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Lean Production and Ergonomics: a synergy to improve productivity and working conditions

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Abstract

The markets globalization erased commercial boundaries and increased the competitiveness of companies all around the world. This competitiveness has forced companies to improve their processes and operations, as well as, their management relationships with suppliers and customers. Emerging from this progress, several needs led to the development of Lean Production (LP) – which proved to be effective in the waste reduction and efficient in providing production flexibility. Through its implementation, LP allows the increase of workers' involvement, their safety and health. The main goal of this paper is to present how LP and Ergonomics improve not only the company productivity, but also the health and safety of the workers throughout continuous improvement processes. This was achieved in a project which purpose was to improve the consumables supply strategies, taking place in an electric mobility company. The implementation of LP tools in this industrial context resulted in improved productivity, reduced cost, enhanced and more efficient operations. This outcome was possible with a synergetic engagement of workers resulting in their ergonomic working conditions improvement.

1. INTRODUCTION

The industrial challenges of the last decades have motivated many companies to adopt new production strategies in order to be more suitable to the markets' demand (Hines, Holweg, & Rich, 2004). Boosted by this transition, the organizations saw on LP a production methodology that fulfils the organization requirements (Womack, Jones, & Roos, 1990). LP is a multidimensional approach, based on the integration of a plurality of management tools and practices (Hallgren & Olhager, 2009). These practices allow the creation of synergies between the different management dimensions of the companies, giving boost to a production system of different competencies that enables high quality production, demand-driven and without waste (Shah & Ward, 2003).

According to Ohno (1988), the methodology focuses on the elimination of all activities that do not add value (*muda*, in Japanese) to the product from the customers' perspective and that they is not willing to pay. Nevertheless, there are many activities that are considered non-added value activities but are necessary, such as transports and motion. These should be reduced when it is not possible to eliminate right way. So, LP will seek the constant search for opportunities to improve the system in order to increase production productivity and flexibility.

People are the most valuable resource for LP, for this reason the methodology focuses on the effective and healthy use of human resources, considering their capabilities, limitations and needs (Arezes, Dinis-Carvalho, & Alves, 2015).

This paper objective is to present LP and Ergonomics synergy when implementing improvements in the consumables supply strategies of an electric equipment company. This Portuguese company provides innovative and evolving solutions to the electric mobility sector. The study undertaken in this company aimed to reduce the out of stock occurrences for consumable items. During the study, several improvement actions focused on the safety and ergonomic conditions of the workers were investigated, aiming to enhance the combination of human well-being and performance of the productive system. Particularly, this paper was related with the solutions adopted to reduce the waste caused by the constant movement of personnel, with the increasing of productivity of the production system, and with the improving of the safety and ergonomic conditions of the workers.

This paper is divided in five sections. After this introduction, a brief literature review about Lean and Ergonomics is provided. The research methodology is presented in section three. Section four presents the Action-Research project developed in the industrial context. Finally, section five put forward some main conclusions.

2. BRIEF LITERATURE REVIEW

The importance given to standardization of processes, productivity and elimination of waste is based, predominantly, on a common denominator: maximize the utilization rate of the labor force (Thun et al, 2011). However, this increase in the utilization rate should be complemented with a proportional improvement in working conditions, where the capacities, limitations and needs of workers should be considered (Arezes, Dinis-Carvalho, & Alves, 2015).

In some cases these considerations were neglected and the consequences of these actions were reflected in both the employees and the organization itself (Dul & Neumann, 2009). For the workers, the result was the deterioration of working conditions, with direct impact on their health and well-being. For the organization, the result was the dissatisfaction and demotivation of its workforce, negatively influencing productivity and product quality.

Some of the principles underlying the Lean can make work highly repetitive, causing workers to adopt inappropriate postures and with great efforts repeated throughout the work day (Kester, 2013). In this way, the focus on the human factor and an integration of ergonomic considerations in the process of reconversion of the production system is essential and helps to attenuate the deviations between the human factor and the production paradigm (Nunes & Machado, 2007). An integrated approach between Lean implementation and Ergonomics enables a holistic management and a synergetic association that supports the change process and helps the long-term ergonomics gains (Tortorella et al., 2017).

A Lean implementation demands a careful attention to working conditions analysis in order to enable their potential success, otherwise the implementation will not have the benefits expected (Maia et al., 2012). The aim of integrating Ergonomics into a Lean system is precisely to identify potential risk factors and to develop worker-oriented solutions that are compatible with their needs, capabilities and limitations, in order to optimize human well-being and overall performance of the system (IEA, 2016).

