Efficiency improvement through the application of lean methodologies and tools: the case study of a metalworking production company

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ABSTRACT

Competitive pressure in current markets leads companies to focus on increasing the efficiency of their operations in order to deliver products in greater quantity and quality, with the same or lower costs. Creating value for customers and reducing the waste of operations, two basic principles of lean management, are now in focus in the current business strategy. Coupled with lean management, comes the concept of *Kaizen*, which adds the need of involving all employees of a company and highlights the importance of acting on the *Gemba* and using visual management. Company A is a Portuguese metalworking production company that intends to increase the efficiency of its operations in order to remain competitive and thereby grow its sales. Moreover, its production system has some structural problems that can compromise the company's medium-term results. This work results from the company's management need of implementing a lean management system and a *Kaizen* philosophy within it.

After conducting a literature review, a multi-methodology of action was created, composed of lean methodologies (*Kaizen* and just-in-time), tools (value stream mapping, root cause analysis, 5S, *Kanban*, *Heijunka* and SMED) and activities (*Gemba* walks, layout change and equipment improvement), adopted during the development of the project, first with an identification and characterization of waste, followed by an implementation of improvements. In the end, an investment priorization framework for improvements is also developed. Finally, the overall equipment effectiveness increased 39.5%, the average setup time of equipment decreased 25.8%, the stock level decreased 21.9%, the average lead-time of company's activities decreased 27.2% and its occupied area decreased 8.4%. There were also gains in infrastructures, logistics, production, ergonomics, quality, leadership and planning.

Keywords: Lean, *Kaizen*, Lean Production, Productivity, Overall Equipment Effectiveness, Framework

1. INTRODUCTION

The economic crisis that hit Europe sparked an alert in the business world, it warned companies that they needed to be more efficient to survive, they had to increase productivity and reduce waste to remain competitive (Waring and Bishop, 2010).

This warning also came to Portugal. With the crisis came a sharp decline in demand, both internal and external, and thus an increase in competitiveness between companies resulting from the lower amount of products purchased on the market and the reduction of prices, which reduced the profit margin of each product sold (Samuelson e Nordhaus, 2005). Since the revenue side in companies' accounts has been seriously disturbed by the national economic conjecture, they could only act on the the costs of their operations to remain competitive and protect their financial results. Without margins for costly investment solutions, companies seek to obtain the same or better results with the same or even less resources, i.e., they want to increase the productivity of their operations (Waring and Bishop, 2010). Defined differently by different authors, in operations management, productivity is regarded as the ratio between outputs and inputs (Sumanth, 1994).

The first major change in the industrial paradigm resulted from the activity of Henry Ford, when he created, in 1913, the assembly line for the model Ford T, causing an unprecedented labor productivity improvement in history. Then, after the Second World War, Japan experienced a deep crisis period and most of its companies were forced to restructure their processes to survive. This event led Shoichiro Toyoda and Taiichi Ohno to create the lean production system, marking the second major change in the industrial paradigm (Womack, Jones and Roos, 1990). The lean concept first appears in the book of Womack *et al.* (1990) entitled "The Machine That Changed the World", characterizing lean production as a set of methods that when combined have the potential to display a particular competitive state of a company.

Melton (2005) synthesizes the fundamental principles of lean production, including the identification of added value, the elimination waste and the creation of a value stream to the customer. Chen, Li and Shady (2010) define waste as any activity for which the customer is not willing to pay, and Melton (2005) divides it in seven groups: overproduction, transport, waiting, over processing, defects, inventory and motion. He also states that the creation of a one piece value stream to the customer, achieved by employing a pull production system, significantly reduces the lead-time to the consumer at all stages of the process. Also, the main benefits of lean production are the reduction of customers' waiting time, the reduction of producers' inventories and more robust processes.

In this work, lean methodologies and tools are applied in a real case, where a metalworking production company aims at implementing a lean management system.

2. STATE OF THE ART

2.1. Lean methodologies

Two of the most used lean production methodologies are *Kaizen* and Just-in-time (JIT) (Melton, 2005).

Kaizen is an improvement methodology that aims at creating value and removing waste, mostly applied through *Kaizen* events, where multidisciplinary teams are formed to find solutions to problems and improve the production systems of companies (Chen *et al.*, 2010). Besides, *Kaizen* is a daily practice of continuous improvement, which includes doing changes, tracking results and adjusting the changes, taking into account the data that is being gathered. Also, *Kaizen* should include all employees from all levels of an organization and be focused on the *Gemba*, the working place where "everything happens" (Chera *et al.*, 2012).

Baykoç and Erol (1998) state that a JIT system has a single goal, to produce the required items in the required time and quantities. In an ideal production system, the inventory at each stage of the process consists of only one unit. However, this goal can not be achieved in real systems due to the stochastic nature of demand and process times. In a JIT system, working in pull, when an order is generated at the end of the line, the item produced in the previous phase is transferred to the end of it. The removal of the item from the previous step generates the production of an additional item at that stage to replace the one taken.

