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Integration of lean manufacturing and ergonomics in a metallurgical industry

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Abstract

Striving to improve productivity, industries have used different management approaches, being lean manufacturing the most used over recent years. Lean manufacturing is based on value creation for the customer and elimination of waste that occurs during the production process, while improving working conditions. The incorporation of ergonomic aspects in the workstation design also contributes for the referred objectives, since it will reduce awkward postures or excessive effort during work, leading to better working conditions and increased productivity. The present study highlights, through a case study in four production areas of a metallurgical industry, the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects. Several ergonomic methods, such as Rapid Upper Limb Assessment (RULA), Strain Index (SI), and Rapid Entire Body Assessment (REBA), were chosen to evaluate the ergonomic situation and lean manufacturing tools such as Value Stream Mapping (VSM) and 7 wastes were also used to analyze the systems and increase the productivity by eliminating several wastes. The results of this study show that it is possible, and desirable, to consider both aspects, ergonomic conditions and productivity, during continuous improvement' implementations. In fact, the improvements reached through the advances in ergonomic conditions can contribute very positively for productivity increasing.

1. INTRODUCTION

The Due to rapidly changing business environment, the organizations are forced to face several dynamic challenges and complexities. Any organization oriented to survive may ultimately depend on its ability to systematically and continuously respond to these changes for enhancing the product value. Therefore, value-adding processes are necessary to achieve this perfection. Hence implementing a lean manufacturing system, by maximizing the value of the product through minimization of waste, is becoming a sustainability core competency for any type of organization (Sundar et al., 2014).

One of the main goals of the Toyota Production System (foundation of lean manufacturing) is to pursuit a JIT (Just-In-Time) production philosophy, being critical to implement efficient tools to produce the exact amount using the minimum necessary resources, which includes the elimination of waste with improved production flow with less lead time, lower costs, better quality, and greater efficiency in services to meet the customer expectations (Santos et al., 2015).

Unfortunately, lean processes can make jobs highly repetitive, while eliminating critical rest time for employees. The repetitive jobs take their toll on employees as stressful postures and high forces are repeated over and over throughout the workday (Kester, 2013).

According to Vieira et al. (2012), it is possible to observe that nowadays there is a high level of concern about the quality of working life in business, because people are not worried about their own health, only when problems arise and this will be bad for both company and the employee because the employee will have to move away due to health problems, and the company will lose one of its employees, which in turn will have to hire and training another employee thereby generating more costs to the company.

The main goal of ergonomics is to develop and apply man adaptation techniques to their working places as well as efficient and safe ways to perform the jobs in order to optimize the well-being and thus increasing productivity (Santos et al., 2015). Nevertheless, managers see ergonomics as a strictly health and safety tool that is useful for injury/illness prevention instead of recognizing its potential to improve productivity and quality and to reduce costs (Neumann & Dul, 2010).

Companies should be convinced that incorporation of an ergonomic approach in a firm's production system would be profitable in the short and long term, as its effects may vary, from human aspects, including reduction of discomfort, pain, and fatigue, to system aspects, such as speed of performance, decreased rejection rates, and good quality of service (Genaidy et al., 2007). In fact, using ergonomic solutions in the workplace is an initiative that can significantly increase the levels of satisfaction, worker efficiency and productivity (Santos et al., 2015).

So, the aims of ergonomics and lean manufacturing are aligned to eliminate or reduce waste especially non value added operations. The 'waste' motion of ergonomics such as stretching, bending, awkward postures and extensive reaching can, not only contribute to the safety and health of workers but also to productivity and efficiency (Yusuff & Abdullah, 2016). In this context, the main research question of this study was the following: would it be possible to improve the production performance and ergonomic conditions, in an integrated way, in order to boost productivity?

The study took place in four different production areas in a metallurgical industry where absenteeism rate and workers' complaints due to shoulder pains and tendinitis were high, owing to the combination of high force and high repetition to perform the manual tasks.