These worker-oriented solutions are enabled by their involvement. Worker involvement is also promoted by the participatory approach to ergonomics. The concept of "participatory ergonomics" emerged at more than 30 years ago, and it is thought that the antipathy that some ergonomists felt for Taylorism is one of the possible reasons for the origin of this type of approach in Ergonomics (Wilson, 1991). This type of approach aims to enable workers to intervene positively in the case of upcoming problems, through their participation and active involvement in improving their working conditions (Nagamachi, 1995). For instance, in cases of overburden or fatigue, workstation disorganization, a machine “secret” no one knows that avoid a lot of defects, the necessary “click” to unblock the machine, are some problems or solutions that only workers feel or know.

Overburden (*muri*) and variability (*mura*), i.e., a standard missing, in the production system are symptoms of *muda*. The three constitute the 3M that must be identified in a Lean implementation in order to be eliminated. To achieve this, many tools could be used, being the most simple the 5S or 6S to include the safety concern (Anvari et al., 2011).

Tight to this tool is the visual management (VM) that is the key to the communicational process and knowledge sharing in a Lean environment (Parry & Turner, 2006). When properly implemented, VM allows that all people to see and understand the different aspects of a production system, transforming their workplace in a knowledge source and information transmission, accessible to all (Figure 1). The visual management practices leads to a productivity increase, supporting the decision-making, motivating and involving the workers in their daily operations. This allows them to become thinkers (Alves et al., 2012).

Other important tools must be used to implement Lean (Feld, 2001) and support the production system reconfiguration and its materials, people and information flows. Namely, a lot of aspects related with ergonomics should be analyzed, from shelves dimension to the materials supply transport, as some case studies exemplify: Queta et al. (2014); Eira et al. (2015) and Vicente et al. (2016). For example, the regularity of materials supply could be established by using a Mizusumashi instead of a traditional forklift (Figure 2).

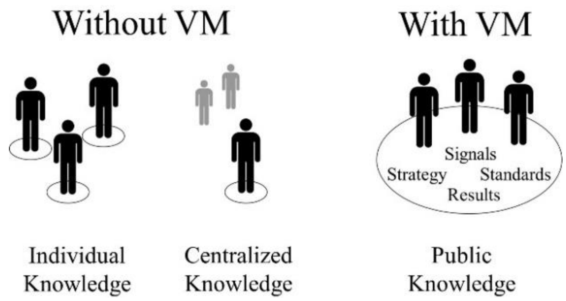

Figure 1. Visual Management (adapted from Jaca et al, 2014)

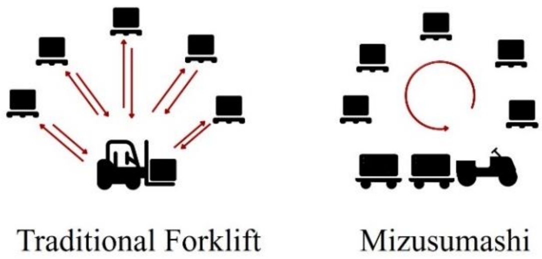

Figure 2. Traditional forklift versus Mizusumashi.

A *Mizusumashi* creates a smooth internal logistic flow, assuring an effective supply to the workstations and providing the materials in the right moment and in the right quantity.

3. RESEARCH METHODOLOGY

This project applies the Action-Research methodology that is characterized by its reflexive, collaborative and interventional nature, based on the direct action of the investigator in the test of formulated hypotheses, initiating an iterative cycle of diagnosis, intervention and learning, shaping theory as a function of experienced results. According to Susman & Evered (1978) the spiral of research and action is developed in five phases: i) diagnosis ii) action planning; iii) action taking; iv) evaluating, and; v) specifying learning. The project followed these five phases, being used in each of them different tools. In the diagnostic phase it was analyzed the flow of supply, the performance indicators and it was identified and characterized the materials consumed by the work stations. To support the diagnosis, tools like ABC analysis; sequence diagram; cause-effect diagram; flowchart; matrix of competencies; and the spaghetti diagram were used.

With regard to the planning of actions, alternative strategies were developed that aimed at eliminating or mitigating the problems identified. Supply and supply of production consumables were emphasized in order to eliminate inventory breaks and distances traveled by workers.

