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Financial and Human Benefits of Lean Production in the Plastic Injection Industry: an Action Research Study

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Abstract

This paper presents the results of a Lean Production project implementation developed in a plastic injection company. The main aim of the project was the application of Lean principles and tools involving the stakeholders of the company. The first tool applied was the VSM to diagnose the production system and to identify the wastes and the main issues for improvement. Some proposals were presented and implemented using Lean tools such as 5S, PDCA cycle, Kanban, SMED and Kaizen. Some tangible and financial results obtained were an increase of productivity of the assembly lines by 12%, of the operating income by 6%, a reduction of the cycle time of six dies to 10% and a reduction by 15% of tool changeover time and an increase of total incomes estimated in €360,000.00. Intangible results were the operators' engagement and involvement with the continuous improvement and with Lean implementation.

Key words: *Lean production, plastic injection industry, Lean financial and human benefits*

1. INTRODUCTION

In a global society, companies are continuously forced to reduce costs in order to maintain competitiveness and to face the growing competition. Companies look for production models and strategies to help them achieve this objective. Lean Production (LP) [1] is a production model that has been implemented in companies in a variety of industries and all over the world [2]-[16] with the aim of reduce costs through the elimination of waste focusing on the quick delivery of "best-in-class" products [17].

Every company could benefit from Lean Thinking principles [18] pursuing the perfection and eliminating the activities that add no value to the products, i.e. wastes. These activities are present in all companies even the ones that are not conscious of these kind of activities. They feel comfortable of having full warehouses of finished products ready to be delivered to the clients and lots of work-in-process (WIP). Potentially, many companies feel this way until the day their clients asks for a product that it is not in stock and their production takes a significant time to produce these goods. This kind of situation exposes weaknesses of companies and, many times, force them to close the doors and go bankrupt.

The plastic injection industry is not an exception and companies from this industry present a value streams with many wastes that do not add value to the product. Examples of these wastes are the problems presented by the company studied in this paper such as: 1) high levels of stock of raw materials and components and high movements between workstations; 2) high levels occupied space and resource utilization at three assembly lines for the same product family; 3) high levels of WIP; 4) low efficiency due to the discontinued flow of the product in the lines; 5) high tool changeover time; 6) high level of rejection due to product defects; 7) high movements in the shipment zone and utilization of various transport means and equipment and, at last, 8) high lead time.

Knowing that the Lean Production model, through its principles and tools, searches for solutions to such problems, the company where this project was developed (the name of the company and their products are not presented due to company confidentiality) considered the implementation of LP in order to reduce costs and increase productivity. The objectives of this paper are to present the project developed in this company, the proposed solutions to the problems identified, the process of implementing these proposals and the discussion of the main findings in the company about Lean implementation that brought, not only financial benefits, but also human benefits.

The action-research methodology was used by the researcher that it is also a worker in this company since a few years. He was one of the main promoters of this project, participating and intervening all the time in the action. Susman and Evered [19] referred that action research can be viewed as a cyclical process with five phases: diagnosing, action planning, action taking, evaluating, and specifying learning. Learning emerges as an iterative process of research and action, since it is implemented what has been learned and consequently the results needed for research are obtained. Later, Dick [20] defined action research "as a family of research methodologies which pursue action (or change) and research (or understanding) at the same time. In most of its forms it does this by using a cyclic or spiral process which alternates between action and critical reflection and in the later cycles, continuously refining methods, data and interpretation in the light of the understanding developed in the earlier cycles. (…) it is an iterative process which converges towards a better understanding of what happens. In most of its forms it is also participative (among other reasons, change is usually easier to achieve when those affected by the change are involved) and qualitative".

The paper is organized in four sections. The first section contextualizes the project and introduces the problems, identifying the objectives of the paper and the methodology used. The second section presents a brief review of Lean production and some of its tools in section three. Section three describes the industry application of Lean principles and tools to a plastic components company and characterizes the production system, presenting the critical analysis necessary to identify the problems. Also present the proposals to obtain improvements and process implementation, discussing the results of these implementations and estimating results for the ones not yet implemented. Finally, section four presents the main conclusions of the project.

2. LEAN PRODUCTION BRIEF REVIEW

This brief review presents the roots of Lean Production and Lean Thinking principles and describes some Lean tools used in project development.

2.1 **Lean Production**

The Lean Production is an organizational production model that had its origin at the company Toyota. The company started to employ this model after the Second World War (1939-45) as Toyota Production System (TPS). Eiji Toyoda and Taichi Ohno were the mentors of this system that searched for the solution to problems caused by the war: reduced availability of resources, space, materials, among others [21], in a "doing more with less" approach. This designation was disseminated by a best-seller book named "The machine that changed the world" that studied the evolution of the automobile industry and compared mainly the North American with the Japanese automobile industry, concluding the supremacy of the latter one at that period in time [1].

Various definitions of Lean Production have been appearing in the literature, namely the definition of Warnecke & Huser [22] that defined Lean Production as a system of measures and methods which used together have potential to improve the competitiveness of a company or the definition of Shah & Ward [3] that saw Lean Production as a multidimensional approach involving various management practices in an integrated system and which main idea is align the production system with the demand producing high quality products with no wastes.

Lean Thinking is a concept advanced by Womack and Jones [18] developed as a methodology for whoever wants to implement Lean Production. The authors stated that this concept is an antidote to wastes and by applying it companies can reduce costs through waste elimination and create value. This is done through the application of principles and tools that will simplify the way the company produce value for their clients while all wastes are eliminated in the value stream [18]. The same authors point out that this thinking allows companies to specify what is value, how to initiate the actions of value creation, what the best sequence is to do this and how accomplish these actions with the best performance without interruption. They defined five principles for Lean Thinking: 1) value; 2) value stream; 3) flow; 4) pull production and 5) perfection. Pursuit perfection means to continuously search and eliminate wastes.

According to Ohno [21] there are seven kinds of wastes: Transports, Inventory, Motions, Waiting, Overproduction, Over-processing and Defects. In order, to eliminate these wastes many tools could be used, such as 5S, Kaizen, Single Minute Exchange of Die (SMED), Plan-Do-Check-Act (PDCA) cycle, Value Stream Mapping (VSM), JIT production, Kanban system, Poka-Yoke mechanisms, among others [23]. To improve the system efficiency and eliminate many of these wastes, namely material handling [24], the reconfiguration of the existent layout in an efficient lean layout is mandatory as Zhenyuan et al. [25] exposed. Implementing these tools demands a competence indispensable in a work environment: teamwork (Figure 1).

