A continuous improvement assessment tool, considering lean, safety and ergonomics

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Abstract

Purpose – The purpose of this paper is to present an 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, as well as safety and ergonomics aspects, were exhaustively researched 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/implications – It would be important to validate it in different companies and different types of industries because each one has its own characteristics.

Practical implications – This tool helps 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 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

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technological changes, the advances in manufacturing technology and more demanding and well-informed customers are forcing manufacturing organizations to optimize their manufacturing processes, operations, and supply chains to be able to deliver value to customers (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 in sustaining 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 a factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires far less than half the needed inventory on site, results in significantly fewer defects and produces a greater and ever-growing variety of products.

Bayou and Korvin (2008) improved this definition by stating that manufacturing leanness is a strategy to incur less input to better achieve the organization's goals through producing better output. "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 of waste includes work in progress (WIP), defects and non-value-added time, such as the time the worker spends waiting for products and executing unnecessary movements. Cost reduction strategies are directed toward specific efforts which reduce the resources spent on poor quality products, reducing the WIP value and decreasing transportation costs. Lean thinking also aims towards 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 using detailed action plans for improvement based on the five steps: specifying value from the perspective of the end customer; identifying the value stream for each product and every action required in the design, order, and provision; making those actions that actually create value occur in a continuous flow; making products flow only at the pull of the customer; and continually reevaluating every value stream to strive for excellence (Shetty *et al.*, 2010).

Some companies focus on the continuous improvement process through the use of lean manufacturing, which refers to the creation of a 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 Ramírez-Cárdenas, 2014). Guaranteeing safe working conditions is a crucial factor for the empowerment of workers. Even though this factor is stated in the description of sustainable industry, not many companies actually contemplate or develop this strategy within their sustainability plans (Alayón *et al.*, 2017). Owing to economic, environmental and social difficulties, from global warming to waste disposal at a local level, there is also a significant need to improve manufacturing performance in order for there to be less industrial pollution, less material and energy use, less wastage, and fewer psychological disorders in human resources (Kumar, 2014).

According to Yusuff and Abdullah (2016), ergonomic intervention can be used as a tool in reducing wasteful motion, through identifying ergonomic risk factors while doing work.

“Waste” motions in ergonomics, such as stretching, bending, awkward postures and extreme reaches may not only have a negative impact on the safety and health of workers, but also lower productivity and efficiency. (Yusuff and Abdullah (2016). Galante (2014) stated that lean ergonomics had the potential to 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 ergonomics strategies can increase productivity, reduce work injuries and improve workstation design and layout. Workplace ergonomics and lean manufacturing are highly inter-related. Ergonomic risks may lead to lean wastes and vice versa. Ergonomics can support a lean transformation and a lean transformation can lead to the reduction of ergonomic risk. In fact, one of the fields of ergonomics application is the prevention of occupational risks in the workplace, preventing the appearance of musculoskeletal disorders (MSDs) (Naranjo-Flores and Ramírez-Cárdenas, 2014).

Totorella *et al.* (2017) stated that the 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 (Totorella *et al.*, 2017). From a worker’s perspective, the consideration of ergonomic issues related to workstation design, such as access to materials, equipment and tools and communication between workers, is imperative for operator safety while working in the cell (Fiore, 2016).

According to Botti *et al.* (2017), future studies are needed to document the best practices in the integration of MSD prevention into the organizational framework, including the management system. Furthermore, an economic evaluation of such practices will be required to document the cost-effectiveness of these kinds of approaches.

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: they must know “where to start” and “how to proceed”, in addition to being aware of the available tools. For this purpose, lean training, value stream mapping and lean assessment are three major activities to consider upon the implementation of a lean implementation cycle (Wan and Chen, 2009).

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

According to Wan and Chen (2008), in comparison with the efforts made to address “how to become leaner”, less attention has been given to the question of how lean the system is.

Among the huge set of lean tools, most of them were created to solve specific problems, such as high work-in-process levels, low availability of equipment or long setup times. Only a few of them (e.g. value stream mapping and lean assessment tools) support lean practitioners in identifying 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 experience of lean implementation, even though 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 on the comprehensive implementation of lean manufacturing practices.

According to Bhasin (2011):

> 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.

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. Workstations therefore play a critical role in manufacturing processes. Lean workstations should be designed from the operators' perspective, with a focus on minimizing waste and concentrating those operators on critical issues.

In the current paper, the key aspects needed to have a safe, ergonomic and lean workstation are considered and a tool to objectively measure and evaluate them is proposed. This assessment tool (ErgoSafeCI) aims to improve ergonomics and safety conditions while keeping productive performance indicators are in focus as well. It is based on the insight that when we combine lean with worker well-being in a workstation improvement project, productivity increases and 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, as well as safety and ergonomics aspects, considered to be essential in lean manufacturing, with the ultimate goal of finding a way to improve the workplace while taking into account the efficiency and well-being of workers. The first step was the development of preliminary items, in a checklist format which consisted of 73 evaluation questions divided into 9 sections: efficiency, continuous improvement, safety standards, visual management, process and operations, material flow, zero defects, ergonomics and discipline. These nine requirements were identified as ways to have a productive, safe, ergonomic and lean workstation. An evaluation model and a tool to assess each requirement was developed because of the difficulty in finding other assessment tools.