In the phase of implementation of the actions the solutions outlined in the previous phase were implemented, which passed through the application of Lean tools. Supermarkets were designed to supply the lines according to the anthropometric measurements of the Portuguese working population (Barroso, Arezes, Costa & Miguel, 2005). Then, in the evaluation and discussion of results, a comparative analysis of the system performance, before and after, was carried out.

Lastly, in the learning specification, an assessment of the strengths and weaknesses of the project was made, identifying, finally, new opportunities for improvement, perpetuating the idea that it is always possible to do more and better.

4. PROJECT CONTEXT, IMPROVEMENT PROPOSALS AND RESULTS

The company where this project was developed assembles electric equipment such as public chargers for electric vehicles. The singularities of the equipment for electric mobility produced by the company, namely its complexity and high degree of customization, together with the increased frequency of orders, make the consumables' management process too complex and time consuming. To expedite this process, all manufacturing consumables were left out of the bill of materials - which made it impossible to manage these items through the Enterprise Resource Planning (ERP) system. Therefore, all of these items were managed by the logistics department, which is responsible for ensuring their availability in the warehouse.

Additionally, it was crucial to meet the requirements of a pioneer, growing and constantly changing market, where the capacity to offer product customization is seen as an opportunity to set a position and gain competitiveness. Also, the reduced lead times are a requirement from customers that are looking to gain a foothold in this booming market. This fact forces the companies to analyze their own processes, making them more agile, efficient and flexible.

4.1. Current situation and diagnosis

During the diagnosis process, a set of tools was used such as the ABC analysis, cause-effect diagrams, Pareto analysis, spaghetti diagrams, Business Process Modelling Language (BPML) diagrams (Aguilar-Saven, 2004), as well as sequence diagrams. BPML were used to represent the flow information, namely the ordering process. The results of this diagnosis process were a set of problems based on the 5M (Methods, Management, Materials and Man or People) that caused the stock rupture. The cause-effect diagram is represented in Figure 3.

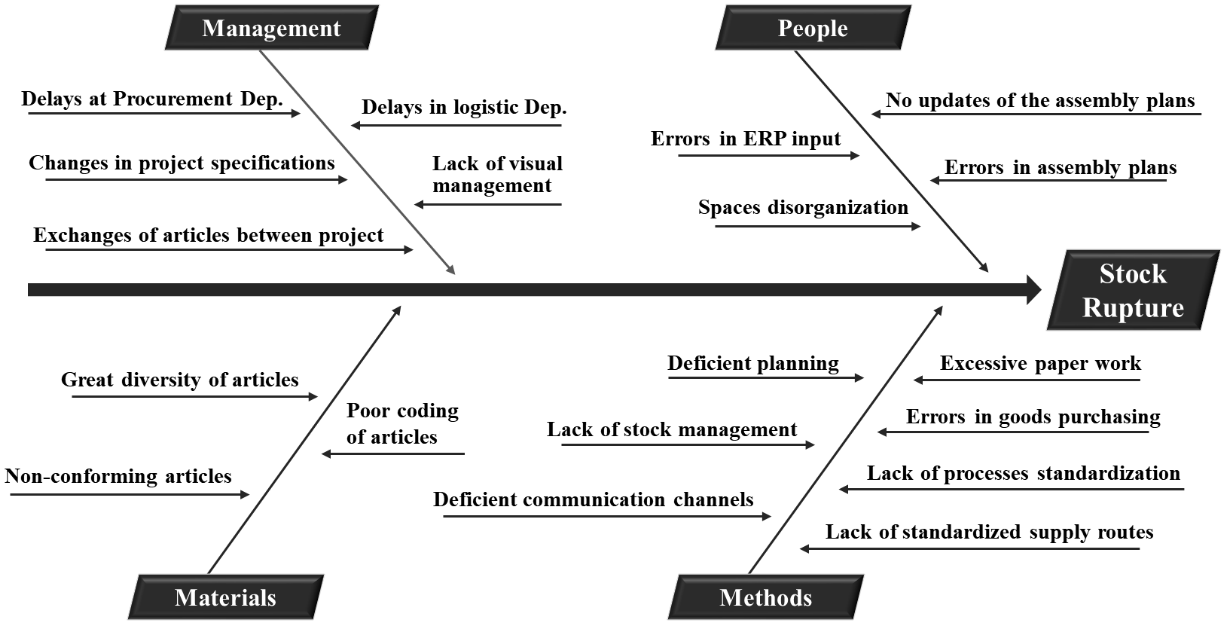

Figure 3. Cause-effect diagram of stock rupture.

