Improving the efficiency of a painting process with Lean methodology

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Abstract

The constantly increasing demand of products and services of a higher quality, whilst providing these with lowering prices, has brought up an ever more challenging and competitive general market. As a means to maintain or amplify their market presence - and therefore the profits -, companies are "obliged" to strongly invest in product development and its respective processing, thus seeking a competitive edge.
The problem at stake looks to apply the Lean methodology to a company operating in the business of industrial painting, which for confidentiality purposes will be known and referred to as "Company C". The business area under analysis focuses on automotive industry parts and components, carrying new demands in processing, deadlines, quantities and quality with it.
The current process will be analysed with the support of Lean practices, and a new value stream will be developed. Based on said analysis, an array of alterations - later validated in simulation environment - will be considered.

Keywords: Lean Manufacturing; Automotive Industry; Painting; MTM; Simulation

1. Introduction

The evolution of industrial paradigms, clearly noticeable in the recent years, has brought upon the production systems a tremendous amount of effort. The globalisation, that has strongly contributed for an increase in competitivity, along with the ever more present Mass Customization (MC), have imposed that these systems be agile, flexible and capable of producing a wide range of high-quality, low-cost products (Harmanto, 2012; Stump & Badurdeen, 2012).

In a race to achieve and cement a prominent position in the market, it is vital that there be a never-ending search for performance-enhancing philosophies. Such as it is, the Lean philosophy is widely implemented by organisations as a way to obtain operational excellence, enhancement of performance, better and cost-cutting products as well as reducing lead time (Harmanto, 2012).

Company C, operating in automotive components painting for various constructors, has registered a growing number of requests, which have steadily presented themselves with higher quality standards and more demanding time requisites.

The motif for the present work comes along with this context, aiming for the implementation of the Lean methodology in a way that the Company C's processes are streamlined, providing the company with an agile, flexible, predictable and consistent system.

The paper is structured as follows: in Section 2, relevant literature on Lean Thinking and their studies is reviewed. In Section 3, the main problem characteristics are presented and the current situation is characterised. Proposed changes are presented in Section 4. In Section 5, the scenarios are validated. Finally, the conclusions are presented in section 6.

2. Literature Review

2.1. Lean principles

The Lean methodology, as presented in the book "Lean Thinking", can be synthesized in 5 principles:

- **Value** - through the elimination of *muda*, Japanese word for waste, the purpose is to only value products or services provided, this being the ultimate goal of *Lean* thinking.

As to the definition of value, the *Lean* philosophy presents a distinct vision, where the focus shifts towards the consumer, hereby acknowledged as a key-element;

Value Chain – Value Chain is a set of specific actions necessary in order to obtain a specific product, and this should only span to actions for which the consumer is willing to pay for.

Flow - After eliminating the *muda* tasks, a continuous flow is to be determined for the remaining. Such flow promotion is aimed at the suppression of Work in Progress amongst the different activities.

Pull - The time savings obtained through waste-disposal allows for a prompter order's satisfaction which can, at its best, contribute to a pull system where the start of the process is only due on order's arrival.

Perfection - according to Lean thinking, perfection requires cutting off activities without valuable output, through a continuous improvement process, therefore fostering only the incorporation of activities of strict value for the consumer.

When considering the implementation of a *Lean* process, the aforementioned topics come together in that they all state, when analysed, that waste disposal is a crucial point (Das, Venkatadri, & Pandey, 2014). In this perspective, below is a list of the 7 main sources of waste, elaborated in order to make the task of finding *muda* easier (Liker & Meier, 2015; Melton, 2005):

Overproduction - the production of items before they are necessary or in greater quantities than required. In this case there will be costs associated with this production, without the confirmation of reciprocated by the consumers;

Waiting times - periods for stopping, be it people, equipment or products awaiting processing;

Transportation - the moving of works in progress (WIPs), materials, parts or final products from one place to another;

Overprocessing or incorrect thinking - when the product goes through steps that add no value whatsoever to the final outcome;

Inventory - the stocking of raw materials, finished products or intermediaries accounts for costs and it hides problems such as production imbalance or suppliers' delivery delays;

Unnecessary movements - generally due to bad workplace organisation, these are movements that workers do during the course of duty but that do not contribute to the end product at all;

Defects - production of faulty parts and/or correction of said parts.

2.2. Studies in Lean methodology

Even though it was first proposed over 20 years ago, the Lean methodology is still widely implemented and studied. The aim is for its application to be made clearer and simpler, therefore more propitious to positive outcomes.

Putting Marodin & Saurin, (2013) and Sangwan, (2014)'s time distributions side by side with the correspondent timeline from the collected articles in the analysis during the period of 2013-2016, Figure 1, we are able to verify that the number of studies in this area remains similar to those going far as 8 years back. It is still visible the interest society has in this methodology.

