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Improvements in Logistics Processes and Associated Working Conditions using the Principles of Lean Thinking, Ergonomics and Simulation

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Abstract. Continuous improvement is an integral part of the management processes of organizations. The success of a company does not involve a linearity of actions, but a constant concern and adaptation to possible changes, in terms of technological or human resources of an organization. Bearing this motivation in mind, this project was developed in a company of metal components for automotive industry, and its main objective was the overall improvement of several logistic processes and their associated working conditions, using Lean Thinking principles, Ergonomics, and Simulation. In particular, the introduction of a milkrun in an autonomous production unit was proposed and assessed, considering its performance, as well as the ergonomic conditions of the operators. Considering this, three types of problems associated with the autonomous production unit under study were identified. Thus, the purpose of this article is twofold: 1) presents and discusses the proposals to solve such problems and 2) assesses the performance of an Automated Guided Vehicle (AGV) to reduce waste and improve internal logistics metrics, using simulation.

Keywords: Lean Thinking, Continuous Improvement, Logistics, Ergonomics, Simulation.

1 Introduction

The evolution of current markets, globalization, competitiveness and business models has an impact on productive capacity, product differentiation, innovation and various other essential factors for the activities of a company. This requires a continuous improvement based on a systematic problem-solving process, defined in several stages by identifying the causes, choices, planning and standardization of solutions.

Lean Thinking (LT) is a customer-focused management philosophy capable to provide such systematic process. Also, it allows companies to be competitive and to fit market requirements (Womack & Jones, 1996). Lean production (Womack et al., 1990) is the operational side of LT that timely deliver products by reducing costs and increase productivity. Such benefits are achieved by eliminating waste (i.e. activities that do not add value to the product in a client point of view) and respecting people and the environment (Alves et al., 2019). To attain this, this model uses principles and tools to improve the processes and flows of materials, information and people (Womack et al., 1990).

Thus, when analyzing the processes in the search for the identification and elimination of waste with a focus on continuous improvement, one must consider the importance of understanding three concepts: *muda* (waste), *mura* (irregularity) and *muri* (overload). These three concepts concern the 3M's model, which refers to the types of waste found in an organization. *Mura* relates to the variation or variability observed along the value chain. *Muri* means overburden and happens when workers or machines operate above their capabilities (Liker, 2004). *Muda* means waste which aims at the total elimination of any activity that does not add value.

To achieve such elimination, it is important to see the system in a global perspective integrating all parts of the system and using all the tools needed to solve the problems. Applying Lean Thinking principles: 1) Value; 2) Value Stream; 3) Flow; 4) Pull production; 5) Pursuit of perfection (Womack & Jones, 1996) to all areas in a company (product development; logistic; office; engineering, among others) will synchronize

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and focused all processes in a value stream. This will allow to do more with less, that is, less time, less space, less human effort, less equipment, and more efficiency and greater understanding of the client's needs (Womack et al., 1990).

Attending to this context, the present study was developed considering three main perspectives: Lean Production, Lean Logistics and Ergonomics. One of the aspects of Muri, referred above, is the excessive effort of operators and it is considered one of the root causes of Muda. To reduce it, it is fundamental to improve of workers' conditions and safety. Before that, it is important to assess their work conditions, as the many examples provided in Alves et al. (2019) did. Also, it must be used the tools needed to make proposals for improvement that eliminate wastes related to processes, irregularity and overburden of people. As so, this paper objectives are to present the project developed, highlighting main tools associated with each proposal, namely, the implementation of an AGV, through a specific study supported by a 3D simulation, and the use of recent technologies to reduce work overload (*muri*), in the production and logistics operations.

This paper is divided in six sections. The first section refers the introduction. The second section presents the materials and methodology used in this article. The third section presents a description, diagnosis and proposals for associated improvements, especially the study carried out in the AGV project, which is the focus of the article. The fourth section presents the AGV proposal evaluation using the simulation. The fifth section discusses the results obtained from the studies carried out in the AGV project. Finally, the main conclusions are discussed in the last section.