During the study, problems related to the constant movement of workers and their impact on both company's productivity and workers health condition were highlighted. This problem is directly related to the centralization of the consumables picking in the warehouse, which results in constant movement of the workers in order to satisfy their material needs. This is due to the fact that, when the stock of material at each workstation runs out, the operator has to go to the warehouse and refill the stock. The spaghetti diagram presented in Figure 4 depicts the operators' movements (non-value activities but necessary) between their respective workstations and the main warehouse to get the required manufacturing consumables.

From the operator's point of view, the work procedure results in: 1) additional fatigue; 2) increased risk of work-related accidents; and 3) reduced concentration levels, which directly contributes to the deterioration of working conditions with direct impact on their health and safety.

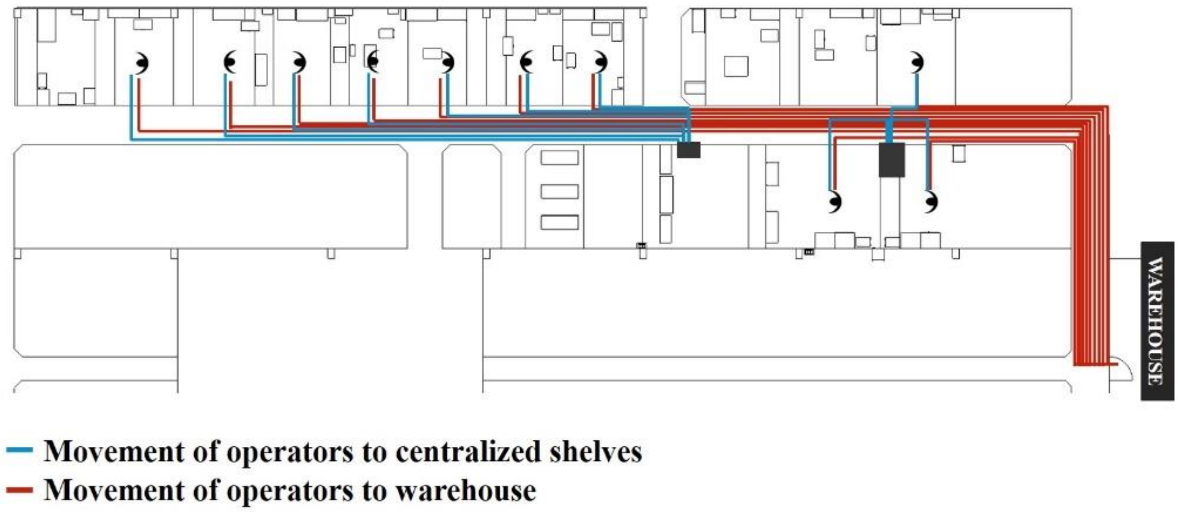

Figure 4. Spaghetti diagram representing the movements of the operators between the workstations and the central warehouse.

From the company's point of view, this reality results in: 1) waste of labor; 2) high production stoppages; and 3) dissatisfaction and demotivation of the workforce. The combination of all these aspects influences the productivity and quality, in a negative way.

It was evidenced that this *muda* represents 90% of the distance travelled by the workers in their working hours. This means that, in average, a distance of 36 km is travelled per year, per employee. In addition, the disarrangement of the workstations increases considerably the risk of accidents and it hinders the production agility.

4.2. Action planning and taking

Attending to the problems identified in the previous section, the reorganization of all workstations was required and urgent, in order to make the work environment cleaner, increasing safety and improving working conditions as well as the company's productivity. Thus, several solutions based on Lean principles and tools were presented. Ergonomic aspects were considered on the design and implementation stages of these solutions, namely, the construction of supermarkets based on the anthropometric measures of the Portuguese population (Barroso, Arezes, Costa & Miguel, 2005).

This was an iterative process where, in its different stages of development, it was tried to bring together all the requirements to provide synergies from logistic to productive processes, focusing on people and their welfare.

In the design of the shelves, the following conditions were defined:

- ☐ Consideration for the layout of the manufacturing plant;
- ☐ Consideration for ergonomic aspects, aiming comfortable and productive workstations.

The first condition is justified by the need to develop these new structures in such way that they fit the space constraints of the manufacturing layout. The second one is related to the need to reduce labor wear and assure the safety and satisfaction of operators.