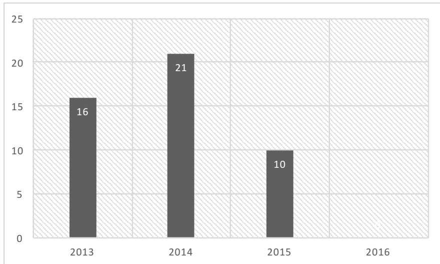

Figure 1 - Temporal distribution of articles

Such interest is greatly due to the results it delivers. One cannot contest that the *Lean* methodology manages so that it still puts value in its most recent productive processes, such as in Bertolini M., (2013), where *Lead Time* was reduced by 80% through rearranging the *shop floor* and introducing the one-piece-flow logic. This is not an isolated case, with some other highlighted (Bevilacqua, Ciarapica, De Sanctis, Mazzuto, & Paciarotti, 2015; Dal, Akçagün, & Yilmaz, 2013; Faieza, Ng, & Norzima, 2014) as recent representatives of improvements after the implementation of *Lean* tools.

However, not every aforementioned case shows real results, some of which being the product of a simulation output or of a future VSM (Ramnath, Chandrasekhar, Elanchezhian, Vinoth, & Venkataraman, 2014; Taylor, Taylor, & McSweeney, 2013).

From a wider analysis, (Jezierski & Janerka, 2013) exhibited research conducted in several industrial compounds, wherein 71% of the cases had positive outcome from the application of *Lean* methodology.

Though vastly researched, implementation of this methodology is never a linear process. The non-existing framework is not, however, an impeditive factor to the key-step generation in a

Lean approach. In recent case studies, one notices a widespread step sequence, most commonly attributed to the VSM tool, which operates as follows:

1. Choose a particular product or a product family to be analysed;
2. Develop the current product's VSM;
3. Critical analysis of the current VSM, identifying improvement opportunities where Kaizen events could be held and what *Lean* techniques to apply in said events;
4. Develop future VSM;
5. Kaizen events and subsequent implementation of *Lean* techniques.

This step sequence will also be somewhat follow throughout the present study.

3. Case Study

3.1. Characterization of the current situation

With a painting process totally automated, it is expected to find problems and wastes to eradicate in the activities subsequent to painting. Painting adjacent area is stratified by zones, Figure 2, where different activities, which will be described later, are conducted.

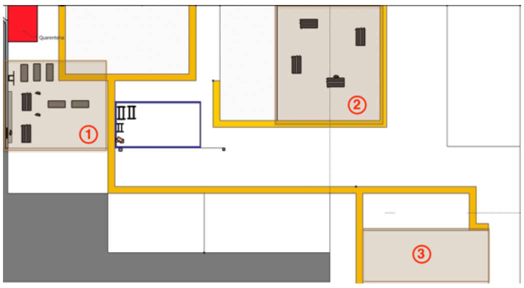

Figure 2 - Plant

Figure 3 presents the sum of activities' sequence followed by a piece after painting process.

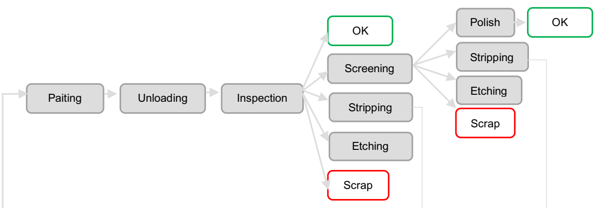

Figure 3 - Possibles sequences

In the list of possible activities for a piece to follow, there are:

Discharge – transporter pieces' removal, named in the company as jig;

Inspection/Visual control – common to all products, visual control is performed off the production line by workers. This visual control allows the classification of pieces in two main categories:

- OK – ready for expedition
- NOK – the piece is not in good conditions, having the possibility to be reworked allowing its improvement, passing to OK state.

Examples of rework processes are:

Screening – process of imperfect varnish surface removal;

Polish – minor flaws correcting process;

Stripping – conducted process when defects are more serious or varnish layer has flaws;

Etching – when pieces have very serious painting defects, etching is the solution, leading pieces to be painted again.

One of the biggest company concerns is the lead time reduction through elimination of time needed in painting adjacent processes. Thus, all eligible projects for submission to all activities are selected.

Selected family projects may follow several activity sequences. However, representation of all sequences would make VSM complex and analysis dispersed.

In a first study, main flow analysis is recommended. Information related to pieces proportion that follows each possible sequence is collected. Results are present in Table 1.

Table 1 - distribution of parts by destiny

	Projects			
	Malas Mokka	Door trim	F15	Puxadores
Ok (%)	36%	58%	66%	64%
Polish (%)	52%	40%	17%	14%
Stripping (%)	12%	2%	17%	22%

Table 1 suggests the majority of pieces focuses mainly in the first or second variant. In other words, pieces essentially go to OK stage or to polish process. Therefore, representation and consequent flow analysis according to first and second sequence is the best option. Figure 4 represents current VSM for Door trim project, showing a representation of the remaining family projects.

In current VSM, information and material flows are characterized. In material flow there is a system inventory besides the promotion of a continuous flow is somehow visible.