Human resources are the most important asset available to companies and since the origins of TPS this was recognized in various publications, namely, Sugimori et al. [26] that called TPS as "...the 'respect-for-human' system, where the workers are allowed to display in full their capabilities through active participation in running and improving their own workshops". Liker [27] points out the untapped human potential as an eight kind of waste. This human potential has also to do with the respect for the people, as the authors above referred to, seeing them as much more than "a pair of hands" [28].

Figure 1. Some Lean tools and the teamwork relevance

Lean implementation requires involvement and commitment of all people and, as a payback, promotes thinkers continuously unsatisfying with the status quo, searching all the time problems and solutions to these problems [29]. Factors related to stakeholders' involvement and commitment influences the potential success of Lean implementation [30]. According to Wilson [31] three fundamental issues are essential for a cultural change: the leadership, the motivation and the problem solvers assessment, as the first step before the Lean project implementation. Having these issues it is possible to start the journey to implement Lean tool. Some of these tools are described in the next section.

2.2 **Summary of some Lean tools**

Some tools briefly described in this section are Kaizen, Value Stream Mapping (VSM), 5S program, PDCA cycle, SMED, Visual management and Kanban system.
Kaizen [32][33] is the Japanese word for continuous improvement. To achieve this continuous improvement all stakeholders must be involved in identifying the processes of improvement and improve the performance of the company, implementing these changes including small investments. According to Imai [32] Kaizen is an umbrella term that embraces all improvement techniques; harmoniously joining them to take what each one of them has to offer.
Value Stream Mapping (VSM) is a tool to identify wastes in a company. Through this "pencil and paper" tool it is possible to analyze and classify company activities in three kinds of activities: activities with no value (wastes); those that do not add value but are necessary and those activities that add value to the product from the point of view of client. Rother & Shook [34] explained how to build a map for the value stream of a product or family of products that are really important for the clients. This tool is one of the first tools to implement because it diagnoses the system, showing graphically the wastes found out in the system and helping to prepare the road to go through a Value Stream Mapping of future state.
The 5S program is a work methodology that promotes the discipline within a company through the responsibility and involvement of all stakeholders. This contributes to a work environment that is safe, pleasant, productive and efficient. Hirano [35] presented this program as a methodology to sustain the JIT production [26][36]. Being a base of this important pillar of TPS, normally it is one of the operational Lean tools to implement on the shop-floor, making it a visual workplace.
PDCA cycle means Plan-Do-Check-Act cycle and is a tool centered on problem-solving. With this simple tool Shewhart created a new way of thinking and acting being Deming the responsible person to disseminate this tool, around the 50s, in the Japan. Toyota was one of the companies that adopted and converted this in a strategy of supporting the continuous improvement and leadership of all management levels [37]. This cycle is behind the methodology Six-Sigma strictly related with Lean Production that had been implemented in many companies [38][39].
The Single Minute Exchange of Die (SMED) permits the analysis and time reduction on tool changeover and setup time. The SMED tool was developed by Shigeo Shingo [40][41] and the objective are improve the setup conditions in order to reduce time and increase system flexibility for being able to make more setups. In this way, the system is prepared to produce more product variety, ordered by the same or different clients.
Visual management is the application of information in a visual manner, allowing for the rapid detection of anomalous operations, aids the operators to complete tasks more quickly and promote the standardization of processes.
Kanban system was developed by Taiichi Ohno, his ideas about Kanban were inspired by the American supermarkets, where the shelves were replenished when emptied. Kanban is a system used for controlling the movement of parts and materials that respond to signals of the need for delivery of parts or materials. This applies to both to delivery to the factory and delivery to each workstation [42]. Kanban clearly identifies needed work, allows for job-sharing, reduces the number of defective parts produced and gives instant visual indicators of productivity and constraints. This tool application also contributes for the inventory leanness. This impacts the financial performance [43].

3. INDUSTRY APPLICATION

This section presents an overview of the case study company and describes the production system and materials flow before the Lean implementation. A critical analysis to a family of products is followed to identify the main problems. Then, the presentation of proposed improvements is presented and the results obtained were presented and discussed.

3.1 **Description of the company**

This section presents an overview of the case study company and some of their products and describes the production system and materials flow before the Lean implementation.

3.1.1 *Main clients and products*

The project described in this paper was developed in a company dedicated to thermoplastic injection and belongs to a big Portuguese group. The actual production of this company is around 10 million of injected parts per year. The main clients are from the automobile, childcare and packing industry. Figure 2 presents some products which incorporate components from this company.

a) b) c)

Figure 2. Some products that integrate components produced by the company: a) baby chair; b) parts for automobile interiors; c) gas cylinder

3.1.2 *Production process and materials flow*

The company has a productive area of 10,000 m2, 43 machines, between the 80 and 1600 tons of closing force and 324 stakeholders working in three shifts. The main processes are the injection by moulding and the assembly. The layout in Figure 3 presents three distinct areas represented by three coloured rectangles: red, blue and green.

1. Red rectangle – Plastic injection area is composed by 3 production modules: module 1- green; module 2 – yellow; and module 3 – blue. In this area the raw-material is converted in semi-finished or finished products.
2. Blue rectangle –area of assembly lines and semi-finished and is named module 4. In this area the semi-finished and components are assembled to create the final products.
3. Green rectangle – is the final product warehouse: receipt, stock and expedite the final product.
   The blue arrows in Figure 3 indicate the final product and empty containers flow and the red arrows represent the raw-material and components supply.

3.1.3 *Critical analysis of actual situation, KPI values and problems identification*

The selected products for the detailed analysis were the baby chair because the client of this product contributes to 32% of the income. Additionally, this product is one of those with greater incorporation of raw-materials and components, having a high impact in the resources involved (people and space), which makes production more complex. There are four models of baby chairs: Chair 1, Chair 2, Chair 3 and Chair 4. To give an example of the consumption of materials and people, the company produces 2000 chairs per day (650 Chair 1, 300 Chair 2, 600 Chair 3 and 450 Chair 4), needs by month 25 injection machines, 61 dies, 98,757 kg of PP PHC25 (raw-material) and 41,000 Kg of PP PHC 26 (another raw-material) and all components for each chair. It also needs 65 operators (35 for injection area and 30 to the assembly lines).