2.2. Lean tools and activities

There are several lean tools that are used, currently, to help enhancing the productivity of companies: Value Stream Mapping (VSM), root cause analysis, 5S, *Kanban*, Single Minute Exchange of Die (SMED) and *Heijunka* (Brunet and New, 2003; Melton, 2005).

Melton (2005) describes the VSM as a map that shows each step of a value chain, which is used to collect data and to distinguish value added activities from non value added activities. The VSM should be applied in three steps: mapping the current state, identifying the root causes of the identified waste and mapping the future state (Rahani and al-Ashraf, 2012).

Root cause analysis is a problem solving method used to identify the real causes of problems so that they can be solved at its source. Two techniques used in this method are the "5 Whys" technique, where the question "Why?" is asked several times until the cause of a determined problem is found, and the Ishikawa diagram technique, which is used to depict problems throughout a productive process, working as a causal diagram (Chera et al., 2012).

5S is a five-step process used to organize workspaces and to make them suitable for the practice of visual management: sort, straighten, shine, standardize and sustain. Also, visual management is the identification and standardization of workspaces and the visual monitoring of performance indicators (Melton, 2005).

Kanban is a card in which certain information of a material to be "pulled" in a given system is written. It serves as a mean of communication to trigger the start of the next unit of production and to "pull" the item processed between the different stages of a production system, thus helping to control the movement of materials (Baykoç and Erol, 1998).

SMED is a five-step procedure used to turn a setup in a more quick and effective process: mapping of the initial situation, separating internal and external setup (all setup activities that can be done with the equipment stopped and working, respectively), converting internal setup to external setup, reducing or eliminating the internal work and reducing or eliminating the external work (Ulutas, 2011).

Heijunka ensures that production is scheduled to produce the same sequence of products in a given time interval, in which the production sequence may vary according to the degree of rotation of the items being produced. It protects the producer from the variability of the system (Hüttmeir *et al.*, 2009).

Furthermore, there are other activities conducted to improve productivity in plants, such as, changing the shop floor layout or improving the existing equipment. Aase, Olson and Schniederjans (2004) state that, for example, changing the traditional straight-line layouts to U-shaped layouts can increase labor productivity. According to Jit Singh and Khanduja (2009), machine design is one of the major factors contributing to high setup times and, thereafter, lower productivity and higher manufacturing costs in the production industry.

3. METHODOLOGY

3.1. Main approach

After an extensive literature review, it was found that none of the studied authors used an implementation approach of a lean production strategy that applied all the lean methodologies (*Kaizen* and JIT), tools (VSM, root cause analysis, 5S, *Kanban*, *Heijunka* and SMED) and activities (*Gemba* walks, layout change and equipment improvement) previously identified. Thus, Sundar, Balaji and Kumar (2014) state that a lean production strategy to be implemented in a successful manner requires a simultaneous integration and execution of various lean elements, i.e., various lean methodologies, tools and activities, implemented in a well defined sequence. Due to the absence of examples in the studied literature, it is proposed a multi-methodology of integration of all these lean elements to be applied during the project (Figure 1) (Mingers and Gill, 1997). This multi-methodology consists of three successive stages, supported by *Kaizen*, with the carrying out of *Kaizen* events, and by JIT, with the adoption of the concept of pull planning.

3.2. Stage A: identification of causes

This stage starts with *Gemba* walks on the shop floor of the company. During these *Gemba* walks, the production director of the company, as well as other employees, should be present so that clarifying questions can be asked whenever needed. This activity is done to know the Gemba, to visualize its processes and to identify some initial waste.

Then, a VSM is done to understand all the processes that occur in the company since the arrival of raw materials to the expedition of finished products. It also helps to identy more waste. The VSM should be applied, during a *Kaizen* event and in two days, in three successive steps: mapping the current state of the company, identifying the root causes of the identified waste and mapping the future state of the company. A multidisciplinary team, composed by the production director, the logistics deputy director, the quality deputy director and the production planning manager, should be present to improve coordination and decision making (Fleissig, Jenkins and Catt, 1996).

In the second step of the VSM, to identify the origin of waste, two root cause analysis techniques should be applied: the Ishikawa diagram and the “5 Whys”.

3.3. Stage B: implementation of improvements

In the second stage, the focus is on the actual implementation of improvements, starting with the layout change of the company shop floor in order to correct some of its structural problems and organize it, mainly regarding the distinction between logistics activities and production activities. Due to the strong logistics and operational component of these changes whenever one area appeared to be remodeled, all employees of that area of the company should stop their functions to assist in the change, until it is finished. Because of the heavy weights and big dimensions of equipment and due to the technical knowledge necessary to assemble and disassemble them, external specialized help could also be hired.