Following the implementation of lean principles already started in other areas of the company, VSM, SMED (Single Minute Exchange of Dies), Poka Yoke, 5S and waste reduction were the tools used in order to improve productivity. Changing the layout from process to cellular configuration was also performed in some areas to reduce wastes through the elimination of the physical distance between processes and to make possible the repetitiveness reduction by the enrichment of the tasks.

The team also suggested some workstation changes, based on anthropometric studies in order to reduce the WMSD risk.

Simulation was used for performance assessment and quantitative decision-making (Fowler et al., 2015). In this study, a simulation in Arena software was performed to dynamically analyze the initial situation and to help in the decision of layout reengineering.

Productivity was the indicator chosen to evaluate the results of this study due to the fact that nowadays a company must be efficient and productive in order to stay competitive and profitable.

This study intends to evidence the benefits of using an integrated operations management' approach to improve, simultaneously, production performance and ergonomic conditions.

2. METHODS

In This research was conducted by a case study methodological approach. According to Yin (2003), a case study should be defined "…as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context." Following this key idea, the case study, as a research methodology, helps to understand, explore or describe a given system/problem in which several factors are simultaneously involved, in a real context. The first step was the election of a multifunctional team, including operators, to analyze the processes of the production area under study and evaluate the initial situation in terms of ergonomic conditions and productivity.

Productivity was calculated using the number of pieces produced per day (throughput or production rate) because it is the measure typically used in the system-in-analysis, being also one of the most well-known measures of productivity in the industrial sector.

Regarding ergonomic conditions, the team choose the most appropriate tool(s) to assess the level of WMSD risk, such as: SI, REBA and RULA. The SI purpose is identifying jobs that place workers at increased risk of developing disorders in the distal upper extremities (DUE) and RULA is especially useful for scenarios in which work-related upper limb disorders are reported. REBA is similar to RULA providing a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures.

Complex and/or large systems were analyzed with the help of a simulator (Arena® software) and several simulation studies were used to analyze and validate different scenarios suggested by the team.

SMED methodology was used when the study occurred during a setup and other lean tools, such as: Poka Yoke, 5S, etc.…. were used taking into consideration the needs of the system .Anthropometric studies were also used in order to improve the ergonomic condition by the workstation redesign.

Finally the proposals given by the team were implemented and the results evaluated. If they have met the defined objectives, the standards have been implemented. If not, new proposals for improvement were given until the defined objectives are reached. Monitoring the new standards was essential to ensure that they are properly sustained and fulfilled.

The flowchart in Figure 1 depicts these steps.

2.1. Lean Manufacturing Tools

Lawson (2011) The key idea of lean manufacturing, or simply lean, is "doing more with less", where less means less space, less inventory, fewer resources, among others (Womack et al., 1990). Lean means fundamentally to create value for the customers spending few resources through the elimination of any kind of waste. In this study, the team decided to use VSM (Value Stream Mapping) to map the production process of the key product family and to identify and characterize the main wastes that occurred on the areas under analysis.

A Value Stream encompasses all the actions, both value added and non-value added, currently required to bring a product (good or service) through the main production flows, from the raw materials to the customer. VSM is a pencil and paper lean tool that helps to see and understand the flow of materials and information as a production makes its way through the value stream (Rother & Shook, 2003).

Regarding manufacturing systems, Ohno (1988) was the first to identify the main seven types of waste (or muda):

- Overproduction: occurs when operations continue after they should have ceased resulting in an excess of products, products being made too early and increased inventory;

- Waiting: occurs when there are periods of inactivity in a downstream process because an upstream activity has not delivered on time; sometimes idle downstream processes are used for activities that either do not add value or result in overproduction;

- Transport: unnecessary motion or movement of materials, such as WIP, being transported from one operation to another; in general transport should be minimized as it adds time to the process during which no value is added and handling damage can occur;

- Extra processing: extra operations such as rework, reprocessing, handling or storage that occur because of defects, overproduction or excess inventory;

- Inventory: all inventory that is not directly required to fulfil current customer orders; inventory includes raw materials, work-in-progress and finished goods and requires additional handling and space; its presence can also significantly increase extra processing;

- Motion: refers to the extra steps taken by employees and equipment to accommodate inefficient layout, defects, reprocessing, overproduction or excess inventory; motion takes time and adds no value to the good or service;

- Defects: finished goods or services that do not conform to the specification or customers' expectation, thus causing customer dissatisfaction.