Can be seen by comparing the percentage of value added, Table 2, that the sources of waste are presented in the activities after painting. Low value add percentage after painting requires a more detailed analysis performance regarding activities present in this part of the flow.

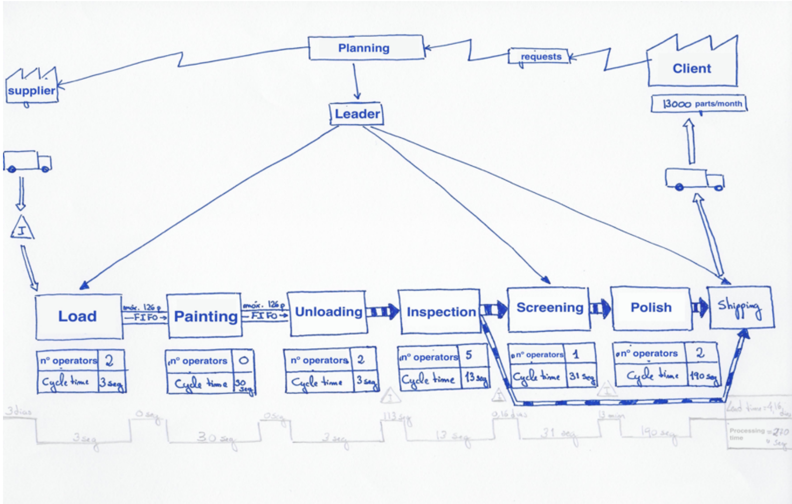

Figure 4 - Actual VSM

Table 2 - value add before and after painting

	VA	Total time	% VA
Load + Painting	63	63	100%
Unload + Inspection + Screening + polish	237	6340	4%

The aim of this analysis will be the identification of other wastes and problems.

3.2. Activities Analsys

Activities to be analyzed are selection and polish processes.

Each process and the corresponding activities, focusing on wastes' identification, will be described in the following paragraphs.

Selection process

In region marked with number 1 in Figure 2, selection process discharge and inspection activities are performed.

Due to the importance of selection process, its performance suffers some adaptations according to the project, being this conducted as fast as possible. Selection process is performed by two different ways:

A. uninterrupted performance of discharge and inspection activities; larger pieces case;
B. separation of the 2 activities; smaller pieces case;

Activities attentive observation allows to immediately detect, in B mode, the existence of waiting times during discharge. Discharges pieces, which are placed on an adjacent table, reach a higher cadence than the cadence from which they are taken by inspection activity operators, who are placed in the opposite side of the table. When table reaches its saturation point, there are discharge operators working rhythm breaks due to lack of space.

Movements made during each selection process are then analyzed and registered using spaghetti diagram tool.

Spaghetti diagram done for each mode, Figure 5 and Figure 6, show several movements, being performed for each piece a pair of movements present in the figures. Thus, registered movements for mode A are expected to have some expression during cycle time.

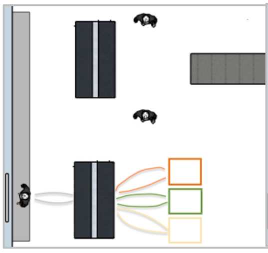

Figure 5 - Spaghetti diagram, selection of small parts

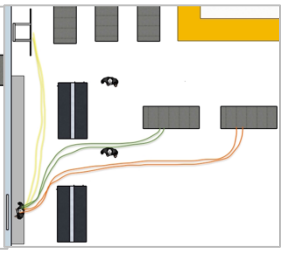

Figure 6 - Spaghetti diagram, selection of big parts

Polish process

In working areas 1 and 2, Figure 2, polish process is analogously conducted, respectively for larger and smaller pieces. Polish process includes screening and polish activities.

