Universidade de Aveiro Departamento de Economia, Gestão, Engenharia Industrial e Turismo
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Marlene Ferreira Brito

Lean Manufacturing e Ergonomia na Industria Metalúrgica: uma abordagem integrada para a melhoria de desempenho

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Engenharia e Gestão Industrial, realizada sob a orientação científica da Doutora Ana Luísa Ramos, Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro e sob coorientação científica da Doutora Paula Machado de Sousa Carneiro, Professora Auxiliar do Departamento de Produção e Sistemas da Universidade do Minho e da Doutora Maria Antónia Maio Nunes da Silva Gonçalves, Professora Adjunta do Departamento de Mecânica do Instituto Superior de Engenharia do Porto.

dedicatória

Dedico este trabalho ao amores da minha vida

Leonor e
Tomás

minha fonte de motivação e inspiração.

o júri

presidente

Doutor Delfim Fernando Marado Torres
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Doutora Isabel Maria do Nascimento Lopes Nunes
Professora Associada com agregação da Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa

Doutora Ana Luísa Ferreira Andrade Ramos
Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro

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palavras-chave

Lean production, Ergonomia, Casos de Estudo, Bem-estar dos trabalhadores, Melhoria Continua, Produtividade, Simulação.

resumo

Atualmente, devido ao mercado cada vez mais competitivo, a maioria das empresas só sobrevive através da melhoria contínua, aumentando a produtividade e diminuindo os custos. O Sistema de Produção *Lean* (SPL) é cada vez mais usado com esse objetivo. No entanto, o bem estar dos trabalhadores é muitas vezes negligenciado, levando a problemas músculo-esqueléticos e a outras doenças profissionais.

Diversos autores identificam uma falha na literatura quanto à identificação das melhores práticas na integração da prevenção das doenças músculo-esqueléticas num SPL.

O objetivo principal desta tese é clarificar a relação entre a Ergonomia e um SPL e desenvolver as ferramentas necessárias para ajudar os profissionais na implementação de um SPL ergonómico nas suas áreas produtivas.

Para atingir esse objetivo foi realizada uma revisão sistemática à literatura e foram desenvolvidos casos de estudo em quatro áreas produtivas numa empresa metalúrgica onde foram usados vários conceitos *Lean*, análises ergonómicas e a simulação.

Através dos resultados encontrados na literatura e validados nos casos de estudo, concluímos que a integração da ergonomia durante a implementação de um SPL resulta em ganhos de produtividade e simultaneamente melhora as condições de trabalho. Para potenciar estes resultados, diversos fatores devem ser considerados, nomeadamente: a integração da ergonomia no desenho do posto trabalho, nas ferramentas de monitorização e avaliação, na formação e a automatização das tarefas manuais.

Para além dos resultados obtidos através dos casos de estudo, e da identificação de algumas “best practices” através das lições aprendidas ao longo deste trabalho, foram ainda desenvolvidas e validadas duas ferramentas importantes no apoio à implementação de futuros estudos em diferentes áreas produtivas e setores: a ErgoSafeCI (ferramenta para avaliar e monitorizar a implementação de um SPL considerando os aspetos ergonómicos e de segurança numa área produtiva) e uma proposta de metodologia geral para abordar a questão da integração das práticas *Lean* com as práticas de ergonomia.

Este trabalho apresenta um contributo, que se espera valioso, para investigadores e profissionais por demonstrar como a integração da ergonomia num SPL potencia a produtividade fornecendo as ferramentas necessárias para a replicação da metodologia proposta noutras áreas produtivas.

keywords

Lean production, Ergonomics, Case Studies, Worker’s health, Continuous improvement, Productivity, Simulation.

abstract

Due to an increasingly competive market, most companies can only survive through continuous improvement, by increasing their productivity and reducing costs. The Lean Production System (SPL) is more and more often used for this purpose.However, the workers' well-being is often neglected, leading to musculoskeletal problems and other occupational diseases.
Several authors have identified a gap in the literature regarding the identification of the best practices in the integration of the prevention of musculoskeletal diseases in an SPL.
The main objective of this thesis is to clarify the relationship between Ergonomics and LPS and provide the necessary tools for practitioners to implement an ergonomic LPS in their production areas. To achieve this objective, a systematic review was performed and case studies were conducted in four production areas in a metallurgical company using Lean concepts, ergonomic analysis and simulation.
From the results found in the literature, which were validated by the four case studies, we can conclude that the integration of Ergonomics during an SPL implementation has the potential to result in gains in productivity and simultaneously improve working conditions. To potentiate these results, several components must be taken into account, namely: the integration of ergonomics in the design of the workstation, the tools for monitoring and evaluation, training and the automation of the manual tasks.
Beyond the results obtained and the lessons learned from the case studies, two important tools were developed and validated which were a great support to the implementation of future studies in different areas or sectors: the methodology flowchart and ErgoSafeCI (a tool to evaluate and monitor the LPS implementation while taking into account the ergonomic and safety aspects of a production area).

This work offers a valuable contribution for researchers and professionals because it demonstrates how the integration of ergonomics into an SPL increases productivity by providing the necessary tools which make it possible to replicate the procedure in other production areas or sectors.

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LIST OF ABREVIATIONS

DUE	Distal Upper Extremities
EUROFOUND	European Foundation for the Improvement of Living and Working Conditions
EUROSTAT	Statistical Office of the European Communities
IEA	International Ergonomics Association
LPS	Lean Production System
MSD	Musculoskeletal Disorders
PVD	Physical Vapor Deposition
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
SMED	Single-Minute Exchange of Dies
SI	Strain Index
VSM	Value Stream Mapping
WMSD	Work-related Musculoskeletal Disorders

1

INTRODUCTION

Contents:

Includes a general introduction which describes the relevance of the theme, objectives of the thesis, expected contributions, the methodology and the structure of the thesis.

1.1 PRESENTATION AND RELEVANCE OF THE THEME

In today's competitive and globalized markets, companies need to focus on eliminating wastes in their processes and implement continuous improvement initiatives (Aqlan and Al-Fandi, 2018). Lean manufacturing philosophy has been adopted by numerous organizations in order to respond to economic recession occurred at the beginning of the twenty-first century. Two key reasons for this trend are associated with attempting to cost reduction and customer satisfaction improvement (Khani Jazani et al., 2018).

The concept of Lean manufacturing originated at Toyota, the Japanese automaker that has been thriving in the global competition for decades (Cirjaliu and Draghici, 2016). After emergence of the system of Henry Ford , the volume per vehicle has risen sharply to 2 million units a year the Model T, but the departure of virtually all producers craft market did drop the variety of products from thousands to tens of offers. Lean production began in Japan, as he comments Womack et al. (1990), it originated with the Japanese engineer Eiji Toyoda, he left for a three-month study by the Ford Rouge plant in Detroit, after studying carefully the system of factory production, the largest and most efficient manufacturing complex in the world, after much analysis and studies he came to a conclusion that mass production would never work in Japan "In this early experiment was born what Toyota came to call Toyota Production System, and finally Lean production". In 1988, the Toyota Production System (TPS) was introduced (Vieira et al., 2012). Womack et al. (1990) predicted that Lean manufacturing would revolutionize manufacturing in the United States and abroad because its principles of teamwork, communication, continuous improvement, and waste elimination, which would lead to better quality, productivity, and market responsiveness (Womack et al., 1990; Womack and Jones, 1996).

Lean manufacturing operates by reducing unnecessary variation and steps in the work process, and consists of a set of operational tools and a strategic or philosophical part. The philosophical level concerns how to understand value (what is needed and wanted by the customer or client) and how the work process can be improved by removing steps without value (Womack and Jones, 1996; Womack et al.1990). Just-in-time (JIT) practices, waste reduction, improvement strategies, defect-free production and work standardization are the principal characteristics of Lean thinking (Botti et al., 2017).

Lean is a management style based on the human factor and suggests that staff work with a mindset oriented towards reducing losses and waste (Tajri and Sherkaoui, 2015). Eight different types of wastes were identified: transportation, excessive inventory, unnecessary movements, overproduction, overprocessing, waiting time, quality/defects and intellect underuse (Nunes, 2015), which means anything other than the minimum amount of equipment, materials, parts, space and employee time necessary to produce the required products is waste (Suzaki, 1987).

According to Seppala and Klemola (2004) and Toralla et al. (2012), a true Lean production model may tax the workers' muscular, cognitive, and emotional resources to the limit. Soon after Lean was suggested, however, it was criticized for having adverse effects on the employees. It was pointed out that Lean would intensify work, increase management control, and have a negative impact on employee health (Hasle, 2014).

Previous studies investigating the variations in the quality of working life due to the implementation of Lean Production System (LPS) have shown both negative and positive effects on workers' health and perceptions of workplace safety and job satisfaction (Miguez, 2018).

Ensuring safe working conditions is a key factor for the empowerment of workers. Even though this factor is considered within the description of sustainable industry, few companies actually consider or develop this strategy within their sustainability plans (Alayón et al. 2017). However, good ergonomic practices and their effects at the micro and macro-economic levels constitute a strong input to sustainability; as such, measures in practice aim to protect people against negative health consequences, promote the integrity of their health and quality of life, and also reduce costs to enterprises (Falck et al., 2012). Due to the economical, environmental and social problems from global warming to local waste disposal, there is also a strong need to improve manufacturing performance so that is less industrial pollution, less material and energy consumption, less wastage, and less psychological disorders for human resources. (Kumar, 2014).

According to IEA (2007), Ergonomics is a scientific discipline that studies the interactions of men with other elements of the system, making application of theory, principles and design methods with the aim of improving human well-being and overall system performance (Vieira et al., 2012). The main goal of Ergonomics is to develop and apply the man adaptation techniques to their work and efficient and safe ways in order to optimize the well-being and thus increasing productivity (Santos et al., 2015). In fact, improved ergonomics factors will lead to better working conditions and thus increased job satisfaction. There are numerous benefits with the increase of job satisfaction in any factory, such as: higher work morale, reduced turnover, higher commitment, and increase productivity (Wong and Richardson, 2010).

Research into Ergonomics and working conditions has, for a long time, largely focused on regular production work. However, Backstrand et al. (2013) comment that it is important to see Ergonomics/Human Factors as a part of Lean production practices.. Furthermore, it is often argued that failure to consider the holistic, process view of Lean production and the socio-technical aspects of the interaction between human behavior and operational tools leads to restricted success (Liker and Morgan, 2006 and Joosten et al., 2009)

Although it is known that Ergonomics can contribute immensely to productivity improvements, the Ergonomics approach is still not an accepted discipline in many industrially developing countries (IDCs) struggling to increase productivity. They think that Ergonomics is expenditure rather than investment (O'Neill, 2000). Furthermore, many workers are not aware of the ergonomic aspects of their work. This is mainly due to the fact that they have no references about how ergonomic postures and limb movements look like and which ones are ergonomically not recommended. Also, the threshold when a certain movement leaves the recommended area is not known. Instead, most workers follow motion sequences that they are familiar with because they seem to be comfortable or effective. Some of these motions might not be favorable, but workers will not necessarily notice that unless the motion immediately leads to pain or discomfort. Instead, the motion might have a negative long-term effect if repeated regularly. But if a long-term effect occurs, it is too late to intervene and the worker cannot relate it to the actions that have caused it. Several publications show, that work-related musculoskeletal issues are a common problem in the industry (Bernard and Putz-Anderson, 1997 and Armstrong, 1993).

Stuart et al. (2004) reported that when Lean improvements give too big an emphasis to processes, health and safety sometimes suffer because of the creation of new Ergonomics problems. According to Kester (2013), Lean processes may make jobs exceedingly repetitive, while removing critical rest time for employees. In fact, the amount of money companies spend on compensation claims is essentially a waste - which is against the key Lean principle of reducing waste.

Tortorella et al. (2017) stated that the Lean manufacturing method presents the human element as a vital factor for continuous improvement sustainability. According to Yasdani et al. (2018) organizations should present Ergonomics and Musculoskeletal disorders (MSD) prevention as an important component of their business via its inclusion in management practices.

Since LPS and Ergonomics share the goals of eliminating waste and adding value, there are natural ergonomic integration points in most Lean processes (Wilson, 2005 and Khani Jazani et al., 2018). Most of the authors agreed that the integration of Ergonomics during the Lean implementation has the potential to attain gains in productivity and simultaneously improve working conditions. However, there is a lack of case studies in which researchers and practitioners could learn better how this integration might work (Hasle, 2014). Furthermore, Brannmark and Hakansson (2012) concluded that there is a tendency for increasing the risk of WMSD (Work-related Musculoskeletal Disorders) when Lean implementation is not accompanied by an ergonomic intervention program focused on addressing issues such as reducing monotony and repetitiveness of work.
According to Botti et al., 2017, future studies are needed to document best practices in integration of MSD prevention into organizational-wide framework including management system. It would also be interesting to verify the impact of the evolution of LPS and Socio-technical and ergonomics practices on organization’s performance indicators (Tortorella et al. 2017).

Overall, there are significant knowledge gaps in what concerns the impact of LPS on workload and labor conditions in manufacturing (Santos and Nunes, 2016).

Taking this into account, the main objective of this thesis is answering the following questions:

1. What are the consequences of a Lean transformation on workers’ health?

2. How can one integrate ergonomic aspects during the implementation of Lean Production Systems (LPS) in order to bring benefits and well-being to workers and at the same time potentiate productivity?

At the end, it is expected to clarify the relationship of Ergonomics and LPS and give the necessary tools to help practitioners implement an ergonomic LPS in their production areas.

1.2 METHODOLOGY

According to Yin, there are several possible ways to follow a methodological path: “a conventional starting place would be to review literature and define your case study’s research questions. Alternatively, however, you might want to start with some fieldwork first, prior to defining any theoretical concerns or even examining the relevant research literature. In this latter mode, you might be entertaining a contrary perspective: that what might be “relevant,” as well as the pertinent research questions, may not be determinable ahead of knowing something about what’s going on in the field”. (Yin, 2003). This thesis followed the second path in the definition of the research questions, i.e.,

some fieldwork was carried out first and then the research question came up naturally based on the unsatisfied needs of the company. These questions were then validated by bibliographic review, in order to guarantee that they had not been fully answered before.
The choice of the most appropriate methodology to answer the research questions was based on Table 1.

Table 1. Relevant situations for different research methods (Yin, 2003 based on Cosmos corporation).

Method	(a) Form of Research Question	(b) Requires Control Over Behavioral Events?	(c) Focuses on Contemporary Events?
Experiment	how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Archival Analysis	who, what, where, how many, how much?	no	yes/no
History	how, why?	no	no
Case Study	how, why?	no	yes

The following sections explain in detail the methodology used as well as the tools chosen during the development of the thesis.

1.2.1. Systematic Literature Review

The methodology used to answer the first investigation question: "What are the consequences of a Lean transformation on workers' health?" was based on a literature review of the relationship between LPS and their impact on occupational ergonomic conditions, as well as on workers' well-being. The context was LPS implementations in industrial environments, and mainly in manufacturing industry workplaces. To carry out this study, a Systematic Literature Review (SLR) approach was used, which according to Denyer and Tranfield (2009), identifies existing publications, selects and evaluates contributions, analyses and synthesizes data, reporting evidences in such a way that allows relevant conclusions to be drawn regarding what is already Known and consolidated and what remains understudied.

This SLR followed the framework proposed by Tranfield et al (2003), who highlight three core stages for conducting a systematic literature review: (1) planning the review, (2) carrying out the review, where the papers for analysis are selected and synthesis of the data obtained is made and (3) communication and dissemination of the results obtained, reporting the recommendations and evidences in the whole review conducted. The searching process was performed on 18 May 2018. To ensure a comprehensive set of significant contributions concerning the core objective (Denyer and Tranfield, 2009), and simultaneously minimizing bias, the data of this SLR were collected using two databases which are two of the largest repositories in business research and are frequently used in such research projects; Thomson Reuter' Web of Science (Social Sciences Citation Index – SSCI) and Elsevier's Scopus. Our aim in defining the searching keywords was to identify as many papers as possible, approaching information technologies in the context of Lean manufacturing. Our aim in defining the searching keywords was to identify as many papers as possible, approaching information technologies in the context of Lean manufacturing. Thus, regarding the SSCI database, the search was carried out using as keywords "lean" AND "ergonomic*" , "lean" AND "industry 4.0" and "industry 4.0" AND "ergonomic*" on the topic field. To ensure the quality of this paper, our review was restricted to articles or reviews written in English, and with no time restriction. Concerning the SCOPUS database, we used the same research keywords as for the SSCI in three alternative fields: title, keywords and abstract. Based on these parameters, 598 articles were obtained accordingly to the Table 2.

Table 2. Search Results in each of the databases.

Keywords / No of articles	"lean" and "ergonomic*"	"lean" and "industry 4.0"	"industry 4.0" and "ergonomic*"	Total
Scopus	315	77	19	411
Web of Science	121	54	12	187
				598

The results obtained indicates that Scopus is the most relevant academic database for finding articles relating to the integration of Ergonomics, Industry 4.0 and Lean.

According to Meline (2006) an important part of any systematic review is to establish inclusion and exclusion criteria. This ensures an objective reasoning behind the choice of literature. The inclusion criteria, guiding the choice of data-bases and filtering settings in the database, are as follows: all available peer review documents available up to and including June 2018 were considered.

After obtaining the initial set of articles from the different databases, the first step was to remove the duplicates.
Next, the first screening process investigated the titles and abstracts of the identified articles and excluded articles that were: (1) not in English, (2) not related to Ergonomics, Industry 4.0 and lean manufacturing, or (3) without a full text assessing. For the remaining articles, full-text articles were collected and screened. Articles were excluded in this second screening process if they were considered only vaguely related to this topic. The typical examples of articles excluded because of this criterion are articles that mention ergonomics and/or Lean manufacturing as examples without further analysis between the two and/or studies from non-manufacturing contexts were also excluded from the results.
The exclusion criteria are summarized in Table 3. The remaining articles at this stage were included in the literature analysis.

Table 3. Inclusion and exclusion criteria.

Inclusion Criteria	All available peer review documents available up to and including June 2018
Exclusion Criteria	Non-English (NE) Not related to Industry 4.0 and lean manufacturing (NR) No full text (NF) Vaguely related to Industry 4.0 and lean manufacturing (VR)

Based on this methodology, the initial sample of 598 articles was reduced to 37 articles for the literature analysis. As shown in Figure 1, the process of filtering articles is depicted according to the PRISMA flowchart.

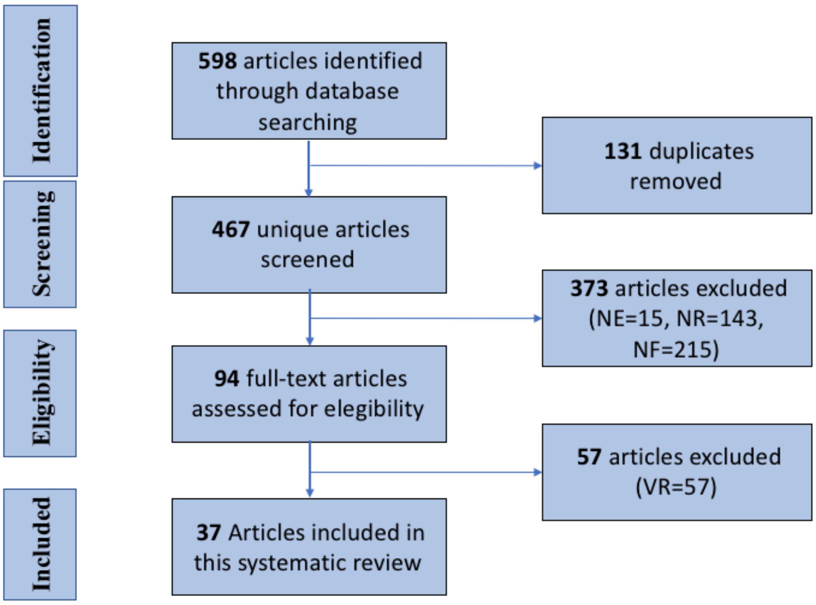

Figure 1. The PRISMA flowchart illustrates the different phases in the systematic literature review (Adapted from Moher et al. (2009). See Table 3 for explanations of the exclusion codes.

The whole research strategy (including both databases) originated a sample of 598 articles. 131 duplicated papers, 15 non-English papers, 215 not full assessed papers and143 non relevant papers were detected and thus removed. In a further screening process, 57 papers was considered irrelevant for the purposes of this research, and thus excluded. Therefore, the final sample included a total of 37 papers over a period of 19 years, considered relevant for further analysis. The relevant articles were collected in a database where they were sorted, categorized and had their main standpoint and findings extracted.

1.2.2. Case study

The methodology used to answer the research question "How can one integrate ergonomic aspects during the implementation of Lean Production Systems (LPS) in order to bring benefits and well-being to workers and at the same time potentiate productivity? was the case study. According to Yin (2003), "How" and "why" questions are more explanatory and likely to lead to the choice of a case study, history, or experiment as the favorite research method. Case studies are favored when the relevant behaviors still cannot be manipulated and when the wish is to study some contemporary event or set of events.
The case study's strength is its ability to handle a full variety of evidence - documents, artifacts, interviews, and direct observations, and also participant-observation (Yin, 2003).

Experiments demand that an investigator manipulates behavior directly, precisely, and systematically. This may occur in a laboratory setting, where an experiment can focus on one or two isolated variables (and presumes that the laboratory environment can "control" for all the remaining variables beyond the scope of interest), or it may be done in a field setting, in which the term field (or social) experiment has arisen to cover research where investigators "treat" whole groups of people in various ways, such as providing (or not providing) them with multiple kinds of vouchers to purchase services (Boruch & Foley, 2000). The complete range of experimental research also includes those situations in which the experimenter is not able to manipulate behavior but in which the logic of experimental design still may be put into effect.

For case studies, this niche is when a “how” or “why” question is being asked about a present-day set of events which a researcher has little or no control over. To choose the questions that are the most pressing on a topic, as well as to gain some precision in formulating these questions, demands much preparation. One approach is to review the literature on the subject (Cooper, 1984).

The key is to explain the presumed causal links in real-world interventions that are too complex for survey or experimental approaches. A second application is to describe an intervention and the real-world context where it took place. Third, a case study may illustrate certain topics within an evaluation, once more in a descriptive mode. Fourth, case study research can be used to enlighten those situations in which the intervention being assessed has no clear, single set of outcomes. Regardless of the application, one constant theme is that program sponsors - instead of researchers alone - may have a significant role in defining the evaluation questions and relevant data categories (Yin, 2003).

In short, a case study can be defined “…as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context.” Following this essential idea, the case study, as a research methodology, helps to understand, explore or describe a given system/problem in which several factors are at the same time involved, in a real context (Yin, 2003).

After analyzing the characteristics of the case study and comparing it with other types of methodology, there was no doubt that this would be the best method of investigation to be used to answer the second research question. It was also decided to conduct multiple case studies because: “ the chances of doing a good case study will be better than using a single-case design …More important, the analytic benefits from having two (or more) cases may be substantial” (Yin, 2003).

Figure 2 depicts the iterative process of a case study research.

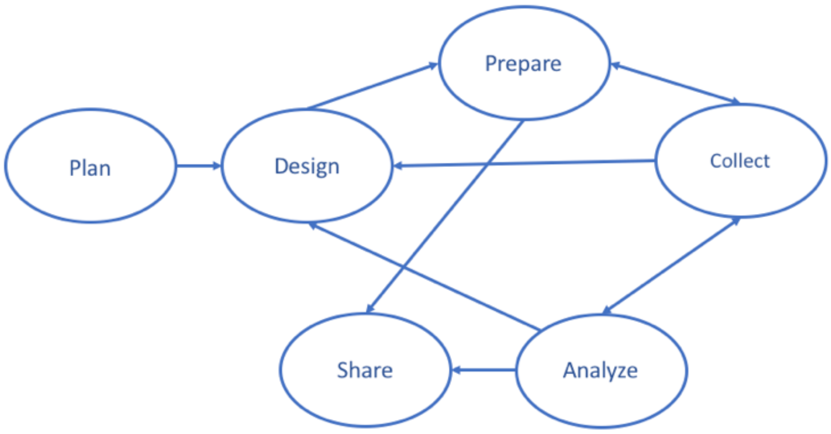

Figure 2. The iterative process of a case study research (Yin, 2003).

The metallurgical company chosen in which to carry out the case studies produces bath and kitchen taps, door handles, locks, access controls and other bath accessories and has 12 production areas which deal with different difficulties and needs. Besides, they were in different stages regarding ergonomic conditions and performance indicators. Therefore, it was necessary to develop a tool (Chapter 4) to help the team prioritize the most critical areas in what concerns Lean, safety and ergonomics. Using this tool, later named ErgoSafeCI, four production areas were identified as the most critical, and afterwards several studies were conducted in these areas:

Case study in a Coating Production Area (Chapter 5): This case study took place in a PVD coating production area, where workers' complaints due to shoulder pains were rising considerably. These complaints come mainly from the processes of loading and unloading pieces from the suspension, before and after the product entering the PVD machine, respectively. This is a repetitive job and involves several awkward postures such as: flexion of the arms above 45º, trunk flexion, and move manually heavy suspensions. The research question of this case study was: "How can be improved the workstation design of loading and unloading processes of a PVD coat production area, considering ergonomic aspects and productivity?".

Case study in a Turning Production Area (Chapter 6): This research took place in a turning production area of a metallurgical factory where workers' complains due to shoulder pains and tendinitis were high, due to the awkward postures and forceful hand exertions to perform the manual tasks. The research question of this case study was: "Would it be possible to reduce the setup time, using SMED (Lean tool) and improve ergonomic conditions at the same time?".

Case Study in a Packaging Production Area (Chapter 7): The aim of this study was to evidence the benefits of using an integrated operations management approach, using Lean concepts, to improve productivity and ergonomic conditions simultaneously and document the best practices during this process. The study took place in a packaging production area, where absenteeism rate and workers' complaints due to shoulder pains and tendinitis were high, due to the combination of high force and high repetition required to perform the manual tasks.

Case Study in a Sanding and Polishing Production Area (Chapter 8): The aim of this work was to identify the benefits of using an integrated operations management' approach, using Lean and agile concepts, to improve, simultaneously, productivity and ergonomic conditions The study took place in a sanding and polishing production area, where workers' complaints due to the strength needed to perform manual tasks as well as their repetitive pattern led to cases of shoulder pain and tendinitis. The research question of this case study was: "How the integration of both LPS and Ergonomics can benefit the workers' welfare while increasing productivity?".

The steps taken in the development of these case studies are described in a flowchart (Figure 3), which was improved throughout the development of this thesis.

The first step was to provide training in Ergonomics, safety and Lean to all company employees. According to Kester (2013), training is, a critical component of any Lean process. Basic Ergonomics concepts and ergonomic design factors should be included in the training so that team members can recognize risk factors and apply these ergonomic design options as they develop conceptual designs (Kester, 2013). At the same time, a tool developed by the team called ErgoSafeCI (explained in detail in chapter 4) was used, in order to prioritize the production areas of the company according to their criticality, considering ergonomic aspects, safety and production performance.

The next step was the definition of goals for performance indicators and then the election of a multifunctional team, including operators of the production area chosen. Processes of the production area under study were then analyzed and evaluate in terms of ergonomic conditions and performance indicators, such as: productivity (number of pieces produced per day - throughput or production rate).

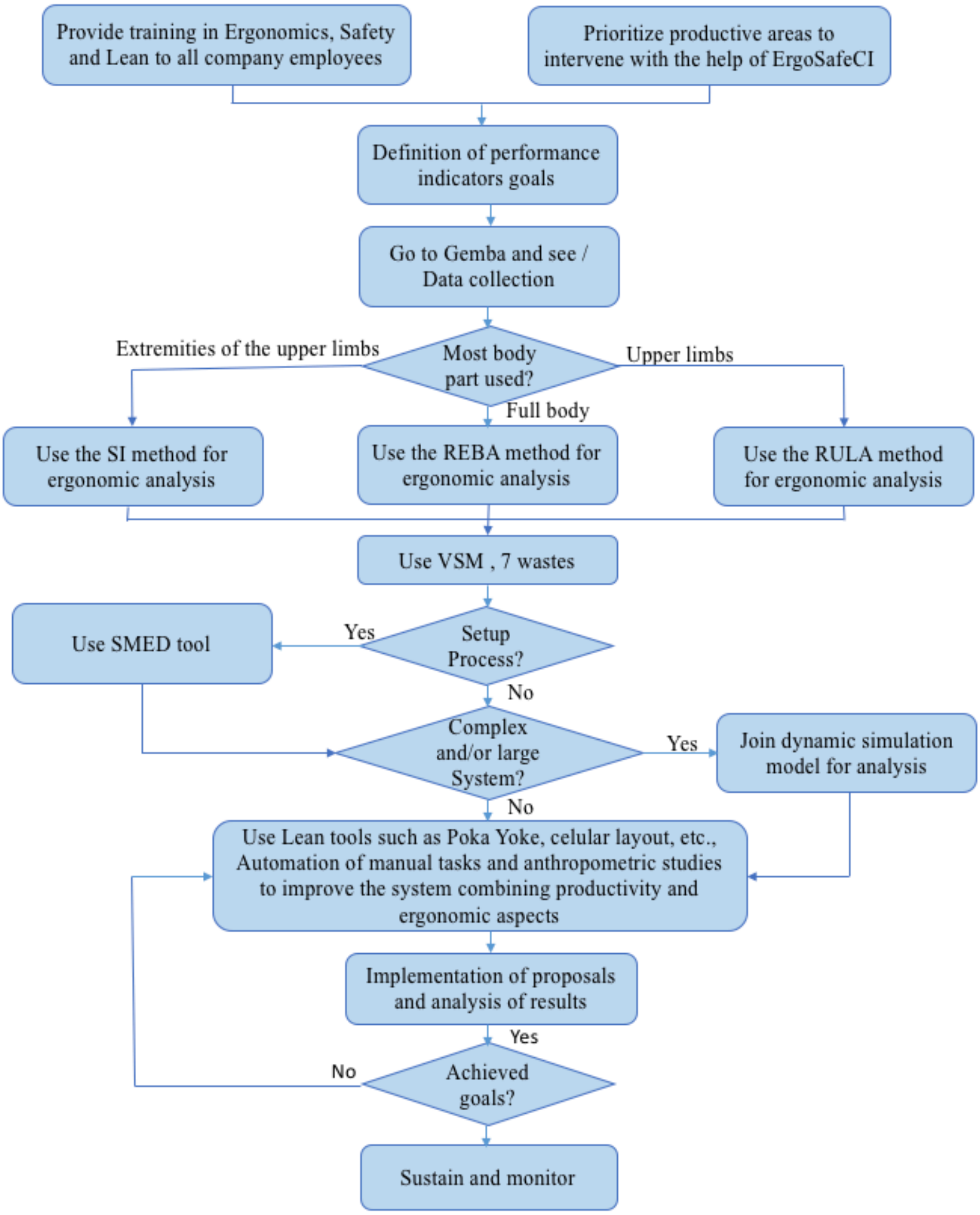

Figure 3. Methodology Flowchart.

Regarding ergonomic conditions, the team choose the most appropriate tool(s) to assess the level of Work-related Musculoskeletal disorders (WMSD) risk, such as: Strain Index (SI), Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (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.
Single-Minute Exchange of Dies (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 and the automation of manual tasks 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.

1.2.3 Lean Manufacturing Tools

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 and 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 SMED. This methodology provides a rapid and efficient way of converting a manufacturing process when product changes (Shingo, 2000).

Contrary to popular belief, Lean Production does not exclude automation. According to its founder Ohno and existing studies, repeating and value-adding tasks should be automated (Ohno 1988). Ohno called this principle Autonomation.

1.2.4 Ergonomics Analysis

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 and 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., 2006). 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 4 depicts the REBA action levels.

Table 4. 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

1.2.5 Simulation Analysis

Ingalls (2011) defines simulation as “the process of developing a dynamic model, from a real system, in order to understand the behavior 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 analyze manufacturing systems. This tool is adequate to dynamically model large and complex systems with several interdependencies and stochastic behavior. 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 analyzed, 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.

1.3 THESIS STRUCTURE

The thesis is divided into ten chapters. The content of each chapter is given below.