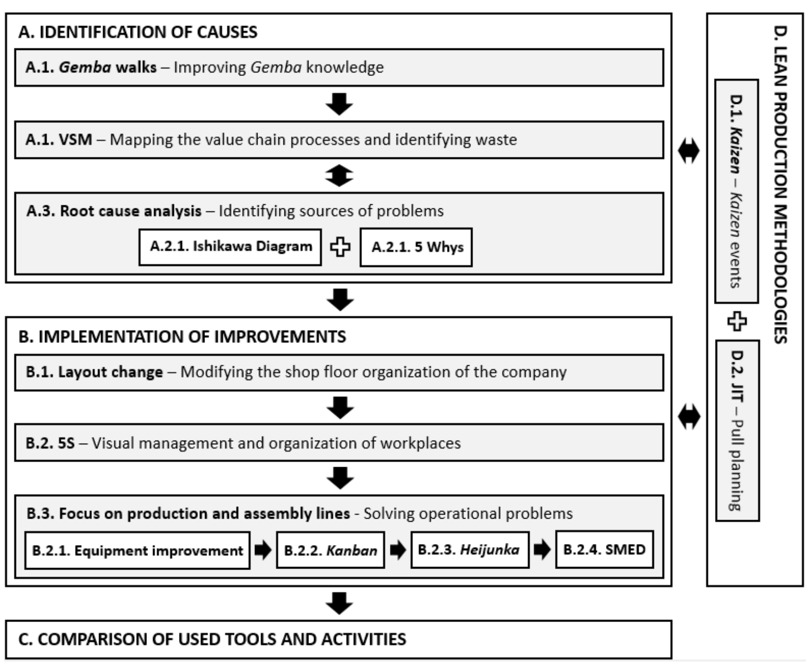

Figure 1 - Multi-methodology of integration applied in this work.

Then, the 5S lean tool is implemented to organize workspaces, cut out unnecessary waste and introduce visual management. Its implementation methodology is organized in four phases:

1) Choose pilot teams and training in the 5S tool - a pilot team is chosen for each main area of the company, each composed by 5 elements. It is given theoretical training to pilot team members, in lecture format, in two sessions.
2) Implementation of 5S in the workspaces of pilot teams - the 5S tool is implemented in the selected workspaces. This phase also works as a 5S practical training to previously selected teams.
3) Implementation roll out to the remaining teams in the company - with the support of the workers of the pilot teams, already trained in the method, the 5S tool is implemented in the remaining workspaces of the company, involving, finally, the remaining teams of employees.
4) Conducting audits to all teams - to ensure the correct implementation of 5S and the achievement of intended results, it is performed, based on a binary evaluation grid ("1" for satisfy and "0" for not satisfy") an audit to all working teams.

In the last step of this stage, the focus is on solving the company's structural problems and improving the operational performance of its production and assembly lines by improving the existing equipment, by implementing a *Kanban* system and a *Heijunka* box and by applying SMED to the existing equipment.

Based on the waste identified in stage A, and its causes, a technical study about possible improvements to existing equipment should be done in order to remove or minimize the waste. This study should consider both benefits and costs of improvements.

Regarding the SMED implementation, if the number of equipment is big enough, the implementation method should consider two different steps to save time: choose an equipment for each different group of equipment and implement a SMED pilot in it and do a roll out of the lessons learned to all equipment in the company. The SMED pilots should follow the five-step procedure stated in the previous chapter.

3.4. Stage C: comparison of used tools and activities

In this last stage, it is carried out a comparison of used tools and activities in order to analyse the impact of each one in the company, as well as the investment made to achieve the respective impact. With this comparison, it is intended to order the activities and tools used by order of preference of utilization so they can be implemented by the defined order, if any restrictions of money or time exist, as well as defined objetictives of impact. In the end, an investment prioritization framework is elaborated to facilitate this ordination of tools and activities in future similar projects with a similar used methodology.

4. CASE STUDY: COMPANY A

4.1. The company and the metalworking industry

Company A belongs to the group of Portuguese companies that want to improve their efficiency in order to remain competitive. It operates in the metalworking industry and produces mostly metal sets and components for the automotive industry by blanking, stamping, assembling and welding. It has 20 stamping presses and 14 welding equipment executing this set of operations. Its stamping presses are divided in three groups, regarding their dimensions and complexity of operations performed: 7 conventional stamping presses (that perform stamping in a single phase, 9 progressive stamping presses (that perform stamping in a sequence of phases) with 250 ton or less and 4 progressive stamping presses with more than 250 ton. The conventional stamping presses are the ones with the smaller dimensions and complexity of operations performed, while the progressive stamping presses are the ones with the bigger dimensions and complexity of operations performed.