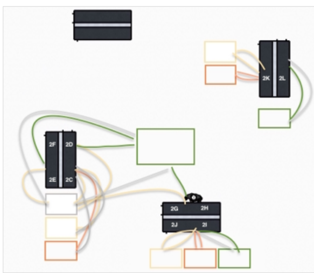

Figure 7 - Spaghetti diagram, polish of small parts

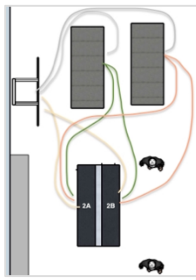

Figure 8 - Spaghetti diagram, polish of big parts

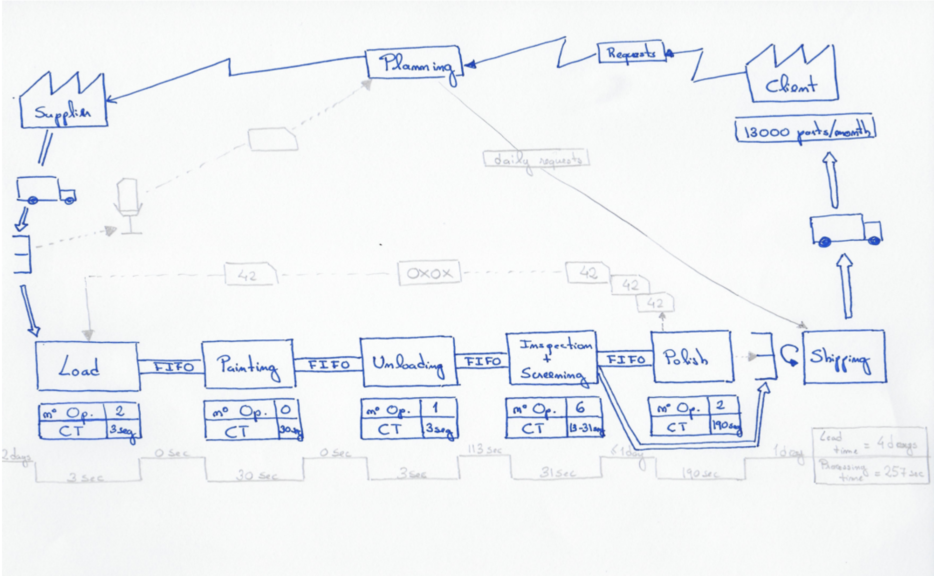

Figure 9 - Future VSM

Observation of this process allows to identify movements waste as a possible improvement opportunity. Registered movements through spaghetti diagram are present in Figure 7 and Figure 8, corresponding respectively to larger and smaller pieces cases.

It is possible to see in Figure 7 and Figure 8 that each piece has several associated movements, which cumulatively have impact on operating time and where their elimination may originate time and monetary significant returns. Moreover, in spaghetti diagram, lack of equality can also be observed in the polish process since each operator is in different distances from the collecting point and pieces storage.

The observation of the activities allowed the detection of unexpected amounts of product added to stripping, after being performed at screening. Aiming to identify the reasons causing this phenomenon, 5 Why's tool application is conducted. Results are present in Table 3.

Therefore, 5 Why's tool allowed to identify a possible case of overprocessing.

Table 3 - 5 Why's

Question	Answer
High amounts of product to stripping	
why?	Because parts with depth defects cannot be recovered by polishing;
Why these parts come to the polish?	Because the inspection is sometimes poorly executed and the product that should go directly to stripping, ends up in polish;
Why?	Lack of knowledge of operators and / or doubtful defects that make distinction difficult;
Why?	Operators are unaware of the screening activity, then they have less sensitivity to the defects, thus taking wrong decisions. Also, sometimes, only after screening it is possible to be sure about the part destination;
Solution	Require that any operator minimally dominate screening activity and this activity following the inspection activity, seeking to eliminate any doubts;

4. Proposed changes

After wastes identification, a proposal of process improvement is done. The new value stream is developed from the current VSM and from the identified wastes in its activities.

With the intermediate inventories extinction and with the creation of links between subsequent activities resulting from the introduction of the First In First Out (FIFO) politics, there is now a unique rhythm (shipping activity in this case), which is defined by the pacemaker. The introduction of a FIFO politics between activities along with the stipulation of maximum limits for the same regions promotes the generation of a continuous flow and the minimization of the waste overproduction.

The new flow, developed according to the company current needs, is exposed in the future VSM, Figure 9.

Finally, in order to reach the information and the emphasized materials flows, some alterations and process improvements are needed, which are specified in the future VSM through Kaizen events.

Descriptively, Kaizen events aim to:

- Redefine polish team in order to guarantee lead time between this activity and the previous one (less than or equal to one day);
- Reduce or eliminate the physical distance between activities, specially between inspection and screening, through their relocation or through the creation of a transporter between activities;

During the definition of operators' average number needed for polish activity, the total time required is analyzed on a monthly and historical perspective.

Analysing the calculations made for March (the representative month), there is an average necessity of 11 operators to rework all the daily generation of product to be polished.

During the development of layout restructuring solutions and operations, the following general characteristics are considered, as key points to the mitigation of the identified wastes:

1. Creation of an intermediate storage structure placed between screening and polish activities;
2. Creation of two operational regions, one designed for smaller pieces and the other one for bigger pieces;

For the smaller pieces region, the following characteristics are also considered:

3. Creation of a dynamic storage region that guarantee enough space for the discharged material placing;
4. Creation of at least 8 working areas designed for the smallest products inspection and/or screening;
5. Creation of at least 11 working areas for polish activity incorporation, close to discharge region;

Lastly, for bigger pieces, the following characteristics are considered:

6. Creation of at least 3 working areas designed for inspection and screening;

Based on the presented points, a brainstorming is firstly conducted, followed by a natural process of maturation, which culminates in the definition of alternatives to the current situation.

4.1. Alternatives

Considering all the characteristics previously showed, solutions present in Figure 10 and Figure 11, named Version A and Version B respectively, are reached.

After satisfactory solutions in global projects are found, they are analyzed in comparison to the current layout.