Chapter 1 includes a general introduction which describes the relevance of the theme, objectives of the thesis, expected contributions, the methodology and the structure of the thesis.

Chapter 2 presents a manuscript of a systematic review about the impact of the LPS adoption, in manufacturing companies, from the ergonomics point of view. It reports, based on the literature reviewed, how the integration of both LPS and ergonomics, from the workstation design phase, can bring benefits to the workers' welfare and simultaneously potentiate productivity. It also present trends and opportunities for future studies in this area.

Chapter 3 presents the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects through a case study in four production areas of a metallurgical industry (this four case studies are more detailed in the Chapters: 5, 6, 7 and 8).
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 show that it is possible, and desirable, to consider both aspects, ergonomic conditions and productivity, during continuous improvements'.

Chapter 4 presents a manuscript of an instrument containing operational measures of Lean combined with safety and ergonomics in a workstation or production line. The operational tool aims to help researchers and practitioners to prioritize and evaluate the LPS implementation as well as the ergonomic and safety conditions, in an integrated way. It allows managers to evaluate their business and identify the priority areas to improve according to the previously defined company's aims.

Chapter 5 presents a manuscript of the first case study about the redesign of two workstations in a PVD (Physical Vapor Deposition) coating production area, considering productivity and ergonomic aspects. The study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements. It used Lean concepts to identify the wastes on the production area and concluded that by their elimination, awkward postures were also reduced and consequently productivity increase and ergonomic risk reduced. RULA was the chosen method to evaluate the ergonomic situation and anthropometric studies were performed to find the ideal ergonomic solution. The study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements.

Chapter 6 presents a manuscript of the second case study which took place in a turning production area of a metallurgical factory where workers' complains due to shoulder pains and tendinitis were high, due to the awkward postures and forceful hand exertions to perform the manual tasks. The aim of the study was to prove that it is possible to reduce the setup time, using SMED (Lean Tool) and improve ergonomic conditions at the same time. Through the SMED tool and increasing ergonomic conditions, the setup time was reduced and the MSD risk also decreased. REBA was the chosen method to evaluate the ergonomic situation.

Chapter 7 presents a manuscript of the third case study which highlights the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects. The study focus the packaging production area of a metallurgical industry and, in particular, a given product family.
SI was the chosen method to evaluate the ergonomic situation due to the forceful hand exertions and a simulation model was performed in order to evaluate the "best" layout. Lean manufacturing tools such as VSM and *Poka Yoke* were also used to analyze and increase the productivity by eliminating several wastes. Through the automatization of manual tasks, implementation of job

rotation and by changing process layout to a cellular configuration it was possible to increase the productivity and improve considerably the ergonomic conditions.
The study shows that ergonomic condition' improvements should be considered to potentiate productivity.

Chapter 8 presents a manuscript of the fourth case study reporting the benefits of using an integrated operations management approach, using Lean and agile concepts, to improve the production performance and ergonomic aspects of a production system.
The main objective was to evidence that it is possible to reach an efficient production that meets safe and ergonomic requirements, by using Lean and agile principles. Through the enlargement of tasks, the reduction of waste and the reconfiguration of a process layout to a cellular arrangement it was possible to increase responsiveness and flexibility of the production system, to improve key performance indicators such as Lead time and Work in Progress, and to considerably improve the ergonomic conditions of the workers.
RULA was the chosen method to evaluate the ergonomic situation due to the forceful arm and hand exertions and a simulation model was developed to dynamically evaluate the initial situation and as a decision support tool to choose the "best" layout configuration.

Finally, **Chapters 9 and 10** presents the major contributions, the overall discussion of the results, the main findings and conclusions and underlines future perspectives for research indicating possible lines of work to complement and further development of the studies undertaken during this thesis. It also presents final reflections.

The structure of the manuscripts was maintained according to the journal guidelines in which they were submitted.

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2

ERGONOMIC ANALYSIS IN LEAN MANUFACTURING AND INDUSTRY 4.0 - A SYSTEMATIC REVIEW

Contents:

Presents a manuscript of a systematic review about the impact of the LPS adoption, in manufacturing companies, from the ergonomics point of view. It reports, based on the literature reviewed, how the integration of both LPS and ergonomics, from the workstation design phase, can bring benefits to the workers' welfare and simultaneously potentiate productivity. It also present trends and opportunities for future studies in this area.

Brito, M. F., Ramos, A.L., Carneiro, P. & Gonçalves, M.A. (2018). Ergonomic analysis in Lean manufacturing – a systematic review. Chapter Book: "Lean thinking for Global Development" (Submitted).

Abstract

In 2015, the UN defined well-being and decent work/economic growth as two of 17 sustainable development objectives. Nevertheless, the extreme pressure for businesses to be competitive in their markets of choice seems to be having a negative effect on workers' well-being. In the manufacturing sector, the effective inclusion of Ergonomics in processes and installations has been proven to decrease costs related to disability, extra or overtime hours, medical care and premiums or fines for occurrences.

The aim of this work was to review the existing scientific knowledge about the impact of adopting LPS (Lean Production Systems - a model used to increase competitiveness by the creation of more value for customers with fewer resources) in manufacturing companies from the point of view of Ergonomics. It reports, based on the literature reviewed, how the integration of both LPS and Ergonomics principles, from the workstation design phase onwards, can bring benefits to the workers' welfare and simultaneously potentiate improvements in productivity.

This paper also intends to present trends and opportunities for future research in this area, including in the Industry 4.0 field. In the authors' opinion, this paper is a valuable contribution for practitioners, in manufacturing environments, and researchers.

1. Introduction

In today's competitive and globalized markets, companies need to focus on eliminating wastes in their processes and implement continuous improvement initiatives (Aqlan and Al-Fandi, 2018). Lean manufacturing philosophy has been perceived by numerous organizations in order to respond to economic recession occurred at the beginning of the twenty-first century. Two key reasons for this trend are associated with attempting to cost reduction and customer satisfaction improvement (Khani Jazani et al., 2018).

Lean is a management style based on the human factor and suggests that staff works with a mindset oriented towards reducing losses and waste (Tajri and Sherkaoui, 2015). Eight different types of wastes were identified: transportation, excessive inventory, unnecessary movements, overproduction, overprocessing, waiting time, quality/defects and intellect underuse (Nunes, 2015).

Previous studies investigating the variations in the quality of working life due to the implementation of LPS have shown both negative and positive effects on workers' health and perceptions of workplace safety and job satisfaction (Miguez, 2018).

Stuart et al. (2004) reported that when Lean improvements focus too much on processes, health and safety sometimes suffer due to the creation of new Ergonomics problems. According to Kester (2013), Lean processes can make jobs highly repetitive, while eliminating critical rest time for employees. In fact, the amount of money companies spend on compensation claims is fundamentally a waste - which is against the basic Lean principle of reducing waste.

On the other hand, and since LPS and Ergonomics share the goals of eliminating waste and adding value, there are natural ergonomic integration points in most lean processes (Wilson, 2005 and Khani Jazani et al., 2018).

Hasle (2014) reported that there is a need for case studies, in which researchers join forces with practitioners in the workplace to introduce LPS in a form that is expected to result in a favorable employee outcome.

Overall, there are significant knowledge gaps in what concerns the impact of LPS on workload and labor conditions in manufacturing (Santos and Nunes, 2016).

However, the development towards Lean is neither possible nor desirable to discontinue. The global market requires rational production systems, and a need to find forms of ''the good work'' that fits into the Lean framework (Johansson and Abrahamsson, 2009).

The aim of this work was to review the scientific knowledge on the impact of adopting LPS from an Ergonomics' point of view. This paper also intends to present trends and opportunities for future studies in this area.

The contribution of this paper is valuable for researchers and practitioners because it clarifies the relationship between LPS implementations and its consequences for the workers' well being. Furthermore, it reports, based on the literature reviewed, how the integration of both LPS and Ergonomics can bring benefits to the workers' welfare while increasing productivity.

1.1 Background

In 2015, the General Assembly of the United Nations (UN) approved 17 sustainable development goals (SDGs). The purpose of these goals is to set attainable objectives that can accomplished by 2030 for sustainable development; e.g., "the goals and targets will stimulate action over the next 15 years in areas for critical importance for humanity and the planet" (UN 2015, p. 5)Figure **1.** The systems approach to sustainability applied to the 17 SDGs (Barbier and Burgess, 2017). Figure 1 represents the 17 SDGs across the three interlinked systems: economic, environmental and social. Sustainability can be achieved only by balancing the tradeoffs among the various goals of the three systems. This paper will focus on the relation between Ergonomics (#3 SDG – Good health and well-being and #8 SDG – Good Jobs and Economic Growth) and LPS and Industry 4.0 (#9 SDG - Industry, Innovation and infrastructure.)

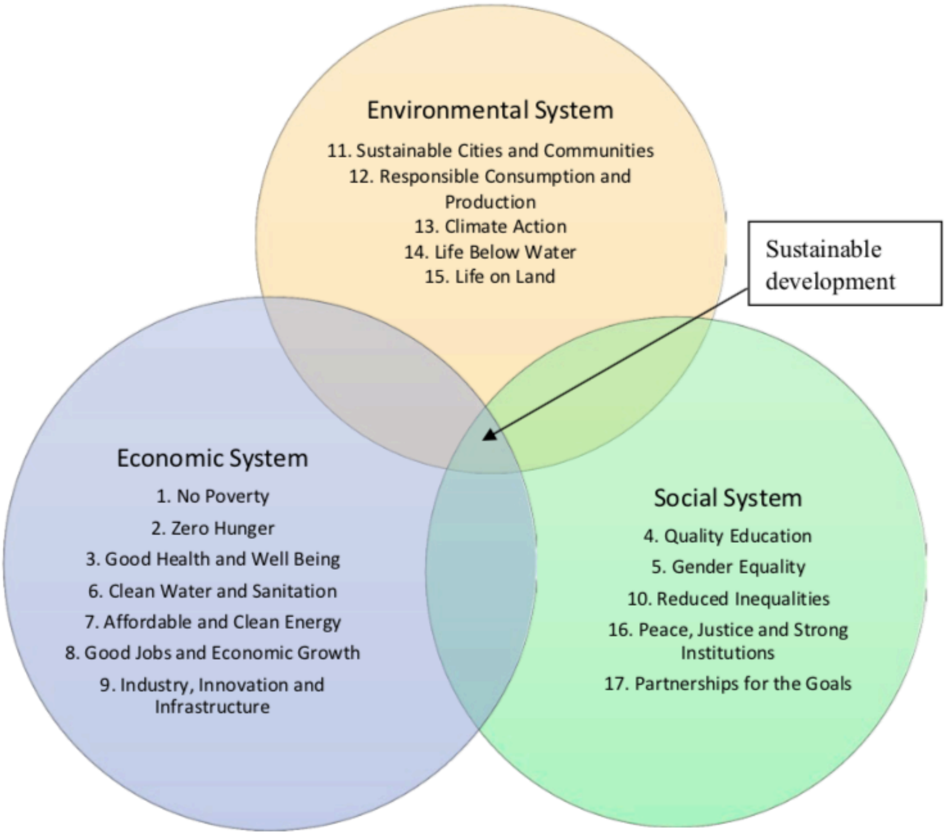

Figure 1. The systems approach to sustainability applied to the 17 SDGs (Barbier and Burgess, 2017).

1.1.1 Lean Production System

The idea of Lean manufacturing had its origin at Toyota, the Japanese carmaker which has been thriving in the global competition for decades (Cirjaliu and Draghici, 2016). Following the emergence of Henry Ford's system, the vehicle volume rose sharply to 2 million units a year for the Model T, but the departure of practically all the producer craft market caused the variety of products to drop from thousands to tens on offer. Lean production began in Japan; as described by Womack et al. (1990), it started with the Japanese engineer Eiji Toyoda, who conducted a three-month study of the Ford Rouge plant in Detroit. After studying the system of factory production carefully, at what was the largest and most efficient manufacturing complex in the world, he came to the conclusion that mass production would never work in Japan. From this first experiment originated what Toyota came to call the Toyota Production System, which eventually became Lean production. In 1988, the Toyota Production System (TPS) was introduced (Vieira et al., 2012). Womack et al. (1990) forecast that Lean manufacturing would cause a revolution in manufacturing in the United States and abroad due to its principles of teamwork, communication, continuous improvement, and waste removal, which would result in increased quality, productivity, and market responsiveness (Womack et al., 1990; Womack and Jones, 1996).

Lean manufacturing functions by decreasing unnecessary variation and steps in the work process, and comprises a set of operational tools as well as a strategic or philosophical side. The philosophical level is dedicated to understanding value (what the customer or client needs and wants) and how the work process can be improved by eliminating steps with no value (Womack and Jones, 1996; Womack et al.1990). Just-in-time (JIT) practices, waste reduction, improvement strategies, defect-free production and work standardization are the main traits of Lean thinking (Botti et al., 2017). Eight diverse categories of wastes were identified as part of the Lean philosophy: transportation, excessive inventory, unnecessary movements, overproduction, overprocessing, waiting time, quality/defects and intellect underuse (Nunes, 2015).

In an LPS any activities such as “bending to work”, “pushing hard”, “lifting heavy weights”, “repeating tiring actions” and “wasteful walk” are seen as Muri and therefore must be eliminated. Any implementation of LPS that does not lower Muri or, even worse, increases it, should not be seen as a representation of the ‘true spirit’ of the LPS implementation (Cirjaliu and Draghici, 2016). Yet, and according to Seppala & Klemola (2004) and Toralla, Falzon, & Morais (2012), a true Lean production system may tax the workers’ muscular, cognitive, and emotional resources to the maximum. According to the same authors this system must deploy an integrated set of work energizers to bring compatibility with the muscular, cognitive, and emotional requirements. Work energizers might include task variety, employment security, financial incentives, development and utilization of skills and knowledge, and awareness of organizational performance, among others (Seppala and Klemola, 2004). From that viewpoint, Lean could be said to have clear connections with Scandinavian socio-technical thinking (Gustavsen, 2007), which emphasizes teamwork and employee involvement. Soon after Lean was proposed, however, it was criticized for having negative effects on the workers. It was concluded that Lean would make work more intense, raise management control, and impact employee health negatively (Hasle, 2014).

1.1.2 Ergonomics

According to IEA (2007), Ergonomics is a scientific discipline which looks into the interactions of man with other elements of the system, applying theory, principles and design methods with the goal of improving human well-being and overall system performance (Vieira et al., 2012). The main objective of Ergonomics is to develop and apply adaptation techniques to work in efficient and safe ways so as to enhance well-being and thus increase productivity (Santos et al., 2015). In fact, improved ergonomics will lead to superior working conditions and therefore increased job satisfaction. There are several benefits of the increase of job satisfaction in any factory, such as: higher work morale, reduced turnover, stronger commitment, and improved productivity (Wong and Richardson, 2010).

Research into Ergonomics and working conditions has, for a long time, largely centered around standard production work. In spite of this, Backstrand et al. (2013) comment that it is important to look at Ergonomics/Human Factors as a part of Lean production practices. Moreover, it is frequently argued that failure to consider the holistic, process view of Lean production and the socio-technical facets of the interaction between human behavior and operational tools leads to limited success (Liker and Morgan, 2006, and Joosten et al., 2009).

Although it is known that Ergonomics can greatly contribute to productivity improvements, the Ergonomics approach is still not an accepted method in many industrially developing countries (IDCs) struggling to improve productivity. They view Ergonomics as expenditure rather than investment (O’Neill, 2000).

Additionally, many workers are not aware of the ergonomic features of their work. This is mainly because they have no references about what ergonomic postures and limb movements look like and which ones are ergonomically inadvisable. Also, the threshold when a certain movement gets out of the recommended area is unknown. Most workers follow motion sequences that they are familiar with because they are seen as comfortable or effective. Some of these motions may not be favorable, but workers will not necessarily notice that unless the motion immediately causes pain or discomfort. The motion, however, might have a negative long-term effect if repeated regularly. But if a long-term effect manifests itself, it is too late to intervene, and the worker fails to relate it to the actions which have caused it. Several publications show that work-related musculoskeletal issues are a common issue in industry (Bernard and Putz-Anderson, 1997 and Armstrong, 1993).

According to Yasdani et al. (2018) organizations ought to present Ergonomics and Musculoskeletal disorders (MSD) prevention as an significant component of their business via its inclusion in management practices.

1.1.3 Industry 4.0

Since the late eighteenth century there have been three technological developments in industry. The first industrial revolution took place in the change from manual labor to steam-powered machines, which resulted in new opportunities and facilities for industrial production. The second revolution, which happened in the mid-nineteenth century, had as its key components the use of electricity, introduction of mass production and the division of labor. The third revolution, which took place in the 70s and whose effects remain to this day, is characterized by the use of electronics and information technology for improved automation systems (Yin et al., 2018).

We are currently in the midst of the fourth technological revolution and the rise of a new technology and digital industry, known as Industry 4.0. The term 'Industry 4.0', coined in 2011 at the Hannover Fair in Germany, designates an industry whose main characteristics encompass connected machines, smart products and systems, and inter-related solutions. These aspects are used together for the creation of intelligent production units based on integrated computer and/or digital components which monitor and control the physical devices (Lasi et al. 2014). In this sense, the goal of Industry 4.0 is an autonomous and dynamic production, which integrates Information and Communication Technologies (ICT) to enable the mass production of highly customized products (Tortorella and Fettermann, 2018).

Figure 2 depicts the time line of industry from 1.0 to 4.0. (Yin et al., 2018).

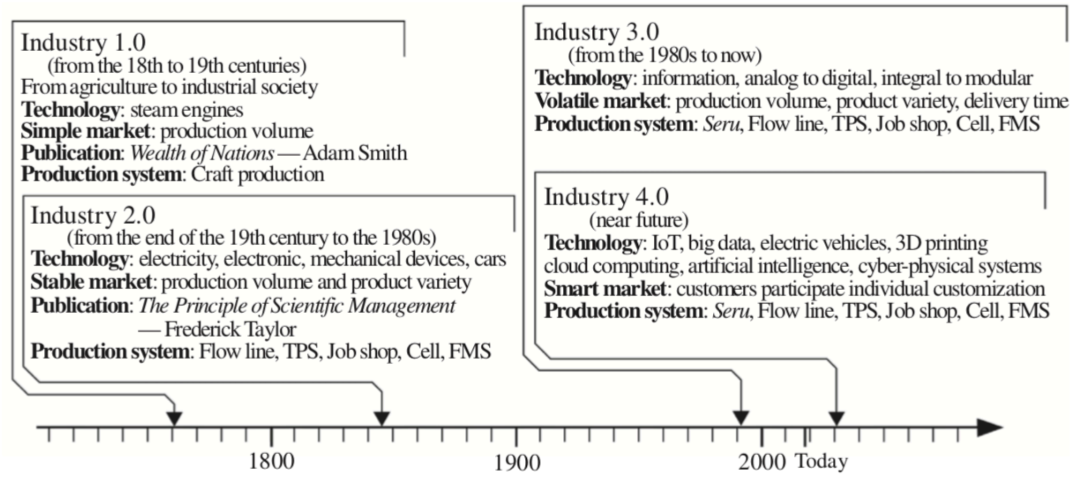

Figure 2. Timeline of industry 1.0-4.0 (Yin et al., 2018).

According to Rubmann et al. (2015), the transformation must be intensified by nine grounds of advanced technology: autonomous robots, simulation, horizontal and vertical systems integration, the industrial Internet of things, cybersecurity, cloud computing, additive manufacturing, augmented reality and bi data and analytics. For the development of an Industry 4.0 environment, Deloitte developed a framework with the concepts that form the fourth industrial revolution interface, shown in Figure 3.

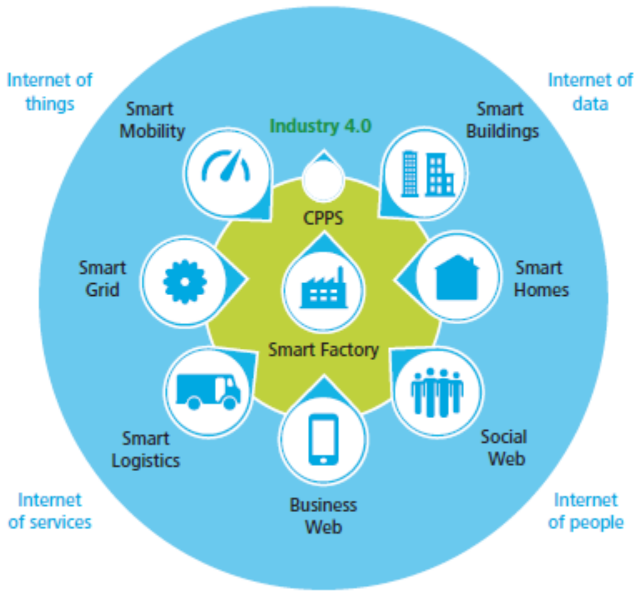

Figure 3. Nine technologies that transform the industrial production. (Doh et al., 2016).

The main components of Industry 4.0 include the ‘Internet of Things (IoT)’, ‘Internet of Services (IoS)’ and ‘Cyber-Physical Systems’ (CPS). Collectively, the technologies make continuous communication possible and permit a ceaseless trade of information and interaction between people (C2C), people and machines (C2M) and machines themselves (M2M). That relationship is required to enable the executive level to uphold connectedness to the customer base and the wider heterogeneous community. As fluctuations in customer and market trends become apparent, the executive level can make informed decisions to maintain strategic relationships without relying exclusively on lower tier recommendations. The traditional relationship of a management system mainly controlling workers will give way to active engagement. The engagement will be a two-way transfer of knowledge between the management and operational levels. Management decisions will be enhanced based on the shared knowledge (Davis et al. 2017).

Industry 4.0 is a technology-driven method to build up a modular and changeable production setting. Lean Automation tries to put together Lean Production and Industry 4.0 to get the best from both worlds (Kolberg et al., 2017). Unlike what is commonly thought, Lean Production does not exclude automation. According to its founder Ohno and current studies, repeating and value-adding tasks ought to be automated (Ohno 1988). Ohno named this principle Autonomation.

Researchers defend that automation will not lead to less human interaction or worker-less production facilities but the competence necessities might change. In reality, the individuals' skills requirements will probably increase and become even more specialized (Tortorella and Fettermann, 2018). It will be more necessary for workers to execute complex and indirect tasks such as collaborating with machines in their daily work (Levy and Murnane, 2013). This trend is heading towards the following three outcomes: workers will need to (1) solve unstructured problems, (2) work with new information, and (3) perform a number of non-routine manual tasks (Siemens, 2013). Handling continuously new information and a large quantity of data plus communicating with machines are therefore the basic elements of future work tasks (Gehrke et al., 2015).

Tortorella and Fettermann (2018) show that LP practices are positively liked with Industry 4.0 technologies and their concurrent implementation paves the way to larger performance improvements. Accordingly, smart feedback devices, worker support systems and improved man-machine interfaces facilitate better empowerment and involvement of workers in the organization (Karre et al., 2017).

2. Research Design

This work is based on an extensive literature review of the relationship between LPS and Industry 4.0, and their impact on occupational ergonomic conditions, as well as on workers' well-being. The context is LPS implementations in industrial environments, and mainly in workplaces in the manufacturing industry. To execute this study, a Systematic Literature Review (SLR) approach was used. According to Denyer and Tranfield (2009), it identifies current publications, selects and evaluates contributions, analyses and synthesizes information, reporting evidences in such a way that relevant conclusions can be drawn regarding what is already known and consolidated as well as what is still understudied.

This SLR followed the framework proposed by Tranfield et al (2003), who highlight three core phases for conducting a systematic literature review: (1) planning the review, (2) conducting the review, where the papers for analysis are selected and a summary of the data obtained is made, and (3) communication and dissemination of the results, reporting the recommendations and evidences from the whole review. The search process was performed on 18 May 2018. So as to obtain a comprehensive set of noteworthy contributions concerning our core goal (Denyer and Tranfield, 2009), and at the same time minimize bias, the data of this SLR were collected using two databases, which are two of the greatest repositories in business research and are often used in such research projects: Thomson Reuter' Web of Science (Social Sciences Citation Index – SSCI) and Elsevier's Scopus. Our goal in defining the search keywords was to find as many papers as possible which looked at information technologies in the context of Lean manufacturing. Thus, in regards to the SSCI database, the search was carried out using as keywords "lean" AND "ergonomic*", "lean" AND "industry 4.0" and "industry 4.0" AND "ergonomic*" on the topic field. To guarantee the quality of this paper, our review was restricted to articles or reviews written in English, and there was no time restriction. As for the SCOPUS database, we used the same research keywords as in the SSCI in three alternative fields: title, keywords and abstract. Based on these parameters, 598 articles were found, as can be seen in Table 1.

Table 1. Search results in each of the databases.

Keywords / No of articles	"lean" and "ergonomic*"	"lean" and "industry 4.0"	"industry 4.0" and "ergonomic*"	Total
Scopus	315	77	19	411
Web of Science	121	54	12	187
				598

The results obtained indicate that Scopus is the most pertinent academic database for finding articles concerning the integration of Ergonomics, Industry 4.0 and Lean.

According to Meline (2006), a significant part of any systematic review is the definition of inclusion and exclusion criteria. This makes sure there is an objective reasoning behind the choice of literature. The inclusion criteria, guiding the choice of databases and filtering settings in the database, are the following: all peer review documents available up to and including May 2018 were taken into account.

After obtaining the first set of articles from the different databases, the initial step was to eliminate the duplicates. Afterwards, the first screening process investigated the titles and abstracts of the identified articles and removed articles which were: (1) not in English, (2) not related to Ergonomics, Industry 4.0 and Lean manufacturing, or (3) lacking a full text assessment. As for those remaining, full-text articles were gathered and screened. Articles were omitted in this second screening process if they were considered only vaguely connected to the topic. The typical examples of articles excluded because of this criterion are those that mention ergonomics and/or Lean manufacturing as examples without further analysis between the two and/or studies from non-manufacturing contexts.

The exclusion criteria are summarized in Table 2. All remaining articles were included in the literature analysis.

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	All available peer review documents available up to and including May 2018
Exclusion Criteria	Non-English (NE) Not related to Industry 4.0 and lean manufacturing (NR) No full text (NF) Vaguely related to Industry 4.0 and lean manufacturing (VR)

Based on this methodology, the initial sample of 598 articles was cut down to 37 articles for the literature analysis. As represented in Figure 4, the method of filtering articles is depicted in accordance to the PRISMA flowchart.

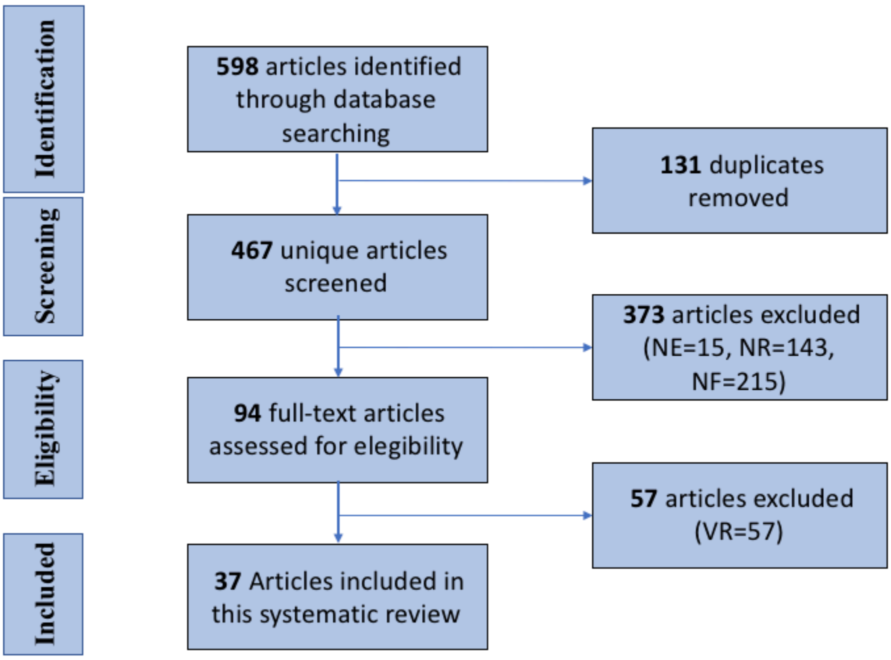

Figure 4. The PRISMA flowchart shows the different phases in the systematic literature review (Adapted from Moher et al. (2009)). See Table 2.2 for explanations of the exclusion codes.

The whole research strategy (including the two databases) resulted in a sample of 598 articles. 131 duplicated papers, 15 non-English papers, 215 not fully assessed papers and143 irrelevant papers were found and promptly removed. In a further screening stage, 57 other papers were considered irrelevant for the purposes of this research, and therefore excluded. As a result, the final sample included a total of 37 papers done over a period of 19 years, which were deemed relevant for further analysis. The relevant articles were put together in a database where they were sorted and categorized and had their key standpoint and findings extracted.

3. Results of the descriptive analysis

The review identified 37 articles that comply with the inclusion and exclusion criteria and thus present a contribution towards explaining the link between occupational ergonomic conditions and LPS and Industry 4.0.

The results are structured in two parts: a quantitative analysis and a qualitative thematic analysis detailed in the next section.

The number of publications related to the association of the concepts of "Lean", "Industry 4.0" and "Ergonomics" has been growing over the last few years. It is clear that this is an emerging research area, with most of the studies being published in 2016 and 2017. Figure 5 shows this evolution.

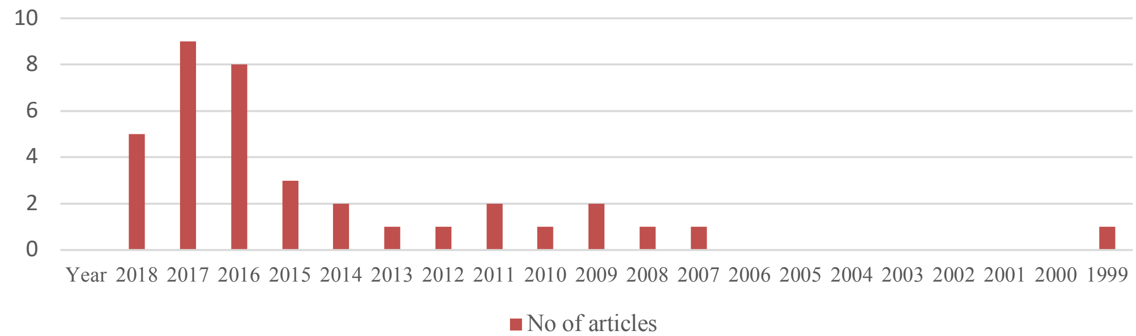

Figure 5. Evolution of the publications over the years.

Regarding the source where the studies were published, nearly 50% come from the following journals: International Journal of Production Research, Human Factors and Ergonomics in Manufacturing and Applied Ergonomics. These are followed by the publications in Procedia Manufacturing. Figure 6 depicts these results, corresponding to the source of the reviewed publications with two or more entries.

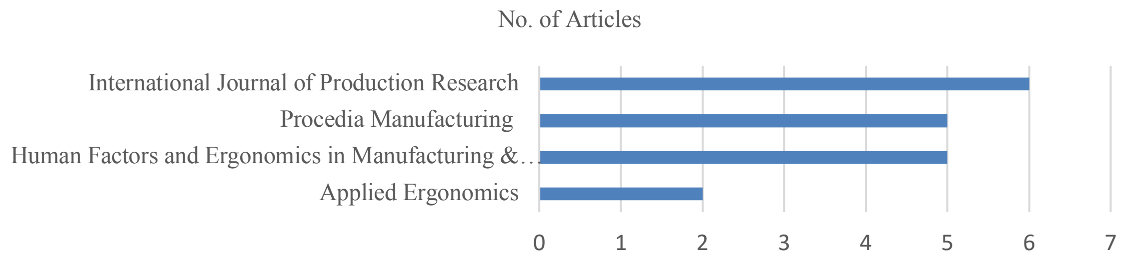

Figure 6. Source of the publications with two or more entries.

Figure 7 presents the research methods utilized in the articles reviewed in this SLR. The Case Study leads, followed by the Literature Review. Both represents 54%of the methods used in the articles of this SLR.