In order to reduce the risks and the physical efforts of the workers, the maximum and minimum height of the shelves were defined at the outset. Thereby, it should never be higher than the shoulder height or lower than the height of the wrists. In this way, workers would not need to raise their arms above shoulder height (protecting their joints), nor would they need to lower or flex the trunk to reach materials (protecting the lower back and/or legs). Based on these assumptions, the values were determined to meet 90% of the population, male only (see Table 1).

Table 1. Ergonomic considerations regarding the supermarkets design.

	minimum	**maximum**
Height (mm)	832	1 366
Limiting factor	Wrist height of the tallest people	Shoulder height of the lowest people

However, the accomplishment of these requirements would make the project unfeasible, since the combination of these height restrictions with the number of items to be stored would require the creation of shelves of such length that would obstruct the working space. Thus, a consensus solution was pursued, based on the two previously defined conditions and limiting the maximum height of the structures. In this case, the visibility of the contents of the boxes, by 90% of employees, was established as another condition. Thus, the height of the structures (Figure 5) was adjusted to a maximum of 1 567 mm limited by the height of the eyes of the lowest people.

The lower levels of the shelves were saved to larger and heavier items (including the coils of electrical wires), since the weight of these boxes can reach 16 kg. Due its weight, any movement activity should be minimized. For that reason, a section of drawers was created in the lower levels of the shelves, allowing to the operators an easy access to the materials and, simultaneously, avoiding unnecessary efforts handling the items. The goal was to create a mechanism that works as a mobile shelf, as shown in Figure 6.

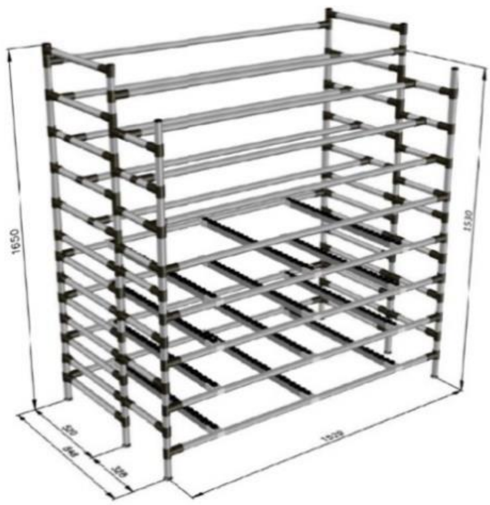

Figure 5. Design of the shelves to serve as supermarkets at the workstations.

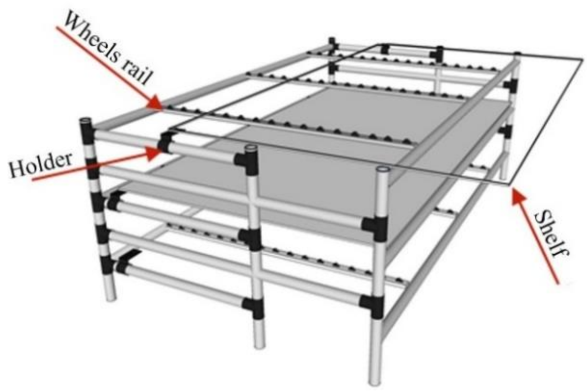

Figure 6. Detail of mobile shelf of the designed structure.

Therefore, the worker will only have to pull the drawer corresponding to the material that he intends to use and pick the desired quantity.

In order to supply these supermarkets on the workstations, a *Mizusumashi* was put in place and a standardized route for its operation was created (Figure 7). This measure aimed to create a supply flow and ensure its efficiency by making the items available on the workstations at the right moment and quantity.

It was decided that this route should be operated in two daily cycles, taking place at the first working hours in the morning and in the afternoon, 8 AM and 1 PM, respectively. The goal was to ensure the warehouse's responsiveness, since this is the sector of the company overloaded with this working methodology. These two daily cycles intend to prevent the accumulation of items to order. On the other hand, the definition of fixed schedules aims to minimize the interference of the supply process in the activities of the workstations, which starts at the same time.

The identification of the needs at the first hours of the shifts allows passing the orders to the supplier in the same day, avoiding delays or production stops due to material shortage. Throughout the project, some changes in the organization of the warehouse and manufacturing area were made. In this sense, the concepts of 5S and Visual Management were introduced.

The first action taken towards the reorganization of the warehouse corresponded to the sorting of consumables located in the picking area. All the consumables were identified and those that did not justify their place in the warehouse were separated and some of them were even dispensed. This action was followed by the sale of these items at their residual value, making possible a financial profit for the company and the release of space, as well as the reorganization of the warehouse. After that, measures and rules were defined regarding the organization of consumables in storage.