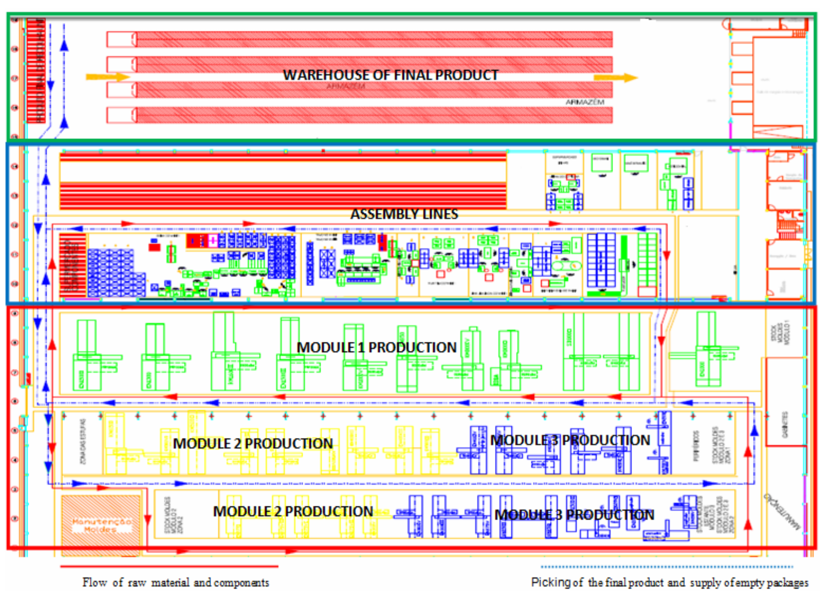


Figure 3. Company general layout

In the general layout of the company of Figure 4 it is possible to identify the different flows of the chair production process that is common to the four models:

1) Red route - represents the raw-material flow, since the exterior warehouse until the supermarket. After, this raw-material is pushed to the injection machines according to the needs.
2) Blue route – represents the injected parts movements to the semi-finished supermarket.
3) Purple route – represents the assembled chairs (final product) going to the final product warehouse.

Figure 4. Routes of raw-material (red route), injected parts (blue route) and assembled chairs (purple route)

The travelled distances and the transport time of each route are illustrated in Table 1.

Table 1. Travelled distances and transport time of each route

Partial routes	Route	Distance (meters)	Route time (seconds)
1. Raw-material warehouse-> supermarket	Red	230	300
2. Supermarket-> injection machines module 1		112	65
3. Supermarket-> injection machines module 2		130	70
4. Supermarket-> injection machines module 3		180	80
5. Injection machines module 1-> semi-finished stock	Blue	125	68
6. Injection machines module 2-> semi-finished stock		125	68
7. Injection machines module 3-> semi-finished stock		150	75
8. Semi-finished stock -> assembly lines		3	20
9. Assembly lines -> final product warehouse	Purple	80	35

Each chair model requires a different number of injected parts, number of assembly operations, workstations and operators. All models include injection and assembly operations. The injection operations that produce the injected parts could be processed in parallel but the assembly operations are, mainly, sequential. Table 2 presents these numbers for the different models, collected in a process analysis diagram drawn for each chair model.

Table 2. Number of injected (Inj.) parts, assembly (Assbl) operations, workstations, operators and operations total time in minutes

Model	Inj. parts	Assembly operations	Work-stations	Operators		Operations total time (minutes)
				Inj.	Assbl	
Chair 1	8	32	14	4	15	16,5
Chair 2	15	24	8	9	7	17,0
Chair 3	16	21	7	15	8	15,5
Chair 4	6	10	3	4	3	9,5

Some of key performance indicators (KPI) used in the company are: productivity (in costs structure), WIP level, operational income (OI), tool changeover time in minutes (min) and parts rejected per million (ppm). The actual values of these KPI are presented in Table 3.

Table 3. Actual values of KPI of Baby Chair product family before Lean implementation

KPI		Before
Productivity (%)		10%
WIP (days)		2
Lead time (days)		22
OI module (%)	1	84
	2	88
	3	89
	4	84
Tool changeover time in module of injection (min)	1	60
	2	50
	3	36
ppm chair (%)	1	2
	2	4
	3	6
	4	4
Value added (%)		5

The productivity is measured by the cost reduction in the company structure, such as the reduction of direct and indirect labor, energy, stock reduction, among others. The WIP reflect the material that is incorporated in the assembly lines. The operational income (OI) measures the efficiency of the machines and assembly lines in the accomplishment of the production orders. The tool changeover time is the time between the last part produced of one reference and the good quality first part of the next reference. The parts rejected per million represent the total products with defects internally produced by 1 million of parts produced (ppm).

To visualize the value chain for each model, the VSM tool was applied (Figure 5). Using this tool it was possible to take a snapshot of the actual situation of the system for this family of products and to identify the wastes. Due to the VSM dimension it is not possible to show the VSM here but the summary of its results were very worrying. The activities of value added were only 5,4% (29 hours) of all activities in a lead time of 22 days (528 hours).

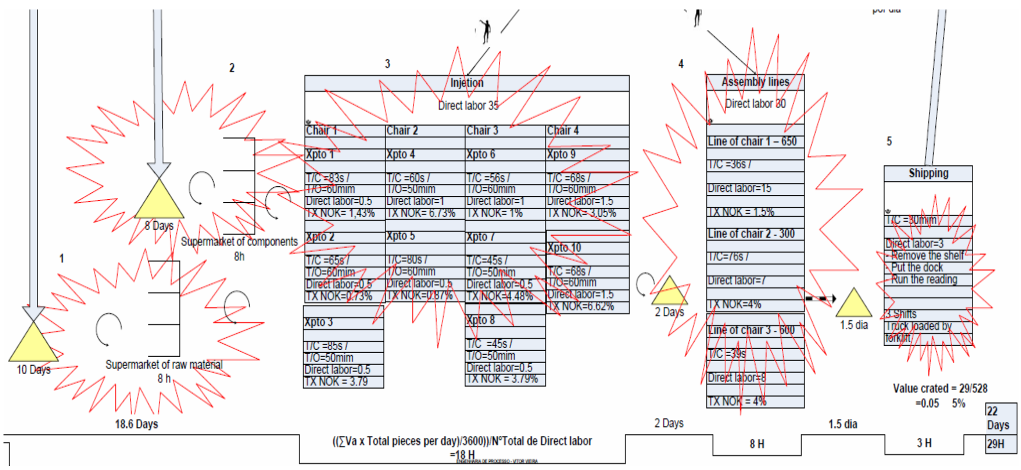


Figure 5. – VSM of actual situation

Looking at the VSM, it was decided to classify the problems according to the area/section where they were found. So, it was possible to identify problems related with the following areas:

1) raw-material supply
2) components supply
3) injection section
4) assembly section
5) shipment

The raw-materials could wait 10 days until be consumed and some of this is kept outside of the company facilities, being exposed to the atmospheric conditions and occupying a space of 238 m2. Normally they were supplied in bags or pallets and these provoked high movements (unload the truck, give order to the warehouse, storage and transport to the supermarket twice per shift). These movements bear some risks in the operation of load/unload, which can necessitate more resources.