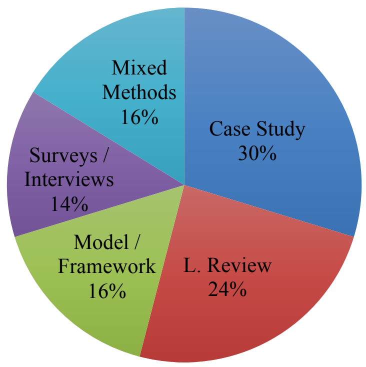

Figure 7. Research methods in the investigated articles.

Brazil is the biggest contributor for the 37 articles analyzed in this review, with 7 articles, followed by the USA with 6 articles and then Germany and Italy, both with 3 articles. Figure 8 depicts the origin of all the articles reviewed.

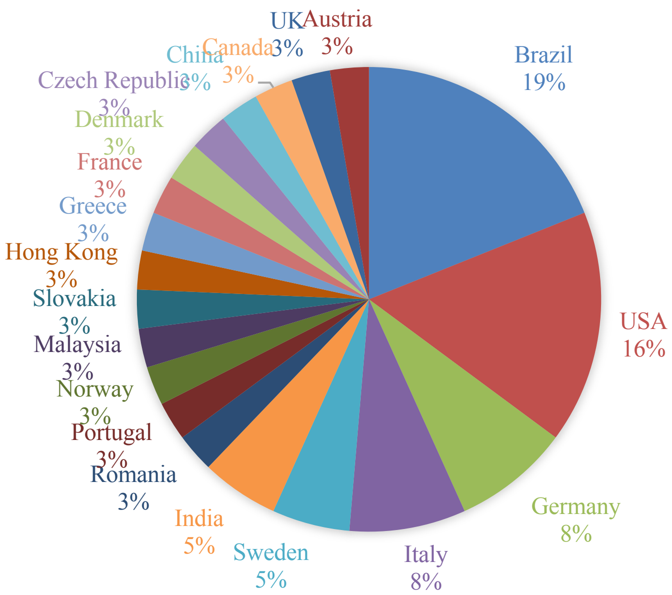

Figure 8. Origin of the articles reviewed.

The articles can be categorized according to the three arrows describing the relationships between the keywords used in the databases. Figure 9 presents the categorization of the articles according to the proposed conceptual framework.

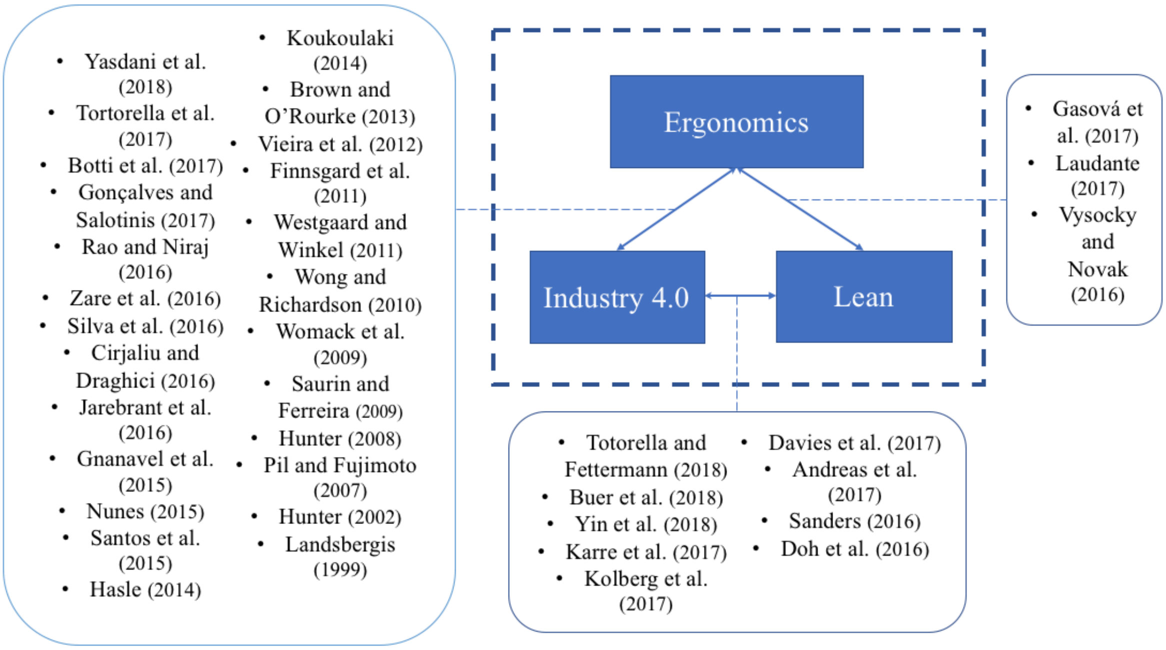

Figure 9. Categorization of the articles according to the proposed conceptual framework.

The first study examined was the work "The impact of lean production and related new systems of work organization on worker health". This paper, published by Landsbergis and colleagues, in 1999, in the Journal of Occupational Health Psychology, with a total of 244 citations, was one the first studies that examined the impact of Lean production quality management on occupational injuries, illnesses or on job characteristics related to job strain.

4. Results of the thematic analysis

In order to enrich the qualitative analysis, more publications were added based on the references suggested in the 37 articles found using the methodology described in section 3.

4.1 Health effects in a Lean environment

The comprehension evolution on Lean production may be summarized as an emphasis on quality in the literature of the early 1990s, through quality, cost, and delivery (late 1990s), to customer value from 2000 onward (Silva et al. 2016).

Until 1990, LPS implementation was entirely tool focused and normally neglected the human aspects of the high-performance work system core of the Lean manufacturing approach (Koukoulaki, 2014). In reality, Lean production tools are frequently put in place in order to remove non-value-adding activities and reduce variability in the work process, without considering the Lean production philosophy (Shah and Ward, 2007). Consequently, most studies in the 1990s report adverse effects on employee health (Hasle, 2014).

Landsbergis et al. (1999) reviewed 19 studies from the car industry. Twelve of those presented information about health consequences in the form of musculoskeletal disorders (MSD), fatigue, stress, and tension. Six of these studies demonstrated a clear connection to MSD and two an equivocal link. Four showed a clear association with fatigue, stress, and tension, and three an equivocal link. A few found no association and none found any beneficial consequence on health. The result of the review undoubtedly indicated negative consequences for workers in the form of intensification of work, stress, and MSD. Berggren (1993) reported that Lean means working more smartly and also harder, not just more smartly. The same author noted other downsides of LP, such as the standardization of cycle time, which stops employees from managing the pace at which they work. Still, and according to Hasle (2014), some of these results ought to perhaps be interpreted as outcomes of traditional Tayloristic rationalization and not as results of Lean by itself.

After 1990, there was a steady broadening of focus away from the shop floor to diverse sectors by businesses which adapted their production systems to embrace a new design based on "Lean principles" (Womack and Jones, 1996). These principles entailed the identification of customer value, the management of the value stream, the developing of the capability for production flow, the use of "pull" mechanisms to sustain the flow of materials at constrained operations, and, lastly, the pursuit of perfection through cutting down to zero all forms of waste in the production system. Concerning risk factors and health effects, the research focus began moving from mechanical exposure and health effects, for example, MSDs, to psychosocial risk factors and stress. The conclusions from these studies are mixed, with some job characteristics being impacted negatively and others positively (Table 3).

Table 3. Some of the adverse and positive effects in an LPS, as reported in the literature.

Adverse Effects		**Positive Effects**	
Authors	**Results**	**Authors**	**Results**
Parker (2003)	Increased job depression	Finnsgard et al. (2011)	Reduced trunk flexion and shoulder elevation due to the use of smaller containers (Lean concept)
Westgaard and Winkel (2011)	Mental Problems	Jackson and Mullarkey (2000)	Work roles with greater breadth, more variation, higher skills utilization and higher cognitive demands
Landsbergis et al., (1999)	Stress, low job satisfaction, and low decision control	Westgaard and Winkel, (2011)	Job enlargement

Jackson and Mullarkey (2000)	Fewer timing controls, higher demands and more conflicts in the Lean teams	Saurin and Ferreira (2008), Hunter (2006)	Improved working conditions
Koukoulaki (2014)	Stress and increase of musculoskeletal risk symptoms	Koukoulaki (2014)	Autonomy and empowerment

According to Koukoulaki (2014) the reported harmful results may be a reflection of 'rigid' Lean implementation strategies applied in the automotive industry, caused by Just-in Time (JIT) systems. It seems that these JIT practices are the basis of an intensification of work that is connected to increased levels of strain and stress. Furthermore, pressure from team working may have stopped workers from reporting their symptoms and forced them to work in pain (Koukoulaki, 2014).

Parker and Conti defend that Lean production is not by definition negative and that what matters most are the choices companies make in Lean implementation. For example, a company might choose to apply one Lean characteristic to its extreme, (e.g. removal of 'waste activities'), which would have a direct effect on work intensification, while minimizing other characteristics that might act as a buffer to stress (e.g. autonomy and group support in teams). According to these authors, this dangerous combination could only result in the harmful effects of Lean production (Koukoulaki).

In general, the findings of the surveys and literature reviewed show that the effects of Lean production on working conditions are more evident in the car industry (increased stress and symptoms of MSDs) and less evident in other manufacturing sectors, which is logical given that in the automotive industry the Lean implementation is full and its effect on working conditions can be expected to be more obvious (koukoulaki, 2014). Lewchuk et al. (2001) also indicate that a more strenuous working environment is in place and a higher level of psychosocial discomfort (tense feelings and exhaustion) occurs in the auto plants with the most comprehensive enforcement of Lean. Nevertheless, it is not clear whether this is the result of Lean or an industrial context and implementation strategy characterized by management pressuring employees and poor industrial relations (Hasle, 2014). Moreover, Lean implementation is not the same across diverse companies, sectors and continents and the results can depend upon what is implemented and how (Koukoulaki, 2014).

In effect, and according to Murray et al. (2010) and Pai et al. (2009), misapplication of Lean techniques could originate safety issues, health problems and accidents, which is in accordance with Arezes et al. (2014): "the reported disadvantages of LPS implementations may result from the misunderstanding of the Lean principles and possibly by implementing similar solutions that may be effective in a specific work context but not suitable to all possible situations".

Several studies have also attributed the increased work pace and lack of recovery time in Lean companies to JIT practices and work standardization (Saurin & Ferreira, 2009). In the origin of such a phenomenon is the fact that Lean processes often result in highly repetitive operations, stressful postures and high forces, while removing critical rest periods for employees (Kester, 2013). Injured workers are not capable of working, and replacement workers are not as efficient at executing the tasks. As a result, increased injury rates compromise the desired results for Lean processes. In the long term, the economic savings from quality, productivity and efficiency improvements pay for the bigger cost of employees' compensation claims for MSDs (Botti et al., 2018).

On the other hand, when Lean production was first introduced, it was described as an efficient system for production that also had beneficial results for workers, increasing their autonomy and empowerment (Koukoulaki, 2014).

The ambiguity of the consequences of LPS on working conditions was detected by Saurin and Ferreira (2008), who looked at 52 scientific articles on the subject, and listed the number of positive or negative results that were cited. Overall, 48% of the citations were connected to positive impacts and 52% referred to negative impacts, although most studies showed that positive and negative impacts occurred at the same time. Furthermore, and according to the same author, due to the intrinsic characteristics of LPS, such ambiguity might also be a result of a number of factors, such as:

- the impact of each company's organizational culture, in particular the extent to which safety and ergonomics are core values;
- the different degrees of maturity of companies' Lean systems, which in turn depend on a set of variables (e.g. the types of products and processes, the length of time since LP was adopted);
- •the socio-economic context of the region where the plant is situated (e.g. unemployment rates; labor standards, the role of unions);
- the degree of workforce involvement in the LPS implementation process.

In what concerns positive effects, Hunter (2006) reported ergonomic and productivity improvements, and Saurin and Ferreira (2008) pointed out that employees had a positive perception of their working environment and that working conditions got better after the adoption of LPS. Hunter also described a lowered repetitive motion injury risk in a cellular (Lean concept) manufacturing job enlargement methodology. Under this scheme, workers have more tasks to execute on each cycle around the cell, which allows microinjuries further time to heal (Hunter, 2002). Finnsgard et al. (2011) demonstrated that materials exposure using smaller containers, a LPS concept, makes workstation performance better in terms of less non-value adding work, reduced space necessities for materials exposure and reduced trunk flexion and shoulder elevation demands on operators.

Womack et al. (2009) looked at the link between work organization and job characteristics under Lean manufacturing and work-related musculoskeletal disorder (WMSD) risk factors. The results suggested that Lean manufacturing does not necessarily make workers' risk for WMSD injuries higher.

Schouteten and Benders (2004) consider that the ambiguity of these findings has to do with the lack of an external assessment framework supported by validated research instruments.

4.2 The integration of ergonomic aspects during Lean implementation

What numerous companies fail to realize is the potential for further increasing the productivity gains if ergonomic principles were integrated and implemented at the same time as Lean Systems (Nunes, 2015). Since Ergonomics is most commonly housed within the Occupational Safety and Health (OSH) department (essentially to answer legal requirements and to perform risk management), managers have a tendency to inadvertently narrow its scope of intervention to hazards, instead of taking advantage of its help to advance organizational effectiveness, business performance and costs (Nunes, 2015). According to Westgaard and Winkel (2011), integrating the requirements for effective production and a healthy workforce in the analysis and devising of production systems could be a solution to the apparent conflict of interest between Ergonomics and rationalization. Moreover, the integration of ergonomics during the Lean manufacturing implementation can potentially lead to obtaining considerable gains in productivity, lowering absenteeism (Santos et al., 2015) and simultaneously improving working conditions (Alves et al., 2016).

Since ergonomic hazards can lead to Lean wastes and vice-versa, workplace ergonomics and Lean manufacturing are deeply inter-related (Aqlan et al., 2013, and Aqlan et al., 2014). Lean Ergonomics may decrease lead time by eliminating the waste of nonproductive manual material handling movements and activities (Galante, 2014), such as stretching, bending, awkward postures and extensive reaching, as well as increase the efficiency, safety and health of workers (Yusuff and Abdullah, 2016). Thus, the Lean team must take into account Ergonomics and safety, at the same time as waste reduction and value creation, core values of the Lean process (Wilson, 2005). For instance, by incorporating risk assessments into the value stream mapping process (Kester, 2013), obtaining parts efficiently in the workstations and finding tools quickly (Webber, 2005).

The literature has several examples of the benefits of integrating Ergonomic aspects in an LPS, such as:

- Miguez (2018) showed good results by getting together a multidisciplinary team of certified ergonomists, engineers, managers and direct employees in the use of concepts of Ergonomics and LPS to improve a workstation, such as lowered costs and lead time as well as improved health and safety of workers.
- •Williams and Douglas (2011) improved efficiency by more than 40 percent by becoming more organized, improving standards, cutting down excess motion in the cells, improving Ergonomics and safety, creating common processes and reducing the number of procedures required to assemble a product.
- Scheel and Zimmermann (2005) reported significant results when integrating ergonomic principles within a Lean implementation process in a Kaizen event, such as: shortened cycle times, travel distances reduced in square footage, from 67% to 100%, and reductions in the existing ergonomic risk factors.

Furthermore, Brannmark and Hakansson (2012) concluded that there is a tendency for expanding the risk of WMSD (Work-related Musculoskeletal Disorders) when Lean implementation is not done side by side with an ergonomic intervention program focused on addressing matters such as reducing monotony and repetitiveness of work.

As discussed in the previous section, the literature is not consensual about the workers' health in a Lean environment. In fact, when ergonomic aspects were not considered during the implementation of an LPS both positive and negative aspects were identified. However, when ergonomic aspects were considered during LPS implementation, the literature is consensual in identifying only positive aspects. Figure 10 depicts these results:

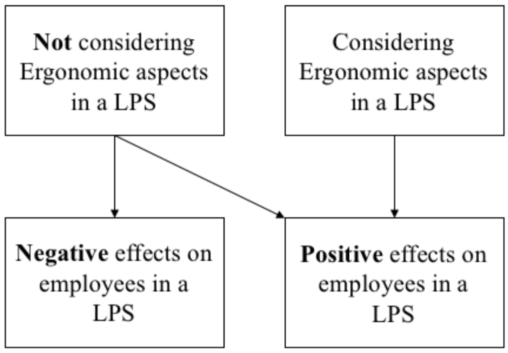

Figure 10. Some of the adverse and positive effects in an LPS, as reported in the literature.

In summary, the importance of integrating ergonomic aspects in Lean manufacturing is consensual. The following subsections explain some important components to consider during the implementation of an LPS, considering Ergonomics.

4.2.1 Training

According to Kester (2013), the misunderstanding of the Lean principles might be solved by training, which is a key component of any Lean process. Basic Ergonomics concepts and ergonomic design factors need to be included in the training in order for the team members to recognize risk factors and apply these ergonomic design possibilities as they develop conceptual designs (Kester, 2013). Griffiths et al. (2007) reported increased productivity and product quality, lowered life cycle costs, reduced lost work days and error rates, and improved worker satisfaction after the development of Ergonomics training to educate engineers in the principles and methodologies of Ergonomics, quality, and Lean manufacturing.

According to Browne and O'Rourke (2007), essential to worker safety in Lean production operations is understanding the merit of informed, empowered, and active workers with the knowledge, skills, and opportunity to act in the workplace to remove or reduce hazards.

4.2.2. Design

Yusuff and Abdullah (2016) defined Ergonomics as a method of designing workstations, work practices and work flow to house the capabilities of workers. According to Greenwald (2009) employers must avoid only adding Ergonomics at the end of a project and instead use it throughout the project as an essential component. Since the goals of Ergonomics design complement the goals of the LPS and can alleviate the risk created by some Lean solutions (Greenwald, 2009 and Kester, 2013), this integration (Lean and Ergonomics) ought to be done early, in the design of the workstation (Murray et al., 2010).

In reality, ergonomic hazards originate from badly designed workstations and chairs that do not alleviate highly repetitive assembly operations often involving forceful motions and awkward positions (Brown and O'Rourke, 2007). Yusuff and Abdullah (2016) share this opinion: "Good ergonomic design will reduce awkward postures or excessive effort during work".

Workstation design is therefore a key process to ensure effectiveness, customization, automation and competitiveness in high volume environments, requiring less time, space, cost and inventory. With that in mind, workstations play an essential role in manufacturing processes. Lean workstations ought to be designed with a focus on minimizing waste and concentrating operators on critical issues, and from the operators' perspective (Gonçalves and Salotinis, 2017).

Jackson and Mullarkey (2000) suggest that the balance between positive and adverse effects of LPS depends on management options in the form of work design. From a worker's perspective, the attention to ergonomic issues related to workstation design, like access to materials, equipment and tools, and communication among workers, is essential for the operator's safety while working in the cell (Fiore, 2016).

Weber (2005) reported that workstation need to be comfortable for the operator, and include the tools and supplies required to execute the current task, allowing for maximum performance without adverse effects on physical workloads (Tajri and Sherkaoui, 2015). In Hunter's (2008) opinion, the main goal of the Lean production cell designer is job enlargement, by giving the worker additional work tasks, which lends itself to beneficial ergonomic effects given that the added time required to do more work provides the human body with more time to heal micro injuries.

4.2.3 Development of Tools and Monitoring Ergonomics in Lean Implementation

Given that Lean implementation tends to affect both the technical and socio-cultural aspects of an organization, human factors must be intrinsically considered alongside this process change. This key point, however, is beyond the scope of traditional Lean implementation roadmaps, or looked at separately as a secondary approach (Totorella et al., 2017).

According to (Yazdani et al., 2015), MSD risk assessment tools and techniques appear to be partially outside the main management process due to their complexity. As a result, MSD prevention may end up not being "on-the-table" and not be given enough attention.

MSD prevention is usually approached via an MSD prevention program and is diverse from other organizational management systems such as a Quality Management System (QMS) or an Occupational Health and Safety Management System. As a distinct program, it is frequently overlooked and poised to be subject to

cuts during financial downturns. Moreover, it is hard to implement since it doesn't make use of the existing management systems that the company has in place. Present practices for MSD prevention activities are usually limited to short-term projects to address a specific issue or a program consisting of multiple projects. These projects and programs normally stand alone, in isolation from the main business structure and the way that organizations address other issues including quality, general health and safety and environmental issues (Yazdani et al., 2018).
On the contrary, MSD prevention might benefit from incorporation into approaches such as QMS, and continuous improvement approaches including Six-Sigma and Kaizen. Including MSD prevention in a framework already adopted by these companies, by maximizing similarities and compatibility for integration, allows the program to have increased sustainability, undergo continuous improvement and incur less costs for the organization. This can be achieved by using common language, tools, goals, and framework (Yazdani et al., 2018).

Thus, MSD prevention practices ought to be designed in a way that is completely compatible with and facilitates integration into other management infrastructures through, for instance, the use of a quantifiable, repeatable, reliable, and measurable risk assessment tool, such as RULA. This is consistent with Perez and Nuemann (2015) and Village et al. (2014).

According to Naranjo-Flores (2014), it is necessary for there to be a methodology of intervention focused on the correct application of both concepts (LPS and Ergonomics) in order to achieve results without neglecting the human factor.
The first tool found in the literature, developed by Toyota in the early 1990s, is a measuring instrument known as TVAL (Toyota Verification of Assembly Line), which analyzes the workload of each assembly job quantitatively. Based on experiments, Toyota assesses work posture and load, along with task length at each workstation. TVAL enables process planners to recognize physically demanding jobs in an objective manner, prioritize the workstations to be improved, and concentrate efforts for improvements where they will have the biggest impact. Alterations include low-cost automation assists, height-adjustable conveyors, power assist devices, and the distribution of high-strain tasks. Job rotation also became more frequent, with a 2-hour rotating pattern being made into the norm at Toyota Kyushu in 1995 (Pil and Fujimoto, 2007).
Various tools have emerged in recent years:

• Wong et al. (2014) developed a Lean index to assess the leanness level of the organization in sustaining Lean transformation from a socio-technical perspective, which considers the interdynamics of human, system and technology.

• Jarebrant et al. (2016) proposed the application of the Ergonomic Value Stream Mapping (ErgoVSM), a tool which aims to improve ergonomic conditions while productive performance indicators are also in focus in a LPS. The implementation of ErgoVSM on its cognitive modality is an effort for acknowledging the significance of assessing health risks within each workstation at companies.

• Gonçalves and Salonitis (2017) proposed a tool to measure and evaluate Lean and ergonomic principles in order to design leaner and safer workstations. This model has the form of a checklist which is based on the current best practices in Workstation Design of assembly lines.

• Aqland et al. (2013) developed a framework that combines Lean and ergonomic steps to effectively eliminate Lean and ergonomic wastes.

• Tortorella et al. (2017) proposed a method that comprises a combination of techniques which allow for the identification of deficiencies related to the adoption Lean Manufacturing practices which may support the implementation of socio-technical practices, indicating a prioritization of improvement opportunities to better sustain them.

• Botti et al. (2017) proposed a mathematical model to design Lean processes in hybrid assembly lines. The aim was to provide an effective, efficient assembly line design tool that meets the Lean principles and ergonomic requirements of safe assembly work.

• Rao and Niraj (2016) proposed a model of a framework regarding the integration of Ergonomics and Lean manufacturing systems based on various tools.

• Nunes (2015) presented a model of a framework regarding the integration of Ergonomics and Lean Six Sigma (LSS) based on the DMAIC cycle to help the decision-making process in the execution of the integrated implementation of Ergonomics and LSS continuous improvement processes.

• Gnanavel et al. (2015) developed a methodology which incorporates Ergonomics in layout design in aCellular Manufacturing System (Lean concept) - the Suzhal layout. This methodology can be easily adopted to improve productivity by providing workers with a safe workplace.

4.2.4 Lean Automation

The motives to automate the manufacturing processes include improved quality and efficiency demands, as well as the presence of hazardous working conditions and the high cost of specialized manual workers. Using technology to automate hard or repetitive tasks positively has a positive effect on safety and ergonomic issues, as well as other labor challenges experienced by several organizations, e.g. an aging workforce and the related expected increase of injuries in the labor force (Botti et al. 2017).

Although automation has been extensively adopted in manufacturing, many companies still rely on manual workers to perform assembly operations. The current practice demonstrates that the decision to automate rather than include manual workstations is chiefly guided by economic considerations and production needs. Robot technology is broadly used in the manufacturing industry when products are well-defined and properly designed. In particular, high production volumes allow a reasonable payback time for the sizeable investment in automatic machines (Lien & Rasch, 2001). Nevertheless, the present market requires companies to find a balance between the advantages of automated production and the dynamic demand for customized products. When automation is not able to provide great flexibility, production system design demands the joint optimization of human and technical aspects (Botti et al. 2017).

Beginning with its Kyushu factory, Toyota abandoned full automation efforts in assembly, shifting its focus instead to ‘‘in-line mechanical’’ automation. This automation consists of equipment and component jig-pallets in synch with the auto bodies moving on the traditional continuous conveyers. This makes it possible for automation zones and manual assembly zones to coexist on the same assembly line. With in-line automation, mechanical means of alignment between auto bodies, jigs, equipment and component are used to the extent possible rather than sophisticated methods such as vision-sensing technologies. Since mechanical methods are less expensive, simpler, and easier to monitor and fix, production workers can assume responsibility from maintenance staff. The equipment is also designed as a complement rather the substitution of production workers' assembly tasks. For instance, in the case of under-body bolting equipment, an employee sets parts and positions bolts, which are then tightened to the proper torque by in-line equipment (Pil and Fujimoto, 2007).

Figure 11 depicts important components to consider during the implementation of an LPS, considering Ergonomics.

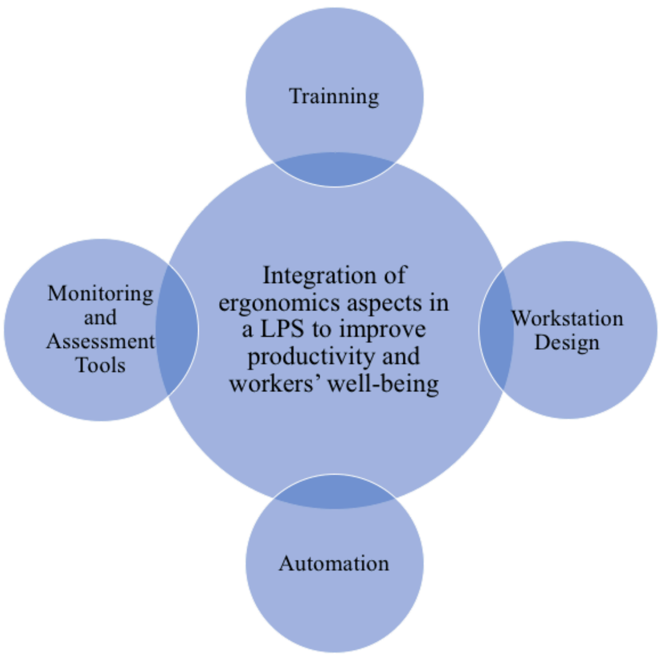

Figure 11. Components to consider during the implementation of an LPS, considering Ergonomics.

4.3 Industry 4.0 and Future Trends

According to Heng (2014) few practitioners can provide a concrete definition of Industry 4.0. Researchers and practitioners have diverging opinions regarding which elements compose Industry 4.0, how these elements relate to one another and where Industry 4.0 is applicable (Buer et al., 2018). Some even defend that Industry 4.0 does not bring anything new, that it merely brings together existing technologies and concepts in a new package with a catchy marketing name (Drath and Horch, 2014). This ambiguity and absence of a clear definition will lead to communication problems and complicate research and education on the subject (Pettersen, 2009), and also make it more difficult for companies to identify and implement Industry 4.0 solutions.

Sanders et al. (2016) argue that Industry 4.0 together with Lean manufacturing may increase productivity, reduce waste and as a result reduce costs. Rüttimann and Stöckli (2016) predict that Industry 4.0 will materialize in pieces that need to be integrated into existing Lean frameworks and will ultimately increase the flexibility of Lean manufacturing. Thus, the introduction of Industry 4.0 does not remove Lean manufacturing but instead helps to increase the maturity of the firm's Lean program. Khanchanapong et al. (2014) likewise suggest that advanced manufacturing technologies (AMTs) might need to be supported by Lean practices to maximize the manufacturing performance increase.

With the appearance of computer integrated manufacturing, there was s peculation that factories of the future would operate autonomously without the need for human operators. Although such a statement proved to be infeasible in a practical scenario, it originated the concept of Lean automation, in which robotic and automation technologies are employed to achieve Lean manufacturing (Sanders et al., 2016). According to Vysocky and Novak (2016) robots are used in the sense of robotic assistants to increase the quality of work of the human worker.

Human–robot collaboration introduces new opportunities in the cooperation between humans and machines. Personnel share the workspace with the robot, which helps them with non-ergonomic, repetitive, uncomfortable or even dangerous tasks. The robot monitors its movements by using advanced sensors that allow it not to limit and primarily not to endanger its human colleague. Currently, industrial robotics is about robots replacing workers who are tasked with non-ergonomic duties. For instance, manipulation with heavy payloads, manipulation in positions which are uncomfortable for the worker, or dangerous tasks, such as manipulation with toxic or hot objects. Robots are similarly installed in monotonous tasks which are uncomfortably repetitive or demand high accuracy (Vysocky and Novak, 2016).

Through a multiple case study, Strandhagen et al. (2017) find that organizations with repetitive production systems as the norm should have an easier transition to Industry 4.0 than non-repetitive production systems. Other researchers defend that only big enterprises will be able to take advantage of Industry 4.0 and that small and medium-sized enterprises (SMEs) might quickly become the victims of Industry 4.0 (Sommer, 2015).

According to Davies et al. (2017), while it is vital to have a well-defined technical architecture to support Industry 4.0, the deployment of the initiative will also depend on appreciating socio-technical features. The virtualization of processes and the employment of virtual reality in an industrial context create Virtual

Ergonomics, through which it is possible to offer valuable support in decision making as part of the design process of new production lines, or parts of it, lowering the need for physical prototypes and cutting down time and costs of development. Through this technique it is possible to evaluate the Human Factors (HF) by introducing, in virtual environments which have already been created for the prototypes of product and process, virtual dummies, digital biomechanical models which simulate man from the kinematic and dynamic point of view (Laudante, 2017). The use of digital models allows a mathematical account of the operator's movement during the operational stages which, in parallel with the visualization techniques of virtual environments, provide the designer-ergonomist with data not available otherwise. Through data processing, requirements are confirmed to comply with the manual workstation or the usage of certain equipment present along the production line including visibility, accessibility and affordability, monitoring of ergonomic indexes and anthropometric analysis (Laudante, 2017).

Current, standard methods have been present for long time and are made through a series of models that are generated and based on the direct observation of operators at work. By using this new method for the detection of ergonomic data it will be possible to introduce substantial innovation in existing production environments, one which devotes increased attention to the welfare and safety of the operator. Through technological support, the improvement of workers' activities is an essential feature for achieving their full potential in performing the different processing steps (Laudante, 2017).

There is no doubt that throughout the years the way of focusing on Ergonomics has changed. Electronic tools are a new way forwards in Ergonomics. For example, with the support of mobile applications it is now a possibility to see a way to create healthy conditions at work for production and non-production employees as well as assembly and logistics. At the dawn of the 20th century, most the people had no idea what Ergonomics was, the quantity of risks which occur at work which are connected with the health of employees, and the fact that special methods and tools for their identification, analysis, evaluation and identification could be developed. These days there are many methods and tools of modern ergonomics which enable everyone to solve ergonomic problems. It should be a requisite to conduct ergonomic evaluation perfectly, extensively and, most of all, quickly. The slowness of some solutions discourages managers and directors and makes an effective improvement of work conditions impossible. Considering this, Gasová et al. (2017) developed a mobile application which works as a screening tool to assist big companies which have dozens of workplaces and fail to identify work risks by themselves.

Since Industry 4.0 is still a very recent field of research, many gaps in the literature were found regarding the relation between Lean manufacturing, Ergonomics and Industry 4.0. Several authors proposed future investigation to clarify some of these gaps:

- In the opinion of Kolberg et al. (2017), LPS is not suitable to fulfil future market requirements. Other authors do not agree, so the question is who is right.
- Companies that have already implemented Lean manufacturing need guidelines on how to integrate the new technologies from Industry 4.0 into their existing Lean manufacturing systems (Buer et al., 2018).