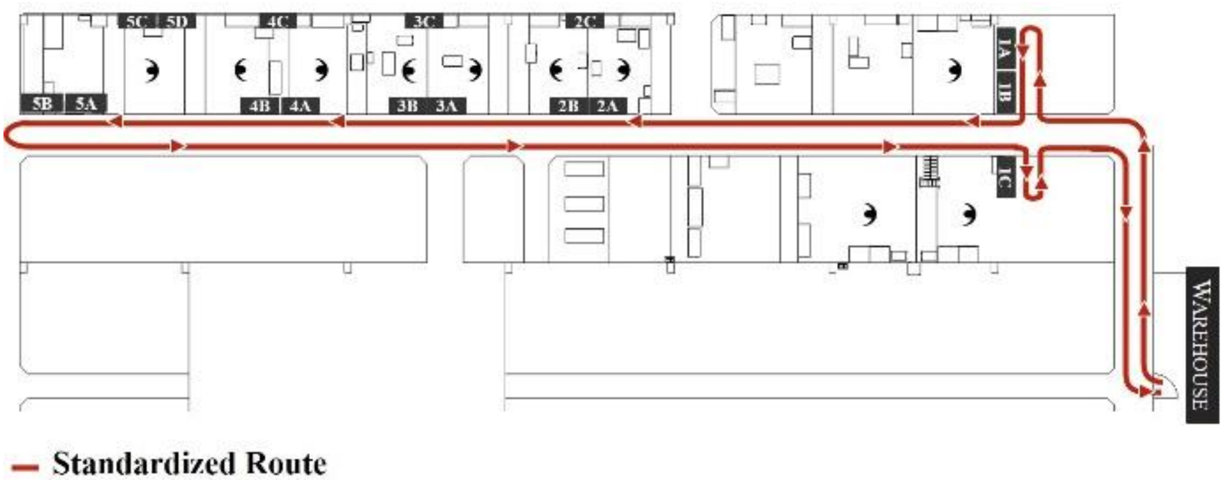

Figure 7. Standardized route of the *Mizusumashi* for the supply cycle of the workstations.

This procedure required an explicit identification process, since an incorrect identification of the items resulted in orders with incongruent quantities, wrong breakout perceptions, delays in the location of the consumables, among other problems.

Thus, a standard identification model was created for the consumables in the warehouse. A bar code reading device was made available to the warehouse for the reformulation of the needs survey process which is now carried out by bar codes reading of the consumable labels.

During the project, it was also identified the need to know the workers skills in order to help the decision-making of allocating the workers in each workstation. To achieve this, it was designed a skills (or competences) matrix, as represented in Figure 8. The activities performed by the workers are in the matrix columns and it is possible to see that some workers are not skilled in some activities (squares blank). This will help to allocate the "best person for the right job" and, at the same time, to know the need of workers qualifications. This also allows designing a training plan in order to improve each worker skills, contributing for their personal development.

Nowadays, the reality of organizations changes quickly. The continuous improvement of processes, the gradual reduction of wastes and the availability of communication channels are differentiating aspects. In fact, they have an inevitable preponderance in sustainability. Good and assertive quality information, offers competitive advantages to the organizations, avoiding errors and loss of opportunity. The creation of production frameworks was proposed to serve as an open and iterative tool of communication.