The components can be stored up to 8 days without being consumed, and the longer the lead time the greater the quantity in stock, which represents more occupied area, about 20 m2, and the greater the number of movements (unload the truck, give order to warehouse, storage, transport to the supermarket one time per shift), and also the greater the resources and equipment involved. The company maintained a high stock of components to avoid running out of materials, but the costs of having an inventory like this costs €100,000.00.

The injection section had enormous problems with machines, dies and tools. The machines are very big, which can make the maintenance occasionally difficult (for example, on the top of the machine) and accidents happen when workers fulfill these activities without proper care and conditions. Additionally, all electronic connections were old and damaged provoking operation errors and difficulties in detecting errors. The frequency of these errors led to changeover times longer than expected. In practice, they take at least 5 minutes more per each changeover, and with the machine stopped. This problem also happened with the oil connections, heating plugs and with oil depressurization system that were identified as faulty and incorrectly installed and caused the same problems leading to further maintenance costs for the company.

The support cars and tools were old and disorganized, making the changeover operations more difficult and causing waiting times while locating the correct tools, which on average took at least 2 minutes. For example, the die exchange needed a particular screwdriver of which the company only owns one. Consequently, when 2 workers needed the same screwdriver one of them had to wait.

This section also identified a high rejection level and long cycle times. The high rejection level was analyzed recurring to the 5Why and to the 5W2H tool. This analysis indicated the presence of burrs on the part, which happens when the die starts to show signs of wear, causing corrections by the operator (non-value added operations). It was also possible to identify that some dies had a long cycle time resulting in high utilization of machines and stakeholders. All section was characterized by high movements of forklifts, disorganization and cleanness lack, as Figure 6 shows.

Figure 6. Examples of disorganization and dirty spaces

The main problems identified in the assembly lines were related to assembly line halts due to semi-finished unsupplied and need to pick up of the final product, flow discontinuous and more resources than needed with 3 assembly lines for products of the same family. This also suffered from high movements due to the quality wall (as the company designated this area – black circle in the Figure 7) that was the space dedicated to the quality inspection. All parts to be controlled were transported by forklift from the assembly lines to this wall (Figure 7) in a distance to and from the wall of 100 meters.

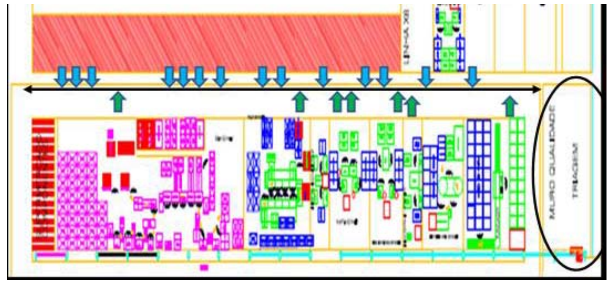
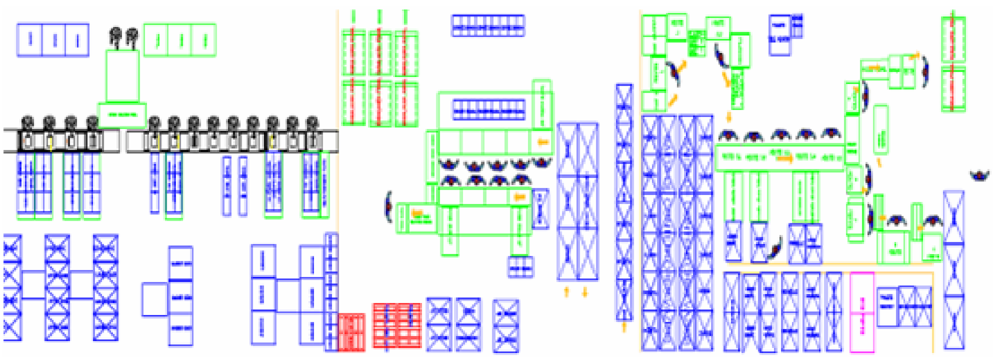


Figure 7. Input (blue arrows) and output (green arrows) of the materials before alterations

In the Figure 7 it is also possible to see the inputs (blue arrows) of semi-finished products from the semi-finished warehouse and output (green arrows) of the final product from assembly lines to finished warehouse showing a work flow confuse and mixed. The operating income (OI) of the assembly lines was 84% due to several stops because of the lack of supplies. Moreover, there were some deviations of stock because when someone withdrew from the stock of semi-finished material did not register in the system this withdrawal, causing stoppages in lines due to the lack of components. The consequences of this were high response times related to sorting out these problems.
Another problem was the excessive resources needed for the baby chair models, being assembled in 3 lines (Figure 8).



a) b) c)

Figure 8. Layout of 3 assembly lines: a) Chair 3 line; b) Chair 2 Line; c) Chair 1 Line

Table 4 shows the resources and space necessary for the 3 assembly lines.

Table 4. Resources and space for baby chair lines

	CHAIR 3 Line	CHAIR 2 Line	CHAIR 1 Line
Total assembly time (seconds)	262	307	486
Number of employees	8	7	15
Number of workstations	7	8	14
Occupied space (m2)	175	150	200

Finally, the shipment section also presented some problems related with too many operations that did not add any value to the product and the difficulty in the load preparation due to the lack of space.
This shipment was executed by 3 employees that performed the following tasks: removing the load from the shelf, putting it on the floor and proceeding with the data reading. The alveolus load had a capacity of 10 meters being insufficient for one truck, which has a capacity of 13 meters, necessitating the use of two alveoli. The pier space allowed six full truck loads. Since the quay was filled with cargo, the workers had to wait for the output of a load in order to carry out the following charge separation. Table 5 summarizes the problems identified, the place they occurred, the area related and the waste type.

Table 5. Problems identified, local of occurrence and area related and waste type

Problem	Local	Related with:	Waste type
High stock of raw-material and components	Warehouse	Raw-material and components (1 e 2)	Stock
High movements from stock to stock and inadequate supply of raw-materials and components	Warehouse and injection machines		Transports and energy
Raw-material stored outside of the plant	Plant exterior		Stock
High movements of forklifts	Injection machines and assembly lines	Injection and assembly lines (3 and 4)	Transports and energy
High changeover times of tools	Injection machines	Injection (3)	Waiting and motion
High number of parts rejected			Defects
High cycle times, machines and resources occupation			Waiting and energy
Processes with operations that do not add value	Injection machines and assembly lines	Injection and assembly lines (3 and 4)	Waiting and processing
Disorganization of production, dirty spaces, material excess	Injection machines and assembly lines	Injection, assembly lines and shipment (3, 4 and 5)	Stock, waiting and overproduction
Too much resources and occupied spaces (3 assembly lines for the same product)	Assembly lines	Assembly lines (4)	Overproduction, motion and transports
Motions and movements to the quality wall			Transports and energy
High WIP occupying space and stock management needs			Stocks
Line stoppages and disorganization due to the inexistence of a continuous flow			Waiting, motion and transports
High movements with different equipment; no space for workload preparation	Shipment	Shipment (5)	Waiting, transports, energy and systems inappropriate

3.2 **Presentation and implementation of proposed improvements**

The presentation of proposals followed the PDCA cycle, separating the proposals for each of the area/section referred above, in an actions plan presented in Table 6. A team of departments responsible was formed with 12 members in order to involve all people in the improvements. This plan implied great changes in the company with high impact in the routines and procedures of the departments. By involving all employees, it was possible to ensure the implementation of the changes and a continuous improvement culture that would subsist and grow inside the company. The responsible for each action is presented in Table 6 in the column “Resp.” with the initials of the person in charge of this action. In this table it is also possible to see that some actions did not start in the week (wk.) planned due to preparation of the work, operators and suppliers.