- According to Sanders et al. (2016) the integration of both Lean manufacturing and Industry 4.0 is an important research field which needs to be extensively explored. It is unclear which Lean practices could be combined in Industry 4.0, which ones complement each other, and which contradict each other.
- Further research is needed to understand the full socio-technical impact of Industry 4.0 on how people can work efficiently in a digital environment (Davies et al., 2017).
- Detailed case studies are necessary to explain how to create, manage, operate, and maintain production systems in the context of Industry 4.0 (Buer et al., 2018).
- The VSM should combined itself with simulation and the use of real-time data and universal interfaces. The value stream is therefore no longer a focal point only in project-related practices, but much more in the center of day-to-day business processes (Andreas et al. (2018)).

Beyond the Industry 4.0 field, other gaps regarding the integration of Ergonomic aspects in an LPS were found in the literature, as well as investigation proposals, such as:

- Koukoulaki (2014) questions if there are characteristics in Lean production that mean it cannot lead to the good quality jobs that are fundamental tenets in sociotechnical systems theory.
- Hasle (2014) reports that there is a need for further case studies, in which researchers join forces with practitioners in the workplace to introduce LPS in a form that is expected to bring about a favorable employee outcome.
- Future studies are needed to document the best practices in the integration of MSD prevention into the organizational framework, including the management system. Furthermore, the economic evaluation of such practices will be required to document the cost-effectiveness of these kinds of approaches (Botti et al., 2017).
- It would be interesting to verify the influence of the evolution of LPS and socio-technical and ergonomics practices on an organization's performance indicators (Tortorella et al. 2017).
- It is important to develop a method to assess the LPS impacts on the working conditions of white-collar employees (Saurin and Ferreira, 2009).
- Schouteten and Benders (2004) consider that the ambiguity of the results about the health effects in an LPS has to do with the absence of an external assessment framework supported by validated research instruments.
- Psychosocial factors should also be included in the assessment management tools (Herrera and Huatuco, 2011).
- Overall, there are significant knowledge gaps in what concerns the impact of LPS on workload and labor conditions in manufacturing (Santos and Nunes, 2016).

5. Results discussion and Conclusions

Future occupational health and Ergonomics intervention research may have a greater chance of success by focusing on insights that help to balance production performance and worker well-being, resulting in a move towards more sustainable production systems (Westgaard and Winkel, 2011). However, survey studies among manufacturing managers demonstrated that they still view ergonomics as a health and disease prevention tool instead of as a method for cost saving and waste reduction (Zare et al. 2016).

The extensive use of LPS raises a question about the ergonomic consequences for employees (Hasle, 2014). The present review found several studies reporting positive and negative effects in the workers' health during Lean implementation. This lack of consensus could originate the misinterpretation and misuse of Lean tools.

On the other hand, most authors of the studies analyzed agreed that the integration of Ergonomics during Lean implementation has the potential to result in gains in productivity and simultaneously improve working conditions. However, there is a lack of case studies in which researchers and practitioners could learn better how this integration might work. There are several important components to consider during an Ergonomics LPS implementation, such as: Workstation Design, Training, Automation, Monitoring and Assessment Tools.

Nowadays the competitive market requires companies to find a balance between the advantages of automated production and the dynamic requirements for customized products. According to Ohno (1988) and existing studies, repeating and value-adding tasks ought to be automated. Workstation design also plays a critical role in an LPS to achieve workers' well-being. Thus, as important as training, workstation design and integration of Ergonomics in the LPS implementation is monitoring it, in order to reduce workers' health problems and achieve positive effects. In recent times, several tools have appeared to evaluate and guide Lean implementation while considering ergonomic aspects. In the authors' opinion, despite the existence of several tools, they are general in scope and none of them is dedicated to workstations or the production area. Therefore, it is our opinion that it would be valuable for practitioners if a Lean implementation monitoring tool considering ergonomic aspects in a more restricted scope were developed, to be used in a production area or in a specific workstation.

In order to clarify several investigation questions which were brought to light during this work and reduce the existent gaps in the literature found during this SLR, the authors propose further supporting evidence and scientific clarification, such as:

- More case studies in different areas, to support that LPS and sociotechnical systems are compatible and in what way;
- Development of tools which integrate Ergonomic aspects in existent managerial tools, to assess the LPS impacts on the working conditions of white-collar employees and define a unique, standard assessment tool validated in all areas (health care, construction, manufacturing, maintenance, etc.). This tool should include psychosocial factors and should also act as a guide in the implementation of Lean while considering ergonomic aspects.
- Identification of the effect on an organization's performance indicators by integrating the evolution of LPS and socio-technical and ergonomics practices, including financial ones.

- Clarification of how to integrate the new technologies from Industry 4.0 into LPS.
- Transformation of traditional Lean manual tools, such as VSM and Ergonomics manual assessment tools such as RULA, into digital tools, so as to not be left behind in the fourth revolution.
- Clarification of the full socio-technical impact of Industry 4.0 on how people can work successfully in a digital environment;

According to Kolberg et al. (2017), Lean Production was created in the 1950s and therefore does not take into account the potential of innovative ICT and digital communication. In standard Lean Production, changes in production processes, buffer stocks or cycle times require laborious modifications. Thus, the suitability of Lean Production for limited product life cycles and highly customized products is inadequate because it is not changeable enough for the mass production of highly customized products. Not only that, it does not use the potential of modern information and communication technology (ICT). Taking this into consideration, the authors wonder what the future of Lean will be, if it will be replaced by another concept or philosophy and what this will mean for the well-being of workers.

A particular research challenge is that rationalization intervention is a never-ending process which must adapt to continuously changing contextual factors to maintain competitive production systems (Hunter, 2008).

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3

INTEGRATION OF LEAN MANUFACTURING AND ERGONOMICS IN A METALLURGICAL INDUSTRY

Contents:

Presents the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects through a case study in four production areas of a metallurgical industry.
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 show that it is possible, and desirable, to consider both aspects, ergonomic conditions and productivity, during continuous improvements'.

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Integration of Lean Manufacturing and Ergonomics in a metallurgical industry

M. Brito[a], A. L. Ramos[b], P. Carneiro[c] , M. A. Gonçalves[d]
[a]Research Center of Mechanical Engineering (CIDEM), DEGEIT - University of Aveiro (marlenebrito@ua.pt) ORCID: 0000-0002-7016-599X. [b]GOVCOPP Research Centre, DEGEIT - University of Aveiro (aramos@ua.pt) ORCID: 0000-0003-4401-7747. [c]ALGORITMI Centre of Engineering, University of Minho (pcarneiro@dps.uminho.pt) ORCID: 0000-0003-0874-8593. [d]Research Center of Mechanical Engineering (CIDEM), Polytechnic of Porto (mag@isep.ipp.pt) ORCID: 0000-0001-8751-1708.

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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.

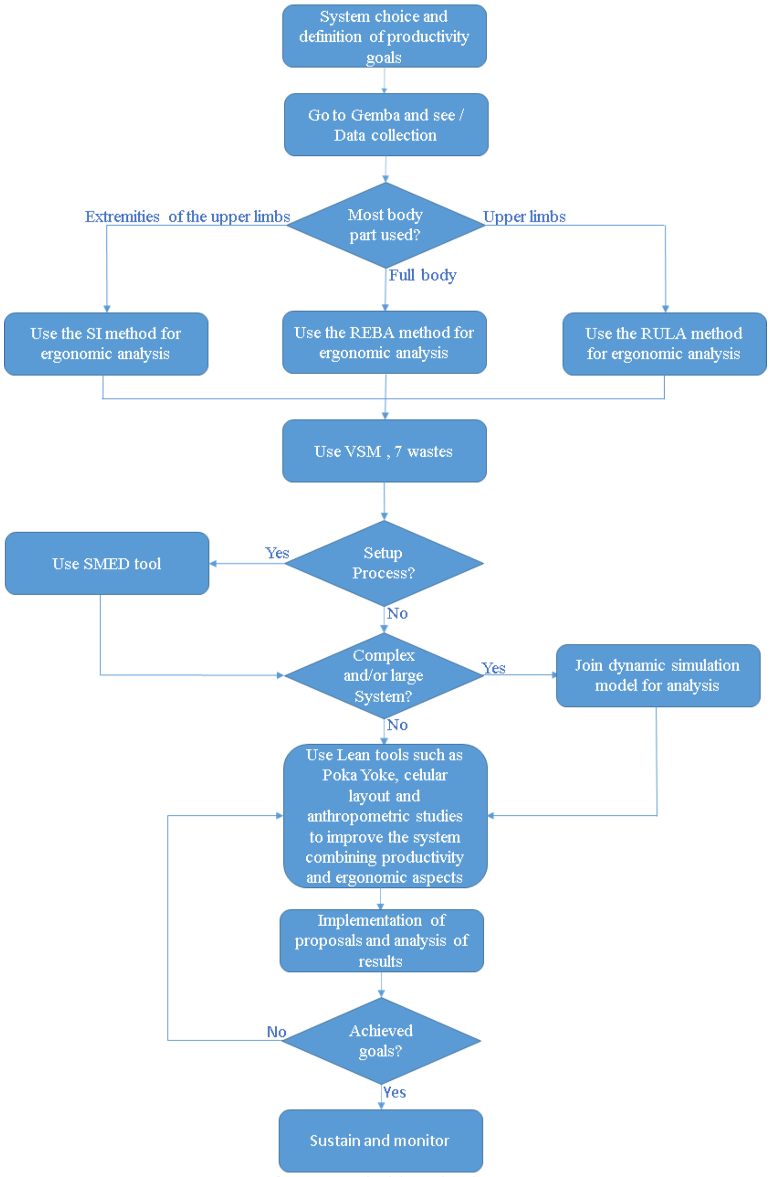

Figure 1. Methodology Flowchart

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).

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.

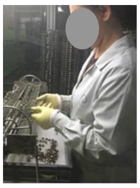

Figure 4- Horizontal Solution

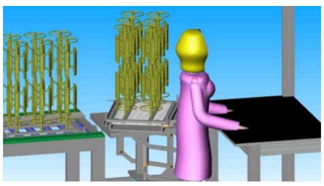

Figure 5- Structure with a rotating base

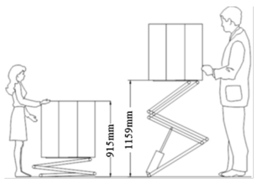

Figure 6- Work plan adjustment

Figure 7- Lift Car

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

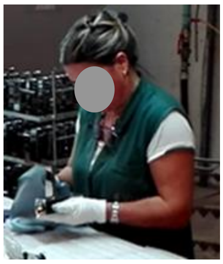

Figure 9 - Cleaning and selecting operations

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.

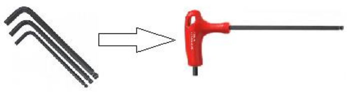

Figure 10. Tool change: "Umbrako" for "Ergonomic T-handle"

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.

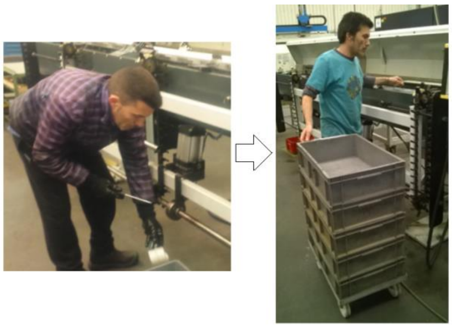

Figure 11. Operator performing the activity of replacing the gutters from the machine before and after the implementation of the tray cart (Posture 2)

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 Overal 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.

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4

AN OPERATIONAL TOOL FOR ASSESS CONTINUOUS IMPROVEMENT

Contents:

Presents a manuscript of an instrument containing operational measures of Lean combined with safety and ergonomics in a workstation or production line. The operational tool aims to help researchers and practitioners to prioritize and evaluate the LPS implementation as well as the ergonomic and safety conditions, in an integrated way. It allows managers to evaluate their business and identify the priority areas to improve according to the previously defined company's aims.

Brito, M. F., Ramos, A.L., Carneiro, P. & Gonçalves, M.A. (2018). An operational tool for assess continuous improvement. International Journal of Lean Six Sigma. (2nd revision).

Purpose - The purpose of this paper is to present the first attempt to develop an instrument containing operational measures of lean combined with safety and ergonomic conditions in a workstation or production line. This operational tool aims to help researchers and practitioners to prioritize and evaluate the lean implementations as well as the ergonomic and safety conditions, in an integrated way.
Design / methodology / approach - Lean manufacturing methods and principles were exhaustively researched as well as safety and ergonomics aspects with the ultimate goal of finding a way to improve the workplace by taking into account the efficiency and well-being of workers.
The instrument was validated in an interactive process between theory and practical insights. At the end, it was tested in several workstations/production areas.
Findings – The study reveals that high scores are derived from a good interaction between lean, ergonomics and safety.
Research limitations – The case study was developed in several workstations of a metallurgical factory. The sample size is too small. More study is needed in different companies and in different types of industries.
Practical implications - This tool help practitioners (technicians and ergonomic practitioners from manufacturing companies) assess the implementation of Lean principles and the safety issues in their processes. It also allows managers to evaluate their business and identify the priority areas to improve according to the previously defined company's aims.
Originality / value – As Peter Drucker said: "If you can't measure it, you can't improve it". For a successful implementation, managers should start the Lean journey with a Lean assessment and make it in a regular basis. To the authors' knowledge there are various lean assessment tools but this work is innovative because it provides an assessment instrument to evaluate organizations' workstations/production areas simultaneously in these three dimensions: lean, safety and ergonomic aspects.
Keywords Assessment; Ergonomics, Lean, Safety, Case Study
Paper type Case Study

1. Introduction

Today, businesses are under tremendous pressure to be competitive in their chosen markets. The existing market conditions challenge manufacturing firms to strengthen and maintain their capabilities to compete in the marketplace. The current globalizing trends, the rapid technological changes, the advances in manufacturing technology as well as ever-demanding and well-informed customers are forcing manufacturing organizations to optimize their manufacturing processes, operations, and their supply chains to be able to deliver customers value (Karim and Arif-Uz-Zaman, 2013).

Manufacturing organizations are under pressure to improve productivity and reduce costs through the realization of lean manufacturing (Chauhan and Singh, 2012). Its practices and tools are among the key concepts that assist managers and engineers sustain competitiveness in an expanding global market (Zahraee, 2016).

According to Womack et al. (1990), Lean production ... is ‘‘lean’’ because it uses less of everything compared with mass production—half the human effort in factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever-growing variety of products.

Bayou and Korvin (2008) improve this definition as follows: manufacturing leanness is a strategy to incur less input to better achieve the organization’s goals through producing better output, where ‘‘input’’ refers to the physical quantity of resources used and their costs, and ‘‘output’’ refers to the quality and quantity of the products sold and the corresponding customer services.

The key idea of Lean is to be highly responsive to customer demand by reducing waste (Bhamu and Sangwan, 2014). The lean definition for waste includes work in progress (WIP), defects and non-value-added time, such as worker time spent waiting for products and unnecessary movements. Cost reduction strategies are directed toward specific efforts that reduce the resources spent on poor quality products, reducing the WIP value and decreasing the transportation costs. Lean thinking also aims the realization of flexible processes and the reduction of overburden and stress, which generate waste (Benton et al., 2011).

Womack and Jones (2003) defined five lean principles to eliminate waste in organizations: specifying value, identifying the value stream, flow, pull, and perfection. This concept presents a comprehensive view of eliminating/reducing waste by utilizing a detailed action plans. For improvement based on five steps: specify value from the perspective of the end-customer; identify the value stream for each product and every action required for design, order, and provision; make those actions that actually create value occur in a continuous flow; make products flow only at the pull of the customer; and continually reevaluate every value stream to strive for excellence (Shetty et al., 2010).

Some companies focus in continuous improvement process through the use of Lean Manufacturing which refers to the creation of value stream. However, it is necessary to have a methodology of intervention focused on the correct application of these concepts under the premise of achieving results without neglecting the human factor (Naranjo-Flores and Ramirez-Cárdenas, 2014).

According to Yusuff and Abdullah (2016), ergonomic intervention can be used as a tool in reducing motion which is a wasteful, through identifying the ergonomic risk factors while doing work. The 'waste' motions in ergonomics such as stretching, bending, awkward postures and extremely reaches can, not only not contribute to the safety and health of workers, but also can worsening the productivity and efficiency. (Yusuff and Abdullah (2016). Galante (2014) states that lean ergonomics can decrease lead time and add to throughput by removing the waste of nonproductive manual material handling movements and activities. According to Aqlan et al. (2013), effective ergonomic strategies can increase productivity, reduce work injuries, and improve workstation design and layout. Workplace ergonomics and lean manufacturing are highly inter-related. Ergonomic risks can lead to lean wastes and vice versa. Ergonomics can support lean transformation and lean transformation can lead to ergonomic risk reduction. In fact, one of the fields of ergonomics application is the prevention of occupational risks in the workplace, preventing the appearance of musculoskeletal disorders (MSD) (Naranjo-Flores and Ramirez-Cárdenas, 2014).

Tortorella et al. (2017) stated that Lean manufacturing approach presents the human element as a fundamental factor for continuous improvement sustainability. From a lean perspective, ergonomics improves productivity, removes barriers to quality, and enhances safe human performance by aligning products, tasks, and the work environment to people (Tortorella et al., 2017). From a worker perspective, consideration of ergonomic issues related to workstation design, like access to materials, equipment and tools, and communication among workers, is imperative for operator safety while working in the cell (Fiore, 2016).

Liker (1997) stated that Lean implementation is both a process and a journey, without an end state. He suggested that a firm implementing Lean should continuously monitor itself to identify the present level of leanness and future path of improvement: ‘‘where to start’’ and ‘‘how to proceed’’ in addition to knowing the available tools. For this purpose, the lean training, value stream mapping, and lean assessment are three major activities to initiate a lean implementation cycle (Wan and Chen, 2009).

Audit enables an organization to recognize the juncture that it has accomplished and develops a regular rhythm, engaging managers in predictable ways with assigned responsibilities (Bhasin, 2011).

According to Wan and Chen (2008) compared with the efforts made to address ‘how to become leaner’, the statement ‘how lean is the system’ has received less attention.

Among the huge set of lean tools, most of them were created to solve specific problems, such as high work-in-process level, low availability of equipment, or long setup time. Only a few of them (e.g., value stream mapping and lean assessment tools) support lean practitioners on identifying the problematic areas to be improved. However, choosing the right lean tools to apply at the right time on the right spot often requires extensive knowledge and experiences of lean implementation; while this kind of expertise is not always accessible or affordable (Wan and Chen, 2009). According to Nawanir et al. (2016) high business performance (in terms of profitability, sales and customer satisfaction) is dependent upon the comprehensive implementation of Lean Manufacturing practices.

An audit keeps people aware of things they should address. Getting your people involved in their portion of the process brings that spark you need to get people fired up about the whole Lean effort; suddenly, there is a buy into the culture of Lean. This entails a sharp shift from key performance indices numbers to numeric process data (Bhasin, 2011).

Workstation design thus is a crucial process to ensure effectiveness, customization, automation and competitiveness in high volume environments, using less time, space, cost and inventory. Taking that into account, workstations play a critical role in manufacturing processes. Lean workstations should be designed with a focus to minimize waste and concentrate operators to critical issues and from the operators' perspective (Gonçalves and Salotinis, 2017).

In the current paper, the key aspects to have a safe, ergonomic and lean workstation are considered and a tool to objectively measure and evaluate them is proposed. Thus, this audit tool aims to improve ergonomic and safety conditions while productive performance indicators are also in focus. It's based on the insight that when we combine lean with worker well-being in a workstation improvement project, productivity increases and the work accidents as well as absenteeism decrease.

To support this work, both research papers and practitioner works were examined to identify a comprehensive set of manufacturing practices considered to be essential in a lean manufacturing as well as safety and ergonomic aspects with the ultimate goal of finding a way to improve the workplace by taking into account the efficiency and well-being of workers. The first step was the development of preliminary items, in a checklist format which has 73 evaluation questions divided by 9 sections: efficiency, continuous improvement, safety standards, visual management, process and operations, material flow, zero defects, ergonomics and discipline. These nine requirements were identified to have a productive, safe ergonomic, lean workstation. An evaluation model and a tool to assess each requirement was developed due to the difficulty in finding other assessment tools.

The answers to these questions result in a visual indicator in the form of a radial graphic with the score of each assessment element. This instrument was validated in several workstations/production areas of a metallurgical industry and based on the results obtained, improvements are introduced in order to improve productivity and workers well-being. This instrument aims to be a systematic long-term self-assessment model and was designed to be used in manufacturing companies by practitioners.

With the lack of such measure, companies have difficulty to identify which are the most critical areas and prioritize them, before improvement interventions. In fact, it’s not easy to set goals to the future if we don’t have the proper tools to measure the present. This instrument aims to be a systematic long-term self-assessment model and was designed to be used in manufacturing companies by practitioners.

2. LITERATURE REVIEW

With the publication of the book The Machine That Changed the World, lean manufacturing practices have found acceptance in many manufacturing operations over more traditional mass production techniques. Womack et al. (1990), studied the implementation of lean manufacturing practices in the automotive industry on a global scale.

In 2003, Womack and Jones summarize five critical elements of lean implementation, namely: value, value stream, flow, pull, and the pursuit of perfection. Using the lean thinking, the value stream mapping (VSM) technique introduced by Rother and Shook (1998) provided a practical, simple and effectiveness guiding tool for lean implementation for most lean practitioners.

2.1. Assessment Audits based on Lean tools

As Lean Thinking implementations started increasing, impetus to researchers and practitioners to develop various mechanisms and methodologies to perform an assessment of the system to understand the effectiveness of implementing Lean Thinking also increased (Narayanamurthy and Gurumurthy, 2015). Nevertheless, most of the existing lean tools (e.g. Kanban system, quick changeover, etc.) focus on ‘how to become leaner’ instead of ‘how lean it is’. According to Wan and Chen (2008), the value stream mapping techniques, lean assessment tools, and lean metrics are three main categories that concern the level of leanness. However the number of studies in literature on leanness assessment is low when compared to that in the area of lean implementation (Gopalakrishnan and Anand, 2015).

Hines and Rich (1997), proposed seven tools and a five-stage approach were proposed - lean processing programme (LEAP) in the UK. However, the toolset has not drawn major attention due to the complexity of the approach. On the other hand, the value stream mapping technique developed by Rother and Shook (1998) becomes one of the most commonly used lean tools. Current state and future state maps visually display the flow of value streams together with time-based performance pressing a sense of urgency and indicating improvement opportunities.

Karlsson and Ahlsrom (1996) develop a lean assessment tool in which identified nine variables to be evaluated, namely: the elimination of waste (EW), continuous improvement (CI), pull of materials (PULL), multifunctional teams (MFT), decentralization (DEC), integration of functions (IF) and vertical information systems (VIS). In 2002, Soriano-Meier and Forrester evaluate the degree of leanness of manufacturing firms using this nine variables suggested by Karlsson and Ahlstrom (1996).

Various others lean assessment surveys, such as Feld (2000), Connor (2001), and Jordan et al. (2001), have been proposed to guide users through the lean implementation. The resulting scores of these surveys represent the gaps between the current state of the system and the ideal conditions of several lean indicators predefined in the survey (Wan and Chen, 2008).

Sanchez and Perez (2001) develop a check-list of 36 lean indicators in six groups to assess the changes towards lean and Detty and Yingling (2000) utilize simulation models with several performance metrics to quantify potential benefits of lean implementation. Allen et al. (2001) categorize the metrics (performance measures for tracking effectiveness of improvements efforts) into productivity, quality, cost, and safety.

Lean Enterprise Self-Assessment Tool (LESAT, 2012), is a questionnaire developed by a team of industry, government and academic members. It is a simple and easy to use guide focused on lean attributes and aligned with business performance planning, which forms the basis for most other lean assessment tools. These lean tools are well-known in the industry but they focus on assessing where the companies are along their lean journey, and not in the evaluation of specific aspects of the workstation. Goodson (2002) created one of the most well-known and useful plant assessment tools which aims to evaluate if a factory is truly lean in as little as 30 minutes - "Rapid Plant Assessment". Then, this information should influence decisions related to benchmarking, continuous improvement, competitor analysis, and acquisitions.

Pavnaskar et al. (2003) organize 101 lean tools and metrics to match manufacturing wastes with appropriate tools; however this matrix provides only the problem-tool connection without a measure of leanness.

Srinivasaraghavan and Allada (2006) propose an alternative that evaluates the distance between the current state of the system and the benchmarking performance. That means that the outcome depends heavily on the quality of the benchmark. The model delivers a quantitative measure of leanness, but exemplar performance benchmark needs to be gathered from peers and competitors.

Bayou and Korbin (2008) utilized a fuzzy-logic methodology to measure and compare the production leanness of Ford Motor Company and General Motors. They select Honda Motor Company as the benchmarking firm and just-in-time, Kaizen and quality controls as lean attributes.

Wan and Chen (2008) proposed a methodology to quantify the leanness level of manufacturing systems based on a benchmark of ideal leanness obtained from historical data. Although this measure could be applied in various scopes of a value stream, such as a cell, a production line, or the whole factory, it has not yet been tested in any real-world study (Wan and Chen 2008). In 2009 the same authors presented an adaptive lean assessment approach that provides an effective way to guide the lean implementation process. Using the web-based program, an assessment model was generated adaptively for each user to evaluate the current status of the system, pinpoint the urgent targets for improvement, and identify the appropriate tools and techniques for developing action plans. This tool pretended to answer two essential questions from lean practitioners - ‘‘how lean the system is’’ and ‘‘how to become leaner’’ (Wan and Chen, 2009).

Saurin et al. (2011) noticed that the existing methods were mostly designed to assess the level of Lean Production implementation in the plant as a whole rather than in specific units of the manufacturing system, such as cells, job shops or assembly lines. According to that, they introduced a framework for assessing the use of lean production practices in manufacturing cells.

An extensive audit, piloted in 20 manufacturing organizations in the UK was developed by Bhasin (2011) to be able to establish the juncture of organization’s Lean journey.

Maasouman and Demirli (2016) proposed a framework to assess lean maturity based on grounded lean manufacturing principles. They also suggested a dynamic process to adopt de- signed framework according to firm’s strategies and priorities. A framework for the assessment of green and lean implementation was developed by Duarte and Machado (2016). The framework was designed using key criteria to identify green and lean and guidelines for each criterion. Validation was conducted in different organizations in the automotive industry.

2.2. Integration of human factors in Lean Assessment audits

Companies fail to realize the potential for further improving the productivity gains if ergonomic principles were integrated and implemented simultaneously with Lean Systems (Nunes, 2015). According to Westgaard and Winkel (2011) integrating the needs for effective production and a healthy workforce in the analysis and development of production systems may be a solution to the apparent conflict of interest between Ergonomics and rationalization.

Tortorella et al. (2017) stated that Lean manufacturing approach presents the human element as a fundamental factor for continuous improvement sustainability. From a lean perspective, Ergonomics improves productivity, removes barriers to quality, and enhances safe human performance by aligning products, tasks, and the work environment to people.
Santos et al. (2015) reported that the integration of Ergonomics during the LPS implementation has the potential to reduce the absenteeism and obtain substantial gains in productivity.

According to Aqlan et al. (2013) Ergonomics can support Lean transformation by eliminating the related wastes and Lean transformation can lead to ergonomic risk reduction (Aqlan et al., 2013). So, Lean team must consider Ergonomics and safety, just like waste reduction and value creation, core values of the Lean process (Wilson, 2005). For example: incorporating risk assessments into the value stream mapping process (Kester, 2013), integrating ergonomic principles within a Lean implementation process in a Kaizen event (Scheel and Zimmermann, 2005), etc.

Regarding Lean Assessment Tools, Wong et al. (2012) develop a lean index to assess the leanness level of the organization in sustaining lean transformation based on socio-technical perspective which considers the interdynamics of human, system and technology.

Jarebrant et al. (2016), proposed the application of the Ergonomic Value Stream Mapping, a tool that aims to improve ergonomic conditions while productive performance indicators are also in focus. This work aims to provide academics and practitioners with a tool capable to satisfy current needs in manufacturing environments, regarding cognitive ergonomics assurance at workplaces. The implementation of ErgoVSM on its cognitive modality is an effort for acknowledging the significance of assessing health risks within each workstation at companies.

According to Gonçalves and Salotinis (2017), the assessment of workstation design must focus on both lean and ergonomic aspects. Lean assessment tends to reduce the waste in the workstations and ergonomic assessment safeguards employee safety and comfort. This relationship is essential to ensure success, mainly in a long-term period (Gonçalves and Salotinis, 2017).

Seven Workstation Design, namely: "Health and Safety", "Work environment, cleanliness and orderliness", "Waste elimination", "Inventory and material logistics", "Flexibility", "Visual Management" and, lastly, "Quality" were identified by Gonçalves and Salotinis (2017). These authors developed an evaluation model and a tool to assess each requirement based on lean and ergonomic aspects and specific for workstation design. This model has the form of a checklist that is based on the current best practices in Workstation Design of assembly lines. The assessment tool was validated in an automotive assembly line and based on the results obtained, improvements in the associate working zones, workstation dimensions, storage areas or parts feeding system are introduced to improve "Waste elimination" and "Inventory and material logistics". Although this tool brings together the elements of safety, ergonomics and lean, it is more directed to the design of the workstation and does not take some other key requirements into account, such as indicators of performance, continuous improvement, etc.

Tortorella et al. (2017) proposed a method that comprises a combination of techniques that allow the identification of deficiencies related to the adoption Lean Manufacturing practices that may support socio-technical practices implementation, indicating a prioritization of improvements opportunities to better sustain them.

A parallel path investigates the use of mathematical models to design lean processes that meet the lean principles and ergonomics requirements. For example: Al-Zuheri et al. (2014) developed a framework based on the simultaneous application of mathematical and meta- heuristic techniques for productivity and ergonomics requirements in an assembly line design and Botti et al. (2018) proposed a mathematical model to address the design of hybrid multi-model production lines with both manual and automatic workstations considering ergonomic risk assessment and following the principles of the lean production.

All of these tools, as well as safety and ergonomics checklists /assessment tools, such as "Ergonomic Workplace Analysis" (Ahonen, 1989), Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000), Strain Index (SI) (Moore and Garg, 1995) and RULA Rapid Upper Limb

Assessment (RULA) (McAtamney & Corlett, 1993) were analyzed in detail and served as input in the construction of the proposed audit tool in this article. Lean concepts, such as: 5S, Poka-Yoke, VSM (Value Stream Mapping), Kaizen meetings, Andon, Kanban, TPM (Total Production Maintenance), etc. were also considered during the development of this tool.

The difference of these tools for the audit instrument proposed in this article is in the evaluation of jobs through the combination of the key dimensions: continuous improvement, productivity, safety, ergonomics, quality, visual management, work organization, and materials flow.

3. Methodology

The methodology used in this work was the case study. According to Yin (2003), a case study is 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 proposed method embraced three main steps:

Step 1 - Definition of the key requirements in terms of lean, safety and ergonomics with the ultimate goal of finding a way to improve the workplace by taking into account the efficiency and well-being of workers.

Step 2 - Development of a checklist in order to assess each requirement and present the results in a visual, simple and comprehensive way.

Step 3 – Validation of the assessment tool in an industrial context with practitioners. If not fully accepted, return to Step 1.

It took several cycles of interactive process between theory and practical insights to reach the final tool presented in this paper. One of the difficulties found during the development of the tool was the division of the requirements among the categories to be assessed. Another concern was the size of the tool due to the limited time available by those who will have to use it. The audit instrument has a format of a checklist with 72 evaluation questions divided by 9 sections: efficiency, continuous improvement, safety, standards, visual management, process and operations, material flow, zero defects, ergonomics and discipline. These questions should be given by the form of: yes, no and not applicable (NA). This checklist must be answered by the production manager of the area to be evaluated, preferably, together with operators, the lean manager, the process engineer, the quality manager and the health and security engineer.

Below are the checklist questions:

1. Performance Indicators. The performance measurement is essential in the management process. Numerous studies have shown that, to adopt the best decisions regarding development of the organization, managers must have accurate and actual data about the performance of processes taking place within the company (Borsos et al., 2016).