Currently, the wrong interpretation of the real needs of the market and customers when designing products and the misuse of human capital complete the list of wastes described above.

Eliminating waste is considered, according to lean manufacturing philosophy, one of the best ways to increase productivity and the profits of any business.

Lean manufacturing dedicates a particular attention to setup time reduction, in order to get rapid changeover of dies and equipment. In 1985, Shigeo Shingo introduced his methodology, which was later to be widely known as Single Minute Exchange of Dies (SMED). This methodology provides a rapid and efficient way of converting a manufacturing process when product changes (Shingo, 2000).

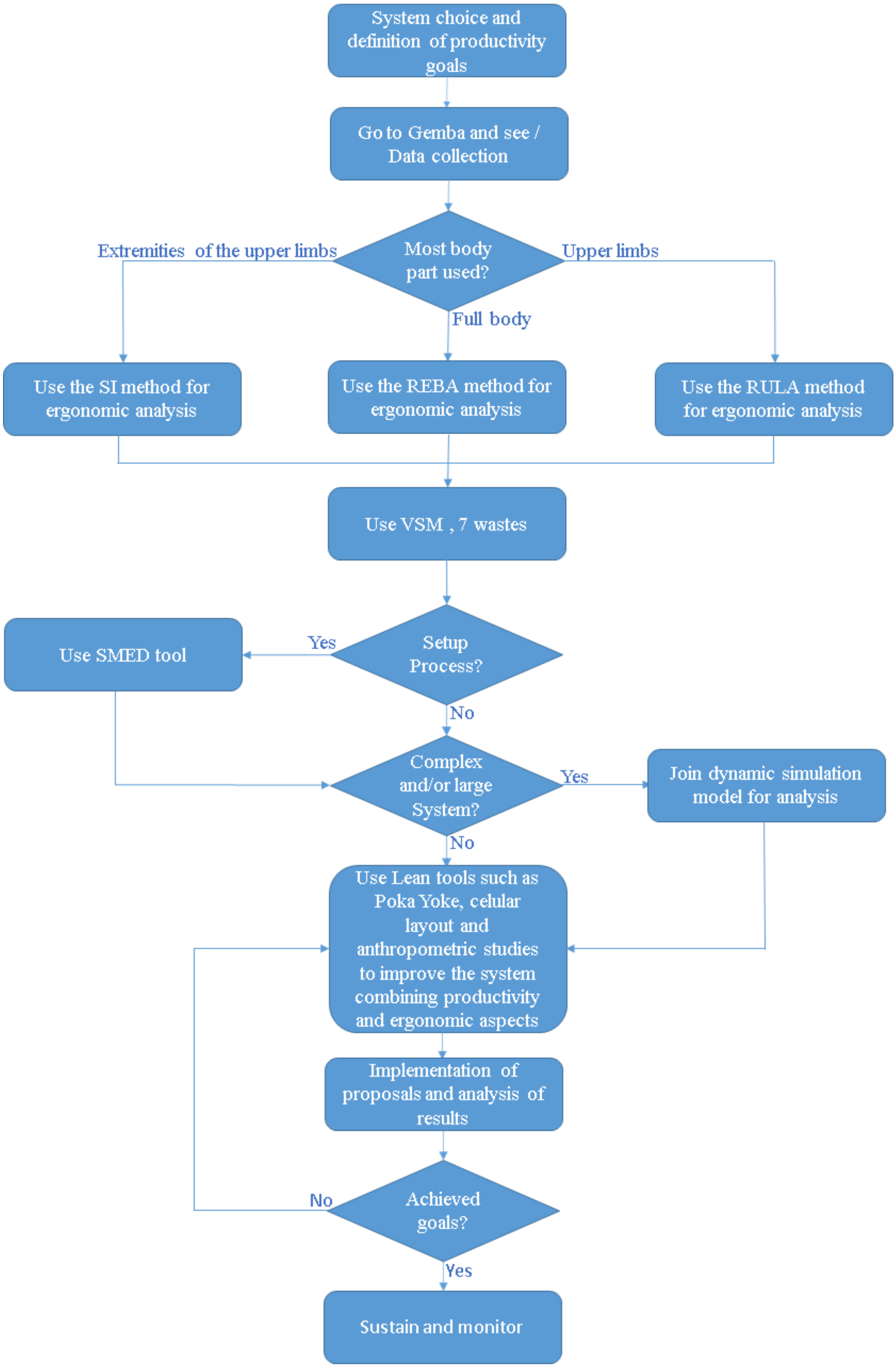

Figure 1. Methodology Flowchart

2.2. Ergonomic Analysis

In RULA was the tool used to assess the postures, movements and forces exerted by the worker while performing the job.

The higher the RULA score - varies from 1 to 7, defining the action level to be taken- the higher risk associated and the greater the urgency to carry out a more detailed study and introduce modifications to the job/workstation. The scores 1 and 2 (action level 1) indicates that the posture is acceptable if it is not maintained or repeated for long periods of time. The scores 3 and 4 (action level 2) indicates that further investigation is needed. The scores 5 and 6 (action level 3) indicates that changes are required soon. The score 7 or more indicates that changes are required immediately (McAtamney & Corlett, 1993).

The SI method (Moore and Garg, 1995) suggests estimating the intensity of exertion using a 1–5 rating scale with verbal descriptors (light, somewhat hard, hard, very hard, near maximal), measuring external force and normalizing the data based on maximal strength data (as a percentage of maximum voluntary contraction - MVC) and using the Borg CR-10 scale (Borg, 1982; Bao et al., 2006a). According to the original methodology (Moore and Garg, 1995), a job with a SI score <3 is probably "safe", a job with a SI score >7 is probably "a problem" and a job with a SI score between 3 and 7 cannot be reliability classified.