On average figures, companies that operate in the metalworking industry generate about 2.7 times more turnover, and have 2.5 times more employees than the average company in Portugal, in 2013. Within the manufacturing industries, the metalworking industry has a significant impact in Portugal, accounting for 24.9% of turnover, 25% of workers and 23% of the total amount of companies. By size classes, the industry is mainly made up of micro-enterprises (up to 10 employees and a turnover of less than € 2M). However, large companies (over 250 employees and turnover of more than € 50M), although only 1% of the total, accounted for 53% of the turnover, in 2013. Company A is positioned in the remaining 26% of companies with a turnover of around 15M €, i.e., in the small or medium enterprises of the sector. Regarding the growth of the industry, between 2009 and 2013, the total turnover of the industry increased 0.8 percentual points, while the number of companies decreased 0.2 percentual points. The EBITDA of the sector grew 5% in 2013, where 56% of the companies improved their indicator. This industry is characterized by a high external openness, where in 2013, 60% of its total turnover came from external markets (Banco de Portugal, 2015). These good indicators are mainly due to the productivity improvement and waste reduction that has been occurring in the industry as whole.

With more than 150 employees, Company A seeks to increase the overall productivity of its plant in order to grow its sales, without having to make high financial investments, and to keep up with the good indicator of its industry. In addition, the company management knows that its production system has some structural problems that can compromise the company's medium-term results. This project comes from this set of necessities of Company A.

4.2. Identification of waste

After the *Gemba* walks, a VSM was also performed with the presence of a multidisciplinairy team, composed by elements of Company A (described in section 2.2.). The processes of the company were mapped, resulting in the following four actual streams of activities:

- Stream 1 - it begins with the stamping process, followed by the degreasing of stampings required to remove unwanted contaminants such as hydrolic oils (of the the lubricating system of the presses) or the oils used in the actual manufacture of parts. Then when necessary the manufactured parts are painted. The last operation is the packaging, before the parts are stored in the finished goods warehouse. This flow, in number of parts produced, corresponds to 79% of the total volume.
- Stream 2 - it begins with the stamping process, followed by the welding process. After they are welded, the parts need to be subjected to a quality inspection. In the end, the parts are packed and stored at the finished goods warehouse. This stream corresponds to 11% of the total volume.
- Stream 3 - after being stamped the parts go to the middle stock that supplies the assembly lines. Then when necessary the manufactured parts are painted. The last operation is the packaging, before the parts are stored in the finished goods warehouse. This stream corresponds to 7% of the total volume.
- Stream 4 - it begins with the stamping process, followed by the welding process. After they are welded, the parts need to be subjected to a quality inspection. Then when necessary the manufactured parts are painted. Finally, the parts are moved to the assembly lines and, in the end, they are stored in the finished goods warehouse. This stream corresponds to 3% of the total volume.

The main wastes found in the company are reported in Table 1. This organization of waste helped the team to have a clear, comprehensive and structured picture of the existing waste. In a conversation with the multidisciplinary team, it was asked to identify the most relevant waste, so it could be studied in greater detail. The team identified the high lead-time of the activities as the most relevant waste of all of them.

In order to delve into the causes of this problem, an Ishikawa diagram was done. It organized all possible

Table 1 - Main waste identified in Company A.

TYPE OF WASTE	DESCRIPTION
Overproduction	High work in progress. The production schedule is not adjusted to the demand.
Transport	The loading of tools and raw material coils into the stamping presses are done exclusively with the lift-truck.
Waiting	The four analysed streams of activities have a very high lead-time (customers' wait).
Over processing	Excessive occupation of the working area (excessive resources processing).
Defects	The quality inspection is a work that results from defects that may occur in the company's activities
Inventory	High level of inventory, mainly because of the high levels of middle stock (before and after all operations that occur in the company).
Motion	The disorganized and maladjusted layout hinders the logistical supply and it makes employees walk too much to execute their functions.

causes of this traditional productive and logistic problem in five groups, known as the "5M": machine, method, man, material and measure (Ishikawa, 1990). With this exercise, it was concluded that the high lead-time present in the four streams of activities analysed was a cause, both direct and indirect, of almost all the waste identified in the beginning.

As identified in section 3.1., increasing the productivity of Company A is one of the main goals of this project. Since it is a production company, its global productivity results mainly from the productivity of its equipment, measured with the KPI Overall Equipment Effectiveness (OEE), calculated by multiplying three factors measured in percentage (Muchiri and Pintelon, 2008):

1) Availability - ratio between the actual running time of equipment and the running time planned for the same equipment. Identifies and quantifies the planned and unplanned stops of equipment.
2) Performance - ratio between the total amount of produced parts and the maximum number of parts that can be produced in the actual running time of equipment. Identifies and quantifies empty cycles and microstoppages of equipment.
3) Quality - ratio between the number of parts produced with acceptable quality for sale and the total number of parts produced. Identifies and quantifies the non-production of quality.