2 Materials and methods

The project described in this paper was developed in a work environment of a company. The first author of this paper was integrated in this company as an apprentice to develop his master dissertation in Industrial Engineering Master. The project lasts for seven months and during that time, the researcher participate and influence the action and decisions taking through constant dialogue with the employees.

The research methodology used was the action-research where the researcher initiative various cycles of action and research until implement proposals. The five phases of the action-research methodology are 1) diagnosis and problem definition; 2) actions planning; 3) implementing; 4) measure and evaluate and 5) learning specification (O'Brien, 1998).

For the first phase, dialogues, observations, documental analysis, time study, work sampling, Sue Rodgers ergonomic analysis, risk assessment in manual material handling tasks (applying the NIOSH equation), and posture evaluation (applying OWAS methodology) were used to correctly define the problems. In the second phase, some actions were planned to solve such problems, being proposed 5S, *Standard Work*, visual management, layout reconfiguration. In the third phase, most of these tools were implemented. The fourth phase implied the evaluation of the proposals and it was used simulation and Analytic Hierarchy Process (AHP), among others. The fifth phase implied the learning specification and the proposals for future work in order to start new cycles of action-research.

3 Description, diagnosis and proposals presentation

This section presents briefly the company and the diagnosis developed. Additionally, it presents the proposals that were proposed to solve the problems identified during the diagnosis.

3.1 Characterization of the company

The company where the project was developed is a multinational company of metal parts for automobile industry. It is a "dirt" company working "heavy" and long parts, e.g., stamped pieces. The company has around 600 employees and it is structure in 10 departments. The production department was structured in autonomous production units (APU). The APU of this study was APU2.

3.2 Critical analysis and problems identification

For about two years, the company has been trying to implement milkruns in order to improve the physical flow of materials, including all automatic production units. With this, the company intended to improve the company's internal value stream, by implementing a just-in-time culture. Start this, by placing the desired material on the edges of the line or together with the machines, at the right time and in the appropriate quantity. This tentative was carried out as part of a continuous improvement project, based on the Lean Production and with the aim of reducing the waste associated with the supply and performance of the machines.

Two main production processes could be found in this company: 1) stamping and 2) welding. In the shop floor, it was possible to find three types of supply/supplies: boxes of small components, boxes with stamped parts for welding processes, and containers, also called packaging, because these containers are delivered to the end customer with the finished products. A logistic train placed empty containers (packages), so that the production workers put the parts produced by the machines. Then, they were collected by the milkrun logistic worker.

When filling a container with parts made of steel or aluminium, their weight becomes significant, reaching weights between 500 and 850 kg, which make it difficult to manoeuvre these packages located on a rolling support, reaching up to 1200 kg. In this case a forklift is used to collect the container.

The case is most notable when the logistics worker, whose task is to place the empty containers on the edge of the machines and collect the full containers, pushes/pulls the full containers into the milkrun carriages. Because these packages are heavy, one or two press workers help the train driver to perform these tasks. This situation leads to great risk of Work-related Musculoskeletal Disorders (WMSD), providing high forces exerted, pain in the lumbar region, in the shoulders and in the back. Additionally, it conduces to an increase in the cycle time of the tasks performed by both the machine workers and the logistic train, and a high rate of absenteeism and turnover due to the high difficulty of the task.

In addition, the number of tasks of the logistic worker is high. He had to follow a route and left the empty containers at the edge of the line and collected the full containers. Before starting the route, the logistic worker placed empty containers inside the carriages and at the end of the route removed the full containers with the forklift. This situation provides waiting and stoppages to the machines since the logistic worker did not arrive in time to place the empty containers next to the machines. This happened in the autonomous printing production unit, located in a specific point for the printing lines, which had two presses, considered essential for the company. These stamped most small printed parts, medium and large size, whether parts of the final product or in the process. Some waiting times of the machines associated with internal logistics existed. Waste was observed in terms of material handling and transport, which alone provides the need to find other alternatives to improve the physical flow of materials. In addition to logistic and ergonomic problems, there were other generic problems in the autonomous production unit, identified in the description and analysis of the project.