REBA was proposed by Hignett and McAtamney (2000) in the UK as a requirement observed within the range of postural analysis tools, specifically with sensitivity to the type of working postures that are very changeable. REBA provides a quick and easy measure to assess the risk of WMSD in a variety of working postures. It divides the body into sections to be coded independently, according to movement planes and also offers a scoring system for muscle activity throughout the entire body, stagnantly, dynamically, fast changing or in an unsteady way. REBA also gives an action level with a sign of importance and requires minor equipment: pen and paper method (Hignett and McAtamney, 2000).

Table 1 depicts the REBA action levels.

Table 1. REBA action levels

Action level	REBA score	Risk level	Action
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very High	Necessary NOW

2.3 Simulation Analysis

Ingalls (2011) defines simulation as "the process of developing a dynamic model, from a real system, in order to understand the behaviour of the system or evaluate different strategies for its operation". According to Kelton et al. (2010), the main reason for simulation's popularity is its ability to deal with very complicated models of correspondingly complicated systems that makes it a versatile and powerful tool. Simulation is used by operations managers to identify waste, overload, unbalanced work, bottlenecks, to design/redesign layouts, to test scheduling plans and dispatching rules, etc. According to Rossetti (2016), "if you have confidence in your simulation you can use it to infer how the real system will operate. You can then use your inference to understand and improve the systems' performance".