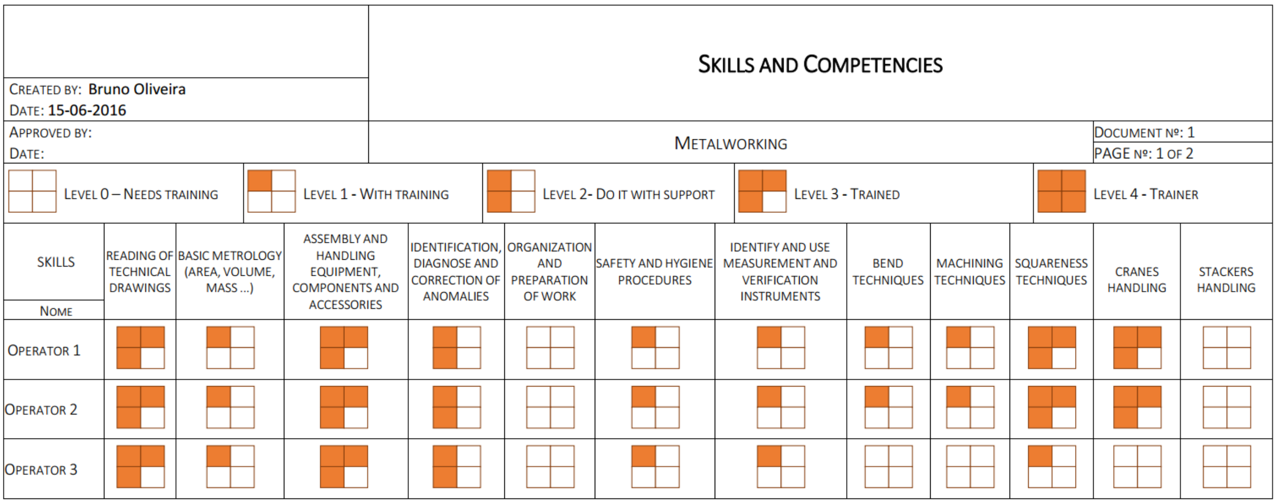

Figure 8. Skills matrix extract.

4.3. Evaluating

The improvement achieved with the solutions adopted led to a significant increase on the company's organization and safety.

The implementation of supermarkets has significantly improved the control and supply of consumables to production, reduced the risk of accidents and streamlined processes.

The creation of specific locations in warehouse for each type of consumables, as well as the inclusion of bar codes, allowed automating the search for purchase needs. This new method was immediately put into action by the warehouse operators who had participated actively in this reformulation. The automation of the process made it possible to eliminate some gaps associated with the human factor and to increase the speed of communication and information processing. The gains obtained with this improvement are presented in Table 2.

Table 2. Gains from the new implemented method to identify consumable needs.

	Previous Method	**New Method**	**Gain (%)**
Consumable code collection (seconds per item)	6	2	66
Code and designation of the identified consumables (seconds per item)	19	8	≥56

The values presented in this table were obtained by timing the respective tasks. This reformulation speed up the communication processes of consumables' needs search by more than 56%. In the development and implementation stages, all operators were involved in the proposed solutions.

Since the task of compiling data took a fixed duration of 8 seconds, regardless of the number of items, the savings obtained would be large, the greater the number of items registered in the needs search assessment.

The creation of *Mizusumashi* and its standardized route for the supply of consumables at the workstations allowed reducing the movements and material transports carried out by operators. This outcome reflects an enhancement in working conditions and an increase in productivity. In this way, operators stop interrupting their production tasks to travel long distances when they need additional consumables.

A considerable reduction of the distances traveled by the workers and the time spend with movements were achieved. Figure 9 presents the results regarding the movement's economy promoted by the implemented measure.

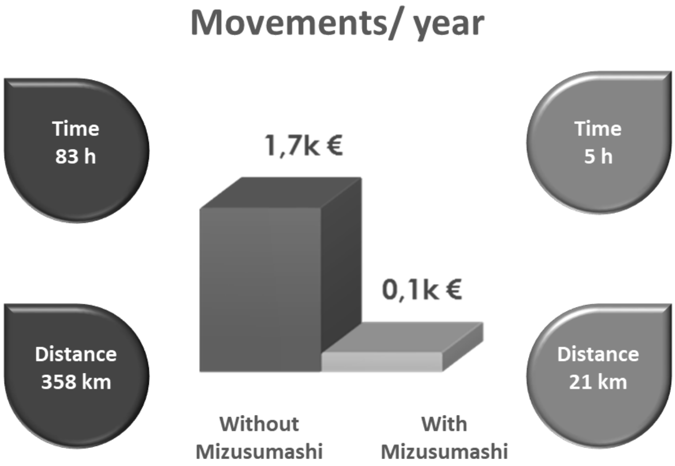

Figure 9. Gains from the implementation of the *Mizusumashi*.

To better understand the impact of this improvement, the operator's movements were represented in the layout of the manufacturing area after the implementation of the referred proposal (Figure 10). Through the Figure 4 and Figure 10 it was possible to compare the number of movements before and after the placement of the supermarkets in the labor area.

Furthermore, it was possible to visualize that the introduction of the *Mizusumashi* had clearly limited the travelling distances carried out by the workers to reach the consumables required in the workstations. In quantitative terms, this solution has reduced the walking distance in 94%, which reflected in better working conditions and increased productivity, as the workers will have more time to do more added value activities. It was also possible to reduce the inventory's value by 15%.