Before initiating the actions a VSM of future state was designed for everyone know where to go, i.e., what and where act to increase the activities that add value to accomplish the objectives defined. With the action plan of Table 4 the company expected to increase these activities from 5,4% to 11%, increasing from 29 to 40 hours and decrease the activities that do not add value from 22 days to 15 days (360 hours). To achieve the objectives some tools were applied like 5S, diagram of cause-effect, VSM, SMED, Kanban and Kaizen, in order to have continuous improvement.

3.2.1 *Automatic feed system of raw-material*

In order to eliminate all wastes related with the high movements and high utilization of equipment and people to carry them out, improper conditions of packing and high space utilization to accommodate raw-materials, a solution was designed that implies an automatic feed system of raw-material. This system is composed of stocking silos and tubes that transport the raw-material to the injection machines.

3.2.2 *Kanban application to the components suppliers*

Implementing an electronic kanban tool with the suppliers enables a reduction in the quantity of components stock, consequently a reduction in the inventory stocks and the warehouse space and the leveling of the supplier deliveries, according to the client demand. In this way the information flows quickly and efficiently with alerts for the stock ruptures, according the initial parameterization of the system. The functioning mode is as following:

1. The company elaborates a list of components necessary for the client demand.
2. Daily send a list with the components needs consumed in the day before, in order to replenish the defined maximum level.

3.2.3 *Proposals to implement in the injection machines*

This section presents the various proposals to improve the injection machines section: milk-run application, application of SMED, Kaizen tool implementation, cycle time reduction and 5S implementation.

Table 6. Actions plan

Area/ section	Problem	Proposal (Plan)			Do
		Action	Resp.	Date (prev.)	Date (real)
1. Raw-material	1.1. High movements from stock to stock 1.2. High utilization of equipment and people to execute these movements 1.3. Space occupied by raw-material and inappropriate conditions of packing	- Study of an automatic feed of raw-material directly to injection machines	AB/VV	Wk. 13	Wk. 16
2. Components	2.1. High movements from stock to stock 2.2. High stock of components	- Kanban and milk-run application in the components suppliers	MV/PO	Wk. 15	Ongoing
3. Injection	3.1. High movements of forklifts	- Milk-run application (collect final product and supply empty containers)	MV/PO/VV	Wk. 40	Ongoing
	3.2. High changeover times of tools	- Application of SMED tool	VV/PA	Wk. 3	Wk. 20
	3.3. High number of parts rejected	- Form Kaizen work teams to improve Iseos and Opal processes	VV	Wk. 6	Ongoing
	3.4. High cycle times, machines and resources occupation 3.5. Processes with operations that do not add value	- Form a work team to reduce cycles times	VV/PA	Wk. 20	Ongoing
	3.6. Disorganization of production, dirty spaces, material excess	- Build win-win client- supplier relationships	MV/PO	Wk. 15	Ongoing
		- 5S application and visual management	AB/RL	Wk. 1	Ongoing
4. Assembly lines	4.1. Too much resources and occupied spaces (3 assembly lines for the same product)	- Reconfiguration of assembly lines layout	VV	Wk. 1	Wk. 1
	4.2. High WIP occupying space and stock management needs	- Combine Fero with Opal/Axiss assembly lines	VV	Wk. 3	Wk. 3
	4.3. High number of operators involved in assembly	- Andon application	VV	Wk. 39	
	4.4. High movements of forklifts; flow discontinuous	- Analyze possibility of assembly lines working with 2 shifts or mix	AB/VV		
		- Alteration of plant layout to create continuous flow from injection to assembly lines and final product warehouse	VV	Wk. 45 Wk. 50	
5. Shipment	5.1. High movements with different equipment.	- Application of concept of pre-load	MV/AP	Wk. 13	Wk. 13

Milk-run application to collect the final product and empty containers

Using forklifts was identified as an inefficient transportation method due to the potentially dangerous and high number of movements. So, in the context of the project it was decided to study a better transportation inside the plant. The system chosen was a milk-run (Figure 9). The milk-run is composed of a tractor (a), a fixed platform (b) and a mobile platform (c) that is attached to the fixed one when the intention is to move the load. These platforms are hydraulically or pneumatically lifted from the floor in order to the only the wheels of the fixed platform touch the ground.

a) b) c)

Figure 9. Milk-run: a) tractor; b) fixed platform; c) fixed platform and platform mobile set

The milk-run is more efficient than the forklift because it enables predefined and standard routes. The functions of milk-run in the company would be:

1. Pick up all materials (final product, semi-finished parts) produced in the injection machines;
2. Ensure the supply of the workstations (components, raw-material, semi-finished);
3. Transport the collected materials to the predefined areas;
4. Collect the empty containers in the predefined areas;
5. Supply the containers to the workstations.

In the context of the project a circuit was prepared, integrating these functions in order to ensure the correct functioning of the collect/supply of the workstations. This circuit has an approximate duration of 20 minutes, so the workstations have autonomy of 20 minutes, having, as a rule, a minimum of 2 containers. In order for this to be accomplished discipline and rigor were needed.

SMED tool application in module 1

The module 1 for the SMED implementation was selected because has the injection machines with the longest changeover times. The SMED implementation started with the phases identification fundamental to the process. Five phases were identified: 1) team creation, 2) actual situation analysis, 3) wastes identification, 4) carrying out of the changes necessary to the improvement and, at last, 5) creation of the continuous improvement process. After team creation was necessary give formation to all members about SMED tool in order to sensitize and enlighten the members about the benefits and phases of SMED motivating them for the following task.