Spaghetti diagram, present in Figure 10 and Figure 11, exhibit a set of structured movements, which are equal between similar working areas, eliminating confusion and inequality detected on the current situation. The mentioned movements performed in the course of activities are analyzed using the measures from the representation in software environment and from a predetermined motion time system, MTM methodology.

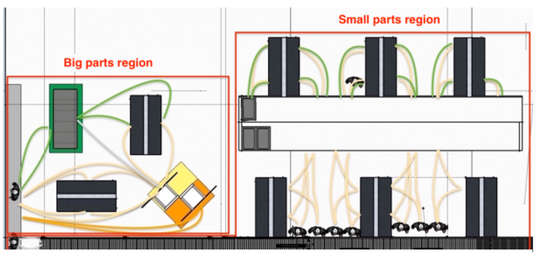

Figure 10 - Solution, Version A

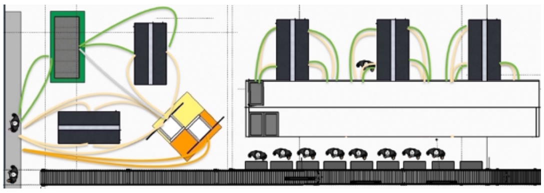
Figure 11 - Solution, Version B

5. Results validation

Solutions validation is performed through the comparison between several scenarios, using software Simul8 version 23.0.

The number of operators required by the proposed solution outperforms the current existences of this resource, posing the current situation and the proposed one in inequality, which can induce unfair inferences in a comparative approach. The creation of several scenarios was the solution found to obtain an embracing vision.

The five scenarios can be divided in two groups, one with 3 scenarios that represent several variants of the current situation, and the other one with two scenarios corresponding to the two solutions presented.

A more detailed description of each scenario is presented in the following paragraphs:

Scenario A1

First scenario characterizes the current analyzed process, considering activities, timeouts and gemba environment registered transports. In this scenario, the number of resources attributed to each activity is the commonly used during productive system working.

Scenario A2

Scenario A2 represents the current process with a different polish operators' allocation.

The only exception to this situation are the major projects, where a smaller team is attributed to them since these projects do not demand it or there is not even that possibility in the line current situation.

Scenario A3

In scenario 3, current and proposed situations are placed in identical conditions in order to make a fair comparative analysis. Extra resources are attributed to the most critical points of the current situation, placing the same number of global operators present in the current situation and in the alternatives under study. Process keeps the same as the current situation.

Scenario P1 e P2

Remaining scenarios, P1 and P2, represent the proposed process in Figures 4 and Figure 5, both with the characteristics presented in chapter 4.

5.1. Limitations and assumptions

During the representation, simulation and results analysis incident on the scenarios previously introduced, the following assumptions will be taken into account:

- Only the part of the process which is being studied is represented, therefore activities as charge and painting are not included;
- System start resource introduces a number of pieces equal to the capacity of the jig of the simulation project in the discharge region, at intervals of 120 seconds;
- Inspection and screening activities show several possible destinies, being the number of pieces attributed to each destiny in average the same as the real distribution of the pieces, for these destinies;
- Only the four most produced projects will be subjected to simulation, since these represent about 76% of the requests
- Transport activity, between inspection and screening, is performed in batch variables which oscillate between the minimum of a filled box and the maximum of a full pallet;
- Performed simulations will reflect the daily demands of each project;
- Obtained results for time in the system have a confidence level of 95%
- Each scenario's monetary impact is evaluated in a productive period corresponding to a month;
- Hours conversion to currency (Euros) will be according to the reference level tabulated by the company;
- Each activities' cycle times are governed by normal distributions, since it is recurrent for the manual process output to follow a normal distribution (Groebner, Shannon, Fry, & Smith, 2010);

The following study also presents the following limitations:

- Limitation imposed by painting line makes the study of changes in monthly produced quantities impossible;
- For the metric Labor cost, 10 runs were made

5.2. Representations

Simulation structures' elaboration specific for each scenario is unnecessary, since between scenarios of the same group, either Group A or P, differences are only in cycle times or in the number of resources.

Figure 12 includes a copy of the figurative simulation of group A. Figure 13 expose the representation of the situation allusive to the proposals.

Figure 12 and Figure 13 represents the small parts simulation being the big parts representation very similar.

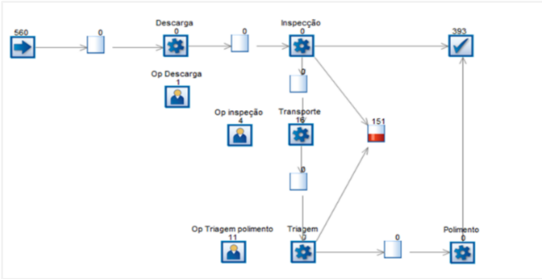

Figure 12 - Representation of group A

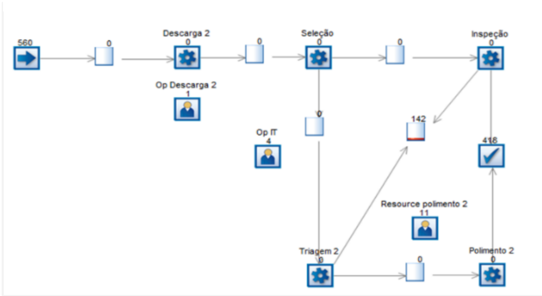

Figure 13 - Representation of group P

5.3. Simulations' results

Evaluation of each scenario is performed through the analysis of relevant metrics for the productive system. Two temporal metrics and one monetary metric, which are presented below, are considered for this evaluation.