Table 1. Evaluation questions on Performance Indicators.

#	1 – Performance Indicators	Yes	No	NA*
1	Is OEE (Overall Equipment Efficiency) above 85%**?			
2	Is the total time of line stoppages above 10%** of the total time?			
3	Is the X KPI (select the most important indicator of the assessed area) within the objective?			
4	Have there been any work accidents in the last 6 months?			
5	Are there any workers with occupational diseases associated with tasks performed at the workstations/production area under analysis?			

* Not Applicable.
**numbers according to the company's objectives.

2. Continuous improvement (CI). CI is one of the core strategies for manufacturing excellent and it is considered vital in today's business environment. A well-known concept related to CI is Kaizen, which has its origin in Japan and means continuous change for the better by involving all employees (Ahmad et al., 2013).

Table 2. Evaluation questions on Continuous Improvement.

#	2 – Continuous Improvement	Yes	No	NA*
6	Have all the performance indicators plus lead time been improving, since the last month?			
7	Are the standards revised and improved monthly?			
8	Is there a current and future value stream map (VSM) of the product or family of products under review?			
9	Have all workers in the production area under evaluation been involved in improvement actions in the last 6** months?			

10	Does the worker, or team, have lean knowledge (recognizes, at least, the difference between value and value and identify correctly the 5S)?			
11	Do all workers feel responsible for continuous improvement, actively and participate frequently (more than once every 6** months) in giving ideas for it?			
12	Is there a period of time, on a daily basis, dedicated to continuous improvement (eg.: 10 min Kaizen meetings) and does this time involve all workers?			

* Not Applicable.
**numbers according to the company's objectives

3. Safety. The tools of risk identification must be useful for the analysis of work contexts in its various aspects.

The better the capacity of the tools to identify situations of arduous work the better the analysis in risk management, and that makes the process more robust and effective (Prottesa et al., 2012).

Table 3. Evaluation questions on Safety.

#	3– Safety	Yes	No	NA*
13	Is the ambient temperature uncomfortable (hot or cold) or are there perceivable air currents (at the workstation and at the resting area) or insufficient ventilation?			
14	Are there releases of smoke, fumes, dust, toxic or flammable substances in the workplace?			
15	Is there loud or irritating noise, which disturbs workers' concentration)?			
16	Is the lighting good (it is properly placed, it is stable, the operator's eye doesn't have to switch between light and dark areas, etc.)?			
17	Do the production tools or machines produce vibrations in the hands, arms or in the entire body of the worker?			
18	Are there dangerous materials or unstable objects?			
19	Does the ground have cracks or discontinuities/not uniform?			
20	Are workers aware of the existence of risk and are they informed about how to protect themselves and avoid health problems (assess whether workers have been trained in safety, use of Personal Protection Equipment, ergonomic postures, etc.)?			
21	Does the operation(s) involve a risk of accidents (eg: work tool slippery or difficult to grasp, etc.)?			

* Not Applicable.

4. Standards and Visual Management. Visual management system is a key theme in lean operation and essential to ensure standardization (Gonçalves and Salonitis, 2017).

According to Brito et al. (2017), visual management, 5S and standardization were very important tools in the achievement of good results in improvement projects. The goal was to make supervisors able to see if the workers were following the standard operations at a glance (Ohno, 1988).

Table 4. Evaluation questions on Standards and Visual Management.

#	4 – Standards and Visual Management	Yes	No	NA*
22	Are there all standards documents required in the production area in place (work instructions, cleaning plan, maintenance plan, scheduling matrix, polyvalence matrix, reaction limits, 5S audits, etc.)?			
23	Are all the Standards documents and action plans properly placed on the workstation (are they visible and/or accessible)?			
24	Are all the Standards documents visual (including photos, figures, etc.) and are they easy to interpret?			
25	Does the worker follow the task according to the standard and in the estimated time?			
26	Is TPM (Total Productive Maintenance) implemented at the workstation or production line (e.g.: are operators involved in the maintenance of their own equipment?)?			
27	Are the 5S audits performed?			
28	Are the first 3S not fully applied (e.g.: is there any equipment that does not work or materials to be identified? Is the workstation clean? ...)?			
29	Is all the information about the daily production targets (quantities to be produced, quantities already produced, stoppages, team performance, …) visible (ex. Andon)?			
30	Is there a "pull the cord" warning light?			
31	Is there a leveling board where Kanban production cards are placed from left to right with increments corresponding to the pitch?			
32	Do the Kanban cards contain the information about the quantities to be produced and the production time for each reference?			

* Not Applicable.

5. Work organization. Process improvements, layout arrangement and work organization were considered as the principal dimensions to encourage the implementation of lean production practices (Yusup, 2016).

Table 5. Evaluation questions on Work organization.

#	5 –Work organization	Yes	No	NA*
33	Is the work organized into teams in which everyone is trained to perform any function?			
34	Is the line balanced (no waiting time between workstations)?			
35	Can anyone stop the line / production work if a problem occurs?			
36	Is there any waste related to waiting times, transportation or moving?			
37	Does the worker perform operations that do not add value (eg, supplying the line, setups, overprocessing, etc.)			
38	Do the setup times exceed 10** min or are there internal tasks (ex: supply materials) in the setup that can be turned into external tasks?			
39	Is there any manual operation which can be done automatically (using automatisms)?			

* Not Applicable.
** numbers according to the company's objectives.

6. Product and Material Flow. It plays a key role in the successful implementation of lean manufacturing. The amount of material flow and its smoothness are as important as sufficient manpower supply and highly available manufacturing equipment in quick responding to customers' demands (Liua et al., 2017).

Table 6. Evaluation questions on Product and Material Flow.

#	6 – Product and Material Flow	Yes	No	NA*
40	Is the layout organized in a way makes it possible to have product and materials flow (eg: cellular layout)?			
41	Is the layout flexible, quickly adjusting to 25%** higher customer demand fluctuations?			
42	Are the production orders placed in a single production station (pacemaker)?			
43	Are the production batches multiples of the customer quantity packs?			

#		Yes	No	NA*
44	Does the plant or production line produce only what the next process needs and when it needs it (information is given through Kanban cards)?			
45	Is produced and sent to the next process one piece at a time - One piece flow?			
46	Are supermarkets used where continuous flow is not possible (eg.: high setups, distant processes, etc.)?			
47	Is there a Heijunka box and a pattern production plan ?			
48	Is the EPEI (Every Part Every Interval) as small as possible?			
49	Is the supply of materials to the station or production line carried out in a standardized manner (eg.: through Kanban, timetable, route)?			

* Not Applicable.
** numbers according to the company's objectives.

7. Quality /Zero Defects: One of the basic tools of Lean is the concept of zero defects and mistake proofing. The major principles of the Lean process improvement methodology include the concepts of value, value streams, flow, pull and perfection. One of the basic tools of Lean is the concept of zero defects and mistake proofing (Glenn and Blackmore, 2013).

Table 7. Evaluation questions on Quality / Zero Defects.

#	7 – Quality	Yes	No	NA*
50	Is it the worker the person in charge of perform the quality inspection of their own work and is the quality verification carried out during the process and not at the end?			
51	Does the operation produce Nok pieces, scrap or rework?			
52	Are defects repaired within the line by the worker who committed them?			
53	Do all problems or deviations from standards have an associated action plan (Plan Do Check Act by Deming)?			
54	Does the worker or team help to find out the root of the problem (eg. using the 5 whys)?			
55	Is the problem fixed in the source and solved so that it does not reoccur?			
56	Are there anti-error systems (e.g. *Poka-Yokes*)?			
57	Is FIFO (First In First Out) guaranteed?			

* Not Applicable.

8. Physical Ergonomics: The design of ergonomic workplaces and jobs reduces injury and absenteeism rates, while improving productivity, quality and reliability (Botti et al. 2014; Fonseca et al., 2013). Previous studies have shown that musculoskeletal disorders lead to significant loss of productivity due to higher absenteeism and injury rates (Cheshmehgaz et al., 2012). Ergonomics comprise three main areas: physical (posture, load handling, repetitive movements, musculoskeletal disorders, workstation design, safety and health); cognitive (mental workload, decision-making, human computer interaction, stress, and training); and organizational (communications, design and programming work, cooperative work, organizational culture, quality management) (IEA, 2000).

Table 8. Evaluation questions on Ergonomic aspects.

#	8– Physical Ergonomics	Yes	No	NA*
58	Does the layout allow social contacts?			
59	Does the worker adopt an static posture most of the time?			
60	Does the worker have enough space (analyze if the worker has some movement restriction due to lack of space for work execution)?			
61	Is there jobs/tasks rotation, considering muscle groups?			
62	Is the force required to perform the work and / or manipulate weights excessive (greater than 2 kg)?			
63	Is effort repeated continuously for at least an hour?			
64	Is the worker obliged to repeat the same technical actions at a high rate (4 times per minute)?			
65	Does the worker have to lift or carry heavy weights (over 3 kg)?			
66	Does the work plan provide breaks for rest? If so, are they long enough and well distributed to allow for a fully recovery?			
67	Does the level of the workstation seem too high or too low for the worker?			
68	Does the worker have to assume an unnatural or forced position in order to be able to see the dials, details of the job or to reach for handles, pieces, etc.?			
69	Does the worker adopt any of the following postures to perform the task: raised arms, twisting and / or flexion of the trunk or neck?			
70	Does the worker extend, flex, or spin the handle to perform the task?			
71	Does the worker make manual "pincer" (with fingers) type handlocks with any frequency?			

72	Does the worker have to push, pull, lift, or lower objects with the torso bent, twisted, or tilted back?

* Not Applicable.

9. Discipline: sustaining improvements. The aim of this section is to measure if the implemented standards are being respected. Sometimes it's easy to implement new things but hard to sustain them.

Table 9. Evaluation questions on Discipline.

#	9 – Discipline
73	Evaluate standards compliance: 0 - no standards are met 25% of standards are met 50% of standards are met 75% of standards are met 100% of standards are met

After the evaluation of each item, the score of the workstation/production area assessed is given in the form of a percentage, which represents the level of the lean implementation considering safety and ergonomic aspects.

4. Case study

The audit instrument proposed in this paper was validated in a metallurgical industry that produces bath and kitchen taps, door handles, locks, access controls and other bath accessories.

Figure 1 shows the most representative family of products: the Spouts family.

Figure 1. Main reference within Spouts family of products.

Audits in all workstations and production areas of the company were performed using the proposed tool, such as: tuning production area, sanding and polishing workstations, PVD coating, packaging, assembling production areas, etc.…Table 10 shows some of the results of these audits.

Table 10. Audit Scores

Production Area / Workstation	Audit Score
PVD coating	26%
Packaging	22%
Polishing / Sanding	21%
Tuning	26%

In the end, the company used the results obtained in the audits to help identify the most critical areas, meaning the ones with the worst audit scores.

The second step was the election of a multifunctional team, including operators, to analyze the process of these critical production areas and suggest some modifications in order to improve ergonomic and safety conditions, and, at the same time, improve performance indicators using lean principles, such as reducing wastes. As an example, below are the results of one of the production areas evaluated using the audit tool proposed in this article, namely the Sanding and Polishing area. It was one of the worst production areas, with an audit score of 21%, far below the target set by the company, which was 51%. Figure 2 shows the audit results of the Sanding and Polishing production area.

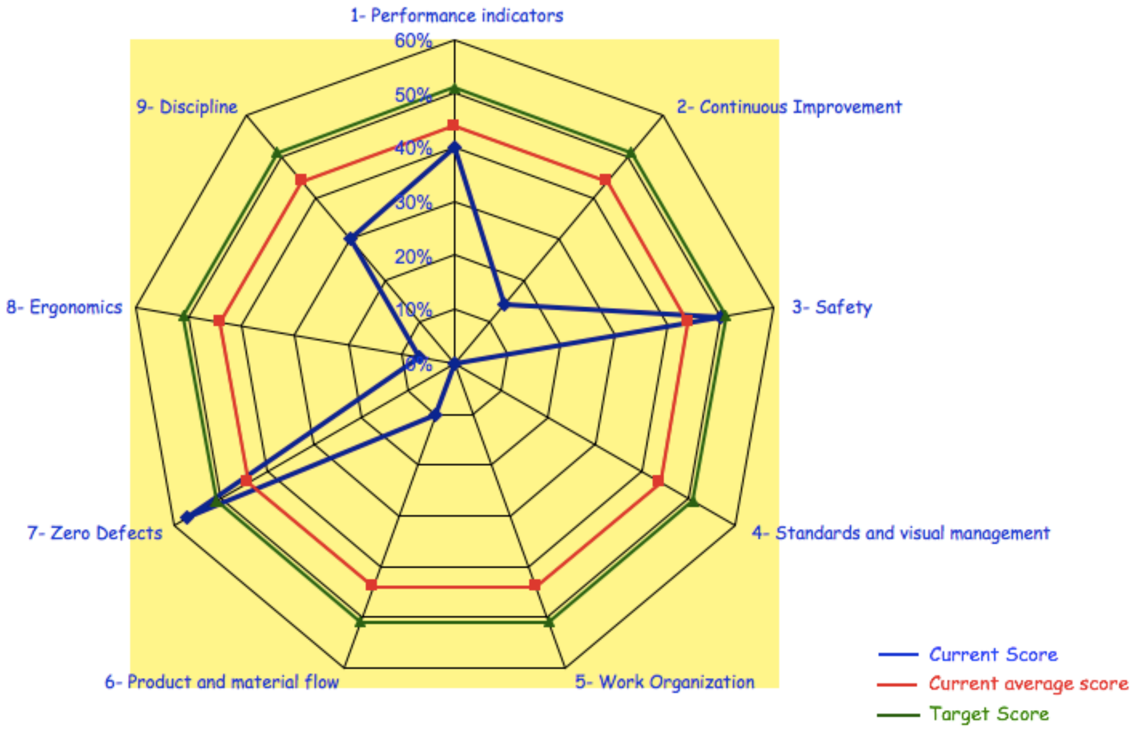

Figure 2. Results of the assessment tool application in the case study – before intervention.

According to the audit results, the key aspects that should be enhanced were: continuous improvement, standards and visual management, work organization, product and material flow and ergonomics.

In order to improve the company performance, urgent improvements in the identified sections were necessary. The next step was a detailed evaluation of the initial situation and 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 these kind of wastes the team proposed to change the layout from a process to a cellular configuration. This change is aligned with lean philosophy principles and previous studies which state that several companies which have implemented cellular manufacturing claim that the new system results in reduced handling time, setups, throughput times and work in process inventories. At the end of the layout change, 5S were implemented in order to improve the visual management and reduce operations motions by bringing the materials closer to the operator.

Attending the complaints of the workers, tendinitis problems and absenteeism verified in this production area, the team identified ergonomic conditions as a big issue to improve urgently. Some of the measures implemented were: changing the height of the work plane to improve the operator posture and the enlargement of the tasks.

Figure 3 depicts the awkward posture needed to perform the manual polishing task.

Figure 3. Posture adopted in manual polishing task.

In the end, the company used the results obtained in the audits to help identify the most critical areas, meaning the ones with the worst audit scores.

The second step was the election of a multifunctional team, including operators, to analyze the process of these critical production areas and suggest some modifications in order to improve ergonomic and safety conditions, and, at the same time, improve performance indicators using lean principles, such as reducing wastes. As an example, below are the results of one of the production areas evaluated using the audit tool proposed in this article, namely the Sanding and Polishing area. It was one of the worst production areas, with an audit score of 21%, far below the target set by the company, which was 51%.

Figure 4 shows the audit results of the Sanding and Polishing production area.

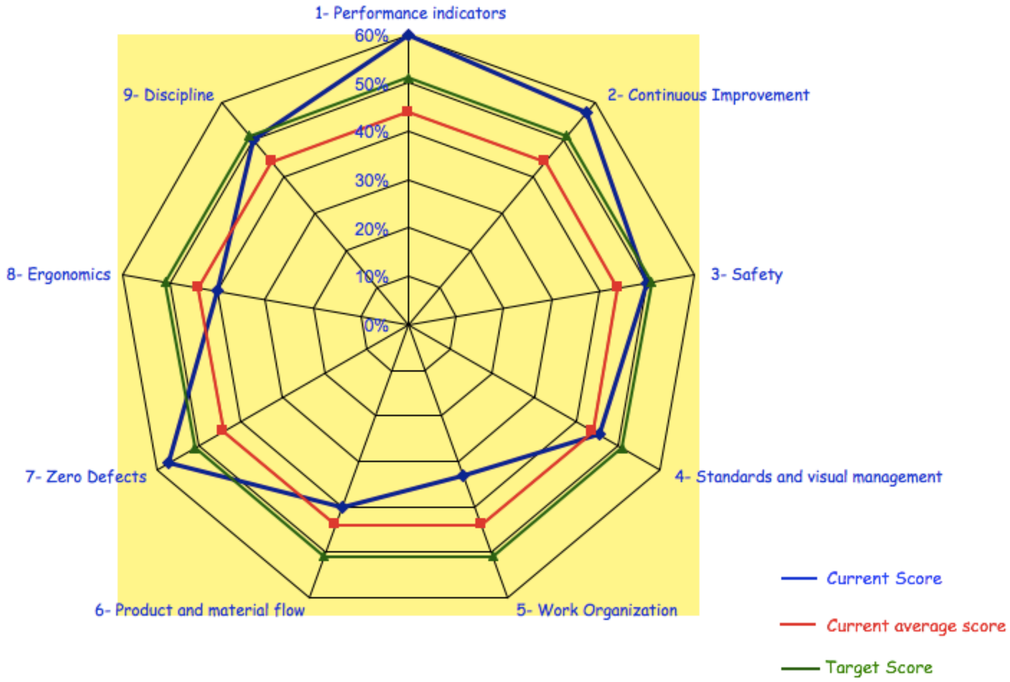

Figure 4 . Results of the assessment tool application in the case study – after intervention.

Despite the good results, these were not enough to achieve the company's objectives in some of the areas, namely: standards and visual management, work organization, product and material flow and ergonomics. However, productivity increased by 33% after the improvements intervention, meaning the tool helped in the identification of the critical areas, which had a lower score on the audit tool, and an improvement on these sections resulted in a huge improvement in productivity.

5. Conclusions

To be up-to-date on Lean Thinking implementation progress, repetitive evaluation of leanness, by frequent audits becomes a necessity, as it would help in assessing the contribution of lean practices implemented by the firm toward improving its performance.

The successful introduction of new production paradigms, such as lean manufacturing, depends among others on a human factor oriented approach. Changes on the working conditions (e.g., reduction of work cycle times and task variety) may lead to increased job demands and low job control situations. High strain jobs present high risks for musculoskeletal disorders and psychological load, and lead to company losses. The use of decision support tools, namely, ergonomic risk assessment methods and computer-based simulation represent a major contribution for the design of lean manufacturing systems, allowing the application and integration of ergonomic and safety design principles (Nunes and Machado, 2007).

Many researchers have attempted to develop various methods and procedures to quantify leanness. Many quantitative and qualitative studies were conducted, and a plethora of assessment techniques have been proposed (Narayanamurthy and Gurumurthy, 2015).
Audits also help manufacturers sustain Lean, and in addition they provide an excellent way of determining if past suggestions have been acted upon and improvements made, or if they have been neglected, contributing to waste. Done well, audits are the ultimate measuring stick. Done poorly, they are next to useless. Often, the tools require in-depth knowledge of the organization and significant resource commitment, including external experts, in order to be used effectively (Bhasin, 2011).
Not having found a tool that would allow for a detailed and exhaustive analysis to a workstation or production area, linking three key dimensions of lean, safety and ergonomics, the authors developed the audit tool proposed in this paper. This instrument audit allows managers to evaluate their business and identify the priority areas to improve according to the previously defined company's aims.
The instrument was validated in an interactive process between theory and practical insights. At the end, it was tested in several workstations/production areas in a metallurgical factory. However, the sample is too small. It would be important to validated it in different companies and different type of industries because each one has its own characteristics.

The study reveals that high scores are derived from a good interaction between lean, ergonomics and safety. To the author's knowledge there are various lean assessment tools but this is the first paper to provide a detailed assessment instrument to evaluate organizations' workstations/ production areas simultaneously in these three dimensions: lean, safety and ergonomic aspects.

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5

ERGONOMIC DESIGN INTERVENTION IN A COATING PRODUCTION AREA

Contents:

Presents a manuscript of a case study about the redesign of two workstations in a PVD (Physical Vapor Deposition) coating production area, considering productivity and ergonomic aspects. The study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements. It used Lean concepts to identify the wastes on the production area and concluded that by their elimination, awkward postures were also reduced and consequently productivity increase and ergonomic risk reduced. RULA was the chosen method to evaluate the ergonomic situation and anthropometric studies were performed to find the ideal ergonomic solution. The study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements.

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

Ergonomic design intervention in a coating production area

M. F. Brito
DEGEIT - University of Aveiro, Aveiro, Portugal

A. L. Ramos
GOVCOPP Research Centre, DEGEIT – University of Aveiro, Aveiro, Portugal

P. Carneiro
ALGORITMI Centre, University of Minho, Portugal

M. A. Gonçalves
ISEP - Polytechnic of Porto, Portugal

ABSTRACT: The aim of this study is to redesign two workstations in a PVD coating production area, considering productivity and ergonomic aspects. Through the elimination of wastes such as unnecessary movements and transportations and by reducing the awkward postures as arm flexion larger than 45º, the productivity in the loading and unloading workstations increased 9% and 5%, respectively, and the ergonomic risk was improved from medium to acceptable. RULA was the chosen method to evaluate the ergonomic situation and anthropometric studies were performed to find the ideal ergonomic solution. This study shows the importance to consider ergonomic conditions when designing or redesigning a workstation in order to get effective productivity improvements.

1 INTRODUCTION

Due to demographic variation, fewer young workers are available and the overall number of workers will decrease. The length of absenteeism, especially due to musculoskeletal disorders (MSDs), increases with age (Müglich et al., 2015).

Work-related musculoskeletal disorders (WMSDs) cause muscles, tendons and nerves at the joint of the neck, shoulder, elbow, wrist, finger, back, leg, etc. to be stressed and traumatised due to excessive or repetitive exertive force, awkward body posture, less resting time, cold working environment, vibration and so on (Cheol-Min et al., 2011).

With regard to Europe, the data emerging from the 5th European Survey on Working Conditions (ESWC) in 2010 (Eurofund, 2012) reports that 33% of all European workers spend at least 25% of their working time performing manual load handling. About 47% of the labour force is exposed to awkward postures during at least 25% of their working time, and over 33% of European workers perform repetitive movements of the upper limbs for almost their entire working time.

Moreover, when considering WMSDs as an occupational disease, upper limb MSDs such as hand-arm tendonitis, epicondylitis and carpal tunnel syndrome represent more than 55% of all occupational claims reported in the different insurance systems (Eurostat, 2010). It was reported by Muggleton et al. (1999) that rotator cuff tendonitis is closely associated with the upper arm abduction and forward flexion. It has been shown that, with arms raised or abducted, the blood vessels supplying the tendons of the supraspinatus muscles were compressed (Grieco et al., 1998), thus altering blood circulation. Such postures render the shoulder-arm system vulnerable to MSDs.

An ergonomic approach to the design of an industrial workstation attempts to achieve an appropriate balance between the worker capabilities and the work requirements to "optimize" both worker productivity and the total system productivity, as well as to provide worker physical and mental well-being, job satisfaction and safety. In a real world design situation, the implementation of the recommendations or guidelines needs the matching of the population anthropometry with the various components of the workstation (Das and Sengupta, 1996).

Often, in industry, the workstation is designed in an arbitrary manner, giving little consideration to the anthropometric measurements of the potential user. The situation is aggravated by the non-availability of usable design parameters or dimensions (Das and Grady, 1983a; Das, 1987). The physical dimensions in the design of an industrial workstation are of major importance from the viewpoint of production efficiency, and operator physical and mental well-being. Small changes in workstation dimensions can have a considerable impact on worker productivity, and occupational health and safety. Inadequate posture from an improperly designed workstation causes static muscle efforts, eventually resulting in acute localized muscle fatigue, and consequently in decreased performance and productivity, and enhanced possibility of operator related health hazards (Corlett et al., 1982). The aim of this work is to answer the research question: "How can be improved the workstation design of loading and unloading processes of a PVD coat production area, considering ergonomic aspects and productivity?" This case study takes place in a PVD coating production area, where workers' complaints due to shoulder pains were rising considerably. These com-plaints come mainly from the processes of loading and unloading pieces from the suspension, before and after the product entering the PVD machine, respectively. This is a repetitive job and involves several awkward postures such as: flexion of the arms above 45º (from now on "arms up"), trunk flexion, and move manually heavy suspensions. Being such a specific case study, an identical case was not found in the literature.

The paper is structured as follows: the section 2 explains the methods used to evaluate the initial situation followed by the methods used to redesign the workstation; section 3 provides a discussion of the main results and section 4 points out some conclusions and recommendations.

2 METHODS

The methodology used was the case study. 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 process and measure the initial situation in terms of ergonomic conditions and productivity. Then this team suggested some workstation modifications in order to improve ergonomic conditions, reduce wastes (e.g., unnecessary movements and transportations) and increase productivity. After the implementation of the suggested improvements, the team measured the productivity and the ergonomic conditions and compared them with the base scenario.

Despite the good results in the first redesign intervention, they weren't enough to achieve acceptable ergonomic risk. It was necessary to intervene again, breaking some paradigms and designing the "ideal" workstation that suited any worker with no wastes in terms of movements and transportations.

2.1 *Measurement tools*

RULA (Rapid Upper Limb Assessment) was the tool used to assess the postures, movements and forces exerted by the worker while performing the job, because it is especially useful for scenarios in which work-related upper limb disorders are reported.

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.

The knowledge of the team in lean production was important in the achievement of the better solution in terms of productivity. The key idea of lean is "doing more with less", where less means less space, less inventory, fewer resources, among others (Womack et al. 1990).

Productivity was calculated using the number of pieces produced per hour (throughput or production rate) because it is the measure typically used in this production area, being also one of the most well-known measures of productivity in industry.

2.2 *Workstation Redesign*

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. Waste means, in a lean terminology, something that doesn't add value to the product, this means something that the client doesn't pay for (Womack et al., 1990). The other concern was the elevation of the arms considering the ergonomic aspects and the tiredeness accused by operators, also contributing to a loss in productivity (Figure 1).

Figure 1– Unloading workstation before improvements.

The founded 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.
- 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 2).
- The new structure allows a manual adjustement of the work plan to reduce the arms flexion (Figure 2).

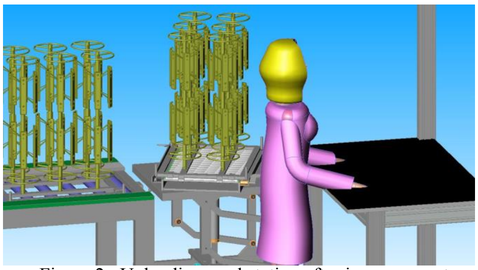

Figure 2– Unloading workstation after improvements

The Figure 3 depicts the worker in the unloading workstation after the implementation of these improvements.

Figure 3– Unloading workstation after improvements

The implementation of an ergonomic solution was also necessary for the container changing process.

The Figure 4 depicts the awkward posture adopted in this process. The container has an average weight of 6kg but could rise to 9kg maximum.

The solution was the implementation of a lift car, similar to the one in Figure 5.

Figure 4– Container changing

Figure 5 – Lift Car

2.2.1 Anthropometrics studies

Anthropometric studies were used to redesign the structure and take into account the adjustment of the workstation to the body characteristics of the operators, e.g., their stature.

In order to adjust the work plan, and eliminate the necessity of arms up above 45º, it was provided an automatism to up and down the suspension, based on the standard cycle time for producing each reference.

It was also provided an option to change from automatic to manual, when worker have difficulties to accomplish cycle time, for some reason.

The existing paradigm of the grids suspensions in rectangular shape was overcome and a round shape was elected (Figure 6). The advantage of this change is the reduction of the distance between operator, suspension and table, resulting in less movements such as trunk rotation.

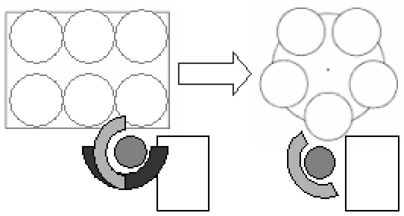

Figure 6–Suspension grid shape: rectangular vs round.

The vertical amplitude of the structure was calculated based on the anthropometric database of the Portuguese population (Barroso et al., 2005): the maximum limit was calculated using the measure of floor-to-elbow of the man's 95 percentile (1159 mm) and the minimum limit was calculated by using the measure of floor-to-elbow of the woman's 5 percentile (914 mm). This structure also includes a rotary base to bring the suspension closer to the worker.

In Figure 7 it is possible to see that the proposed solution allows different types of workers to perform their job without elevating their arms above 20º.

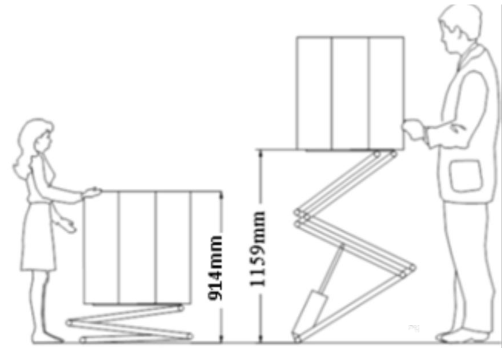

Figure 7–Structure automatized to elevating the suspensions

Like any investment, the costs component is very important in the decision of forward or not with the project. The estimated cost to implement this solution is about 2700€.

3 RESULTS

Productivity was calculated for 23 references which represent 80% of the total quantity produced in this production area.

Table 1 shows how much productivity increased: about 9% in the load operation and 5% in the unloading operation. This difference is due to the bigger distance between the table and the carpet in the loading workstation than the same distance in the unloading workstation.

Table 1. Productivity (throughput in pieces/hour).

Workstation	Initial Situation	After Improvements
Loading	800	872
Unloading	900	945

According to RULA method (McAtamney & Corlett, 1993), the most inappropriate postures before the improvements were moving the suspension and container changing (scored with 6).

The moving suspension task was eliminated and the RULA score to perform the task of changing container was reduced from 6 to 4 by the implementation of the lift car.

Table 2 and Table 3 depicts the RULA score and the percentage of time spent in each posture in the initial situation and after improvements at the loading and unloading workstation, respectively. The time spent in a position implying arms up was reduced from 29% to 24% through the implementation of the horizontal structure and by lowering the work plan. The ideal posture of the arms (arms between -20º to 20º) is achieved when the worker uses the horizontal structure (14% of the time).

Table 2. RULA score and percentage of time spent in each posture (loading workstation) before and after the ergonomic improvements.

Loading Workstation	**Initial Situation**		**After Improvements**	
	RULA	Time	RULA	Time
Arms Flexion -20º to 20º	-	-	3	14%
Arms Flexion 20º to 45º	4	56%	4	52%
Arms Up (>45º)	5	29%	5	24%
Move Suspension	6	5%	-	-
Container Changing	6	10%	4	10%

Table 3. RULA score and percentage of time spent in each posture (unloading workstation) before and after the ergonomic improvements.

Unloading Workstation	**Initial Situation**		**After Improvements**	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	14%
Arms Flexion 20º to 45º	4	57%	4	51%
Arms Up (>45º)	5	30%	5	25%
Move Suspension	6	3%	-	-
Container Changing	6	10%	4	10%

In the initial situation, the weighted average was 5 for both workstations indicating that investigation and changes are required soon.

After the workstation improvements, the action level decreased from 3 to 2 means that more changes may be needed to reach the negligible level (action level 1). For this reason, another workstation redesign was performed, taking into account the anthropometric aspects and the elimination of awkward postures, i.e. trunk flexion and arms up. The team estimated that with this redesign the worker would perform 90% of their work with arms extension/flexion between –20º to 20º (Table 4 and Table 5).

Table 4. RULA score and percentage of time spent in each posture (loading workstation) before and after the final redesign implementation.

Loading Workstation	**Initial Situation**		**After Redesign***	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	90%
Arms Flexion 20º to 45º	4	56%	-	-
Arms Up (>45º)	5	29%	-	-
Move Suspension	6	5%	-	-
Container Changing	6	10%	4	10%

*Estimated values

Table 5. RULA score and percentage of time spent in each posture (loading workstation) before and after the final redesign implementation.