This problem is relevant, because it revealed an opportunity related to the need to implement a lean logistics tool. After the mentioned problems, the purpose of the project was to eliminate inappropriate tasks, in what concerns ergonomic aspects, improving the working conditions of production and logistics workers, improving the physical flow of materials and increasing, if possible, the productivity of machinery and milkrun workers.

3.3 Improvement Proposals

Throughout the project, improvement actions were implemented for the problems encountered. One of these actions involved the implementation of new technologies recognized for internal logistics within an organization. Such technological alternatives, were related to Industry 4.0 (Lasi, Fettke, Kemper, Feld, and Hoffmann, 2014; Vieira, Dias, Santos, Pereira, and Oliveira, 2018), for the transport and handling of loads. In this case, AGV or Mobile Industrial Robots (MIR) were proposed. This was supported by a 3D microsimulation carried out using the SIMIO simulation software, in order to assess the proposals, by incorporating variability in the modelled system. Furthermore, the model was also able to calculate the economic and ecological savings of this implementation.

Thus, implement AGV was also part of the project to improve the working conditions of the operators, reducing the occurrences of WMSD. In this way, AGVs or MIRs replace human operators in the handling of heavy loads, leaving them available to perform more complex and less repetitive tasks. At the same time, ensured efficient, safe and more affordable transport of loads reducing labour costs. With this, the return on investment had a high probability of being short. It was,, also intended to improve the physical flow of material in order to reduce movements, being a clear alternative about the transport and current supply of the autonomous production unit under study.

An AGV is a self-guided mobile vehicle used in environments that require transportation of products in production and in warehouses. It is programmed to transport materials through defined product collection and delivery routes within manufacturing and distribution facilities. They emerge as an alternative to the classic solution of having forklifts and forklift drivers transport raw materials and products on the shop floor (Santos, 2013). The AGVs suitable are AGVs that have a programming facility and software that is easy to be incorporated and perceived before users. The level of accuracy must be adapted depending on the type of cargo that in this case are containers, weighing between 750 kg and 1200 kg, incorporated into the rolling carriers.

One or more AGVs should go to the machines, knowing that their task would be to take the empty containers next to the machines and collect containers full of parts produced to allocate them in the start zone or in the WIP supermarket. On the other hand, the AGV only goes to the machines when the containers have been filled, avoiding waste of transporters and movements (Figure 1).

Fig. 1. AGV path in organization layout.

The type of AGV referenced is the AGV for transport of significant loads, which can be by itself, on platform or requester, which allows to understand how the AGV can take the empty containers and collect the full containers. Therefore, it was justified that there may be two types of AGV of transport of unit loads, associated with the project, the AGV requester adjustable to the type support and AGV of lift or load platform (Figure 2 a)). However, it is intended to have an AGV adaptable to all types of rolling supports as can be seen in the Figure 2 b), and, the AGV will have a specific label reader in order to identify what type of parts it is transporting and where it will have to be allocated. Subsequently, if the project is valid, a bespoke AGV will be developed, suitable for the problems encountered and responding to the main objectives.

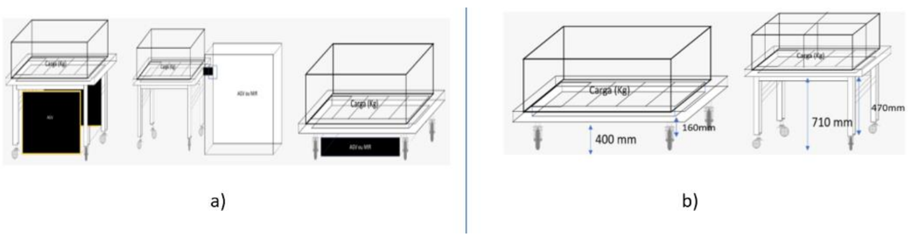

Fig. 2. Improvement proposals: **a)** Type of AGVs (3D representation), b) Types of rolling supports (big and small containers).