Time in the system

The enunciated metric refers to the pieces that reached OK condition, allowing to understand how much time passes since the piece is discharged till the point where it is placed in the region destined for pieces in this condition. All pieces that reach OK condition contribute to this value, independently from the activity sequence. Minimum, average and maximum value will be considered for this metric.

Overall duration of each activity

After unloading the parts there are two points where the finished products appear, after inspection and after the polishing activity. Therefore, the overall duration of inspection activity is a reference to the achievement level of all the finished product that do not need rework.

Polish activity duration is shown to be relevant for the understanding of the overall duration for the process after the painting, that is, until the final product asked by the client is gathered.

Labor cost

The analysis of this metric contains no cost for some activities, since resources are shared, is to the most time consuming activity all the costs incurred with these operators are assigned. The last consideration is about resources use. During the active period of each activity, there are sporadic moments in which, one or more operators, may be free since there are no work. However, the operator is still allocated to this activity, being in employment period, and so obviously counted as operational moment as well as a cost.

5.3.1. Metric time in the system

The obtained results for this metric, for each project, are present in Table 4. Between the 3 metrics presented in Table 4, minimum time is the one that presents less variability. F15 is the only project that suffers a significant modification, with a reduction of almost 50% of the current scenario to the proposed scenario. This metric does not express great symbolisms, allowing to infer it represents the duration associated with the shortest route till considering piece as OK.

In the case of average time and maximum time metrics, in all analyzed projects there is a significant reduction between scenarios, with a positive evolution A1<A2<A3.

In average time metric, differences between scenario A3 and the worst cases between P1 and P2, vary between about 40 seconds and 6 minutes and 30 seconds.

In maximum time values, difference is more significant, being at least 12 minutes or 22 minutes maximum. Registered differences are mean values for each piece, therefore it is expectable they become more expressive during the production of daily asked volumes.

5.3.2. Overall duration metric of each activity

Second metric to be analyzed shows the overall duration average of each activity and for each scenario. Results are present in Table 5.

Obtained results regarding inspection activity present little variability among scenarios. Door trim project is the only which presents a greater difference, about 37 minutes when comparing to scenario P1, the worst of proposed scenarios, and scenario A1. However, when scenario A3 e P1 are compared, for the same project, difference reduces to 9 minutes

With the main changes being essentially on the rework sequence, polish activity duration is compared in order to evaluate the impact caused by these changes. Polish activity duration reveals a reduction of at least 57 seconds when compared to scenario A3 and 1406 seconds (about 23 minutes) when compared to A1.

Comparing the worst proposed scenario with situation A3, polish duration reductions vary from an evolutionary situation almost null to a 23 minutes progress at best, among the different projects. Comparing to scenario A1, values increased, having a reduction of about 23 minutes as the worst case in opposite a reduction slightly higher than 7 hours.

In conclusion, presented solutions are able to offer the final product at least 23 minutes earlier comparing to current process, and 7 hours in Door trim case.

5.3.3. Labor cost metric

Monetary analysis brought together data extracted from simulations, leading to a cost attribution for each activity and, consequently, for each activity and, consequently, for each scenario.

Obtained results regarding monetary analysis are present in Table 6.

Costs reached by each scenario, present in Table 6, follow a different trend from the one found on previous analysis, having in this case the following cost decreasing order for all studying projects:

Costs A3 > Costs A2 > Costs A1

It is now clear time reductions, in scenarios A2 and A3 compared to A1, are obtained with labor costs associated. In turn, solutions P1 e P2 are solid, allowing to reduce system time needed by each piece as well as the overall duration of each activity, in the majority of the cases and without an increased cost as these solutions promote process wastes' elimination.

With almost null differences in overall duration of each activity, both scenarios P1 and P2 present the same monthly costs for operation. Solution P2, which would present higher implementation costs, does not have any advantages compared to solution P1. Thus, it is obviously discarded in favor of P1, which will be the following analysis' main aspect.

In labor costs metric, solution P1 is able to present, in the set of 4 projects, costs of less 1292€ per month comparing to current situation. On the other hand, in puxadores project case, costs associated with the presented solution have an increase of 699€ compared to current situation, resulting from a discrepancy of 9 operators.

Scenario A3, which is the most close to proposed scenario regarding time metrics, has higher costs than current scenario and, consequently, a bigger prejudice when compared to proposal P1.

The referred case A3 would have a monthly overall cost of about 2778,90€ higher. Choosing proposal P1 instead of allocate more resources to the current situation (which was studied in situation A3) will allow to have an annual return of 30 567,90€, in all of the 11 productive months.