Unloading Workstation	Initial Situation		After Redesign*	
	RULA	Time	RULA	Time
Arms Extension/Flexion -20º to 20º	-	-	3	90%
Arms Flexion 20º to 45º	4	57%	-	-
Arms Up (>45º)	5	30%	-	-
Move Suspension	6	3%	-	-
Container Changing	6	10%	4	10%

*Estimated values

After the new workstation redesign, the ergonomic risk could be reduced from the level 4 to the level 3. Although the good results, they are not enough to reach the risk level 1 - acceptable risk. The reason is the repetitiveness of the tasks. A possible solution could involve the enlargement of the job.

Table 6 summarizes the RULA score from the initial situation to the final redesign in both workstations.

Table 6. RULA score summarize.

Workstation	Initial Situation	After Improvements	After Redesign*
Loading	5	4	3
Unloading	5	4	3

*Estimated values

Despite the demonstration made by the team of the working conditions improvements after the redesign implementation, the company decided not to proceed with the redesign due to the high investment value.

4 CONCLUSIONS

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

The conclusions of this study are limited to this case, but the authors believe that is possible to consider both aspects, ergonomic conditions and productivity, during improvements implementation.

As illustrated in the section of results, the improvements reached in the ergonomic conditions can contribute very positively for productivity increases.

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.

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6

COMBINING SMED METHODOLOGY AND ERGONOMICS FOR REDUCTION OF SETUP IN A TURNING PRODUCTION AREA

Contents:

Presents a manuscript of a case study which took place in a turning production area of a metallurgical factory where workers' complains due to shoulder pains and tendinitis were high, due to the awkward postures and forceful hand exertions to perform the manual tasks. The aim of the study was to prove that it is possible to reduce the setup time, using SMED (Lean Tool) and improve ergonomic conditions at the same time. Through the SMED tool and increasing ergonomic conditions, the setup time was reduced and the MSD risk also decreased. REBA was the chosen method to evaluate the ergonomic situation.

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Combining SMED methodology and ergonomics for reduction of setup in a turning production area

M. Brito[a,*], A.L. Ramos[b], P. Carneiro[c], M.A. Gonçalves[d]

[a]*DEGEIT University of Aveiro, Aveiro 3810, Portugal*
[b]*GOVCOPP Research Centre, DEGEIT, University of Aveiro, Aveiro 3810, Portugal*
[c]*ALGORITMI Centre, University of Minho, Guimarães 4804, Portugal*
[d]*ISEP, Polytechnic of Porto, Porto 4249, Portugal*

Abstract

The aim of this study is to prove that it is possible to reduce the setup time and improve ergonomic conditions at the same time. This research took place in a turning production area of a metallurgical factory where workers' complains due to shoulder pains and tendinitis were high, due to the awkward postures and forceful hand exertions to perform the manual tasks. Moreover, the high setup time of 105 minutes caused productivity problems and delays for customers. Through the SMED tool and increasing ergonomic conditions, the setup time was reduced 46% and the MSD risk also decreased.

Peer-review under responsibility of the scientific committee of the Manufacturing Engineering Society International Conference 2017.

Keywords: SMED; setup; lean; ergonomics; musculoskeletal disorders; productivity; continuous improvement; WMSD;

* Corresponding author. Tel.: +0351 937 476 000.
E-mail address: marlenebrito@ua.pt

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1. Introduction

Companies frequently find techniques and tools to enhance productivity and quality for success in the long-term in order to maximize competitive advantage. To date, lean manufacturing principle is one of the successful improvement concepts that have been applied to eliminate waste and non-value added activities that occur in many companies [4].

Market´s acceptance of products and services depends now not only on their price, but also on their quality, on-time delivery, variety and volume flexibility. The required capabilities needed to achieve the above purposes have been developed through the implementation of various technologies and work philosophies that accomplish high levels of waste reduction, integration and coordination among processes. One of the basic, and fundamental programs suggested, consists on the setup reduction in the shop floor [6].

According to [3], this is a key program to increase production capacity utilization, and hence productivity, and at the same time lifting the level of flexibility of the plant in terms of volume and variety of products.

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 [11].

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 day. In the long run, the financial savings from the productivity gains and quality improvements are used to pay for the higher cost of workers' compensation claims for musculoskeletal disorders (MSDs) [3].

With regard to Europe, the data emerging from the 6th European Survey on Working Conditions in 2016 [2] reports that it is clear that posture-related risks– in particular, repetitive hand and arm movements – are the most prevalent and musculoskeletal disorders are one of the most common work-related complaints, affecting millions of workers and costing billions of euros to employers. Some 34% of women are exposed to such movements 'all or almost all of the time'– two percentage points more than men.

The present study took place in a turning production of a metallurgical factory that produces bath and kitchen taps area, where absenteeism rate and workers' complaints due to shoulder pains and tendinitis were high, due to the awkward postures and forceful hand exertions to perform the manual tasks.

The company management is interested in reducing the total setup time as part of an operations strategy to improve productivity and order delivery time. 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 research question of this study was: would it be possible to reduce the setup time and improve ergonomic conditions at the same time?

2. Methodology

This research will be conducted by a case study research. According to [8] 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.

Through the application of the SMED methodology, along with ergonomic analysis, various interventions took place with the purpose of reducing setup times and increase ergonomic conditions.

The first step was the election of a multifunctional team, including operators, to analyze the processes of the production area and evaluate the initial situation in terms of ergonomic conditions and productivity. Regarding ergonomic conditions, the team chose a postural analysis system - Rapid Entire Body Assessment (REBA) - to assess the level of MSDs risk because it provide a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures [10], that fits well to the case study.

After the initial situation analysis, the team suggested some modifications in order to improve ergonomic conditions and reduce the setup time.

After the implementation of the suggested improvements, the team measured both the setup time and the ergonomic conditions, and compared the attained results with the base scenario.

2.1. Ergonomic Assessment

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 changeable working positions.

REBA provides a quick and easy measure to assess a variety of working postures for risk of work-related musculoskeletal disorders (WMSDs). It divides the body into sections to be coded independently, according to movement planes and 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 [10], [1].

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

The team decided to assess the level of WMSDs risk of the four most critical postures regarding ergonomic conditions:

- Posture 1: Replacement of machine gutters
- Posture 2: Use of work tools whose handles are poorly ergonomic
- Posture 3: Difficult access to the machine
- Posture 4: Machine programming

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

2.2. SMED Methodology

The key idea of lean is “doing more with less”, where less means less space, less inventory, fewer resources, among others [5]. As shown by [9], setup time reduction is a key initiative of lean manufacturing. The idea that setup time could be reduced significantly was recognized in 1985, when Shigeo Shingo developed a methodology for that purpose in Toyota.

Setup time has been defined as the time taken from the production of the last item of a product lot to the production of the first item of the next product lot. This definition has been enriched afterwards by [7].

This new definition is described in Figure 1.

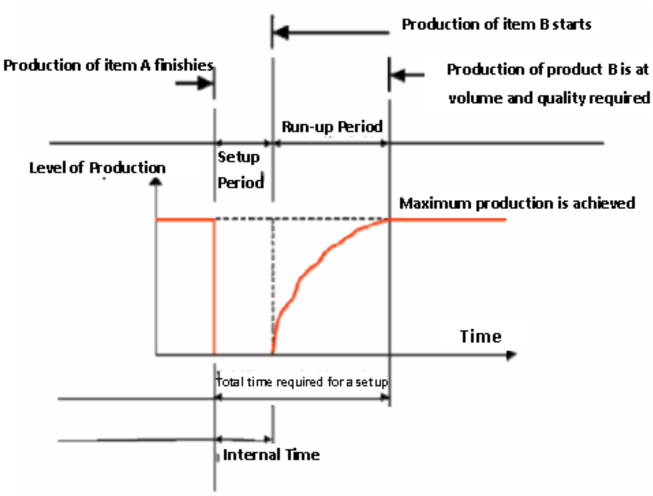

Fig. 1. Description of Setup time [6].

The initial stage consisted of mapping all the activities required to perform a setup. This was performed by using a video recording to collect activities and times data.

Then, the first step had the objective of identifying and separating activities that are internal and those that are external. Internal and external activities are defined as:

Internal time: It is the time taken for setting up while the machine is not running or operating.

External time: It is the time period required to perform setup related activities before and after carrying out the setup period.

This step intended to transform internal activities into external ones.

The second step was conceived to further simplify internal activities. The design of devices, the automation of activities and the coordination and synchronization of operators are activities commonly implemented at this stage. Finally, the last step, aimed to simplify external activities.

Figure 2 depicts these steps in diagram format.

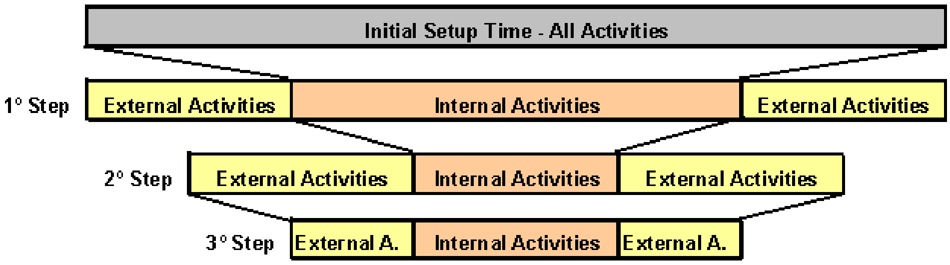

Fig. 2. SMED steps diagram.

3. Results

Regarding posture 2 ergonomic conditions, 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.

This improvement resulted in a productivity gain of 23% in this operation, through the reduction of the time needed to perform the activities of tightening and loosening screws.

Figure 3 depicts this tool change.

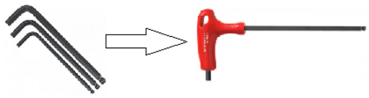

Fig. 3. Tool change: "Umbrako" for "Ergonomic T-handle"

This ergonomic improvement reduced the REBA score from 7 to 5.

The team also proposed to change this manual tool to an automatic one. This proposal would increase productivity and decrease ergonomic risk through the reduction of the forceful hand exertions to perform this manual task. 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 1.

Figure 4 depicts both postures: before and after the implementation of the tray cart.

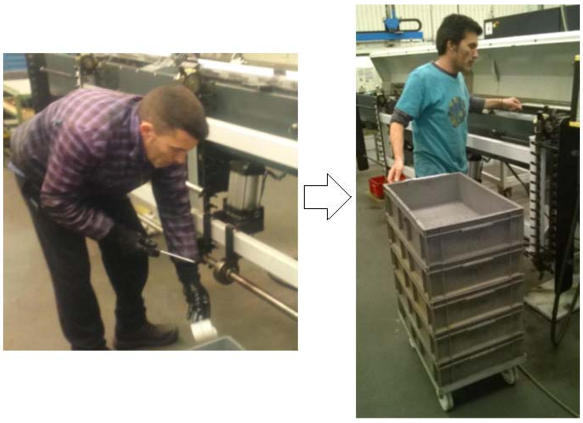

Fig. 4. Operator performing the activity of replacing the gutters from the machine before and after the implementation of the tray cart (Posture 1)

After this ergonomic improvement the physical MSD risk was reduced from very high to low. Furthermore this improvement resulted in a 24% increase in the productivity of this operation.

Table 2 summarizes the productivity gains and the REBA score of the initial situation and the situation after the ergonomics improvements described above.

Table 2. Summary of the productivity gains and the REBA score of the initial situation and the situation after the ergonomics improvements.

Action level	REBA score Before	REBA score After	Operating Time (min) Before	Operating Time (min) After
1	12	3	6.6	5.0
2	7	5	2.4	1.8

The team also analyzed two other awkward postures, one related to the difficult access to the machine and the other related to the access to the machine controls, which are so high that force arm lifting above a 45□ angle for a long period of time (about 62 minutes of the 105-minute setup time).

Figures 5 and 6 depict the awkward postures to perform the programming activity and the machine access, respectively.

Fig. 5. Programming activity (posture 4).

Fig. 6. Difficult machine access (posture 3).

These postures, trunk flexion and arms above 45□ had a REBA score of 10 and 5, respectively. That means that the posture 3 had a high level of MSD risk and the posture 4 a medium level of MSD risk. The team proposed several machine changes to solve these ergonomic problems, such as lowering the command box, but again, these proposals were not accepted by the company top managers due to the high investment.

Regarding the SMED tool, the first step was filming all the setup activities. Then, the team got together to analyze in detail all the activities. They identified the internal activities that could be external, such as data registration, part of the machine programming and the delivery of the ok part plus gauge (from the previous setup) to the quality control department. This change reduced the setup time from 105 to 85 minutes and the number of internal activities from 84 to 71.

The next step was the optimization of the internal activities through the implementation of some measures, such as, the elimination of transport and movement of tools now within reach, identification of the activities that could be performed simultaneously by 2 operators, etc… We can also consider the ergonomic improvements at this stage, as well as other measures to simplify the internal activities. All of these optimizations resulted in a reduction of the number of the internal activities from 71 to 43 and, consequently, a setup time reduction of from 85 to 57 minutes.

The last step was the simplification of the external activities. The reduction of several movements and transport of tools was one of the measures taken at this stage. As well as the simplification of the registration activity through the elimination of useless data filled in by the operator. Four external activities were eliminated at this stage as well as the time to perform the 9 left.

Table 3 summarizes the results of the number and type of activities during all the steps performed.

Table 3. Summary of results of the number and type of activities.

	Internal	External	Simultaneous	Eliminated
1 Step	71	13	-	-
2 Step	43	13	18	10
3 Step	43	9	18	14

At the end, the required time changed from approximately 105 minutes to 57 minutes, which meant a reduction of 46%.

4. Conclusions

Nowadays, it is very important to consider productivity measures while implementing improvements in the shop-floor. On the other hand, jobs are more repetitive leading to musculoskeletal disorders, increasing absenteeism and reducing productivity. The results of this study demonstrated that, according to the evaluation carried out using the REBA method, the level of MSDs risk was reduced (ex. REBA risk level of the Posture 1 was reduced from very high to low). That means that condition' improvements considered in a lean process helps in the achievement of good results.

On the other hand, several measures proposed for improving the production machine, from an ergonomic point of view, to prevent the occurrence of the WMSDs were not accepted because, some decision-makers do not view ergonomics as an investment, but rather as an expense.

There is no doubt that it is very important to evaluate the ergonomic conditions at the moment of purchasing a new production equipment, otherwise changes in the equipment could be very expensive, and difficult to justify.

Lean tools as visual management, such as 5S and standardization were very important in the achievement of these results. Also important was the separation of production tasks from logistics and the operators' involvement since the beginning of the process.

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IMPROVING PRODUCTIVITY AND ERGONOMIC ASPECTS IN A PACKAGING PRODUCTION AREA USING LEAN TOOLS AND SIMULATION

Contents:

Presents a manuscript of a study which highlights the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects. The study focus the packaging production area of a metallurgical industry and, in particular, a given product family.
SI was the chosen method to evaluate the ergonomic situation due to the forceful hand exertions and a simulation model was performed in order to evaluate the "best" layout. Lean manufacturing tools such as VSM and *Poka Yoke* were also used to analyze and increase the productivity by eliminating several wastes. Through the automatization of manual tasks, implementation of job rotation and by changing process layout to a cellular configuration it was possible to increase the productivity and improve considerably the ergonomic conditions.
The study shows that ergonomic condition' improvements should be considered to potentiate productivity.

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Abstract

The study reported in this paper highlights, through a case study, the benefits of using an integrated operations management approach to improve productivity and ergonomic aspects. The study focus the packaging production area of a metallurgical industry and, in particular, a given product family.
Strain Index (SI) was the chosen method to evaluate the ergonomic situation due to the forceful hand exertions and a simulation model was developed as performed in order to evaluate the "best" layout. Lean manufacturing tools such as Value Stream Mapping (VSM) and Poka Yoke were also used to analyse and increase the productivity by eliminating several wastes.
Through the automatization of manual tasks, implementation of job rotation and by changing process layout to a cellular configuration it was possible to increase the productivity about 136% and improve considerably the ergonomic conditions.
This study shows that ergonomic condition' improvements should be considered to potentiate productivity. The proposed method can be replicated in other production areas, as well as other manufacturing sectors, being a valuable tool for researchers and practitioners.

Keywords: Ergonomics; Lean Manufacturing; Productivity; Simulation; Strain Index

1. Introduction

Due to demographic fluctuation, fewer young workers are available and the overall number of workers will go down. The duration of absenteeism, in particular due to musculoskeletal disorders (MSDs), increases with age (Müglich et al., 2015).
Work-related musculoskeletal disorders (WMSDs) cause muscles, tendons and nerves at the joint of the neck, shoulder, elbow, wrist, finger, back, leg, etc. to be stressed and traumatized as a result of excessive or repetitive exertive force, awkward body posture, less resting time, cold working environment, vibration and others (Cheol-Min et al., 2011). With regard to Europe, the data emerging from the 6th European Survey on Working Conditions (ESWC) in 2016 (Euro found, 2016) reports that "…it is clear that posture-related risks– in particular, repetitive hand and arm movements – are the most prevalent in Europe and musculoskeletal disorders are one of the most common work-related complaints, affecting millions of workers and costing billions of euros to employers. Some 34% of women are exposed to such movements 'all or almost all of the time'– two percentage points more than men".

Several studies have reported that exposures to high force, high repetition, non-neutral hand/wrist posture and/or hand/arm vibrations from vibrating hand tools are associated with increased risk of distal upper extremity (DUE) symptoms and musculoskeletal disorders (MSDs) (Moore and Garg 1995; Bernard 1997; Mani and Gerr 2000; Moore, Rucker, and Knox 2001; Garg and Kapellusch 2011; Harris-Adamson et al., 2015). The literature suggests that those jobs requiring a combination of high force and high repetition have a greater risk for DUE MSDs than those jobs requiring exposure to either high force or high repetition alone (Armstrong et al. 1987; Silverstein, Fine, and Armstrong 1987; Moore, Rucker, and Knox 2001; Garg and Kapellusch 2011; Harris-Adamson et al. 2015). Harris-Adamson et al. (2015) reported that the per cent time spent in forceful hand exertions was associated with an increased risk of incident carpal tunnel syndrome in a dose-dependent pattern, consistent with the findings of Moore and Garg (1994). Regarding exposure to force, repetition and posture, it appears that these risk factors interact in a multiplicative manner.

Available assembly system design methodologies do not always consider the industrial environment from beginning to end, or where the assembly is conducted, nor production volume, or job enlargement approach, or work repeatability and learning effect, or organization flexibility, or yet work force turnover and absence (Abdullah et al., 2003).

Zhenyuan et al (2013) demonstrated that the designed lean facility layout system may effectively enhance the productivity efficiency and improve the efficiency of the using of equipment. In many production environments, lean methods of automation are increasingly adopted as they are reliable and economically effective. Greater attention, both from a scientific and industrial point of view, is being paid to repetitive manual tasks executed in assembly lines, where most frequently employees are exposed to WMSDs and where an increase in production rate has a direct connection to an increase in physical workloads (Colombini et al., 2002). WMSDs and loss of efficiency are common issues faced by human based production systems (Thun et al., 2011). The related deterioration of physical and cognitive performances of workforce has a negative impact on the flexibility of human-based production systems, for instance in manual and semi-automated assembly lines. It is necessary to incorporate the human component into traditional scheduling theory, and to evaluate the risk of MSDs in the most reliable way.

Often, ergonomics evaluations are conducted by ergonomists, while workplace layouts are designed by process engineers or operations managers, and the outcomes are many times unsatisfactory, non-integrated and do not increase productivity (Carey and Gallwey, 2002). Past projects on this topic showed the extra value of combining assembly engineering with ergonomics (Van Lingen et al., 2002; De Looze et al., 2003).

According to Westgaard and Winkel (2011), integrating the requirements for effective production and a healthy workforce in the analysis and devising of production systems could be a solution to the apparent conflict of interest between Ergonomics and rationalization. Moreover, the integration of ergonomics during the lean manufacturing implementation can potentially lead to obtaining considerable gains in productivity, lowering absenteeism (Santos et al., 2015) and simultaneously improving working conditions (Alves et al., 2016). However, future studies are needed to document the best practices in the integration of MSD prevention into the organizational framework, including the management system. Furthermore, the economic evaluation of such practices will be required to document the cost-effectiveness of these kinds of approaches (Botti et al., 2017).

The present case study took place in a packaging production area, where absenteeism rate and workers' complaints due to shoulder pains and tendinitis were high, due to the combination of high force and high repetition to perform the manual tasks. This study intends to answer the question: how to use an integrated operations management' approach, using Lean concepts, to improve, simultaneously, productivity and ergonomic conditions?
It was also measured the impact on performance indicators such as: productivity, when ergonomic aspects are considered during the LPS implementation.
This paper provides a unique approach combining Lean manufacturing, and Ergonomics to improve productivity while improving working conditions. The method can be replicated in other production areas, as well as other manufacturing sectors, being a valuable tool for researchers and practitioners.

2. Methods

The methodology used was the case study. 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.
This case study was performed in a metallurgical factory that produces bath and kitchen taps, door handles, locks, access controls and other bath accessories. The focus of this study was on the packaging area processes of the most representative family of products: the 90 Degree family.

The first step was the election of a multifunctional team, including operators, to analyse the process and evaluate the initial situation in terms of ergonomic conditions and productivity. Then this team suggested some modifications in order to improve ergonomic conditions, reduce wastes (e.g., unnecessary movements and transportations) and increase productivity. Lean manufacturing techniques were used to help increase productivity, such as Value Stream Mapping (VSM) and seven wastes identification (it was also necessary to perform a time study to help this process). A simulation study (using Arena® software) was conducted to analyse two different layout scenarios proposed by the team and the Strain Index (SI) method was used to evaluate the ergonomic conditions.

After the implementation of the suggested improvements, the team measured both the productivity and the ergonomic conditions, and compared the attained results with the base scenario.

2.1 Lean Manufacturing Tools

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 do a VSM to map the production process of the product family and to identify and characterize the main wastes that occurred on the packaging area.

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. Value Stream Mapping 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 and 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 work in progress (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.

2.2 Ergonomics Analysis

The Strain Index (SI) is a semi-quantitative job analysis methodology and is based on existing knowledge in the field of physiology, biomechanics and epidemiology. Its purpose is identifying jobs that place workers at increased risk of developing disorders in the distal upper extremity (DUE) (Moore and Garg, 1995). The application of the methodology involves the measurement or estimation of six task variables (intensity of exertion, duration of exertion, efforts per minute, hand/wrist posture, speed of work, and duration of task per day). Intensity of exertion, hand/wrist posture and speed of work, are estimated variables; duration of exertion, efforts per minute and duration of task per day are measured. A multiplier value is assigned to each variable, resulting from an ordinal rating according to exposure data. The SI score is the product of the six multipliers.

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). Forceful hand exertion may be rated subjectively by workers' self-reports (Harber et al., 1994; Punnett et al., 2004; Stetson et al., 1991) or by the observer during on-site observation (Bao et al., 2006a) (based on observer's expertise and experience). A pinch or a power grip force may also be measured using a force matching method, by asking a worker to replicate the forces used in task performance on a hand dynamometer, using similar hand/wrist postures. The reading on the dynamometer is considered to be the handgrip force required in the task (the accuracy and reliability of this method used for handgrip force estimation has not been well studied) (Bao and Silverstein, 2005). A satisfactory assessment of force requirements (peak force) may be categorized as light (<10% MVC), somewhat hard (10–29% MVC), hard (30–49% MVC), very hard (50–79% MVC) and near maximal (>80% MVC) (Moore and Garg, 1995). EMG data can be normalized as a fraction of an individual's maximum (%MVE), which for practical purposes, corresponds to the normalized hand force (%MVC) (ACGIH, 2001).
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. After measuring or estimating values for the six Strain Index task variables, ordinal ratings varying from one to five are assigned according to Table 1.

Table 1. Ordinal ratings of Strain Index method.

Rating	Intensity of exertion	% Duration of exertion	Efforts per minute	Hand/wrist posture	Speed of Work	Duration per day (hours)
1	Light	< 10	< 4	Very good	Very Slow	< 1
2	Somewhat hard	10 - 30	4 - 8	Good	Slow	1 - 2
3	Hard	30 - 50	9 - 14	Fair	Fair	2 - 4
4	Very hard	50 - 80	15 - 19	Bad	Fast	4 - 8
5	Near maximal	> 80	≥20	Very bad	Very fast	> 8

The multipliers for the six Strain Index task variables are derived from the ordinal ratings according to Table 2.

Table 2. Multipliers of Strain Index method.

Rating	Intensity of exertion	% Duration of exertion	Efforts per minute	Hand/wrist posture	Speed of Work	Duration per day (hours)
1	1.0	0.5	0.5	1.0	1.0	0.25
2	3.0	1.0	1.0	1.0	1.0	0.50
3	6.0	1.5	1.5	1.5	1.0	0.75
4	9.0	2.0	2.0	2.0	1.5	1.00
5	13.0	3.0	3.0	3.0	2.0	1.50

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 analyse a process behavior over time and evaluate the impact of a given change without disrupting the system or invest capital.
In this study the simulation study was performed 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 study 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 analysed in order to understand which scenario brings the "best results" for the real system.

3. Results

The base/initial situation, corresponding to the current shop-floor conditions, was analysed using the VSM tool, SI method and simulation modelling. After this analysis, several developments were implemented in order to improve ergonomic conditions and productivity. Two scenarios were simulated using Arena software. The results of these steps are described below.

3.1 Initial Situation

In the initial situation, the 90 Degrees product family went through three processes in the packaging production area: dimensional control, laser engraving and selecting / packaging. These processes were physically separated originating several wastes.

A VSM, represented in Figure 1 was developed to map the current situation. This process mapping was based on observations in the *gemba floor* and involved all the team, including operators.

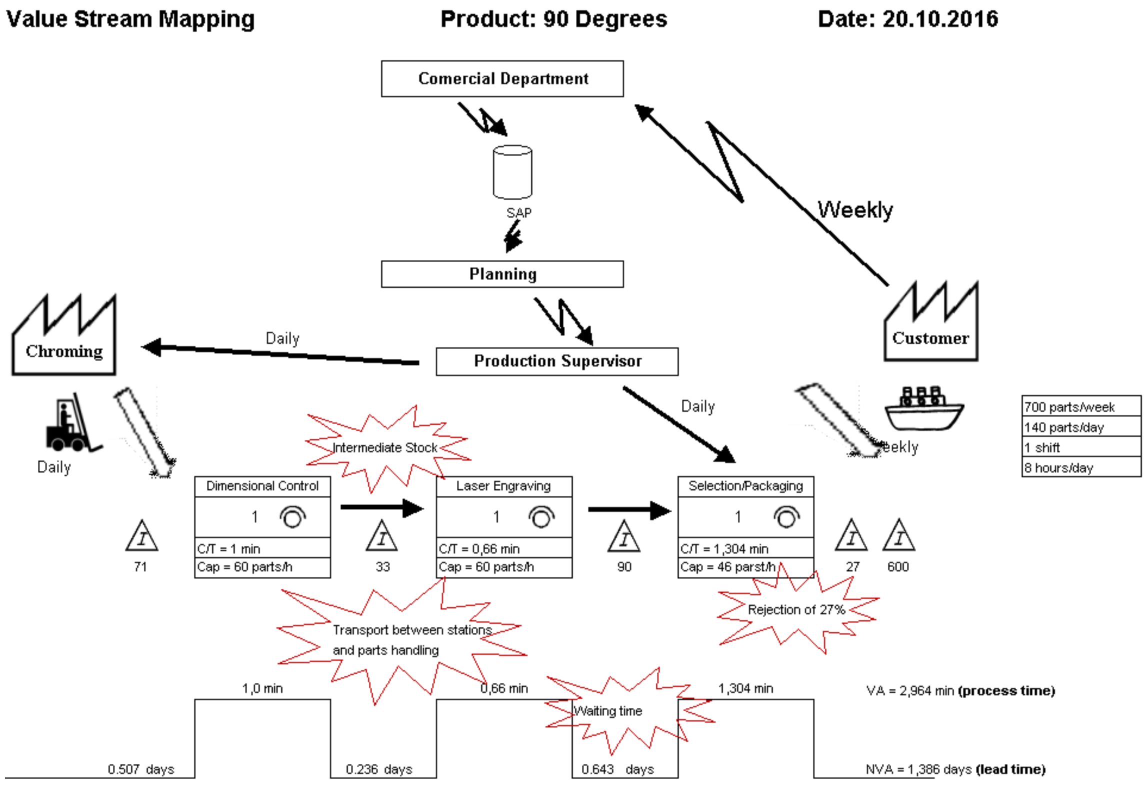

Figure 1. Initial VSM.

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 (Work in Process inventory). 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.

The high percentage (around 27%) of rejections/defects was also a big concern to the team. The rejections were mainly due to cosmetic problems, such as scratches originated during transportation, handling, etc.., or technical issues originated in the previous processes as foundry, polishing and galvanizing. Parallel to this study, a quality team was created to help in the rejections' reduction.

Waiting time was observed during the engraving process when the operator has to wait to the engraving machine to finish the cycle. The idea of the team was to eliminate this waste by junction of dimensional control tasks during the engraving cycle time.

Figure 2 depicts the initial layout of the packaging area and the identification of the 90 Degree products transportations between the processes.

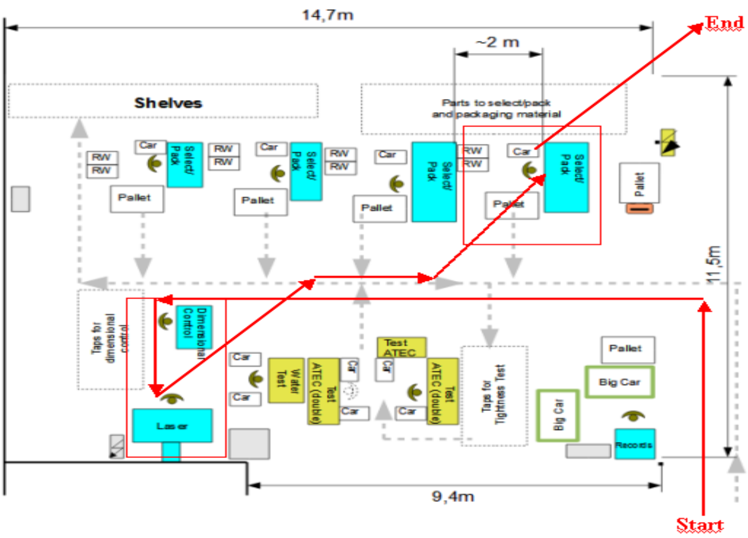

Figure 2. Packaging area layout and 90 degree materials transportation path.

Being such a critic area in terms of ergonomic conditions, the SI scores were not a surprise, as can be seen in Figure 3. Two of the three operations present scores above 7, meaning probably "a problem". Attending the complaints of the workers, tendinitis problems and absenteeism verified in this production area, the team identified ergonomics conditions as a big issue to improve urgently.

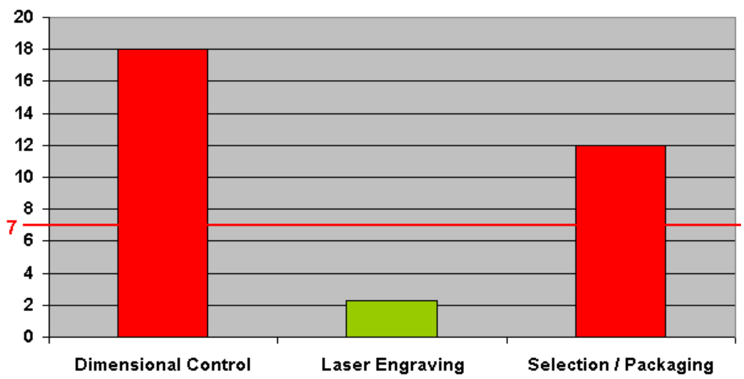

Figure 3. SI scores for the initial situation

The main ergonomic problems are related to the repetition of the task, weight of the taps (around 1kg) and the forceful hand exertions to perform the manual tasks. Figure 4 and Figure 5 depicts some of twisting hand/wrist postures needed to perform the selection and dimensional control tasks.

