29	94	(1)
x_2	$\leq$	520	2000	(2)
x_3	$\leq$	95	511	(3)
x_4	$\leq$	304	9	(4)
x_5	$\leq$	304	9	(5)
x_6	$\leq$	304	818	(6)
x_7	$\leq$	304	682	(7)
x_8	$\leq$	304	68	(8)
x_9	$\leq$	250	188	(9)
x_{10}	$\leq$	250	250	(10)
x_{11}	$\leq$	250	100	(11)
x_{12}	$\leq$	287	36	(12)
x_{13}	$\leq$	287	55	(13)
x_{14}	$\leq$	287	27	(14)
x_{15}	$\leq$	287	68	(15)
x_{16}	$\leq$	287	359	(16)
$x_4 + x_5 + x_6 + x_7 + x_8$	$\leq$	304	-	(17)
$x_9 + x_{10} + x_{11}$	$\leq$	250	-	(18)
$x_{12} + x_{13} + x_{14} + x_{15} + x_{16}$	$\leq$	287	-	(19)

$\sum x_i.* y_i$	$\leq$ 21,94	-	(20)
$x_i\ inteiro$			(21)
$x_i \geq 0, i \in [1;16]$			(22)
$y_i \geq 0, i \in [1;16]$			(23)

Where y_i represents the time coefficient with respect to x_i. The same can be found in Table 5.

Table 5. Variable engraving times per tray

Xi	Hours/ tray(Yi)	*Xi*	Hours/ tray (Yi)	*Xi*	Hours/ tray (Yi)	*Xi*	Hours/ tray (Yi)
1	0,05333	*5*	0,02750	*9*	0,01467	*13*	0,02750
2	0,01000	*6*	0,03300	*10*	0,01867	*14*	0,02383
3	0,04400	*7*	0,02933	*11*	0,02400	*15*	0,02383
4	0,02017	*8*	0,03667	*12*	0,02750	*16*	0,02750

The restrictions from 1 to 16 prevent the impossibility of recording material beyond its availability. Regarding limitation of needs, they exist to avoid the generation of unnecessary stocks, (1 to 16). That is, there are painted references which when engraved give rise to more than a reference, as for example in references x4, x5, x6, x7 and x8 which came from the same batch painted. With this restriction, for example, if no more x4, and / or x4 is required but there are availabilities, this restriction will force the program to produce other necessary references. Knowing that all these references belong to the same lot of primary, it is necessary to ensure that the sum of the production of all of them does not exceed the stocks of that same lot, as it happens in the restrictions of 17 to 19. Since we are only exemplifying the model for the first day, it is necessary to realize the availability of the laser for that day. As a rule, the laser has a daily availability of 24h, however, while developing the simulator for every day until the demand was reached, it was easier to remove some laser time due to the application of the first painting. That would not be a problem because if the model worked in less of 24h, would work for the whole day, (20). Subsequently we follow the restrictions of integer and non-negativity, (21 to 23). Applying the same model until the demand is reached, it is possible to obtain the supermarket results shown in figure 5.

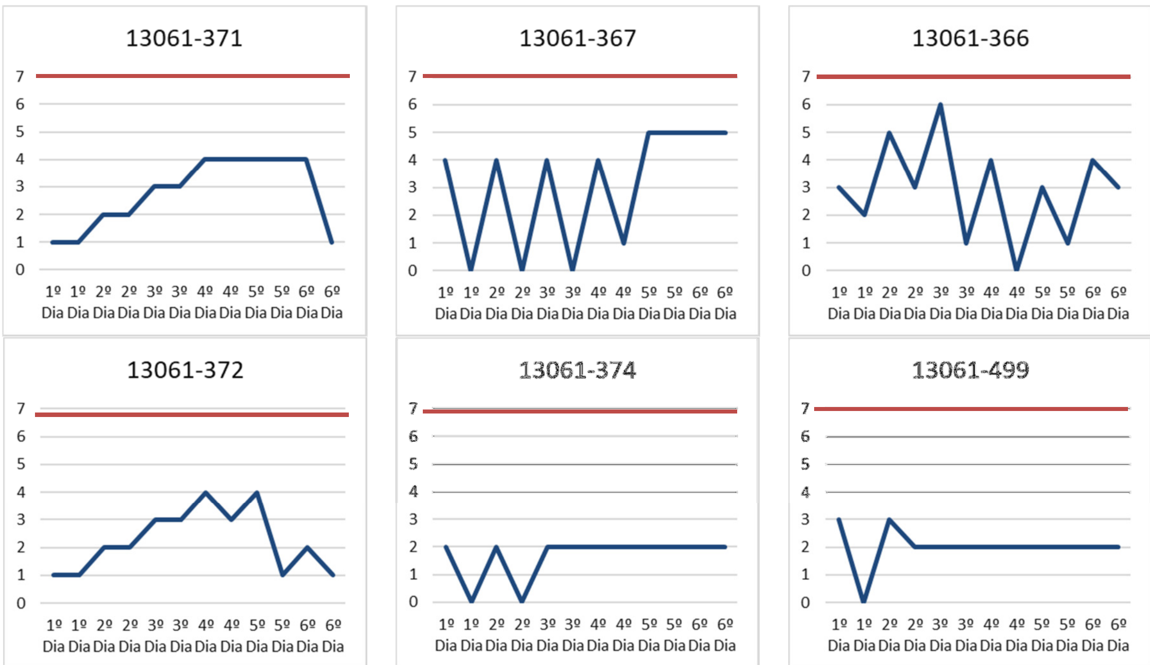

Figure 5. Results obtained from the simulator for the primary lots in the supermarket

As can be seen from figure 5, with this model, the demand for this project is reached in 6 days, each primary reference only occupies a queue in the supermarket without ever exceeding its capacity, 7 positions, it is possible to optimize the production of the laser and of the supermarket, and it is defined a batch size adjusted to demand. The same model was applied in another project and the results are identical.