In order to understand why the OEE value does not display the desired rate, the "5 Whys" technique is applied during a *Kaizen* event, together with the multidisciplinary team. It was concluded that the low values of OEE are caused mainly because of the low values of "Availability" and "Performance". Moreover, the major driver of the "Availability" factor is the high duration of the setups performed in equipment and the major driver of the "Performance" factor is the lack of organization in workspaces.

Finally, a future vision of the company's processes was mapped, together with the multidisciplinary team. In this future state, the planning department plays a key role in the company's strategy since it starts to unfold the customer's daily requests and demand forecasts into shipping orders, through the daily planning of loads, and into producing orders, with the help of a *Heijunka* box. Moreover, the logistics trains start to have a preponderant role in the company's operations, being primarily responsible for the information flow (through the use of *Kanbans*) and material handling over the plant, between presses, welding equipment, assembly lines and the finished goods warehouse. Furthermore, the stocks before and after each process would end.

4.3. Objectives and performance indicators

After the execution of the VSM and the Root Cause Analysis, it was possible to objectively implement the improvements in order to correct specific issues (Table 1). Thus, for each tool or activity was stated the main objective to achieve, as well as the performance indicator to measure its success (Table 2).

Table 2 - Objectives and KPIs of the activities and tools.

TOOL / ACTIVITY – MAIN OBJECTIVE	KPI	INITIAL VALUE
Layout change - freeing some space in the working area	Occupied area	8720 m^2
5S – organising and adjusting workplaces and improving employees' performance	$OEE_{performance}$	67.6%
Equipement improvement - reducing setup times and improving equipment availability	$OEE_{availability}$	65.9%
Kanban* and *Heijunka - reducing the lead-time of activities and the level of inventory	Lead-time / stock	10.3 days / 1033016 parts
SMED - reducing setup times and improving equipment availability	$OEE_{availability}$ / Setup time	65.9% / 66 min

But, to be able to understand the impact of each action, it is necessary to gather information of the inicial state of each performance indicator. The KPI "Occupied area" was based on the total working area of the company, which was all occupied. The value of the lead-time of each stream of activities was given by the multidisciplinary team when doing the VSM. Then, its global value was calculated taking in consideration the percentage of the total volume of each stream. The instant value of the stock was also given by the multidisciplinary team and it represents the exact value of the stock at that time. The average value of the setup time was calculated over a sample of 1034 setups, gathered over 22 working days. The bigger the dimensions of equipement and the complexity of operations performed by them, the higher would be their setup times. Finally, the average value of the OEE and of its factor was calculated over a sample of 748 values, one per day during 22 working days for each one of the 34 equipment. These values were given by the production department. Finally, a common KPI measured for every tool or activity was the OEE value, with an initial average value of 44.3%.

5. RESULTS

5.1. Layout change

The nine major layout changes were the following:

1) The workspace of the tools maintenance department was organized in order to increase its efficiency and capacity. Buesa (2009) states that organizing workspaces can improve its capacity up to 20%.
2) Almost all presses were moved in order to, in the future, having a lower number of employees working in the same number of equipment without having to perform unnecessary travel, according to the cell layout technique (Pattanaik and Sharma, 2009).
3) According to Hart, Taraba e Tomaštík (2014), a correct management of workspaces is mandatory to better control the stream of materials in industrial companies. Regarding that, logistic corridors were created and the existing ones were restructured.
4) The welding equipments were turned so that the employees who worked in them would face the *Gemba* and have natural light on their back. Hales (2006) states that physical characteristics such as light, temperature, availability of utilities and the floor strength must be taken into account when defining the workspaces layouts.
5) The air, electricity, water and exhaust systems were restructured. They were outdated and urgently needed an update (Hales, 2006).
6) The disposition of the quality wall was organized to improve its capacity by 94%, going from 34 references to 66 references with direct access.
7) The expedition area was augmented and organized. Rouwenhorst *et al.* (2000) state that the design of the loading areas is one of the existing tactical problems in the definition of warehouse layouts.
8) An area dedicated to the technical reception of components and packages was created (Rouwenhorst *et al.*, 2000).
9) An area dedicated to the storage of empty containers was created. Rouwenhorst *et al.* (2000) state that the unorganized allocation of new products (in this case, packages) in racks is one of the current operational problems in warehouses.

After the layout changes, during 20 working days, data was gathered. The summary can be seen in Table 3.

Table 3 - Results of the layout changes.