Figure 4. Dimensional control process.

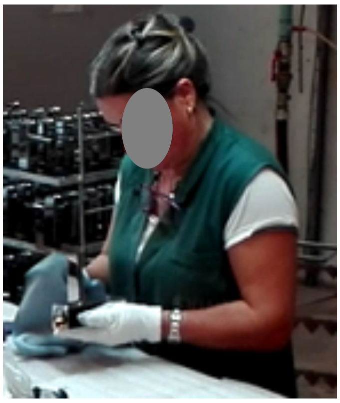

Figure 5. Cleaning and selecting operations.

The initial solutions given by the team to improve ergonomic conditions were:

i) the reduction of manual tasks,
ii) the automatization of manual tasks, and
iii) job rotation.

Table 3 depicts the indicators analysed in the initial situation that the team intended to improve. Lead time, WIP and productivity were measured using the simulator Arena. The simulation was run for 5 working days, 8 hours daily. Also, in order to achieve acceptable 95% confidence intervals for the key performance indicators, a number of 15 replications was settled. SI scores were calculated using videos and photos of the different postures adopted during the performance of the jobs.

Table 3. Initial key performance indicators.

Indicator	Inicial Situation
Lead time (hours)	13.1±0.57
WIP (units)	209±0.75
Production Cost (€ per unit)	0.39±0.01
Productivity (pieces OK per hour)	32±0.47
Waiting Time (seconds per cycle time)	8±0.45
Production Area (m2)	15.96
Transports (min/unit)	1.44
SI - Laser Engraving	2.25
SI - Dimensional Control	18
SI - Selection and Packaging	12

3.2 Improved Situation

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 previous studies which state that several companies which 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. After these implementations, the productivity increased

40.6% and several wastes, such as handling, transports, movements and motions were eliminated or reduced.
Figure 6 depicts the new cellular layout design for the 90 degree family.

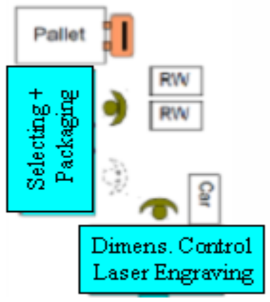

Figure 6. New cellular layout.

Regarding ergonomic conditions, the junction of the two processes (dimensional control and laser engraving) reduced the number of efforts per minute from 8 to 6. Although, that was not enough to reduce the SI score, so the next step was the improvement of the ergonomic conditions of this process. The main ergonomic problem of this workstation was 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 analyses: 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 identified it as over processing waste and for the most critical gauge an automatized solution was implemented. After these implementations the productivity increased about 103% comparing with the initial situation, and the necessary time to satisfy customer orders was also reduced from 6 to 3 hours. All of these factors combined result in a high reduction of the SI scores, especially in the processes of dimensional control and engraving laser. Figure depicts the SI scores before and after these improvements:

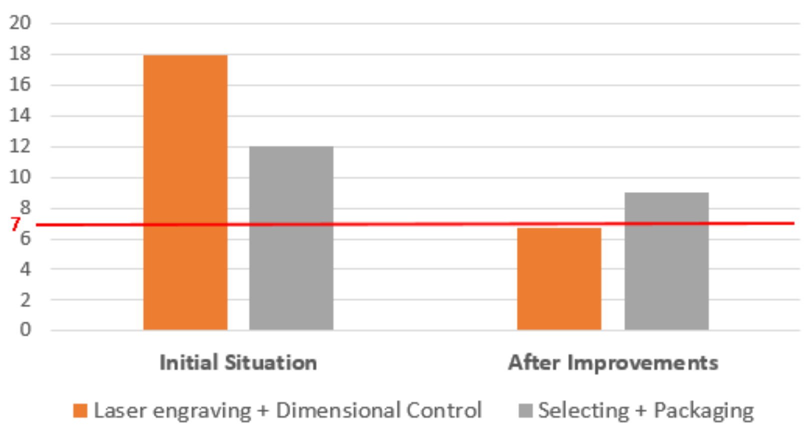

Figure 7. Comparison of SI scores between initial situation and after improvements.

To optimize the selecting and packaging workstation in terms of productivity and ergonomic conditions the team requested technical help from an expert of automatic selecting machines. Despite the productivity and ergonomic advantages, the company decided not to invest due to the high monetary value of this type of machines.

It was also given training to all operators in this production area with recommendations of ergonomic postures to perform the tasks. Unfortunately it is difficult to change habits and some of the recommendations were not taken into account, e.g., support the arms on the table during the selecting operation to reduce the force required, altering the part between the right hand and the left hand, etc... Therefore a job rotation plan was defined to reduce the time exposed to the development of WMSDs. According to SI method the time spent in the selecting and packaging process should be less than 2 hours to reduce the SI score to "not a problem" level. This rotation plan took into consideration the muscle group in effort to perform the other jobs.
Regarding the rejection of parts, two scenarios were analysed using simulation: simulating visual inspection and a first cleaning at the beginning, identified as Scenario 1 and the simulation of this processes at the end, identified as Scenario 2. Figure 8 and Figure 9 depict both scenarios, respectively. Scenario 1 forces a second visual inspection, although, more than 90% of the total rejection was segregated on the first selection. The advantage of this scenario is to avoid the value addiction of laser engraving process on defected parts. The question is: which scenario is better in terms of productivity?

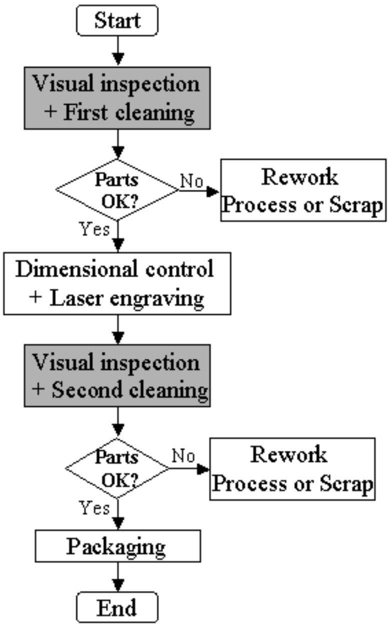

Figure 8. Flowchart for scenario 1.

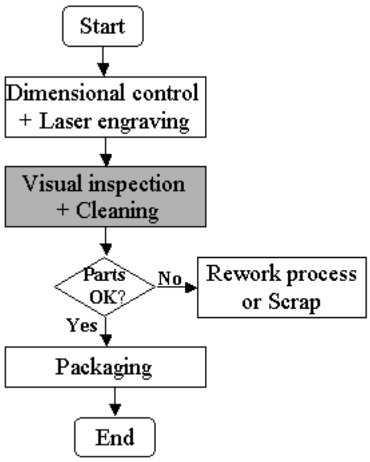

Figure 9. Flowchart for scenario 2.

Table 4 depicts the results of the simulation for both scenarios.

Table 4. Arena simulation results for Scenario 1 and Scenario 2.

Key Performance Indicator	Scenario 1	Scenario 2
Lead time (hours)	9.0±0.35	9.0±0.35
WIP (units)	118.9±0.45	133.9±0.52
Production Cost (€ per unit)	0.23±0.00	0.23±0.00
Productivity (pieces per hour)	77±0.15	65±0.25
Transports (min/unit)	0.83	0.83

Regarding the two scenarios simulated, the critical differences between the first and the second were the productivity and WIP. According to these results scenario 1 shows to be the better one.
After all these implementations, the earnings overpassed the expectations of the team. Lead time was reduced from 13.09 hours to 9 hours, and the waiting time was eliminated. Productivity increased 136% and the production cost in this packaging area was reduced about 41%.

There were also improvements in the WIP, occupied area and transportation.
Table 5 resumes all the gains comparing the initial situation with the situation after improvements.

Table 5. Comparison of the initial average values with the average values after improvements and the respective percentage of gains.

Key Performance Indicator	Initial Situation	After Improvements	Gains
Lead time (hours)	13.1	9.0	30.4%
WIP (units)	209.0	118.9	43.1%
Production Cost (€ per unit)	0.39	0.23	41.0%
Productivity (pieces per hour)	32	77	136%
Waiting Time (seconds per cycle time)	8	0	100%
Production Area (m2)	15.96	10.91	46.3%
Transports (min/unit)	1.44	0.83	42.3%

4. Conclusions

Due to the hard competition, demanding customers and competitive world that companies face, nowadays, it is very important to consider productivity measures 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 study show that it is possible to consider both aspects, ergonomic conditions and productivity, during improvements implementation. In fact, the improvements reached in the ergonomic conditions can contribute very positively for productivity increases.
It is important to highlight that the excellent results reached on the productivity and ergonomic conditions have much to do with a combined operations management approach joining lean manufacturing and simulation to improve the working conditions. The elimination of several *gemba* wastes, the new cellular layout and the automatization of the manual tasks were the key operational improvements simulated and implemented in the packaging area. Regarding job rotation, the team found it very difficult to put in practice. The majority of the other jobs that could be done by the packaging operators have the same group of muscles in effort.
Measures for improving the workplace, from an ergonomic point of view, to prevent the occurrence of the WMSDs were proposed. Unfortunately, some of them were not accepted because on the one hand, some decision-makers do not view ergonomics as an investment, but rather as an expense, and on the other hand there is a resistance to change by operators. There is no doubt that the success of this improvements pass by the involvement of all the team, operators, managers, engineers, etc.
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.

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8

IMPROVING THE PRODUCTION PERFORMANCE AND ERGONOMIC ASPECTS USING LEAN AND AGILE CONCEPTS

Contents:

Presents a manuscript of a case study reporting the benefits of using an integrated_operations management approach, using Lean and agile concepts, to improve the production performance and ergonomic aspects of a production system.
The main objective was to evidence that it is possible to reach an efficient production that meets safe and ergonomic requirements, by using Lean and agile principles. Through the enlargement of tasks, the reduction of waste and the reconfiguration of a process layout to a cellular arrangement it was possible to increase responsiveness and flexibility of the production system, to improve key performance indicators such as Lead time and Work in Progress, and to considerably improve the ergonomic conditions of the workers.

Brito, M. F., Ramos, A.L., Carneiro, P., Gonçalves, M.A. & Vasconcelos, A. Improving the production performance and ergonomic aspects using lean and agile concepts. The open Cybernetics & Systemics Journal (accepted for publication / ready to publish).

Abstract

The study reported in this work highlights, through a case study in a metallurgical company, the benefits of using an integrated operations management approach, following lean and agile concepts, to improve the performance and ergonomic aspects of a production system. The study took place in the sanding and polishing area of the company, where workers' complaints due to the strength needed to perform manual tasks as well as their repetitive pattern led to cases of shoulder pain and tendinitis.

Through the enlargement of tasks, the reduction of waste and the reconfiguration of a process layout to a cellular arrangement it was possible to increase the responsiveness and flexibility of the production system, to improve key performance indicators such as Lead time and Work in Progress, and to considerably improve the ergonomic conditions of the workers. Through these improvements it was possible to increase responsiveness to the client, leading to a better quality service.

RULA was the chosen method to evaluate the ergonomic situation, due to the existence of strong arm and hand exertions. Anthropometric studies were carried out in order to improve workers' workstations and a simulation model was developed to dynamically evaluate the initial situation and as a decision support tool to choose the "best" layout configuration.

The results of this work (a reduction of 80% in transportation times, a reduction of 30% in lead time, a reduction of 50% in Work In Process, and a decrease in the ergonomic risk from 5 to 4, according to the RULA method) prove that it is possible to reach an efficient production system, which meets safety and ergonomics requirements, by using lean and agile principles and companies should consider both ergonomic aspects and production performance during continuous improvement implementations to increase productivity and worker well-being.

It is also proposed a general methodology to replicate the procedure in other production areas or other manufacturing sectors, which can be a very valuable tool for researchers and practitioners.

Keywords: Agile; ergonomics; leagility; lean manufacturing; musculoskeletal disorders; productivity; RULA; simulation.

1. Introduction

These days, there is extreme pressure for businesses to be competitive in their markets of choice. In order to compete in the marketplace, manufacturing companies are challenged by current market conditions to not only maintain their capabilities but also improve them. Firms have been optimizing their processes and supply chains so as to keep up with globalization trends and fast technological evolution, as well as deliver value to customers who are better informed and more demanding than ever before [1].

Historically, the determining factors in manufacturing companies were the economies of scale, with an emphasis on mass production, which went for maximum capacity as a way of maximizing profits. This led to inflexible, hard to reconfigure manufacturing plants which produced goods based on long-term estimates and then released them into the market [2].

From the mid-90s onwards, the paradigm changed and the focus became the fast production of new products. Priority was given to customer requirements, and a company's performance started being measured through the lens of customer satisfaction. This shift carried with it concepts such as agility, flexible manufacturing systems (FMS), etc. These concepts brought pull systems front and center, sidelining the conventional, traditional push systems [3].

Concepts of agile manufacturing, thus, became the norm, with companies operating in an environment of continuous and unforeseen change [2].

Lean production or lean manufacturing grew, with Toyota motors, in post-Second World War Japan. This concept is based on the idea of cutting down waste [4] by running production with a smaller inventory as well as a decrease in human effort, equipment, time and space, in order to meet customer demands in a highly responsive manner. This, in turn, means that the way companies are run must be adapted in order to meet these new challenges and is grounded on the companies' responsiveness and flexibility as well as on the cost and quality of the goods and services that their customers are willing to accept [5]. An agile company must be capable of having a flexible production system, shorter setup times and WIP (Work in Process) and also to circumvent all kinds of waste. These are some of the key components of a lean production system. This means that, if a company wants to be agile, it also has to be lean [6].

What numerous companies fail to realize is the potential for further increasing the productivity gains if ergonomic principles were integrated and implemented at the same time as Lean Systems [7]. Since Ergonomics is most commonly housed within the Occupational Safety and Health (OSH) department (essentially to answer legal requirements and to perform risk management), managers have a tendency to inadvertently narrow its scope of intervention to hazards, instead of taking advantage of its help to advance organizational effectiveness, business performance and costs [7]. According to [8] integrating the requirements for effective production and a healthy workforce in the analysis and devising of production systems could be a solution to the apparent conflict of interest between Ergonomics and rationalization.

Lean Ergonomics may decrease lead time by eliminating the waste of nonproductive manual material handling movements and activities [9] such as stretching, bending, awkward postures and extensive reaching, as well as increase the efficiency, safety and health of workers [10]. Musculoskeletal disorders [MSDs] have been previously demonstrated to lead to significant decreases in productivity, which are caused by higher absenteeism and injury rates [11]. Thus, the Lean team must take into account Ergonomics and safety, at the same time as waste reduction and value creation, core values of the Lean process [11]. For instance, by incorporating risk assessments into the value stream mapping process [12].By creating ergonomic workplaces and jobs, injury and absenteeism rates are reduced; at the same time, productivity, quality and reliability are improved [9] and [10].

Several studies have looked into the potential link between specific lean concepts (e.g. waste reduction and continuous flow) and ergonomics, occupational health and associated risk factors [13],

[14], [15] and [16]. Additionally, high-strain jobs carry a high risk of musculoskeletal disorders and heavy psychological load, which in turn represent an increase in costs and losses on the part of the company [17].

In the past 20 years there has been a widespread dissemination of lean production methods, which has shown the beneficial effects of lean thinking on business performance. The goal of lean manufacturing companies is to strengthen their productivity and use their resources efficiently by removing waste and reducing costs. The lean definition of waste comprises work in progress (WIP), defects and non-value-added-time, such as the time the worker spends waiting for products or performing superfluous movements. Strategies for reducing costs target specific efforts which diminish the resources used on low quality products, lowering the WIP value and cutting down transportation costs.

Another lean thinking component is the execution of flexible processes as well as the reduction of overburden and stress, which are seen as waste generators [18] and [19]. A wide range of studies have investigated the changes in the quality of work life as a result of the implementation of lean manufacturing [20] and [21]. The conclusions have attracted both criticism and eulogistic praise for the strategies involved in lean manufacturing. Improvements in health, job satisfaction and job motivation have been reported as the effects of lean manufacturing through interviews and questionnaires done by workers and the analysis of case studies. As a result, workers have noticed an improvement in working conditions and been able to avoid excessive fatigue and accidental injuries [22] and [13].

The standardization of work processes in lean production methods could have a negative impact on empowerment and job control [16]. On the other hand, many studies have shown a link between the increased work pace and diminished recovery time in lean companies and JIT practices and work standardization [21]. The strict application of lean production methods, particularly, has been associated with musculoskeletal risk factors and stress on the part of manual workers [20] and [23]. This phenomenon arises from the fact that lean processes tend to result in highly repetitive operations, stressful postures and high level of strength requirements, and at the same time remove critical rest times for employees [12].

According to [24] there is a need for further case studies, in which researchers join forces with practitioners in the workplace to introduce LPS in a form that is expected to bring about a favorable employee outcome. Future studies are needed to document the best practices in the integration of MSD prevention into the organizational framework, including the management system. Furthermore, it would be interesting to verify the influence of the evolution of LPS and socio-technical and ergonomics practices on an organization's performance indicators [25]. Although Lean manufacturing (LM) has been discussed in previous studies, leanness is less investigated [26] as well as lean related activities [27] and [28].

The aim of this paper is to answer the question: how the integration of both LPS and Ergonomics can benefit the workers' welfare while increasing productivity? This paper also identifies the benefits of using an integrated operations management' approach, using Lean and Agile concepts, to improve, simultaneously, productivity and ergonomic conditions

The study took place in a sanding and polishing production area of a metallurgical company, where absenteeism rate and workers' complaints were considerable. The strength needed to perform manual tasks as well as their repetitive pattern led to cases of shoulder pain and tendinitis.

Following the lean implementation already launched in other production areas of the factory, Value Stream Mapping (VSM) and waste reduction were the tools used to increase responsiveness and flexibility. By changing the layout configuration from process to cellular, the physical distance between processes was eliminated, thus contributing to a reduction of lead time and WIP. This new configuration also resulted in a reduction in task repetitiveness through the enlargement of tasks. The team also suggested some workstation changes, based on anthropometric studies, in order to reduce WMSD risk.

Simulation was used for performance assessment and decision-making [29]. In this work, a simulation study was conducted to analyze the initial situation and to help in the decision of layout reconfiguration. Productivity, lead time, WIP and transportation times were the key performance indicators chosen to evaluate the dynamic operation of the system and potential improvements, since a company must be productive, efficient and flexible to stay competitive and profitable in today's market.

Summarizing, this paper provides a unique approach combining Lean manufacturing, Agile concepts and Ergonomics to improve productivity while improving working conditions. The method can be replicated in other production areas, as well as other manufacturing sectors, being a valuable tool for researchers and practicioners.

2. Methodology

The method used in this work was the case study. According to [30] a case study is defined "…as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context." So, the case study is a research methodology that helps to understand, explore or describe a given system in a real context, in which several factors are simultaneously involved. The iterative process of a case study research involves, like any empirical study, the case study design (planning the study and define the objectives/research questions), the preparation for data collection, the data collection, the analysis of data, and the reporting of results.

Figure 1 provides a conceptual framework for this case study research. The key research question focus the integration of both LPS and Ergonomics to benefit the workers' welfare while increasing productivity. The research intends to apply this integrated approach and evaluate the improvements in the two dimensions (productivity and ergonomics conditions) proving that the potential benefits of using this combined approach are real and improve the overall system performance.

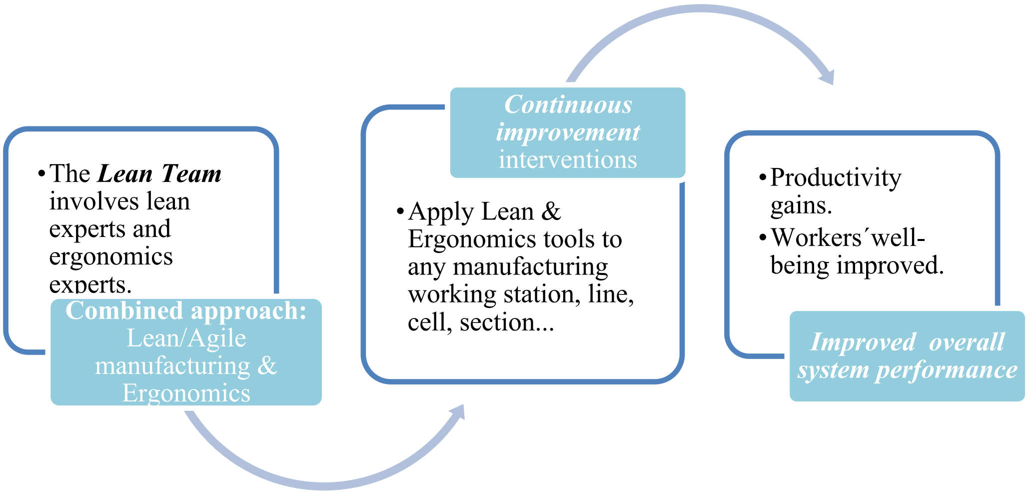

Figure 1. Conceptual framework for the case study research.

This case study was conducted in a metallurgical company which produces bath and kitchen taps, door handles, locks, access controls and other bath accessories. The focus of the study was the sanding and polishing area of the factory and its most representative family of products: the spouts family (Figure 2).

Figure 2. Main reference within Spouts family of products.

The first step was the selection of a multifunctional team, including operators, to analyze the process and to evaluate the current situation in terms of production performance and ergonomic conditions. After an exhaustive analysis, this team suggested some modifications in order to improve ergonomic conditions and reduce waste (e.g., unnecessary movements and transportations), and consequently to reduce lead time and WIP, leading to a more flexible production system. Lean manufacturing techniques, such as Value Stream Mapping (VSM) and seven wastes identification were used to help in the analysis of the system and to accomplish the objectives. A simulation study (using Arena® software) was conducted to perform a dynamic analysis and to evaluate different scenarios, therefore acting as a decision support tool. The RULA (Rapid Upper Limb Assessment) method [31] was used to evaluate ergonomic conditions since it is especially useful for scenarios in which work-related upper limb disorders are reported.

After the implementation of the suggested improvements, the team measured the production key performance indicators and evaluated the ergonomic conditions, comparing the attained results with the base scenario and assessing the desired gains. If the defined objectives were achieved, the standards were implemented. If not, new improvement proposals were given until the defined objectives were reached. Monitoring the new standards is key to ensuring that they are properly sustained and fulfilled.

The flowchart in the Figure 3 depicts these steps. This flowchart can be regarded as a general methodology to apply as an integrated Lean & Ergonomics approach to improve the productivity and the working conditions of workers in any industrial context.

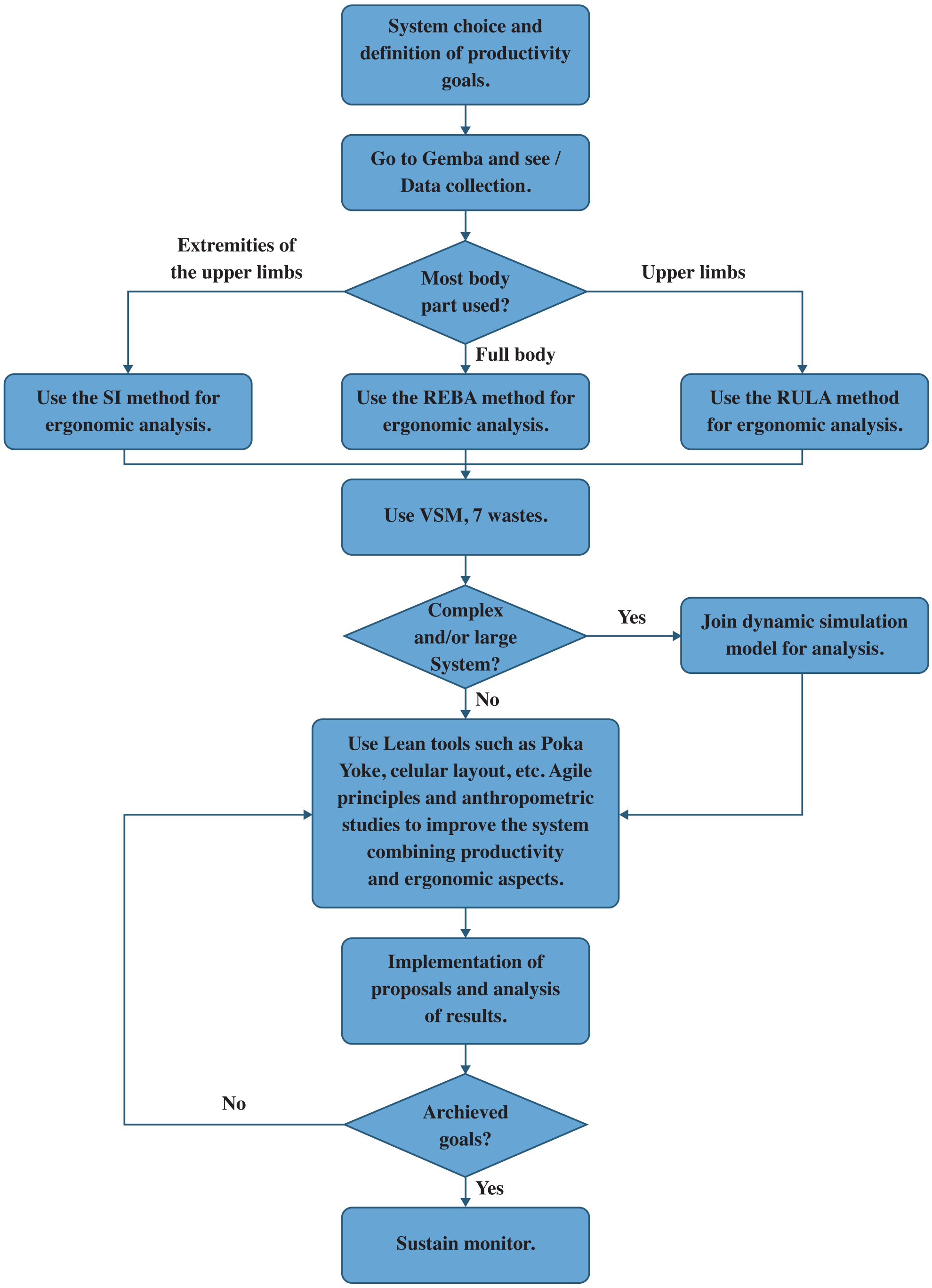

Figure 3. Methodology Flowchart

2.1 Lean Manufacturing and Agile concepts

[30] identified waste “as any human activity which absorbs resources but creates no value”. Value can be defined as “a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer”. Lean thinking provides a focused approach toward creating customer value while “doing more with less”, which means using less equipment, less human effort, less space, and less time. The lean definition for waste includes work in progress (WIP), defects, and non-value-added time, such as time spent waiting for products and unnecessary movements on the part of the worker. Process improvements, layout arrangement and work organization were considered the principal dimensions to encourage the implementation of lean production practices.

Agile manufacturing represents the capacity to respond efficiently to the constant changes of unpredictable demand [31]. Agility requires improvements in several areas such as responsiveness, product development time, product standardization, setup time, operations, etc. [32] and [33].

Organizational agility combines two key concepts: responsiveness and flexibility [34]. Flexibility measures the ability of a firm to adjust to a given level of production using the same technology. Responsiveness is the speed with which a company can respond to changing customer demands, including unanticipated ones [35].

2.2 Ergonomics Analysis

RULA was the tool used to assess the ergonomic conditions of the worker while performing the job, as it is especially useful for scenarios in which work-related upper limb disorders are reported.

The RULA score varies from one to seven. Scores one and two (action level one) indicate that the posture in question is acceptable if it is not maintained or repeated for long periods of time. Scores three and four (action level two) indicate that further investigation is needed. Scores five and six (action level three) indicate that changes are required soon. Score seven indicates that changes are required immediately.

2.3 Simulation Analysis

[36] 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 [37], the main reason for the popularity of simulation is its ability to deal with very complicated models of correspondingly complicated systems, which makes it a versatile and powerful tool.

Simulation is used by operations managers for several tasks such as line balancing, bottleneck identification, layout design/redesign, scheduling plans and dispatching rules testing, etc. According to [38], "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". A verified, validated and accredited simulation model will convince the decision makers and propel their confidence in the results, thus inciting the implementation of suggested solutions.

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. [39] stated that the scenarios of a simulation are used to aid in the decision-making process by helping the company analyze process behavior over time and evaluate the impact of a given change without disrupting the system or investing capital.

In this work the simulation study was performed using the Arena software, a leading computer simulation package with intuitive graphical user interfaces, menus and dialogues. This simulator allows the user to model complex systems as well as to develop 3D animation models which are critical for capturing the decision-makers' attention.

The simulation study followed the well-known major steps [40]: problem formulation, conceptual modelling and data collection, operational modelling, verification & validation, experimentation, and output analysis. 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

The initial situation, corresponding to the current shop-floor conditions, was analysed using, essentially, the following tools: VSM, RULA method and simulation modelling. After this analysis, several improvements were implemented in order to improve production performance indicators, such as lead time and WIP, and also ergonomic conditions. Simulation modelling was also used as a decision-support tool. The results of these steps are described below.

In the base situation, the spouts family of products went through eight processes in the sanding and polishing production area. These processes were physically separated, leading to several kinds of waste.

A VSM, represented in Figure 4 was developed to map the current condition. This process mapping was based on observations in the *gemba floor* and involved all the team, including operators.

The first waste identified by the team was related to layout configuration; in this case, a process layout. This type of layout requires batch production, leading to high amounts of WIP. Other kinds of waste 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, lead times were considerably high.

The high percentage (around 40%) of rejections/defects was also a big concern for the team. The rejections were mainly due to cosmetic problems, such as scratches originated during transportation or handling, or technical issues originated in previous processes, such as foundry. Parallel to this study, a quality team was created to help in the reduction of rejections. Considerable waiting time was observed during the automatic polishing process, when the operator has to wait for the machine to finish the cycle.

Figure 4 – VSM of the initial situation.

Figure 5 depicts the initial layout of the sanding and polishing area and the identification of the spouts products transportation between processes.

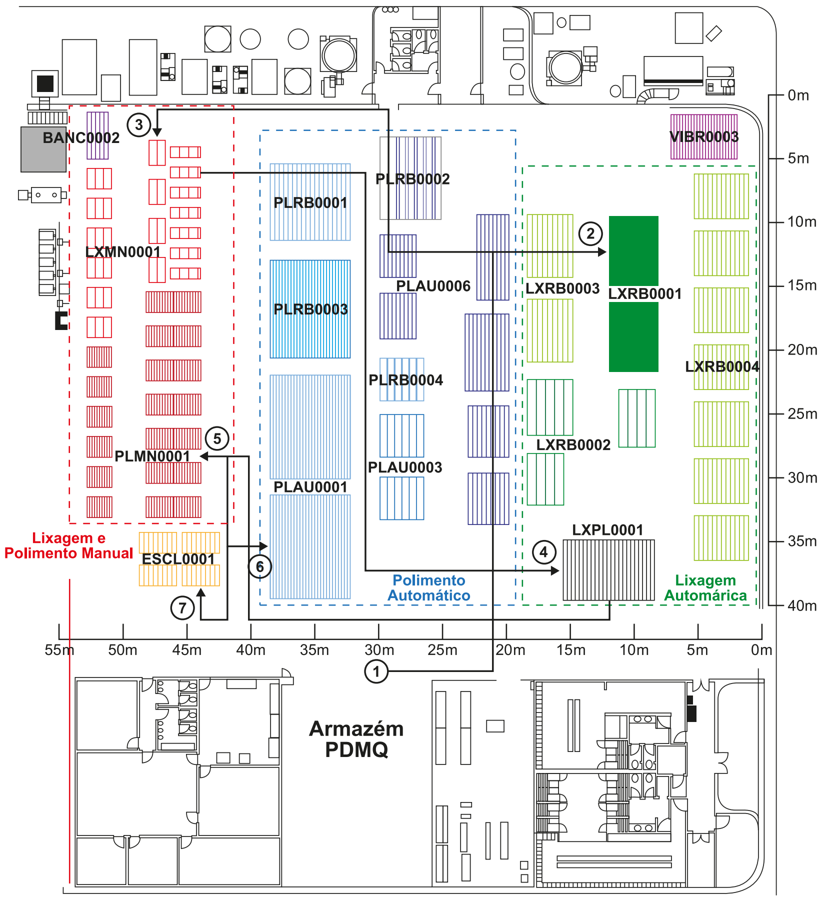

Figure 5 . Sanding and Polishing area layout and spouts transportation path.