Before implementing AGVs, it was essential to perceive the context of the physical space. Thus, the implemented AGVs would had to fit the current physical space of the APU under study. From there, ten alternatives were studied for the AGV project. In order to study the best AGV for the project, it was essential to find a suitable methodology for the market study of standard AGV in the current market. Thus, the Analytic Hierarchy Process (AHP) methodology was referred as being an appropriate methodology for the project, in the sense of being a multi-criteria methodology, used and recognized in supporting decision-making.

This methodology is based on five steps, these being: 1) problem modelling, 2) elaboration, 3) analysis, 4) planning and 5) implementation (Martins, 2009). Thus, through this analysis, it was intended to find the appropriate AGV to meet the desired objectives. Thus, for the preparation of the analysis two specific tables were developed, namely a matrix table that was used for the criteria and for the comparison of the importance of each criterion between them Table 1 a)), and another table that will be used for the final decision (Table 1 b)).

Table 1. Auxiliary tables for AHP method: a) criteria matrix; b) final decision matrix

Criterion Matrix or Criteria Comparasion Matrix											
	Option 1 ou Criterion 1	Option 2 ou Criterion 2	Option 3 ou Criterion 3	…	Option n ou Criterion j	Normalized Matrix					Average Vector
Option 1 ou Criterion 1	1					Cell (op.1 e C1 | op.1 e C1)/Sum column Op1 e C1					Line average 1 Normalized Matrix
Option 2 ou Criterion 2		1				Cell (op.2 e C2 | op.1 e C1)/Sum column Op1 e C1					Line average 2 Normalized Matrix
Option 3 ou Criterion 3			1								
…											
Option n ou Criterion j					1						
Sum	Sum column Op. 1 e C1	Sum column Op. 2 e C2	Sum column Op. 3 e C3		Sum column Op. n e Cj						

a)

	Final decision matrix					
	Criterion 1	Criterion 2	Criterion 3	…	Criterion j	Total
Option 1	(Cell Op.1 e C1)				(Cell Op. 1 e Cj)	(Cell Op. 1 e C1 of the final decision matrix *Average vector of the Criterion Matrix (Criterion 1) +…+(Cell Op.1 e Cj) of the final decision matrix *Average vector of the Criterion Matrix (Criterio j))
Opção 2						
Opção 3						
…						
Opção n						
Weighting	Average vector of the Criteria Comparasion Matrix (Criterion 1)	Average vector of the Criteria Comparasion Matrix (Criterion 2)	Average vector of the Criteria Comparasion Matrix (Criterion 3)		Average vector of the Criteria Comparasion Matrix (Criterion j)	

b)

4 Proposals assessment using simulation

This section briefly presents the simulation study for the of AGVs implementation into the autonomous production units (APU). This explains the simulation project, its elaboration and finally a brief explanation of the analysis of the economic and ecological feasibility of the project.

4.1 Simulation project framework

In this way, it was intended to simulate the operation of routes performed by one or two AGVs and to perform a functional feasibility analysis of the implementation of it. It was, also, needed to calculate how many AGVs (one or two) were appropriate to acquire. For this study, it was used the Simio software. Simulation modelling is being widely used for performance improvement of many systems (Vieira, Dias, Pereira, & Oliveira, 2014).

In this 3D micro-simulation, it was compared the routes performed by the milkrun, and the possible route performed by the AGVs. The routes considered for this implementation are in the Fig. **2**3. Figure 3a) shows the route for milkrun and Figure 3b) shows the potential route for AGV. In these cases, the AGVs route had only two machines supplied by AGVs, unlike the logistics train (milkrun) that had six machines (passing through a part of APU1).