Discrete-event simulation is one of the most well-known operations management techniques used all over the world to model and analyse manufacturing systems. This tool is adequate to dynamically model large and complex systems with several interdependencies and stochastic behaviour. It is possible to evaluate different scenarios through a wide set of performance measures (e.g., throughput, buffer sizes, lead time, utilization of resources) and find opportunities for improvement. Guneri and Seker (2008) stated that the scenarios of a simulation are used to help in the decision-making process helping the company to analyze a process behavior over time and evaluate the impact of a given change without disrupting the system or invest capital.

A simulation study was performed, in two of the four areas analysed, using Arena software.

Arena is a leading computer simulation package with intuitive graphical user interfaces, menus and dialogs. Users are able to model complex systems using the available modules, blocks and elements in the Arena templates using simple click-and-drop operations into the model window.

The simulation studies followed the well-known major steps: problem formulation, conceptual modelling and data collection, operational modelling, verification & validation, experimentation, and output analysis Kelton et al. (2010). The logical model was implemented in software Arena. Ideally, the results should be credible enough to convince decision-makers to use them in the real system. With a validated model, it is possible to study improvement scenarios. Those solutions must be analyzed in order to understand which scenario brings the "best results" for the real system.

3. Results

Almeida (2008) Some of these results were explained in detail in other papers (Brito et al., 2017a, Brito et al., 2017b). The focus of this paper is the methodological part and the combined analysis of the results.

3.1 PVD production area

This area was analyzed using the RULA method and 7 wastes of the lean philosophy. The biggest team concern was the manually suspension movement between the carpet and the table due to the effort and the awkward posture necessary to perform this task and because it involves two kind of wastes: movement and transportation. The other concern was the excessive elevation of the arms considering the ergonomic aspects and the tiredness accused by operators, also contributing to a loss in productivity (Figure 2). The container changing process (Figure 3) was also an issue due to the high container weight (average of 6kg but could rise to 9kg maximum).

Figure 2- Unloading workstation

Figure 3 - Container Changing

The found solutions for these detected problems were the following:

- Construction of a structure to place the lighter suspensions horizontally and reduce the time of arms up (Figure 4).
- Integration of a structure with a rotating base at the end of the machine carpet to load and unload pieces directly and eliminate the necessity of take and move manually the suspension between the carpet and the table (Figure 5).
- This structure allows a manual adjustment of the work plan to reduce the arms flexion (Figure 6). The vertical amplitude of the structure was calculated base on the anthropomeric database of the Portuguese population (Barroso et al., 2005).
- The implementation of a lift car in the container changing process, similar to the one in Figure 7.

Figure 4- Horizontal

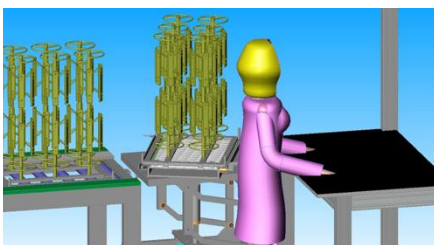

Figure 5- Structure with a rotating base

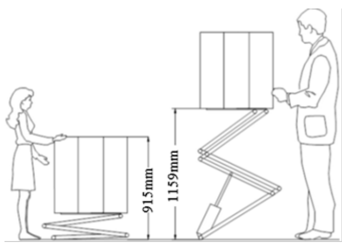

Figure 6- Work plan adjustment

Figure 7- Lift Car

Solution

3.2 Packaging production area

This production area was analyzed using the VSM tool, SI method and simulation modelling.

The main ergonomic problems were related to the repetition of the task, weight of the taps (around 1kg) and the forceful hand exertions to perform the manual tasks. Figures 8 and 9 depict some of twisting hand/wrist postures needed to perform the selection and dimensional control tasks.

Figure 8 - Dimensional control process

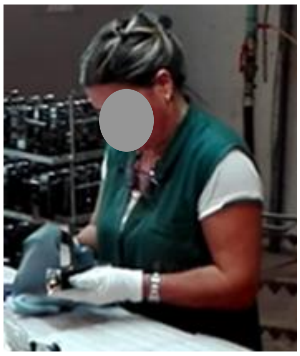

Figure 9 - Cleaning and selecting operations

The first step towards improving the packaging production area was changing the layout from a process configuration to a cellular configuration. This change is aligned with lean philosophy principles and with previous studies, which state that several companies that have implemented cellular manufacturing claim that the new system results in reduced handling time, setups, throughput times and work in process inventories.