Table 4 - Results obtained for time in the system

	A1 (Atual)	A2	Scenarios A3	P1	P2	Reduction from A1 to P1 (%)	Reduction from A1 to P2 (%)	Reduction from A2 to P1	Reduction from A2 to P2 (%)	Reduction from A3 to P1 (%)	Reduction from A3 to P2 (%)
Minimum time in the system (seg.)											
Door trim	18,57	18,57	18,06	18,54	16,57	0,2%	10,8%	0,2%	10,8%	-2,7%	8,3%
Malas	20,73	20,73	20,73	20,82	19,37	-0,4%	6,6%	-0,4%	6,6%	-0,4%	6,6%
F15		18,94		9,72		48,7%	48,7%	48,7%	48,7%	48,7%	48,7%
Puxadores	270,26	147,44		107,84	100,03	60,1%	63,0%	26,9%	32,2%	26,9%	32,2%
Average time in the system (seg.)											
Door trim	4721,29	1517,33	726,58	487,93	441,01	89,7%	90,7%	67,8%	70,9%	32,8%	39,3%
Malas	4215,69	1670,25	1398,22	997,35	1007,76	76,3%	76,1%	40,3%	39,7%	28,7%	27,9%
F15		289,72		150,3		48,1%	48,1%	48,1%	48,1%	48,1%	48,1%
Puxadores	270,26	147,44		107,84	100,03	60,1%	63,0%	26,9%	32,2%	26,9%	32,2%
Maximum time in the system (seg.)											
Door trim	27547,82	4829,51	3510,14	2715,25	2584,42	90,1%	90,6%	43,8%	46,5%	22,6%	26,4%
Malas	16350,92	5964,46	4873,75	3256,32	3514,34	80,1%	78,5%	45,4%	41,1%	33,2%	27,9%
F15		2485,89		1192,91		52,0%	52,0%	52,0%	52,0%	52,0%	52,0%
Puxadores	3302,36	1085,8		352,05	336,11	89,3%	89,8%	67,6%	69,0%	67,6%	69,0%

Table 5 - Global duration of each activity

	A1	A2	Scenarios A3	P1	P2	Between A1 and P1	Between A1 and P2	Between A2 and P1	Between A2 and P2	Between A3 and P1	Between A3 and P2
Door trim											
Discharge	4560	4560	4560	4560	4560	0	0	0	0	0	0
Inspection	6769	6780	5117	4553	4524	2216	2244	2227	2255	564	592
Screening	31968	8931	7585	4576	4544	27392	27424	4355	4387	3009	3041
Polish	32318	9341	8003	6793	6841	25525	25477	2548	2500	1210	1162
Malas											
Discharge	7680	7680	7680	7680	7680	0	0	0	0	0	0
Inspection	7826	7826	7826	7822	7809	4	17	4	16	4	16
Screening	23441	12891	11885	7869	7854	15572	15587	5022	5036	4016	4030
Polish	23944	13412	12405	11159	11183	12784	12761	2252	2229	1246	1222
F15											
Discharge + Inspection		7448		7417		31	31	31	31	31	31
Screening		9207		7355		1852	1852	1852	1852	1852	1852
Polish		9543		8138		1406	1406	1406	1406	1406	1406
Puxadores											
Discharge	1680	1680		1680	1680	0	0	0	0	0	0
Inspection	1819	1828		1820	1813	-2	6	8	15	8	15
Screening	4512	1888		1832	1826	2680	2686	56	62	56	62
Polish	4685	2031		1975	1964	2711	2721	57	67	57	67