TYPE OF GAIN	DESCRIPTION
OEE	• Increased **2.9%**, going from 44.3% to 45.6%
Occupied area	• Decreased **8.4%**, going from 8720 m^2 to 7985 m^2
Infrastructures	• Tolls maintenance department • Air, electricity, water and exhaust systems • Expedition area • Technical reception area • Empty containers area
Logistics	• Logistic corridors
Ergonomics	• Light in the welding workspaces
Quality	• Quality wall efficiency

5.2. 5S implementation

In the sort phase the necessary things were defined and the unnecessary things were identified. Then the sites were freed from the unnecessary things that didn't add value to the customer, directy or indirectly, i.e., some tools, machines and materials were removed. In the straighten phase all necessary things were arranged, in a specific place for each different thing. In the shine phase the workplaces were cleaned, specifically the stations, equipment and tools. In this phase the initial conditions of spaces and equipment should be guaranteed. In the standardize phase a set of rules and norms were created to support the previous three phases. These rules and norms set the difference between a traditional organization and a lean organization that is governed by good visual management practices. In the sustain phase, regular intern audits should be done to guarantee the healthy state of the *Gemb*a. Thus, audits were done and the results were recorded for future monitoring. After the 5S implementation, during 20 working days, data was gathered. The summary can be seen in Table 4.

Table 4 - Results of the 5S implementation.

TYPE OF GAIN	DESCRIPTION
OEE	• Increased **11.4%**, going from 45.6% to 50.8%
$OEE_{performance}$	• Increased **10.8%**, going from 69.7% to 77.2%
Ergonomics	• Safety in the performance of daily functions
Leadership	• Motivation of work teams • *Gemba* knowledge • Ability to manage people and processes

5.3. Equipment improvement

A study about possible improvements to equipment was carried out together with the technical department of the company. The study contained both their benefits and their costs. Finally, it was chosen to implement rapid setup tables in 16 of the 20 existing presses and gantries for raw material loading in 4 of the 20 existing presses. After these improvements, during 20 working days, data was gathered. The summary can be seen in Table 5.

Table 5 - Results of the equipment improvement.

TYPE OF GAIN	DESCRIPTION
OEE	• Increased **3.9%**, going from 50.8% to 52.8%
$OEE_{availability}$	• Increased **4.6%**, going from 65.9% to 68.9%
Ergonomics	• Exchange of the raw material coil • Safety in the execution of the setup

5.4. *Kanban* and *Heijunka* implementation

A *Kanban* system was implemented, ending with the intermediate stocks. With it materials started to be pulled from upstream and information started to be sent downstream via *Kanban* cards. Also, the cycles of the logistics trains were normalized and they began to cover the four streams uninterruptedly. Finally, a *Heijunka* box was introduced, where the production balancing started to be done by the planning department. After these implementations, during 20 working days, data was gathered. The summary can be seen in Table 6.

Table 6 - Results of the *Kanban* and *Heijunka* implementation.

TYPE OF GAIN	DESCRIPTION
OEE	• Increased **0.6%**, going from 52.8% to 53.1%
Lead-time	• Decreased **27.2%**, going from 10.3 days to 7.5 days
Stock	• Decreased **21.9%**, going from 1033016 parts to 806299 parts
Logistics	• Standardization of logistics trains
Production	• Viability of large volumes of different products
Planning	• Push-Pull planning • Response to daily variations in demand

5.5. SMED implementation

All setup activities were grouped in six different categories: tool, raw material, auxiliary equipment, wait, adjustment and motion. This categorization helped finding waste in order to eliminate it during the process. Due to safety precautions, the setup needs to be done by two employees simultaneously. The SMED implementation followed the five main steps specified in the state of the art. After the SMED implementation, during 20 working days, data was gathered. The summary can be seen in Table 7.

Table 7 – Results of the SMED implementation

TYPE OF GAIN	DESCRIPTION
OEE	• Increased **16.4%**, going from 53.1% to 61.8%
$OEE_{availability}$	• Increased **15.9%**, going from 69% to 80%
Setup time	• Decreased **25.8%**, going from 66 min to 49 min
Production	• Standardization of setups • Viability of production of short series of parts
Leadership	• Autonomy in the implementation of the 5S tool