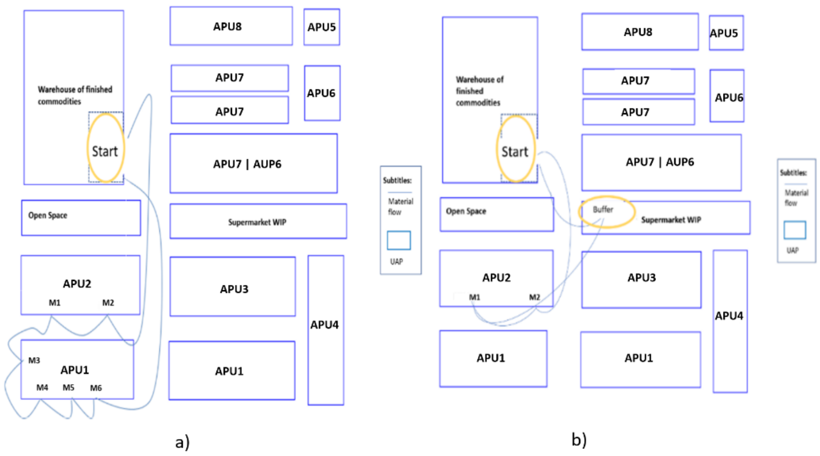

Fig. 3. Routes: a) Milkrun; b) AGV.

4.2 Study of 3D simulation

These entities (milkrun and AGV) had two tasks to perform: 1) Allocate empty containers and 2) Collect full containers. The difference was the route taken by them. In addition to these entities, there are also material and container entities, which are the material processed in the machines and placed in the containers, in both models.

Model Only Train. In the model Only Train (Figure 4), two performance measures, were needed, namely, number of stops per machine and cycle time of the logistic train.

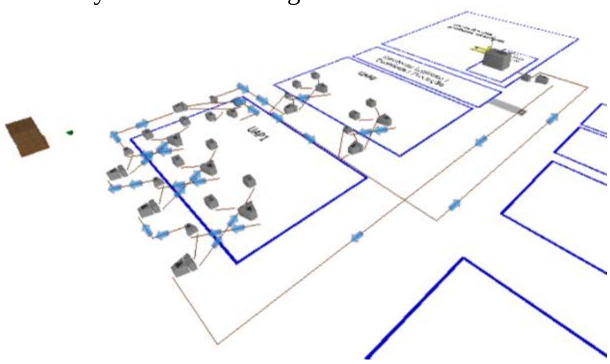

Fig. 4. 3D view of the Model Only Train.

In order to achieve a more realistic model possible, average values of processing times were incorporated, namely the loading time of the logistic train, i.e. the time when a forklift incorporates the empty containers into the carriages before the train starts the two-minute route, the machines (time to process and fill the empty containers), the times of stopping of the trains to allocate the empty containers, and the time to allocate the full containers in the logistics train carriages (Table 2).

Table 2. Average processing times for simulation.

Machine	Machine processing time (min)	Train stop time (min)	Times to allocate full containers (min)
M6	20	1,5	1,5
M5	17	1,5	1,5
M4	16	2	2
M3	18	3	3
M2	15	2	3
M1	15	3	3

Model AGVs. In the AGVs model (Figure 5), the AGV performed the same tasks as the logistic train. However, this was done for the M1 and M2 machines, because the company wanted to implement in a first time in APU2 and only after confirming improvements in the supply time will be subsequently implemented on the entire route or throughout the Ship associated with the stamping processes, in a future work.

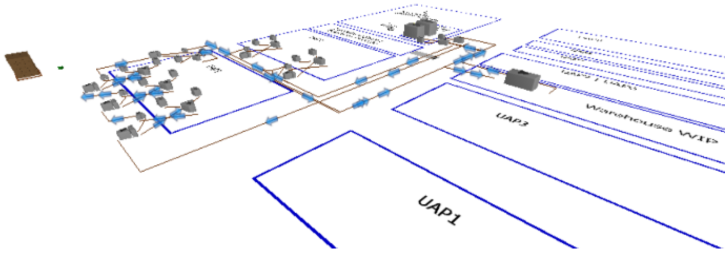

Fig. 5. 3D view of the Model AGVs.

Through this model, it was tried to understand the correct number of AGVs to be implemented. In this case, if an AGV is implemented, it will have to take two empty containers and collect two full (according to model). If it was used two AGVs, each takes a container and collects a container.