The team selected for the study an injection machine in the module 1 with many exchange dies and with a large dimension dies (1500 tons). This die had a cycle time of 83 seconds by part and entered in the machine 2 times by week to satisfy all the orders. Figure 10 shows the injection machine and the die used.

a) b)

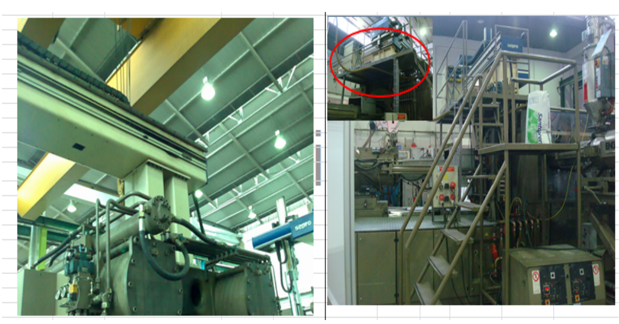
Figure 10. Equipments to support injection: a) injection machine ENGEL 1500 II; b) Die

The exchange of this die implied a process constituted by 13 operations in a total of 78 minutes, i.e., 1 hour and 18 minutes. This process was analyzed following the SMED procedure (identify and classify the internal from the external operations,…) by the team to obtain the maximum number of ideas in a brainstorming session. Forwarding this session, an action plan was developed, following the PDCA cycle (not presented here due to the dimension) and some documents and procedures were proposed:

1. Checklist of preparation
2. Operation mode description, identifying all tasks to execute for each responsible
3. Installation of a stair to access to top of the die in secure
4. Improvement of the connections of the dies signals
5. Acquisition of cars
6. Identification of oil connections
7. Improvement of the heating plugs of connections
8. Acquisition of a screwdriver
9. Installation of a depressurization system for the oil circuit

The checklist of preparation is a document to prepare the exchange, checking all that is needed to execute the change, avoiding waiting times searching for the correct tools and equipment. The tasks in this document were considered external operations. The operation mode description is a document that everyone could consult to inform about which job had to be done when and in what sequence.

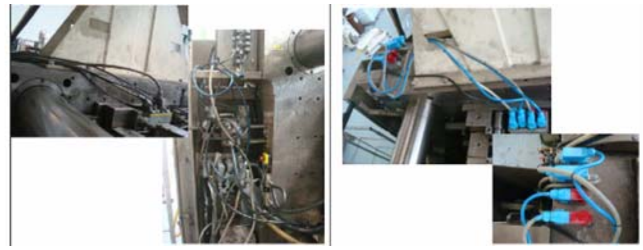
The installation of a stair was important to access the top of the machine and avoid accidents doing this. This was complemented with a platform installed above the machine (Figure 11).



a) b)

Figure 11. Injection machine a) back side b) Stair and platform to facilitate the access

All points referred to were improved through relatively simple solutions and most of them were cheap like for instance the substitution of the heating plugs of dies with cables suitable for the conditions and with the necessary dimensions, allowing the time reduction and error probability reduction (Figure 12).



a) b)

Figure 12. Heating plugs for the dies: a) before intervention; b) after intervention of SMED team

Figure 13 shows the changeover time evolution, according to the introduction and implementation of the actions proposed. A brief analysis show the greater efficacy, reflected in the changeover time reduction.

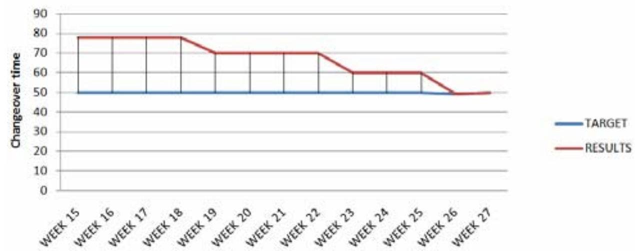


Figure 13. Changeover time evolution

Kaizen tool implementation in the processes Chair 4 and XPTO 4

The implementation of Kaizen started with workshops to teach workers about the kaizen teams. In this context a document-like A3 sheet was prepared to support the team's work with different sections: initial considerations (process and team to analyze), objectives and benefits, actual state, analysis, future state, action plan and results.

In order to solve the problems identified in the Chair 4 and Xpto 4 processes that have many wastes such as high waiting times, excessive movements, high level of rework, defects and over-processing two kaizen teams were created.

The kaizen Chair 4 was developed because of the parts' quality problems and the high number of direct labor to perform this process. This process needed 2 injection machines working simultaneously with the same cycle time and 2 dies. In this worked 3 employees and the rejection level for the 2 machines were 3,05% and 6,67%.

Some proposals to solve these problems were to remove the parings existent in the part provoked by the process introducing an alteration on the process and reconfiguration of the workstation layout. The kaizen Xpto 4 had the same methodology with clear improvements.

Cycle time reduction in the dies

A team was dedicated to the reduction of the cycle times of the chairs dies. This team was composed by a process engineer, a quality engineer a module

manager, a tuner technician and a robot technician. This reduction conduces to the quick production and increased availability of the machines to new projects.
Table 7 presents the cycle time reduction and the gains obtained related with the previous cycle time. These were achieved through optimization of robot velocity, open machine velocity and cooling time.

Table 7. Summary of the cycle time reduction

Die	Client	CT real	CT changed to	Gain (sec.)
Die 1	Baby Chair	66	60	6
Die 2	Baby Chair	55	50	5
Die 3	Baby Chair	83	80	3
Die 4	Baby Chair	80	73,5	6,5
Die 5	Baby Chair	55	50	5
Die 6	Baby Chair	65	60	5

At first sight this reduction seems insignificant but using a particular example the gains are remarkable. For example a 5 second cycle time reduction in a production of 650 chairs per day implied a reduction of 9 days by year that reflected a total gain of €14,110.00 per year (a gain in machine hours of €11,880.00 and a gain of €2,230.00 man hours).

5S implementation

The program 5S started in the company 3 years ago but a lot of problems continued like the disorganization and absence of cleanliness. This shows the difficulties discussed in the literature of this implementation. This implementation implies a change of mentality and a culture to sustain Lean. All improvement actions were identified with weekly “safaris” by the teams responsible for the different areas, where each team identified 12 improvements opportunities per month in the context of 5S. Each action was identified with a label and these actions registered in the 5S fields, pointing out the before and after situations. All actions were closed in the end of the month. This strategy allowed the achievement of many improvements to a visual and to a wastes elimination level like those shown in Figure 14. This improvement was only possible through the involvement of all team members.

Figure 14. Some improvements after teams intervention

3.2.4 *Proposals to implement in the assembly lines*

This section presents some proposals implemented in the assembly lines, namely the alteration of plant layout, Andon and visual management implementation and reconfiguration of assembly lines layout.