The next step was the elimination of the waiting time (waste) by the junction of two processes: dimensional control and engraving process. Regarding ergonomic conditions, the junction of these two processes reduced the number of efforts per minute from 8 to 6. Although, that was not enough to reduce the SI score. The main ergonomic problem of this workstation continued to be the force, high repetition and the hand/wrist exertions needed to perform the tasks, such as the use of six different manual gauges in the dimensional control process. This was a very demanding process only performed by men.

Different solutions were found after a detailed analysis: two of the six gauges were integrated in the jig tool of the engraving machine, as a Poka Yoke: when the operator put the tap in the jig before the engraving process, knows immediately if the product is ok or not through the fitting. This was a big improvement in terms of productivity and ergonomics because beyond the ergonomic improvement by the reduction of two manual tasks, the total cycle time was also reduced and the productivity increased.

One of the gauges was automatically eliminated after the quality member of the team has identifying it as over processing waste and for the most critical gauge an automatized solution was implemented.

A job rotation plan was also defined to reduce the time exposed to the development of WMSD. This rotation plan took into consideration the muscle group in effort to perform the other jobs.

3.3 Tuning production area

Regarding ergonomic conditions, the team chose a postural analysis system, REBA, to assess the level of WMSDs risk because it provide a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures (Hignett and McAtamney, 2000) that fits well to the case study.

In the initial situation, the setup time took an average of 100 minutes and was performed two times per machine, one per shift. Each operator being responsible for 3 machines and doing on average 3 setups per workday.

The team decided to assess the level of WMSDs risk of the four most critical postures regarding ergonomic conditions, being two of them the following:

- Posture 1: Use of work tools whose handles are ergonomically poor;
- Posture 2: Replacement of machine gutters.

The choice was made taking into account the feedback from the operators.

In parallel with a SMED study, the team gave different ergonomic improvement proposals. Regarding Posture 1, one of the taken measures was the replacement of the tool called "Umbrako", which was far from being ergonomic, by another one, which was more ergonomic and agile, called "Ergonomic T-handle" wrench.

Figure 10 depicts this tool change.

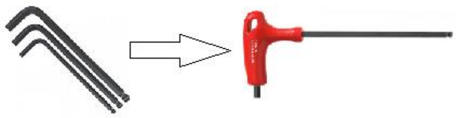

Figure 10. Tool change: "Umbrako" for "Ergonomic T-handle"

The team also proposed to change this manual tool to an automatic one. However, this idea was not accepted because it was considered a high investment.

Another ergonomic improvement was the implementation of a tray cart in order to eliminate the trunk flexion during the activity of replacing the rails of the machine – Posture 2.

Figure 11 depicts both postures: before and after the implementation of the tray cart.

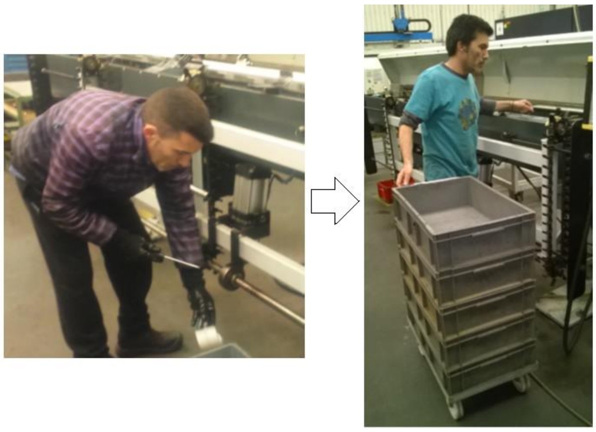

Figure 11. Operator performing the activity of replacing the gutters from the machine before and after the implementation of the tray cart (Posture 2)

3.4 Sanding and polishing production area

The first wastes identified by the team were related to the layout configuration, in this case, a process layout. This type of layout requires batch production leading to high amounts of WIP. Other wastes caused by this type of layout, and also identified by the team, were handling movements, operator motions and transports of materials between processes. As a result, the lead times were considerably high.