4.3 Analysis of economic and ecological viability

The economic and ecological viability of the AGV project concerns the cost comparison associated with the use of milkrun and forklift with the implementation of two AGV, after verification in 3D microsimulation, both at the economic and ecological level of both. Thus, the costs associated with the operations of the stacker and logistics train and the implementation of the AGV were calculated to compare the energy consumptions of both cases and the annual CO_2 (Kg) emissions.

5 Results and discussion

The following section briefly presents the results of the AHP analysis, the analysis of the physical viability of the project and finally the results of the economic and ecological viability, associated with the insertion of AGV in APU2.

5.1 AHP analysis results

Through the AHP analysis of the study, the appropriate type of AGV was a tow trucking AGV. It was also designed a way of fitting the rolling bases (Figure 6), in order to fit efficiently in the AGV.

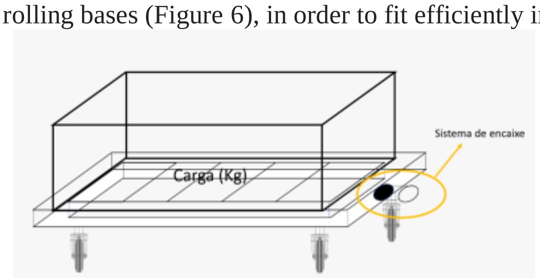

Fig. 6. System for fitting the rolling bases to the AGV.

5.2 Results of physical viability - 3D micro-simulation

Through the 3D micro simulation associated with the AGV project, Table 3 and Table 4 shows a reduction or increase in the delivery time of M1 and M2 machines, depending on the number of AGVs installed. Also, it conduces to a reduction of supply time.

Table 3: Reduction of supply time with one AGV.

Machines	Supply time with the logistic train (minutes)	Supply time with one AGV (minutes)	Supply time reduction (%)
M1	32	31	3%
M2	32	30	6%

Table 4: Reduction of supply time with two AGVs.

Machines	Supply time with the logistic train (minutes)	Supply time with two AGV (minutes)	Supply time reduction (%)
M1	32	16	50%
M2	32	15	53%

Table 5 and Table 6 shows an increase in route time associated with the implementation of an AGV.Thus, it was concluded that the adequate number of AGVs to be acquired were two, in order to significantly reduce the supply times of the machines of the autonomous production unit under study (APU2).

Table 5: Increase in route time made on average by one AGV

Average route time by the logistic train (minutes)	Average route time per AGV (minutes)	Increased average route time (%)
28	31	11%

Table 6: Reduction in route time made on average by two AGVs

Average route time by the logistic train (minutes)	Average route time taken on average by the two AGVs (min)	Reduction average route time (%)
28	17	39%

5.3 Results of economic and ecological viability

The results of microsimulation gives the need to acquire two AGVs, in order to meet the stipulated objectives. In this way, the cost and impact at the ecological level of two AGVs were calculated. The result was compared with the situation of the logistic train and forklift. The operational time considered was 22 hours. In the case of the logistics train and the forklift, the first was operational 75% of the time and the second 25% of the time. On the other hand, the AGVs operate during the entire operational time.

With the incorporation of two AGVs, it was possible to compare the calculations of consumption and costs associated with the use of such equipment. The result was a reduction in total costs (savings) of around 14%, with a 3% reduction in annual energy consumption. These values were for a Li-on type of battery.

Proportionally, there was a 3% reduction in estimated energy costs and there was also a possibility of reducing it by 58% as the recommended CO_2 reduction. The incorporation of two AGVs makes possible to omit the costs associated with direct labour. However, this figure refers to the first year of the implementation of AGVs. It was intended to obtain increased savings per year, with an estimated cost reduction (savings) estimated at around 40% after the first year (Table 7).

Table 7. Economic and ecological feasibility table for the incorporation of two AGVs.

	Reductions (%) implementation of two AGVs in relation to the logistics train and forklift
Energy consumption per year (kWh)	3%
Annual energy costs (euro)	3%
Annual CO2 emissions (kg)	58%
Annual direct labour associated costs (euro)	100%
Implementation costs (euro)	1º year: 14%
	2º year: 40%

6 Conclusion

In the project developed it was intended to improve the processes at the generic level of the autonomous unit of production under study (APU2), internal logistics and worker ergonomic conditions, responding in a global way to the objectives established.