Alteration of plant layout

Attending to the high and cross movements in the corridor next to the assembly lines (Figure 7 referred) due to the input and output of the materials between assembly lines and semi-finished supermarket, the material flow was studied. The objectives were to create a continuous flow, eliminate the movements to the quality wall and to avoid the stoppages for components absence. Also, it was intended to give a better visual aspect to the assembly lines and to increase the operating income of lines to 92%. Figure 15 shows the alteration made to the material flow from and to the assembly lines and shows that a new corridor was created behind the assembly lines for the final product flow. The semi-finished products enter from the direction of the blue arrows and the final products go out via the green arrows. The quality wall was moved to a new position (black circle) to reduce the movements and to be nearer to the warehouse. With this alteration, some space was gained for a new assembly line.

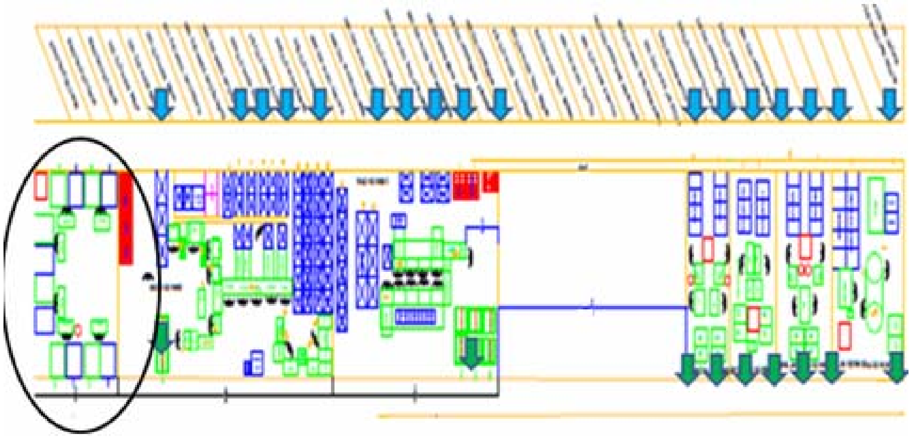


Figure 15. Input (blue arrows) and new output (green arrows) of the materials from the assembly lines

This alteration was only possible with the involvement of production, quality, logistic and maintenance departments.

Andon and visual management implementation

A mechanism Andon was implemented to help the assembly line management and warn the responsible for the need of supply and when to collect of materials from the assembly lines. This Andon, near the assembly line layout, illustrated in Figure 16, is composed of 4 lights:

1) Red – means stop of line;
2) Yellow – means supervisor call;
3) Blue – means components needs (supply);
4) Green - means that all is right, i.e. without problems or needs.

a) b)

Figura 16. Assembly lines: a) without Andon; b) with Andon (in the yellow square)

Reconfiguration of assembly line layout

The reconfiguration of assembly lines was needed because there were 3 products of the same family (baby chairs) sharing the same process but assembled in 3 different assembly lines: 1) Chair 3 assembly line; 2) Chair 2 assembly line and 3) Chair 1 assembly line. A study demonstrated that it is possible to assemble the products in the same assembly line. The assembly selected to assemble the other products was the Chair 3 assembly line. In a 1st phase, it was studied the transfer of assembly of chair Chair 2 in Chair 3 assembly line and in a 2nd phase the transfer of the assembly of chair Chair 1 to Chair 3 assembly line. With this reconfiguration a space of 350 m2 was gained for the new assembly lines, being possible to work in three shifts in order to maximize the equipment utilization or work in mix and assembly 2 products in a shift.

All changes and in particular these related with the assembly lines reconfiguration implied physical alterations like introduction of electrical and pneumatic connections, installation of gutters for the containers transport and Andon mechanisms. These changes had impact in the overall flow of materials simplifying this because the red route is eliminated, reducing the distance travelled by a total of 652 meters.

3.2.5 *Application of pre-load concept*

The concept of pre-load consisted in preparing full loads to the soil which will subsequently be loaded on trucks. The increase of alveoli to 14.40 meters, allows separation of a truck complete per well. It was necessary to push the area of the shelves in a module into the hallway, losing store capacity by 6%. The dock was capable of 10 complete trucks, thus having a capacity increase by about 40%, which allows a better fluidity in charge separation. With this change, stakeholders were able to prepare the loads with a shift forward, they can start the next day or to reserve space for other pre-loads.

With a restructuring, the warehouse was also optimized regarding the process Baby Chair, placing references to soil that had more rotation and thus performed the pre-loads faster. Thus, it eliminated waste handling, waiting times and achieved resources optimization.

3.3 **Results discussion and analysis**

This section presents the results of the proposals implemented that are discussed and analyzed. Some of the proposals were not implemented but it is discussed what is expected with their implementation.

3.3.1 *Improvements with the raw-material and components supply and store*

A space of 100 m2 was gained from the raw-material stock area, being eliminated all flows of raw-material if the automatic feed system was implemented. This proposal and kanban with suppliers was not yet implemented but potential improvements to be achieved are presented in Table 8.

Table 8. Summary of improvements with raw-material and components supply and store

Raw-material	Before	After
Area (m^2)	238	40
Stock (days)	10	10
Distances (m)	652	0
Transport time (min.)	9	0
Components	**Before**	**After**
Area (m^2)	20	10
Stock (days)	8	3

3.3.2 *Improvements in the Injection section*

All proposals were welcome but not all were implemented, mainly, because of the high initial investment of some of them, namely, the milk-run application to collect final product. SMED implementation was implemented and brings benefits to the company. With this implementation the company reduced the changeover time by 15%. This reduction permitted maximizing the resources utilization, allowed producing smaller lots and increasing the machines' capacity. The company becomes more agile and capable to respond to the new variations and demands of market.

The Kaizen action allowed the availability of one collaborator to other sections or projects and reduced the rejection level by 3%. This improvement resulted in a productivity increase by 33% and an annual gain of €14,000.00. The cycle time reduction by 10% of six dies allowed gains of €46,110.00. Table 9 presents such improvements.

Table 9. Summary of improvements in the injection section

Injection	Before	After
Changeover time (min.)	60	50
Cycle time (sec.)	404	373,5
Employees	35	34
Employees Chair 4	3	2
Rejection level (%)	6	3
Productivity (parts/man)	150	225
Gain (€)		14,000.00

Regarding the 5S program, the fact of giving prominence and relevance to the teams responsible for different areas functioned as a great motivational boost, since the improvements were noticeable both in terms of quantity and quality of the same. Tasks like select, organize, clean, standardize and discipline are clearly present in the work teams and these are the golden rules of visual management company.

3.3.3 *Improvements in the assembly lines*

The changes in the assembly lines improve the work conditions, increase the operating income (OI) of lines in 12% resulting in an increase of productivity. With the reconfiguration of the assembly lines the costs could be lower if the option is for shift fixed, optimizing in this way the resources and leveling the labor. Table 10 summarizes the improvements in this section.