4.3. Storage of Painted Material Awaiting Laser in the Future Section

Like the current area, the materials that await laser are stored in the supermarket, and for the new painting area, the company intends to adopt the solution proposed in section 4.1. Therefore, the layout was initially designed and the respective flows for the new section are shown in figure 6 on the left. After that, it was noticed that the distances traveled by both the materials and the operators were too high, table 6, left, so that the layout was changed, figure 6 on the right, and the results were obtained from table 6 on the right.

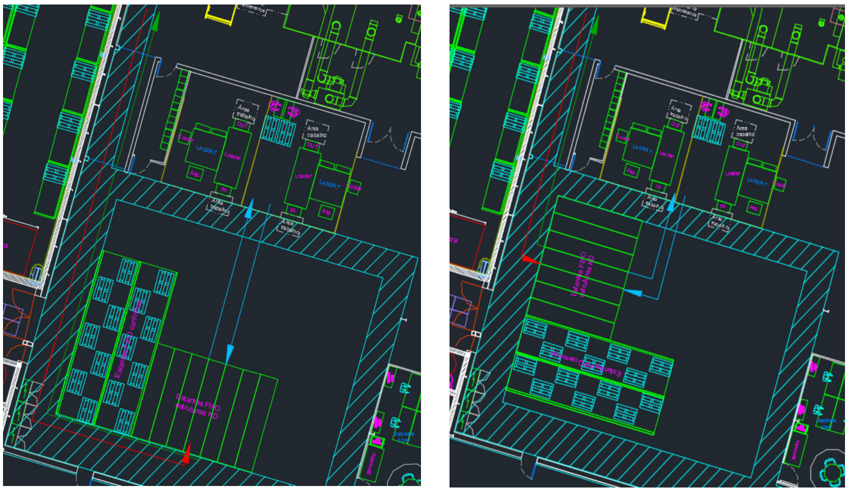

Figure 6. Current layout on the left / layout proposed on the right

This change results in a 48% gain in the routes of the materials and a 43% gain in the routes of the operators compared to the layout initially thought, as can be seen from figure 7. Such gains will also be reflected in the costs associated with these seedlings, as everything is done manually.

Table 6. Distances travelled in the current layout Vs layout proposed

	Initial Layout	Proposed Layout
Material	78,38 m	40,85 m
Laser operator	270,4 m	152,99 m

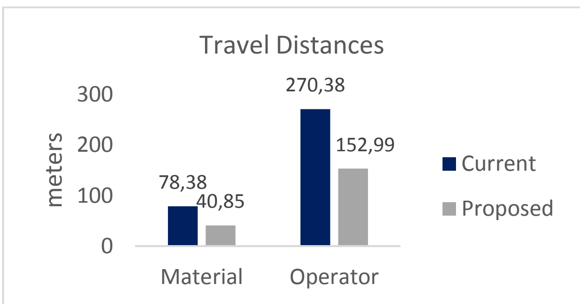

Figure 7. Current Layout vs proposed layout

5. Conclusions

The current growth of the activity demanded a revision of the means of internal logistics flow existing in the factory, particularly around Painting. Throughout the present project, opportunities for improvement have been detected by regular stay on the shop floor, follow-up of the works and constant dialogue with all employees who, from the outset, have been available to clarify any doubts and cooperate in the implementation or development of solutions that were intended to strengthen the section and, ultimately, the company.

As for the current painting section, we started with the analysis of the layouts and the mapping of the material flows existing in it. Subsequently, opportunities for improvement were found and solutions were proposed. Regarding the storage of materials requiring laser, it was proposed to flexibilize the supermarket in order to minimize the routes of the materials and, consequently, the operators, this change gave gains of 74% in both flows. As for the section bottleneck (laser), the batch size of the primer was adjusted, and a linear programming model was defined that maximized resource utilization. This model ensured the fulfillment of the demand, the efficient use of the supermarket and the optimization of the laser production.

In the future area, the layout initially proposed was analyzed and, once the solutions proposed in the current section would be implemented, it was proposed to change it. Such a layout change resulted in gains of 48% and 43% in the routes of the materials and operators, respectively.

Having made significant improvements in areas such as organization, simplification, transport and movement, without sacrificing relevant financial or human resources, we must seek to implement them, as well as to analyze other improvements in efficiency and innovation, without compromising the well-being of human resources.

The behavior of the supermarket should be further analyzed in view of the proposed batch size as well as the existing demand for the surrounding projects, since if the demand is too high the optimum production plan defined may not be sufficient to avoid large volumes of WIP and physical dispersion of the engraved material.

References

Amasaka, K. (2007). Applying New JIT—Toyota's global production strategy: Epoch-making innovation of the work environment. Robotics and Computer-Integrated Manufacturing, 285-293.

Coimbra, E. (2013). Kaizen in logistics and supply chains. McGraw Hill Professional.

Ohno, T. (1997). O sistema Toyota de produção além da produção. Bookman.

Pinto, J. P. (2009). Pensamento Lean: A filosofia das organizações vencedoras. Lisboa: Lidel.

Rother, M., & Shook, J. (2003). Learning to see: value stream mapping to add value and eliminate muda. Lean Enterprise Institute.

Townsend, B. (2012). The basics of line balancing and JIT kitting. CRC Press.

Womack, J. P., & Jones, D. T. (2003). Lean Thinking - Banish Waste and Create Wealth in Your Corporation.New York: Free Press.