In order to reduce the lead time and several wastes such as stocks, transportation, motion, etc., the team proposed to change the layout from a process to a cellular configuration.

Regarding ergonomic problems, they were related to the awkward postures, repetition of the task, weight of the taps (around 1kg) and the forceful hand exertions to perform the manual tasks. Figure 12 depicts the awkward posture needed to perform the manual polishing task.

Figure 12. Manual Polishing process

After the change of layout it will be possible the combination of two tasks that were physically separated: selecting with automatic polishing. This meaning that the selecting task will be covered by the automatic polishing task trough the elimination of waiting time waste. This improvement resulted in a productivity increase and in a reduction of the repetitiveness.

The team also used anthropometric studies, based on the anthropometric database of the Portuguese population (Barroso et al., 2005), to adjust the workstation to the body characteristics of the operators.

3.5 Overall Results

Table 2 summarizes the results before and after implementation of the ergonomic and productive improvements in each of the studied areas.

Table 2. Summary of the results

Production Area -	Productivity (Pieces/Day)		WMSD Risk	
	Before	After	Before	After
PVD – Un(loading)	6800	7272	"Medium"	"Low"
Packaging	256	616	"Probably a Problem"	"Probably not a Problem"
Tuning	379	528	"Medium"	"Low"
Polishing and Sanding	320	480	"Medium"	"Low"

The results show that in all areas there were increases in productivity and in the ergonomic conditions.

Productivity increased about 7% in PVD area, 140% in Packaging area, 40% in Tuning area and 50% in Polishing and Sanding area. WMSD risk decreased from "Probably a Problem" to "Probably not a Problem" in the Packaging area and from "Medium" to "Low" risk in the other areas.

4. CONCLUSIONS

Due to the hard competition, demanding customers and competitive world that companies face, nowadays, it is very important to consider productivity measures and performance indicators while implementing improvements in the shop floor. On the other hand, jobs are more repetitive leading to musculoskeletal disorders, increasing absenteeism and reduced productivity.

The results of this four case studies showed that it is possible to consider both aspects, ergonomic conditions and production performance, during improvements implementation.

The elimination of several *gemba* wastes, the new cellular layout, workstation redesign, implementation of the 5S, automation of the tasks, anthropometric studies and enlargement of tasks were some of the key operational improvements implemented in these four production areas. Regarding job rotation, the team found it very difficult to put in practice in some areas because the majority of the other jobs that could be done by operators, have the same group of muscles in effort.

The use of simulation played a very important role in the demonstration and analysis of the gains. On the other hand, it is a time-consuming tool that requires a lot of dedication of time, which means that it should be used in non-urgent projects and when the systems are complex enough to justify the use of the tool.

The authors' opinion is that ergonomic conditions must be considered when designing/redesigning a workstation in order to get effective productivity improvements. Actually, in general, it is still difficult to implement ergonomic aspects in companies because some decision-makers do not view ergonomics as an investment, but rather as an expense.

The future works of this study include monitoring of the absenteeism rate and follow all the indicators measured in this study to sustain these improvements and implement others in a daily base. After this work, authors' opinion is that resistance to change and sustain the results are the main difficulties in improvement projects.

REFERENCES

Barroso, M. P., Arezes, P. M., Costa, L. G. and Miguel, S. (2005). Anthropometric study of Portuguese workers. International Journal of Industrial Ergonomics, 35(5):401-410.

Bao, S., Howard, N., Spielholz, P., and Silverstein, B. (2006). Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders-Part I: individual exposure assessment. Ergonomics, 49:361-380.