Table 10. Summary of improvements in the assembly lines section

Assembly lines	Before	After
Operating income (%)	84	96
Employees	30	29
WIP (days)	2	1
Area (m2)	525	175

3.3.4 *Improvements in the shipment section*

With the preparation zone alteration an increase of 40% was achieved in the area. The load preparation passes from 6 to 10 pre-loads, with a total gain of 10,197€/year. Table 11 presents the improvements for this section.

Table 11. Summary of improvements in the shipment section

Shipment	Before	After
Alveolus length (m)	10	14,40
Loads number/shift	6	10
Average time per each preparation (min.)	78	48

3.3.5 *Global results and values of performance indicators*

Table 12 shows the evolution of KPI before and after Lean implementation and after implementation of kaizen events and SMED to other machines and modules.

Table 12. Values of KPI of Baby Chair product family before and after Lean implementation

KPI		Before	After	Gain (%)
Productivity (%)		10	10	0
WIP (days)		2	2	0
Lead time (days)		22	15	31,8
OI module (%)	1	84	90	7,1
	2	88	92	4,5
	3	89	93	4,5
	4	84	96	14,3
Tool changeover time in module of injection (min)	1	60	50	16,7
	2	50	40	20,0
	3	36	30	16,7
ppm chair (%)	1	2	1,5	25,0
	2	4	2	50,0
	3	6	3	50,0
	4	4	2	50,0
Value added (%)		5	11	120,0

The increases of value-added means activities that do not add value are reduced. When all action comes to the end the lead time will be 15 days, a reduction of 7 days relating to the initial value. The productivity for now is the same, but the investment amortization will be only 3 years and this permits to reach a productivity of 38%. Table 13 summarizes the investments in resources and gains for each proposal in each section.

Table 13. Summary of investments and gains with the proposals implementation

Area/ section	Action	Investment (€)	Gain by year (€)	Amortization rate
1. Raw-material	- Study of an automatic feed of raw-material directly to injection machines	400,000.00	176,753.60	2,3
2.Components	- Kanban and milk-run application in the components suppliers	---	---	
3. Injection	- Milk-run application		14,400.00	
	- Application of SMED tool	11,000.00	21,700.00	
	- Form Kaizen work teams to improve Iseos and Opal processes	3,000.00	20,000.00	
	- Form a work team to reduce cycles times	0.00	46,110.00	
	- 5S application and visual management			
4. Assembly lines	- Alteration of plant layout	5,000.00	28,953.60	
	- Andon application	1,200.00	?	
	- Reconfiguration of assembly lines layout to combine Fero with Opal/Axiss assembly lines	---	43,507.20	
5. Shipment	- Application of concept of pre-load	0	10,197.00	
	Total	420,200.00	361,621.40	

The implementation of proposals not yet implemented gives expectations of better values because some actions are ongoing. The impact of others, at the moment of this analysis was not so far visible.

4. CONCLUSION

In this project some Lean Production principles and tools were adopted and implemented in a company in the plastic industry. The tools more relevant were the VSM, Kanban and milk-runs application, SMED, kaizen, 5S and Andon mechanism. The VSM allowed the mapping of the process (in this case, the baby chair product family) and the identification of the wastes with the objective of eliminate them.

The Kanban and milk-run applications are important to pull the production, generating raw-material and component needs and permitting a better control and management of these needs. The milk-run introduction permitted a continuous supply of raw-material and components to the workstations and the collection of final product, eliminating excessive movements and energy costs.

The SMED implementation reflected a changeover and waiting time reduction because all stakeholders are prepared and with the equipment needed. Kaizen implementation meant continuous improvement through the common sense allowing suggestions from the employees to be analyzed and evaluated. The 5S program incentivizes and promotes procedures of cleanliness; ordering and organization to keep create a more pleasant work environment.

Additionally, assembly line reconfiguration allowed freeing up space, simplifying processes, reducing movements and facilitating the interaction and intervention of all. In these lines it was important that the Andon mechanisms were installed in order to facilitate the visualization and control of the state of the line by the line manager, reducing the stoppages due to lack of material, breakdown of machinery or other reasons. The pre-load concept was implemented, facilitating the truck load and reducing the time to do this.

Through these principles and tools the objectives were achieved: a standardized and cyclical supply was implemented, better work conditions were created, wastes were eliminated and gains achieved of €360,000.00, approximately, contributing to a better financial performance. The changes to attain the objectives were not easy to implement because of the workforce's resistance to change, so it was important having a top-down approach and proceed to the implementation by phases. It was also necessary to involve all stakeholders to achieve a consensus with this new production model and implementing and measuring the efficacy step by step.

It is undeniable that people are the most important asset to the success of Lean implementation journey because if these are not involved this journey will be unsuccessful. Furthermore, once uncovering further potential among the workforce, it allowed achieving significant results. In this project this happened with the kaizen teams, SMED teams, cycle time reduction teams and assembly lines reconfiguration teams. They know their workstation better than anyone and feel the difficulties and they are in the best position to suggest alterations and help with the improvement. It was only necessary to make the first step for the change and after that every day improvements will happen.

This project was developed in a context of an action-research study with constant cycles of analysis, planning of alternatives, evaluating and discussing the findings. The researcher continues working in this company, constantly identifying new problems and ways to solve them in a cyclical process. These findings are limited to the context of the case study company and the results cannot be generalized. Future research within this company involves continuity of implementation of actions and, more importantly, a design of a Lean Master work model to create value in this company and in the group it belongs to with objectives of creating a common and shared language.

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Finansijske i ljudske dobiti Lean Proizvodnje u industriji ubrizgavanja plastične mase: studija istraživanja radnji

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Rezime

Ovaj rad predstavlja rezultate implementacije projekta Lean proizvodnje koji je razvijen u kompaniji gde se radnje zasnivaju na ubrizgavanju plastične mase. Glavni cilj projekta bio je primena Lean principa i alata koji uključuju sve zainteresovane strane u kompaniji. Prvi primenjen alat je bio VSM kako bi se dijagnostifikovao proizvodni sistem i identifikovali utrošci i glavne oblasti za poboljšanje. Neki predlozi su prezentovani i implementirani korišćenjem Lean alata poput 5S, PDCA ciklusa, Kanbana, SMED i Kaizena. Neki dobijeni opipljivi i finansijski rezultati su povećanje produktivnosti montažnih linija za 12%, operacionog prihoda za 6%, smanjenje vremena šest ciklusa je palo na 10%, smanjenje od 15% vremena promene alata, dok je povećanje ukupnih prihoda procenjeno na €360.000,00. Neopipljivi rezultati su bili učešće operatera i uključivanje u kontinualno poboljšanje sa Lean implementacijom.

Ključne reči: *Lean proizvodnja, industrija ubrizgavanja plastične mase, Lean finansijske i ljudske dobiti*