Table 6 - Labour costs

	A1 (atual) nº of operat.	A1 (atual) Cost (€)	A2 nº of operat.	A2 Cost (€)	A3 nº of operat.	A3 Cost (€)	P1 nº of operat.	P1 Cost (€)	P2 nº of operat.	P2 Cost (€)	Cost difference between A1 and	Cost difference between A1 and
Door trim												
Discharge	2	548,70 €	2	548,70 €	2	549	1	274,35 €	1	274,35 €	274,35 €	274,35 €
Inspection	3	1 247,85 €	3	1 247,85 €	4	1239	0	- €	0	- €	1 247,85 €	1 247,85 €
Screening	0	- €	0	- €	0	0	7	1 920,45 €	7	1 920,45 €	(1 920,45) €	(1 920,45) €
Polish	3	5 947,20 €	11	6 230,40 €	13	6328	11	4 575,45 €	11	4 575,45 €	1 371,75 €	1 371,75 €
Total	**8**	**7 743,75 €**	**16**	**8 026,95 €**	**19**	**8 115,45 €**	**19**	**6 770,25 €**	**19**	**6 770,25 €**	**973,50 €**	**973,50 €**
Malas												
Discharge	1	469,05 €	1	469,05 €	1	469,05 €	1	469,05 €	1	469,05 €	- €	- €
Inspection	4	1 911,60 €	4	1 911,60 €	4	1 911,60 €	0	- €	0	- €	1 911,60 €	1 911,60 €
Screening	0	- €	0	- €	0	- €	5	2 389,50 €	5	2 389,50 €	(2 389,50) €	(2 389,50) €
Polish	6	8 814,60 €	11	9 053,55 €	12	9 133,20 €	11	7 495,95 €	11	7 495,95 €	1 318,65 €	1 318,65 €
Total	**11**	**11 195,25 €**	**16**	**11 434,20 €**	**17**	**11 513,85 €**	**17**	**10 354,50 €**	**17**	**10 354,50 €**	**840,75 €**	**840,75 €**
F15												
Discharge + Inspection	3	1 354,05 €	3	1 354,05 €	3	1 354,05 €	3	1 354,05 €	3	1 354,05 €	- €	- €
Discharge + Screening/Screening	0		0		0						- €	- €
Polish	2	1 168,20 €	2	1 168,20 €	2	1 168,20 €	2	991,20 €	2	991,20 €	177,00 €	177,00 €
Total	**5**	**2 522,25 €**	**5**	**2 522,25 €**	**5**	**2 522,25 €**	**5**	**2 345,25 €**	**5**	**2 345,25 €**	**177,00 €**	**177,00 €**
Puxadores												
Discharge	1	97,35 €	1	97,35 €	1	97,35 €	1	97,35 €	1	97,35 €	- €	- €
Inspection	4	424,80 €	4	424,80 €	4	424,80 €	0	0	0	- €	424,80 €	424,80 €
Screening	0	- €	0		0		4	424,80 €	4	424,80 €	(424,80) €	(424,80) €
Polish	2	566,40 €	11	1 362,90 €	11	1 362,90 €	11	1 265,55 €	11	1 265,55 €	(699,15) €	(699,15) €
Total	**7**	**1 088,55 €**	**16**	**1 885,05 €**	**16**	**1 885,05 €**	**16**	**1 787,70 €**	**16**	**1 787,70 €**	- **699,15 €**	- **699,15 €**
Total of projects											**1 292,10 €**	**1 292,10 €**

Solution P1, with an operating interest for the company process, implies, however, an implementation cost associated with the transporter acquisition and the supermarket. As shown, this initial cost will bring an annual return of more than 30000€ when considering only the reductions with labor costs, being expectable an additional return from cost suppression of delivery delays, which was not considered in this study.

5.3.4. Value add time metric

Present in Lean methodology application context, ratio value add/total time is sometimes analyzed in order to obtain a vision of the incorporated value in the general of the process. This metric is usually calculated using VSMs.

In this case, it will be calculated based on data extracted from the already presented simulations.

Mean time values needed for each piece to go through all activities sequence are extracted using simulations, being these values compared to the corresponding value add time. Table 7 presents this analysis.

Table 7 - value add

	Atual % value add	Proposed % value add	Difference in %VA
Door trim	2%	18%	18%
Malas	6%	26%	26%
F15	22%	43%	43%
Puxadores	9%	70%	70%
Average	10%	39%	39%

Obtained values for both parameters show a positive evolution, with an overall mean increase of 29% in the percentage of value added.

5.3.5. Occupied zone metric

The final evaluation is predicted based on measurements and projections made in 3D modeling software. In this context, was obtained a total of 224 m2 with the solution, compared to the current 278 m2.

6. Conclusion

In this paper it was possible to observe a process optimization study as well as layouts' redefinition of activities performed in the most recent liquid painting line in Company C.

The use of Lean methodology sought to optimize all the adjacent processes to the new painting line, providing the company with a more responsive productive process, with a higher capacity and less associated costs.

The atual value flow characterized and analyzed in detail using VSM tool, is followed by a revolver of all activities present in the flow. Each activity detailed investigation, using tools, flowchart, spaghetti diagram and 5Why's, showed several wastes and its reasons. Having characterized the flow future vision, once again using VSM tool, and having identified the needed changes to obtain pure value added, a set of two solutions capable of originating the desired objectives is then presented.

The found solutions, target of a validation based on simulations, proved to offer better operating results, in comparison to a possible replication of the current structure in order to satisfy Company C current and future needs. The most advantageous solution, according ratio return/implementation cost, guarantees a reduction of needed time for daily production of each project that varies between 15% and 79% when compared to the current situation. This significant time reduction requires more operators, being nevertheless 30 567,90€ per year less expensive regarding labor cost than a current situation identical in time performance.

Therefore, it is suggested to the company the changes presented in Version A, in order to obtain a better performance with lower operating costs.

Registered time reductions, without having higher operating costs, are possible due to the elimination of several wastes present in the current process, which are almost nonexistent in the proposed solution. Actually, changes between current and proposed processes ensure an increase of 29% in the percentage of value add time.

In conclusion, as suggested by literature, Lean methodology is capable of provide positive results through slight changes in the current process. The simple fact of incorporating an increasing value reveals satisfactory returns in all levels.

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