In order to reduce lead time and several kinds of waste such as stocks, transportation, and motion, the team proposed changing the layout from a process to a cellular configuration. This change is aligned with lean philosophy principles and previous studies which state that several companies which have implemented cellular manufacturing layouts have observed improvements in handling times, setups, throughput times and work in process inventories.

Despite the advantages known in theory, in practice there is always great resistance to change. The conversion of layouts requires a huge transformation in working methods as well as a great financial investment and the time availability to make the machine movements. Due to the complexity of the system and according to [41], the team decided to perform a simulation study to analyze potential gains and justify, quantitatively, the execution of the project.

The next step was the choice of the representative family of products and references to use in the simulation study. After an exhaustive ABC analysis, the team selected the spouts family, which met both conditions: production cost and production time, 38% and 43% of the total, respectively.

Within the family of products, a new ABC analysis was performed with the objective of selecting the final references to be simulated, resulting in four references corresponding to 73% of the total production cost within the spouts family.

In developing the simulation model particular care was taken to model the system as close to reality as possible. The availability of data for the processing times of the tasks involved in the process allowed the fitting of proper statistical distributions to these data. The team members who accompanied the research on site were decisive in this process, as they combined the knowledge of the simulation tool being used with the perception gained on the sanding and polishing process.

After the simulation analysis of the current situation, the team designed and simulated a proposal for a new spouts family layout. Figure 6 depicts the new cellular layout proposal.

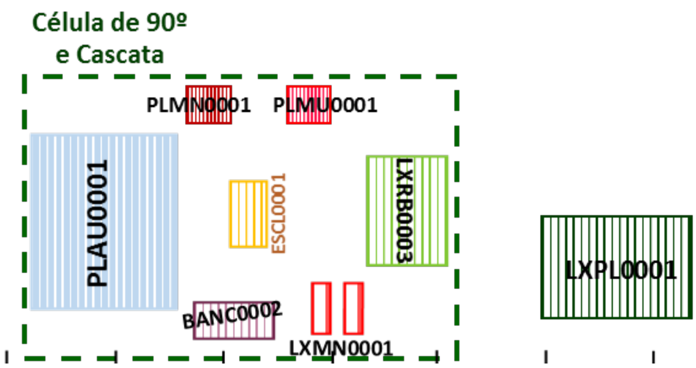

Figure 6. Cellular layout of the Sanding and Polishing area for the spouts family.

The verification and validation process is very important for using the simulation models as decision-support tools. Model verification ensures that the program of the computerized model and its implementation are correct and model validation confirms that the simulation model behaves like the real system, consistent with the modelling objectives. The models were verified and validated using different well-known techniques. The verification techniques used were: model traces, structured walkthroughs, output consistency and model animation. The validation techniques used were: predictive validation, historical data validation and Turing tests.

Both simulations were run for 10 working days, 8 hours daily. Also, in order to achieve acceptable 95% confidence intervals for the key performance indicators, a number of 15 replications was settled upon. According to the simulation study, the proposed cellular layout for the spouts family would reduce approximately 80% of the time spent on transports, 30% of the lead time and 50% of the WIP. Table 1 depicts these results.

Table 1. Simulation results for key performance indicators.

Indicator	Initial Situation	After Relayout	Differential Change
Transportation time (min)	8.3033±0.006	1.5689±0.02	Reduction of 80%
Lead Time (days)	6.38±0.06	4.51±0.11	Reduction of 30%
WIP(units)	2193.91±7.23	1077.18±13.96	Reduction of 50%

After the modification in the layout, it was possible to join different tasks which were initially physically separated, such as selecting and automatic polishing or manual and automatic sanding, meaning that the selecting part would be covered by the automatic polishing task trough the elimination of waiting time. This improvement resulted in a productivity increase of 33% in these two processes.

Regarding ergonomic conditions and given that this production section was such a critical area, the RULA scores were not a surprise, as can be seen in the Figure 7. Two of the three operations present a score of 5 which indicates that investigation and changes are required soon. Considering the workers' complaints, tendinitis problems and absenteeism rates verified in this production area, the team identified ergonomics conditions as an issue to improve urgently.

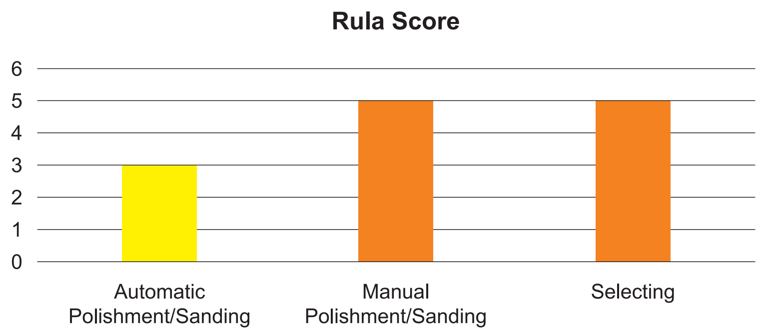

Figure 7. RULA scores for the initial situation.

The main ergonomic problems were related to awkward postures, task repetitiveness, tap weight (around 1kg) and strong hand exertions to perform manual tasks. Figure 8 depicts the awkward posture needed to perform the manual polishing task.

Figure 8. Ergonomic position of manual polishing task.

The team used anthropometric studies to adjust the workstation to the body characteristics of the operators, e.g., their stature. Therefore, in order to adjust the work plane, eliminate the necessity for the non-neutral position of workers' arms and reduce the need for neck flexion, the team proposed an automatism to adjust the machine vertically according to the operator's stature. The vertical amplitude of the machine (using the measure from the floor to the centre of the polishing/sanding wheel) was calculated based on the anthropometric database of the Portuguese population [42], its maximum limit was calculated using the floor-to-elbow measure of men's 95 percentile (1159 mm) and its minimum limit was calculated by using the floor-to-elbow measure of women's 5 percentile (914 mm).

Another solution found by the team to reduce WMSD risk was the extension of tasks, which was only possible to materialize after the layout changes through the physical proximity of the processes. With the combination of processes, by merging the process of selecting with that of automatic polishing, it was possible to reduce the repetitiveness of the selecting tasks and consequently improve the ergonomic conditions of the worker, thereby lowering WMSD risk. The same happened with the manual sanding workstation, which was merged with that of automatic sanding. Figure 9 depicts the new RULA scores after these improvements.

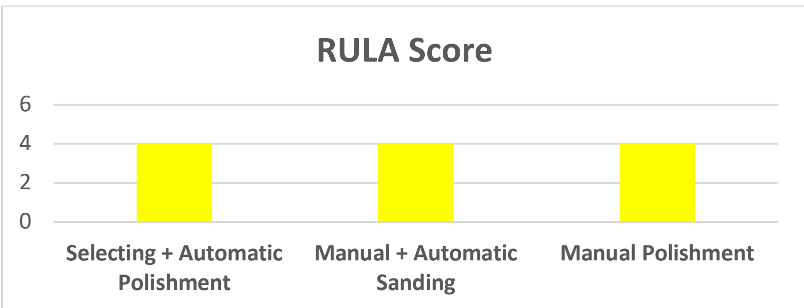

Figure 9. RULA scores after improvements.

According to the RULA method, all tasks now have a score of 4, which means that “further investigation, change may be needed”. Despite the increase in the RULA score in one workstation from 3 to 4, the final balance, in the improvement team's opinion, was very positive due to the reduction of the RULA scores of the other two workstations from 5 (“change soon”) to 4 (“change may be needed”). Furthermore, it was possible to increase productivity by eliminating the waiting time in the automatic sanding/polishing workstations after adding the selecting task.

The implementation of task rotation would not help in this case study as the muscular groups used to perform the different tasks in these processes are the same.

4. Conclusions

Due to the hard competition that companies face nowadays, it is crucial to consider productivity and performance while implementing continuous improvements in the gemba (shop floor). At the same time, jobs are more and more repetitive, leading to musculoskeletal disorders, increased absenteeism and reduced productivity.

The results of this study show that companies should consider both ergonomic aspects and production performance during improvement implementation.

It is important to highlight that the excellent results reached on the performance indicators and ergonomic conditions have much to do with a combined operations management approach linking lean manufacturing and agile concepts. The reduction in lead time by changing the layout configuration led to a more flexible production system and increased responsiveness to the client.

The elimination of several *gemba* wastes, the new cellular layout, the anthropometric studies and the expansion of tasks were the key operational improvements simulated and implemented in the sanding and polishing area. Regarding job rotation, the team found it very difficult to put it in practice. The majority of the other jobs that could be done by operators in this production area make use of the same group of muscles.

The team found some difficulties during this study, such as the resistance to change from operators and especially from the top management, which was the most complicated to overcome. In this case, the use of simulation played a very important role in the analysis and demonstration of the gains. However, it is a time-consuming tool which requires a considerable set of valid input data and lot of time and effort to develop a valid and credible model.

The future works of this study include the monitoring of absenteeism rates and follow-up on all the measured indicators to sustain these improvements and implement others, on a daily basis. Since RULA scores of 1 or 2 (acceptable posture) were not reached, there is still a lot of work to do. It is also important to change the current push system to a pull system, so as to make the system more agile.

After this work, it is the authors' opinion that resistance to change and result sustainability are the main difficulties in improvement projects.

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9

MAJOR CONTRIBUTIONS

Contents:

Presents the answers to the research questions, the major contributions and the overall discussion of the results of this thesis.

9.1 What are the consequences of a Lean transformation on worker's health?

This research question is answered in Chapter 2 by a SLR.

Lean manufacturing is getting adopted by various companies in order to improve their processes due to an increase in the competitiveness in the global market. However, the extensive use of LPS raises a question about the consequences for employees. Several studies in the literature report positive and negative effects in the workers' health during the LPS implementation.

Up to 1990, the LPS implementation was entirely tool focused and generally neglected the human aspects of the high-performance work system core of the Lean manufacturing approach (Koukoulaki, 2014). In fact, Lean production tools are often implemented in order to eliminate non-value-adding activities and reduce variability in the work process, without considering the Lean production philosophy (Shah and Ward, 2007). Therefore, the majority of studies in the 1990s report negative effects on employee health (Hasle, 2014). However, some of these results should perhaps be interpreted as consequences of a traditional Tayloristic rationalization and not as results of Lean as such (Hasle, 2014).

After 1990, there was a gradual widening of focus away from the shop floor and diverse sectors by business adapted their production systems to include a new design based on "Lean principles" (Womack and Jones, 1996). These principles involved the identification of customer value, the management of the value stream, developing the capability to flow production, the use of "pull" mechanisms to support flow of materials at constrained operations, and, finally, the pursuit of perfection through reducing to zero all forms of waste in the production system. Regarding risk factors and health effects, the research focus started to shift from mechanical exposure and health effects, for example, MSDs, to psychosocial risk factors and stress. The findings from these studies are mixed with some job characteristics negatively affected and others positively (Table 1).

Table 1. Some of Adverse and positive Effects in a LPS, reported in the literature.

Adverse Effects		Positive Effects	
Authors	**Results**	**Authors**	**Results**
Parker (2003)	Increased job depression	Finnsgard et al. (2011)	Reduced trunk flexion and shoulder elevation due to the use of smaller containers (Lean concept)
Westgaard and Winkel (2011)	Mental Problems	Jackson and Mullarkey (2000)	Work roles with greater breadth, more variation, higher skills utilization and higher cognitive demands

Landsbergis et al., (1999)	Stress, low job satisfaction, and low decision control	Westgaard and Winkel, (2011)	Job enlargement
Jackson and Mullarkey (2000)	Fewer timing controls, higher demands and more conflicts in the Lean teams	Saurin and Ferreira (2008), Hunter (2006)	Improved working conditions
Koukoulaki (2014)	Stress and increase of musculoskeletal risk symptoms	Koukoulaki (2014)	Autonomy and empowerment

According to Koukoulaki (2014) the reported negative results may reflect 'rigid' Lean implementation strategies applied in the automotive industry caused by Just-in Time (JIT) systems. It appears that these JIT practices are causing intensification of work that is linked to increased levels of strain and stress. However it is not clear whether the results are caused by Lean or by an industrial context and implementation strategy marked by management pressuring employees and poor industrial relations (Hasle, 2014). In addition, Lean implementation is not the same across different companies, sectors and continents and the outcomes can depend upon what is implemented and how (Koukoulaki, 2014).

In fact, and according to Murray et al. (2010) and Pai et al. (2009) misapplication of Lean techniques may lead to safety issues, health problems, and accidents which is in line with Arezes et al. (2014): "the reported disadvantages of LPS implementations may result from the misunderstanding of the Lean principles and possibly by implementing similar solutions that may be effective in a specific work context but not suitable to all possible situations".

The ambiguity of the impacts of LPS on working conditions was detected by Saurin and Ferreira (2008). In their opinion, such ambiguity may also be caused by a number of factors, such as: company's organizational culture, the different levels of maturity of companies' Lean systems, the socio-economic context of the region where the plant is located (e.g. unemployment rates; labor standards, the role of unions) and the level of workforce involvement in the LPS implementation process.

Regarding positive effects, Hunter (2006) reported ergonomic and productivity gains, and Saurin and Ferreira (2008) pointed out that workers had a positive perception on their working environment and that working conditions have improved since LPS was adopted. Hunter also reported a reduced repetitive motion injury risk in a cellular (Lean concept) manufacturing's job enlargement methodology. Under this scheme, workers have more tasks to carry out on each cycle around the cell, thus giving microinjuries additional time to heal (Hunter, 2002). Finnsgard et al. (2011) showed that materials exposure using smaller containers, a LPS concept, improves workstation performance in terms of less non-value adding work, reduced space requirements for materials exposure and reduced trunk flexion and shoulder elevation demands on operators.

Schouteten and Benders (2004) consider that the ambiguity of these results is due to the lack of an external assessment framework supported by validated research instruments.

9.2 How can one integrate ergonomic aspects during the implementation of Lean Production Systems (LPS) in order to bring benefits and well-being to workers and at the same time potentiate productivity?

This research question is answered based on the 4 case studies developed in the metallurgical company (Chapter 5, Chapter 6, Chapter 7, Chapter 8) and by the SLR (Chapter 2).

Systematic Literature Review Results
The major conclusions based on the SLR (Chapter 2) are described below:

In a LPS any actions such as "bending to work", "pushing hard", "lifting heavy weights", "repeating tiring actions" and "waste full walk" are considered Muri and consequently they must be eliminated. Any implementation of LPS that does not reduce Muri, or even worse, if increasing it, should not be considered as fully representing the 'true spirit' of the LPS implementation (Cirjaliu and Draghici, 2016). The majority of this actions are also non-ergonomic postures and could lead to the emergence of MSD. So, since the majority of ergonomic risks, such as manual handling, stretching, bending, awkward postures and extensive reaching can lead to Lean wastes, its reduction, which is the aim of an LPS, leads to an increase in productivity and simultaneously to an improvement of the workers' health. This kind of conclusion in line with Aqlan et al. (2013), Aqlan et al. (2014), Galante (2014) and Yusuff and Abdullah (2016): "ergonomic risks can lead to Lean wastes and vice-versa, which means ergonomics can support Lean transformation by eliminating the related wastes and Lean transformation can lead to ergonomic risk reduction".

Furthermore, Lean team must consider Ergonomics and safety, just like waste reduction and value creation, core values of the Lean process (Wilson, 2005). For example: incorporating risk assessments into the value stream mapping process (Kester, 2013), getting parts efficiently in the workstations and finding tools quickly (Webber, 2005).

The integration of Ergonomics during the Lean manufacturing implementation has the potential to obtain substantial gains in productivity, reduce the absenteeism (Santos et al., 2015) and to simultaneously improve the working conditions (Alves et al., 2016).

According to the literature, when ergonomic aspects are not considered during the implementation of a LPS both positive and negative aspects were identified. However, when ergonomic aspects are considered during LPS implementation, literature is consensual in identifying only positive aspects. Figure 1 depicts these results:

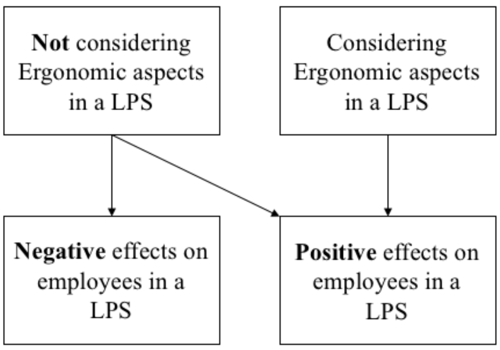

Figure 1. Health effects in a Lean Environment.

What numerous companies fail to realize is the potential for further increasing the productivity gains if ergonomic principles were integrated and implemented at the same time as Lean Systems (Nunes, 2015). Since Ergonomics is most commonly housed within the Occupational Safety and Health (OSH) department (essentially to answer legal requirements and to perform risk management), managers have a tendency to inadvertently narrow its scope of intervention to hazards, instead of taking advantage of its help to advance organizational effectiveness, business performance and costs (Nunes, 2015). According to Westgaard and Winkel (2011), integrating the requirements for effective production and a healthy workforce in the analysis and devising of production systems could be a solution to the apparent conflict of interest between Ergonomics and rationalization.

The literature has several examples of the benefits of integrating Ergonomic aspects in an LPS, such as:

- Miguez (2018) showed good results by getting together a multidisciplinary team of certified ergonomists, engineers, managers and direct employees in the use of concepts of Ergonomics and LPS to improve a workstation, such as lowered costs and lead time as well as improved health and safety of workers.
- Williams and Douglas (2011) improved efficiency by more than 40 percent by becoming more organized, improving standards, cutting down excess motion in the cells, improving Ergonomics and safety, creating common processes and reducing the number of procedures required to assemble a product.
- Scheel and Zimmermann (2005) reported significant results when integrating ergonomic principles within a Lean implementation process in a Kaizen event, such as: shortened cycle times, travel distances reduced in square footage, from 67% to 100%, and reductions in the existing ergonomic risk factors.

Figure 2 depicts important components to consider during the implementation of an LPS, considering Ergonomics.

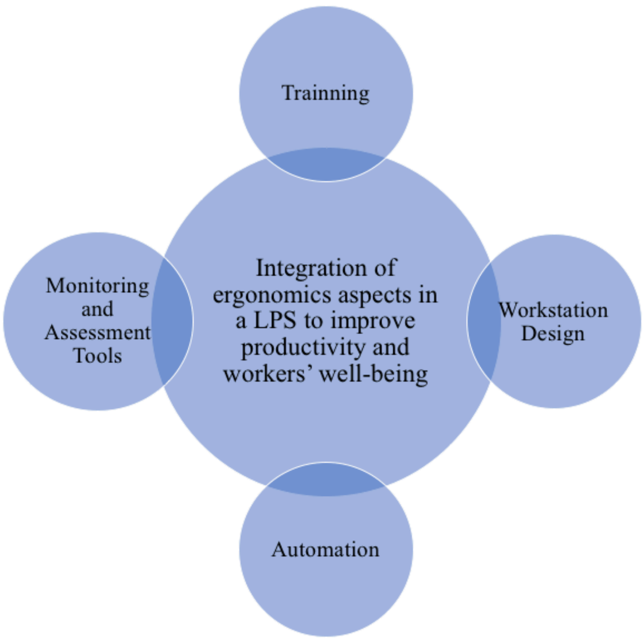

Figure 2. Components to consider during the implementation of an LPS, considering Ergonomics.

Training: According to Kester (2013), the misunderstanding of the Lean principles might be solved by training, which is a key component of any Lean process. Basic Ergonomics concepts and ergonomic design factors need to be included in the training in order for the team members to recognize risk factors and apply these ergonomic design possibilities as they develop conceptual designs (Kester, 2013).

Design: "Good ergonomic design will reduce awkward postures or excessive effort during work" (Yusuff and Abdullah 2016).
Workstation design is therefore a key process to ensure effectiveness, customization, automation and competitiveness in high volume environments, requiring less time, space, cost and inventory. With that in mind, workstations play an essential role in manufacturing processes (Gonçalves and Salotinis, 2017).

Tools: Including MSD prevention in a framework already in place in the companies, by maximizing similarities and compatibility for integration, permits the program to have increased sustainability, undergo continuous improvement and incur less costs for the organization. This can be accomplished by using common language, tools, goals, and framework (Yazdani et al., 2018). Accordingly, MSD prevention practices should be designed in a way that is completely compatible with and makes integration into other management infrastructures easier through, for instance, the use of a quantifiable, repeatable, reliable, and measurable risk assessment tool, such as RULA. This is in agreement with Perez and Nuemann (2015) and Village et al. (2014).

Automation: According to Ohno (1988) and existing studies, repeating and value-adding tasks ought to be automated. Using technology to automate hard or repetitive tasks positively has a positive effect on safety and ergonomic issues, as well as other labor challenges experienced by several organizations, e.g. an aging workforce and the related expected increase of injuries in the labor force (Botti et al. 2017).

Case Study Results

The results found in the literature regarding the integration of Ergonomics in an LPS were validated by the four case studies performed in the metallurgical company. All of them reported good results in workers' health and performance indicators when ergonomics is considered during the LPS implementation.

Table 2 depicts the major conclusions drawn from the 4 case studies.

Table 2. Major Conclusions drawn from the case studies.

Chapter	Major Conclusion
5,6,7,8	Productivity improvement by a combined operations management approach which brings together Lean manufacturing and ergonomic conditions *
5, 6,7,8	The workers' health was improved by eliminating awkward postures, such as: manual handling, stretching, bending, and extensive reaching, which were also Lean wastes *

5,8	Ergonomic conditions, including anthropometric studies, must be considered as early as possible, when (re)designing a workstation *
8	The enlargement of tasks, which is a Lean concept, could reduce MSD risk *
7,8	Changing the configuration of the layout from process to cell (Lean concept) could increase productivity, reduce the lead time and increase workers' health due to the possibility of enlarging tasks and/or rotating jobs *
8	The automatization of the manual tasks reduced waste and was one of the keys to the improvement of productivity and reduction MSD risk *
5, 6,7,8	The use of the instrument tool (ErgoSafeCI – Chapter 4) to assess the areas and priories was essential in the beginning of the study as well as afterwards, in order to sustain the results and monitor the improvement processes

* Also proved in the SLR (Chapter 2)

In what concerns the impact on performance indicators, productivity and MSD risk were the main indicators selected to do this analysis. Productivity was chosen due to the fact that nowadays a company must be efficient and productive in order to stay competitive and profitable.

The productivity indicator was calculated using the number of pieces produced per hour (throughput or production rate) because it is the measure typically used in the metallurgical company analyzed, as well as one of the most well-known measures of productivity in industry.

WMSD Risk was calculated using the most appropriate ergonomic analysis methods, which included Rapid Entire Body Assessment (RULA), Strain Index SI) and Rapid Entire Body Assessment (REBA).

Table 3 depicts the summary of the results after the intervention in the 4 case studies integrating ergonomics and lean concepts, regarding the productivity indicator and WMSD risk.

Table 3. 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" ****

* RULA method
** SI method
***REBA method
**** RULA method

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.

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10

CONLUSIONS AND FUTURE WORK

Contents:

Presents the main findings and conclusions and underlines future perspectives for research indicating possible lines of work to complement and further development of the studies undertaken during this thesis. It also presents final reflections.

10.1 CONCLUSIONS

From the results found in the literature, which were validated by the four case studies we can conclude that the integration of Ergonomics during Lean implementation has the potential to result in gains in productivity and simultaneously improve working conditions.

However, and despite the good results, many difficulties were encountered along this journey, such as:

- Difficulties in implementing ergonomic aspects because some decision-makers do not view ergonomics as an investment, but rather as an expense (Chapter 5, 6 and 7);
- Resistance to change (specially by operators and top managers) and difficulty in sustain results (Chapters 7 and 8);
- Job rotation was very difficult to put in practice because the majority of the other jobs that could be performed by operators in the studied area use the same group of muscles in effort (Chapter 7 and 8);
- Simulation played a very important role in the analysis and demonstration of the gains. On the other hand, it is a time-consuming tool requiring a considerable set of valid input data and a lot of time and effort to develop a valid and credible model (Chapter 8).

Below are some lessons learned during the development of the case studies:

- The involvement of the whole team (operators, managers, engineers…) since the beginning of the improvement process is crucial in the achievement of good results during an improvement process (Chapter 6 and 7);
- It is very important to evaluate the ergonomic conditions at the moment of purchasing a new production equipment, otherwise changes in the equipment could be very expensive, and difficult to justify (Chapter 6);
- Monitoring the new standards was essential to ensure that they are properly sustained and fulfilled (Chapter 5, 6, 7 and 8).

It must be noted that these case studies were developed in only one metallurgical factory. Thus, the sample size is too small and more studies are needed in different companies and in different types of industries.

In my opinion the initial objectives were fulfilled. Beyond the results obtained and the lessons learned from the case studies and the SLR, two important tools were developed and validated which were a great support to the implementation of future studies in different areas or sectors: the methodology flowchart and ErgoSafeCI.

10.2. AGENDA FOR FUTURE RESEARCH

Since the late eighteenth century there have been three technological developments in industry. The first industrial revolution took place in the change from manual labor to steam-powered machines, which resulted in new opportunities and facilities for industrial production. The second revolution, which happened in the mid-nineteenth century, had as its key components the use of electricity, introduction of mass production and the division of labor. The third revolution, which took place in the 70s and whose effects remain to this day, is characterized by the use of electronics and information technology for improved automation systems (Yin et al., 2018).

We are currently in the midst of the fourth technological revolution and the rise of a new technology and digital industry, known as Industry 4.0. The term 'Industry 4.0', coined in 2011 at the Hannover Fair in Germany, designates an industry whose main characteristics encompass connected machines, smart products and systems, and inter-related solutions. These aspects are used together for the creation of intelligent production units based on integrated computer and/or digital components which monitor and control the physical devices (Lasi et al. 2014).

Sanders et al. (2016) argue that Industry 4.0 together with Lean manufacturing may increase productivity, reduce waste and as a result reduce costs. Rüttimann and Stöckli (2016) predict that Industry 4.0 will materialize in pieces that need to be integrated into existing Lean frameworks and will ultimately increase the flexibility of Lean manufacturing. Thus, the introduction of Industry 4.0 does not remove Lean manufacturing but instead helps to increase the maturity of the firm's Lean program. Khanchanapong et al. (2014) likewise suggest that advanced manufacturing technologies (AMTs) might need to be supported by Lean practices to maximize the manufacturing performance increase.

With the appearance of computer integrated manufacturing, there was speculation that factories of the future would operate autonomously without the need for human operators. Although such a statement proved to be infeasible in a practical scenario, it originated the concept of Lean automation, in which robotic and automation technologies are employed to achieve Lean manufacturing (Sanders et al., 2016). According to Vysocky and Novak (2016) robots are used in the sense of robotic assistants to increase the quality of work of the human worker.

There is no doubt that throughout the years the way of focusing on Ergonomics has changed. Electronic tools are a new way forwards in Ergonomics (Gasová et al., 2017).

Since Industry 4.0 is still a very recent field of research, many gaps in the literature were found regarding the relation between Lean manufacturing, Ergonomics and Industry 4.0. Several authors proposed future investigation to clarify some of these gaps:

- In the opinion of Kolberg et al. (2017), LPS is not suitable to fulfil future market requirements. Other authors do not agree, so the question is who is right.
- Companies that have already implemented Lean manufacturing need guidelines on how to integrate the new technologies from Industry 4.0 into their existing Lean manufacturing systems (Buer et al., 2018).
- According to Sanders et al. (2016) the integration of both Lean manufacturing and Industry 4.0 is an important research field which needs to be extensively explored. It is unclear which Lean practices could be combined in Industry 4.0, which ones complement each other, and which contradict each other.

- Further research is needed to understand the full socio-technical impact of Industry 4.0 on how people can work efficiently in a digital environment (Davies et al., 2017).
- Detailed case studies are necessary to explain how to create, manage, operate, and maintain production systems in the context of Industry 4.0 (Buer et al., 2018).
- The VSM should combined itself with simulation and the use of real-time data and universal interfaces. The value stream is therefore no longer a focal point only in project-related practices, but much more in the center of day-to-day business processes (Andreas et al., 2018).

Beyond the Industry 4.0 field, other gaps regarding the integration of Ergonomic aspects in an LPS were found in the literature, as well as investigation proposals, such as:

- Koukoulaki (2014) questions if there are characteristics in Lean production that mean it cannot lead to the good quality jobs that are fundamental tenets in sociotechnical systems theory.
- Hasle (2014) reports that there is a need for further case studies, in which researchers join forces with practitioners in the workplace to introduce LPS in a form that is expected to bring about a favorable employee outcome.
- Future studies are needed to document the best practices in the integration of MSD prevention into the organizational framework, including the management system. Furthermore, the economic evaluation of such practices will be required to document the cost-effectiveness of these kinds of approaches (Botti et al., 2017).
- It would be interesting to verify the influence of the evolution of LPS and socio-technical and ergonomics practices on an organization’s performance indicators (Tortorella et al., 2017).
- It is important to develop a method to assess the LPS impacts on the working conditions of white-collar employees (Saurin and Ferreira, 2009).
- Schouteten and Benders (2004) consider that the ambiguity of the results about the health effects in an LPS has to do with the absence of an external assessment framework supported by validated research instruments.
- Psychosocial factors should also be included in the assessment management tools (Herrera and Huatuco, 2011).
- Overall, there are significant knowledge gaps in what concerns the impact of LPS on workload and labor conditions in manufacturing (Santos and Nunes, 2016).

The aim of this thesis was to clarify some of these questions, using several case studies. Nevertheless, this is a never-ending research area. So, in order to clarify several investigation questions which were brought to light during this thesis and reduce the existent gaps in the literature found during this SLR, I propose to continue to do research in this area, focusing on finding further supporting evidence and scientific clarification, in the following way:

- Following all the indicators measured in these four case studies to sustain these improvements and conduct more case studies in other companies to validate the results and the tool developed during this thesis.
- Development of tools which integrate Ergonomic aspects in existent managerial tools, to assess the LPS impacts on the working conditions of white-collar employees and define a unique, standard assessment tool validated in all areas (health care, construction, manufacturing, maintenance, etc.). This tool should include psychosocial factors and should also act as a guide in the implementation of Lean while considering ergonomic aspects.
- Clarification of how to integrate the new technologies from Industry 4.0 into LPS.
- Transformation of traditional Lean manual tools, such as VSM and Ergonomics manual

assessment tools such as RULA, into digital tools, so as to not be left behind in the fourth revolution.

- Clarification of the full socio-technical impact of Industry 4.0 on how people can work successfully in a digital environment;

During the SLR it was detected that only a few studies in Ergonomics and Lean found in the electronic databases were developed in areas other than manufacturing. Based on that, more steps could be taken in that direction, e.g., conducting a research of several case studies in different areas, such as health care, office, maintenance, construction, etc. .

According to Kolberg et al. (2017), Lean Production was created in the 1950s and therefore does not take into account the potential of innovative ICT and digital communication. In standard Lean Production, changes in production processes, buffer stocks or cycle times require laborious modifications. Thus, the suitability of Lean Production for limited product life cycles and highly customized products is inadequate because it is not changeable enough for the mass production of highly customized products. Not only that, it does not use the potential of modern information and communication technology (ICT).

Taking this into consideration, I wonder what the future of Lean will be, if it will be replaced by another concept or philosophy and what this will mean for the well-being of workers.

10.3. FINAL REFLECTIONS

Doing a PhD became a walk with ups and downs. At the beginning I was assaulted with negative thoughts, such as: “Will I be capable of doing a PhD?” or “Will I be able to deal with the demands a family life with two young children and a full time job and still have time to do a PhD without neglecting everything else?

Almost everyone around me called me crazy, except the important people, and that’s what eventually gave me the strength I needed to go on with this walk which, despite the difficulties, turns out to be one of the best decisions I have ever made. This journey just changed my life. I’ve gained more confidence in myself, my professional career has followed a completely different path, something I wish I had done before but didn’t have the courage to do, I feel now more fulfilled, and most important of all… I give my children the best example: everything is really possible.

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