The idea of applying Lean Logistics was connected to the planned projects of the company to improve the flow of material and to decrease the supply time of the machines of a part of APU1 and the machines of APU2 (M1 and M2). This was previously tried with the forklifts, causing significant waits / stops of the machines.

Through the 3D simulation, implement an AGV, was an appropriate decision. The results conducted to the implementation of two restoring AGVs, one for each machine of APU2 (M1 and M2), reducing the supply time by about 50% for both machines and saving about 14% in the first year of implementation and about 40% in the year after the implementation of AGVs. After economic feasibility studies, this project contributed to an improvement in both internal logistics and environmental levels, reducing energy consumption costs by around 3% and CO_2 emissions by around 58%.

Through the implementation of new technologies for the transport and handling of cargo used in the context of industry 4.0, it was possible to reduce the identified waste by improving working conditions and the physical flow of materials.

The study revealed, however, some fading that was not revealed due to all uncertainties derived from the implementation of AGVs in the current production unit, such as unforeseen events. It is important to notice that simulation was ran with medium values. However, the study reveals a model reliable to prove the possible benefits such as elimination of waste (transport, movements, waits and overloads), ergonomic improvements, the physical flow of material and the internal value chain of the organization. If the physically implemented project proves these benefits, the project will be extended to all stamping lines, and the medium term, in the welding lines of the organization. Due to the paper dimension, others proposals were not discussed such as the exoskeleton to handling workloads, the training programme or the standard work, among others. Future work will be to assure the sustainability of all the proposals implemented and promote the ones not yet implemented due to budget and time constraints.

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References

Alves, A. C., Kahlen, F.-J., Flumerfelt, S., & Siriban-Manalang, A. B. (2019). Lean Engineering for Global Development. Springer International Publishing. https://doi.org/10.1007/978-3-030-13515-7

Alves, A. C., Ferreira, A. C., Costa Maia, L., P. Leão, C. & Carneiro, P. (2019) 'A symbiotic relationship between Lean Production and Ergonomics: insights from Industrial Engineering final year projects', International Journal of Industrial Engineering and Management, 10(4), pp. 243–256. doi: 10.24867/IJIEM-2019-4-244.

Imai, M. (1986). Kaizen: The Key to Japan's Competitive Success. In Irwin/McGraw-Hill. Retrieved from pt.kaizen.com.

Lasi, H., Fettke,P., Kemper, H.-G., Feld,T. and Hoffmann, M.(2014). "Industry 4.0," Bus. Inf. Syst. Eng., vol. 6, no. 4, pp. 239–242.

Liker, J. (2004). The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. 1ª Edição. New York: McGraw-Hill.

Martins, C., Sousa, D., Barros, M. (2009). The use of the hierarchical analysis method (AHP) in decision making managerial - A case study. XLI SBPO 2009 - Operational Research in Knowledge Management. P. 1778 - 1788.

O'Brien, R. (1998). An overview of the methodological approach of action Research. *University of Toronto*, 1–15. Retrieved from http://www.web.ca/~robrien/papers/arfinal.html.

Santos, E. (2013). AGV-based logistics. *Master Thesis*. Faculty of Engineering, University of Porto.

Vieira, A., Dias, L., Pereira, G. & Oliveira, J. (2014). Comparison of Simio and Arena simulation tools. 12th Annual Industrial Conference, ISC 2014.

Vieira, AA. Dias, L.M, Santos, M.Y., Pereira, G.A and Oliveira, J.A. (2018). "Setting an industry 4.0 research and development agenda for simulation – A literature review," Int. J. Simul. Model., vol. 17, no. 3, pp. 377–390.

Womack, J., and Jones, D. (1996). Lean Thinking – Banish waste and create wealth in your corporation. Simons & Schuster.

Womack, J., and Jones, D., and Roos, D. (1990). The machine that changed the World: The story of Lean Production, New York, Rawson Associates.