Borg, G.A.V. (1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, (14):377-381.

Brito, M.F., Ramos, A.L., Carneiro, P. & Gonçalves, M.A. (2017a). Ergonomic design intervention in a coating production area. In Arezes et al. (eds). Occupational Safety and Hygiene V. CRC Press, Taylor & Francis: London.

Brito, M. F., Ramos, A.L., Carneiro, P. & Gonçalves, M.A. (2017b). Combining SMED Methodology and Ergonomics for Reduction of Setup in a Turning Production Area. 7th Manufacturing Engineering Society International Conference. Elsevier's Procedia Manufacturing.

Fowler, J. W., Mönch, L., and Ponsignon, T. (2015). Discrete-event simulation for semiconductor wafer fabrication facilities. A tutorial. International Journal of Industrial Engineering, 22(5):661-682.

Genaidy, A., Salem, S., Karwowski, W., Paez, O., and Tuncel, S. (2007). The work compatibility improvement framework: An integrated perspective of the human-at-work system. Ergonomics, 50(1):3-25.

Guneri, A., and Seker, S. (2008). The Use of Arena Simulation Programming for Decision Making in a Workshop Study. Computer. Applications in Engineering Education, 1-11.

Hignett, S. and McAtamney, L.(2000). Rapid entire body assessment (REBA). J. Applied Ergonomic., (31):201-205.

Ingalls, R. (2011). Introduction to simulation. Proceedings of the Winter Simulation Conference 2011, 1374-1388. doi: 10.1109/WSC.2011.6147858.

Kelton, W.D., Sadowski, R.P., and Swets, N.B. (2010). Simulation with Arena, 5th edition. McGraw Hill, Boston.

Kester, J. (2013). A Lean Look At Ergonomics. Industrial Engineer, 45(3): 28. Retrieved from

http://www.iise.org/IEMagazine/Details.aspx?id=33970

McAtamney and Corlett. (1993). RULA: A survey method for the investigation of work-related upper limb disorders. Applied Ergonomics, 24:91-99.

Moore, J.S., and Garg, A. (1995). The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. American Industrial Hygiene Association Journal, 56(5):443-458.

Neumann, W. P., and Dul, J. (2010). Human factors: Spanning the gap between OM and HRM. International Journal of Operations & Production Management, 30(9–10), 923–950.

Ohno, T. (1988). Toyota Production System: Beyond Large-scale Production. New York: Productivity Press.

Rossetti, M.D. (2016). Simulation Modeling and Arena, 2nd edition. Wiley. New Jersey.

Rother, M., and Shook, J. (2003). Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA. Cambridge: The Lean Enterprise Institute, Incorporated.

Santos, Z.G., Vieira, L. and Balbinottic, G. (2015). Lean Manufacturing and ergonomic working conditions in the automotive industry. Procedia Manufacturing, 3:5947-5954.

Shingo, S. (2000). A Revolution in Manufacturing: The SMED System. Portland, ME: Productivity Press.

Sundar, R., Balaji, A.N. and SatheeshKumar, R.M. (2014). A Review on Lean Manufacturing Implementation Techniques. Procedia Engineering, 97:1875–1885.

Vieira, L., Balbinotti, G., Varasquin, A.and Gontijo, L.A. (2012). Ergonomics and Kaizen as strategies for competitiveness: a theoretical and practical in autimotive industry. Work, (41):1756-1762.

Womack J.P., Jones D.T., and Ross D. (1990). The Machine That Changed the world: The story of Lean Production - Toyota's Secret Weapon in the Global Car Wars. That is Now Revolutionizing World Industry. Free Press. New York.

Yin, R.K. (2003). Applications of case study research. Sage Publications, Inc. California SA.

Yusuff, R.M and Abdullah, N.S (2016). Ergonomics as a lean manufacturing tool for improvements in a manufacturing company(Conference Paper). Proceedings of the International Conference on Industrial Engineering and Operations Management (8-10):581-588.