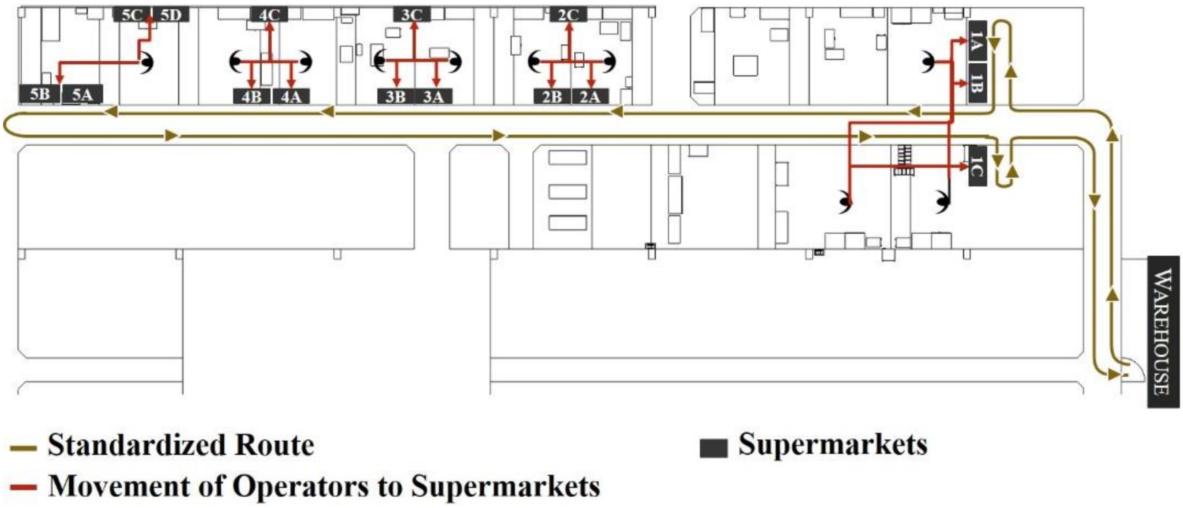

Figure 10. Representation of operators' movements after the implementation of improvement proposals.

4.4. Specifying learning

During the project progress, some changes in the organization of the warehouse and manufacturing area were accomplished. In this sense, the concepts of 5S and Visual Management were introduced. With the implementation of such Lean tools, it was possible to significantly reduce accident risks, improve the productivity and the processes streamline, improve worker conditions, and reduce errors and waste caused by the lack of organization. As a result of this set of measures, it was also possible to carry out a reconfiguration of the manufacturing plant.

The continuous improvement program started with the creation of the competency matrix, based on the idea that small individual improvements could result in a huge impact on the production system. The conclusions drawn from its analysis made it possible to identify some aspects that should be improved as soon as possible, namely with regard to the competence to organize and prepare the work, which proved to be one of the main entropies of the production system.

The proposals for the creation of kit frames, production and continuous improvement, were not implemented due to company restrictions. These proposals were presented with the aim of improving the organization of information and communication channels within the manufacturing unit, taking advantage of Visual Management.

Moreover, its implementation could prove to be the starting point for the pursuit of a work philosophy aimed at continuous improvement.

5. CONCLUSIONS

This paper presented some proposed solutions based on LP principles and tools and ergonomics that allowed a significant improvement of the company's productivity. This was complemented by a proportional improvement in the working conditions, achieved through the inclusion of ergonomic considerations in the different development stages of the solutions. The involvement of the employees was also very important since it allowed the adjustment of the idealized solutions to their needs, promoting the empathy between workers and the proposed work methodologies.

The implementation of supermarkets allowed to change the factory's appearance, making it cleaner and safer. The inventory breakdowns and the intrinsic difficulty of managing these items was also eliminated.

The waste generated by the frequent workers' movements, was eliminated by the implementation of the *Mizusumashi*. This solution allowed the reduction of the accumulated fatigue caused by these travels, the reduction of the risk of accidents, and the improvement of the workers' satisfaction.

Ergonomics is a discipline well-known and taught in classes since a long time. For many people, its association with Lean Thinking (a more recent thinking) does not bring novelty because working conditions improvement it was always the Ergonomics role. Nevertheless, the engagement of the workers in the improvement of their own workplace is something fairly innovator when compared with Taylor Scientific Management principles prerogatives where there was staff (e.g. methods and time study agents) properly trained, focused on the study and improvement of the working conditions. The participatory ergonomics intended to undermine these prerogatives. Nevertheless, one hundred years of work innovation were needed to allow workers to think in the improvement of their own workplace, and Lean contributed for this.

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