6. INVESTMENT PRIORITIZATION FRAMEWORK

6.1. Conception of the framework

An investment prioritization framework, in matrix format, was created to help categorize and compare all activities and tools used during improvement projects in production companies. The created matrix (Figure 2) was based on the risk analysis matrix. The risk analysis matrix allows to assess, qualitatively, the risk of a certain event, taking in consideration the impact (possible consequence) of it and its likelihood of occurrence (Markowski and Mannan, 2008). In the created matrix, the Y-axis represents the impact, like the risk matrix, and the x-axis represents the investment. In this framework, the investment exposes the opportunity cost that the investor will have in putting his money in one of these activities or tools instead of applying it in another investment with an identical objective (Modigliani and Miller, 1958) and it is measured in euros (€). The investment takes in account the amount of money spent but also other factors like the amount of hours worked or the number of times that a specific equipment needs to be used in order to implement a specific activity or tool. In order to turn all these factors in € it is necessary to find conversion factors to do it. For the example of the amount of hours worked, a good conversion factor is, for example, the average wage paid to employees, per hour. The choice of the unit of measurement for the impact should take in consideration the improvements that exist to measure and compare. If the objective of a project is, for example, to improve the productivity of equipment, then a good choice of unit for that project would be the increasing in OEE. On the other hand, if the objective of the project is, for example, to improve quality, then a good choice of unit for that project would be the reduction on the total number of defects. Lastly, the activities and tools should be positioned on the matrix according to the relative values of impact and investment of each one of them, i.e., the positioning of each activity or tool should take in account the best and worst value of impact and investment among all the existing activities or tools.

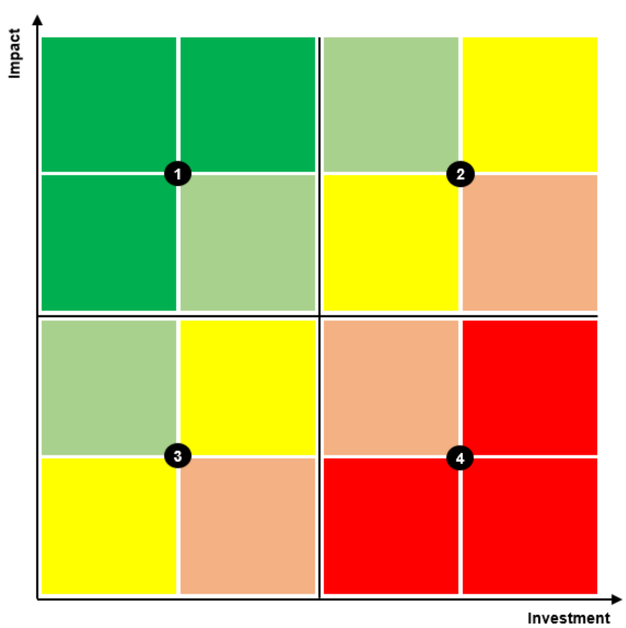

Figure 2 - Investment prioritization framework matrix.

The investment prioritization framework matrix was divided in four quadrants (indicated by black numbered circles), which allow to make a first categorization of the tools and activities performed. The first quadrant was designated of “Green Options”, corresponding to the majority of the squares with a green hue, where fall within the options with higher impact and lower investment. These should be the first to be selected during the preparation of an improvement plan. The fourth quadrant was designated of “Red Options”, corresponding to the majority of the squares with a red hue, where fall within the options with lower impact and higher investment. These should be the last to be selected during the preparation of an improvement plan. Finally, the remaining quadrants are called "Yellow Options", corresponding mainly to the yellow squares. In the second quadrant are the options with higher impact and higher investment, which only should be chosen, in second place, by investors with ambitious impact objectives to attain and at the same time, with a strong investment capacity. In the third quadrant are the options with lower impact and lower investment, which only should be chosen, in second place, by investors with a low investment capacity.

A methodology was then created to help implement this framework over a wide range of production companies, with a different set of investment factors or impact measures, in order to better prioritize and categorize the available activities and tools. This methodology was composed by six consecutive steps:

10) <u>Impact</u> - define the impact unit of measurement.
11) <u>Investment</u> - define all the factors to be included in the investment.
12) <u>Investment conversion factors</u> - find the right conversion factor for each investment factor in order to turn them in €.
13) <u>Calculate</u> - calculate both the impact and the investment for each tool or activity.
14) <u>Position</u> - positionate all the activities and tools in the investment priorization matrix, taking in account their relative impact and investment.
15) <u>Prioritize</u> - prioritize all the activities and tools to be used, based on their position in the matrix. The closer to the top left corner, the better, and the closer to the bottom right corner, the worse.

6.2. Application of the framework to the case study

Since this was a project based on a productivity improvement in a metalworking production company and very focused on the improvement of its equipment efficiency, the chosen impact unit of measurement was the OEE. Besides the financial investment made by the company's management in each step of the improvements implementation, the amount of hours worked by the employees of the company on their implementation was another factor to be included. To turn it in €, the average hourly wage paid to direct employees was asked to the company's financial department. The value was 6 € per hour and it was multiplied by the hours worked to implement each one of the tools and activities. Then, all the impact and investment values for each activity and tool were calculated (Table 8).

Table 8 – OEE improvement, in percentage points, and investments done in each activity or tool.

	Layout change	Equipment improvement	5S	*Kanban* & *Heijunka*	SMED
Δ OEE	1.3 pp	2 pp	5.2 pp	0.3 pp	8.7 pp
Financial investment	216.5 k €	233.5 k €	3.3 k €	4.1 k €	1.8 k €
Hours worked	3400 h	152 h	5039 h	2315 h	2016 h
Total investment	236.9 k €	234.4 k €	33.5 k €	18 k €	13.9 k €

Then the activities and tools were inserted in the matrix according with the calculated results (Figure 3).

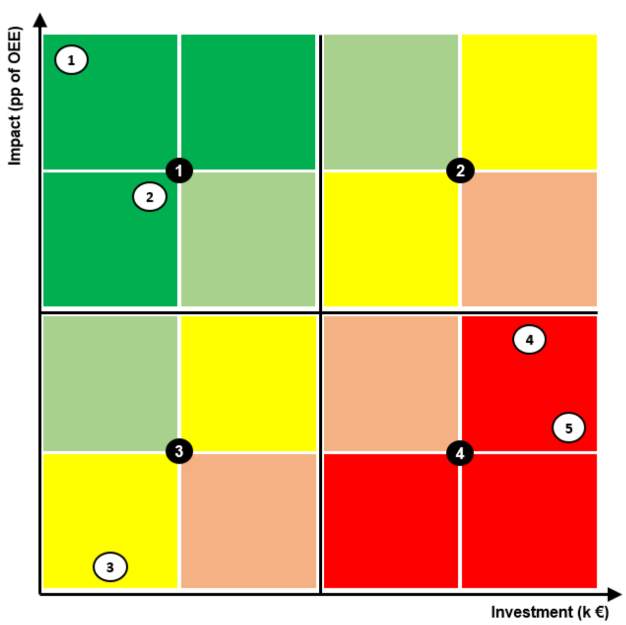

Figure 3 - Investment prioritization framework matrix applied to the case study. Legend: 1 - SMED; 2 - 5S; 3 - *Kanban* & *Heijunka*; 4 - equipment improvement; 5 - layout change.

The activities and tools used were then prioritized according to their position in the matrix:

1) Green Options

- SMED - the SMED implementation would be the first option to choose, since in addition to having the highest impact (8.7 pp of OEE), it also has the lowest investment (13.9 k €).
- 5S - the 5S implementation would be the second option to choose, since in addition to having the second highest impact (5.2 pp of OEE), it also has the third lowest investment (33.5 k €).

2) Yellow Options

- *Kanban & Heijunka* - the *Kanban* and *Heijunka* implementation would be the third option to choose, since it has the second lowest investment (18 k €). On the other hand, it has the lowest impact (0.3 pp of OEE). However, this option was crucial to restructure the company's planning system.

3) Red Options

- Equipment improvement - the equipment improvement would be the fourth option to choose, since in addition to having the third lowest impact (2 pp of OEE), it also has the second highest investment (234.4 k €). However, this is also a viable option for when a quick improvement is needed because its execution requires much less hours of work than the rest of the tools and activities used.
- Layout change - the layout change would be the last option to choose, since in addition to having the second lowest impact (1.3 pp of OEE), it also has the highest investment (236.9 k €). However, this option was crucial for the implementation of the remaining options because it served as a basis for the whole restructuring undertaken in the company.

The investment priorization framework was then validated with its appliance in the current case study. However, after this application, it is considered that it still still can evolve to aggregate two other dimensions of variables to help prioritize activities and tools: 1) the structural impact that activities and tools can have in the target company; 2) the implementation velocity of tools and activities.

7. CONCLUSIONS AND FUTURE WORK

With the implementation of the lean methodologies *Kaizen* and JIT, the lean tools VSM, root cause analysis, 5S, *Kanban*, *Heijunka* and *SMED*, and the activities Gemba walks and equipment improvement, it was possible to increase OEE by 39.5% and to decrease the setup time by 25.8%, the lead-time of activities by

27.2%, the stock level of the company by 21.9% and its occupied are by 8.4%.

An investment prioritization framework was also created, where the lean tools and activities can be categorized taking in consideration the impact of each one and the investment necessary to achieve it. It was concluded that for production companies, like Company A, the best tool or activity to increase the OEE (the chosen impact) is SMED, while the worst one is the layout change, taking in consideration also the investments done.

As a suggestion of future work for Company A, three main points are made: 1) it should continue to invest in icreasing its OEE through workshops of normalization of activities since it still has a high variability of results; 2) study the implemention of a profit sharing program in Company A. According to Kandel and Lazear (1992), when these programs are implemented together with involvement programs for employees, they tend to have a positive impact on productivity; 3) develop the leadership of top management within the company, with the execution, for example, of periodic *Gemba* walks. According to Chiok Foong Loke (2001), the top management of a company, by having an active attitude of leadership, can increase their productivity by 9%.

Regarding the framework developed, it is considered that it still can evolve to aggregate two other dimensions: 1) the structural impact of activities and tools in the target company; 2) the implementation velocity of tools and activitis (for example, in working hours).

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