The answers to these questions resulted 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 company and based on the results obtained, improvements were introduced to improve productivity and worker 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 measures, companies have difficulty in identifying their most critical areas and prioritizing them before improvement interventions. In fact, it is not easy to set future goals if we do not have the proper tools to measure the present. This paper is innovative because it provides an assessment instrument to evaluate organizations' workstations/production areas simultaneously in these three dimensions: lean, safety and ergonomics.

This study is organized as follows: Section 2 covers the review of existing research articles related to assessment audits based on lean tools and the integration of human factors in lean assessment audits; Section 3 describes the methodology used in this study and the assessment tool proposed; Section 4 covers the case study method and the results of the study are presented in Section 5; and Section 6 highlights the conclusions of this investigation.

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

According to Birkie *et al.* (2017), a coherent approach in the pre-, during- and post-implementation phases of the lean change process is required to foster performance sustenance. Shruti and Ravi (2017) identified major discrepancies such as the laxity of researcher toward using existing frameworks, the lack of participation of practitioners and consultants in the development of lean frameworks, and the fact that elements/constructs used in structuring the frameworks are highly incoherent.

2.1 Assessment audits based on lean tools

As lean thinking implementations started expanding, the impetus for 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 and quick changeover) focus on "how to become leaner" instead of "how lean it is." According to Wan and Chen (2008), 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 the 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, the lean processing program (LEAP), in the UK. However, the toolset has not drawn major attention because of the complexity of the approach. On the other hand, the value stream mapping technique developed by Rother and Shook (1998) has become one of the most commonly used lean tools. Current and future state maps visually display the flow of value streams together with time-based performance, resulting in a sense of urgency and indicating improvement opportunities.

Karlsson and Ahlstrom (1996) developed a lean assessment tool in which they identified nine variables to be evaluated, namely: 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). Soriano-Meier and Forrester (2002) evaluated the degree of leanness of manufacturing firms using these nine variables.

Various others lean assessment surveys, such as Feld (2000), Conner (2001) and Jordan *et al.* (2001) have been proposed to guide users through the lean implementation. The scores in 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) developed a checklist of 36 lean indicators in six groups to assess changes towards lean and Detty and Yingling (2000) used simulation models with several performance metrics to quantify the potential benefits of lean implementation. Allen *et al.* (2001) categorized the metrics (performance measures for tracking effectiveness of improvements efforts) into productivity, quality, cost and safety.

The Lean Enterprise Self-Assessment Tool (LESAT, 2012) is a questionnaire developed by a team of industry, government and academy 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 while 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 – the "Rapid Plant Assessment". This information should then influence decisions related to benchmarking, continuous improvement, competitor analysis and acquisitions.

Pavnaskar *et al.* (2003) organized 101 lean tools and metrics to match manufacturing wastes with appropriate tools. However, this matrix provided only the problem-tool connection without a measure of leanness.

Arcidiacono *et al.* (2015) developed the AMSE (assessment, monitoring, sustainability, expansion) Model, which is an approach to implement an effective lean Six Sigma on a permanent basis.

Srinivasaraghavan and Allada (2006) proposed an alternative system which evaluated the distance between the current state of the system and the benchmarking performance. That means that the outcome depended heavily on the quality of the benchmark. The model delivered a quantitative measure of leanness, but the exemplar performance benchmark needed to be gathered from peers and competitors.

Bayou and Korvin (2008) used a fuzzy-logic methodology to measure and compared the production leanness of the Ford Motor Company and General Motors. They selected the 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 had 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 provided an effective way to guide the lean implementation process. Using a 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 was meant 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. In accordance, they introduced a framework for assessing the use of lean production practices in manufacturing cells.

An extensive audit, put in place in 20 manufacturing organizations in the UK, was developed by Bhasin (2011) to be able to establish the juncture of an 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 the designed framework according to a 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, as well as guidelines for each criterion. Validation was conducted in different organizations in the automotive industry.

Frazzon *et al.* (2017) developed a framework to define the threshold values of production variability to support the decision-making process regarding finished-goods lean strategy.

2.2 Integration of human factors in lean assessment audits

Lean is a style of management based on the human factor which recommends that staff work with a mindset directed towards reducing losses and waste (Tajri and Cherkaoui, 2015).

Companies fail to realize the potential for further improving productivity gains if ergonomic principles are 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.

Totorella *et al.* (2017) stated that the 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 work environment to people.

In an LPS, 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).

Santos *et al.* (2015) reported that the integration of ergonomics during the LPS implementation has the potential to reduce absenteeism and lead to 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 the reduction of ergonomic risk (Aqlan *et al.*, 2013). So, the lean team must consider ergonomics and safety, similar to waste reduction and value creation, as core values of the lean process (Wilson, 2005), for example, incorporating risk assessments into the value stream mapping process (Kester, 2013) and integrating ergonomics principles within a lean implementation process in a Kaizen event (Scheel and Zimmermann, 2005).

According to Yazdani *et al.* (2018), organizations ought to present ergonomics and MSD prevention as significant components of their business via their inclusion in management practices.

In the field of lean Assessment Tools, Wong *et al.* (2014) developed a lean index to assess the leanness level of an organization in sustaining lean transformation based on a socio-technical perspective which considered the interdynamics of humans, systems and technology.

Jarebrant *et al.* (2016) proposed the application of the ergonomic value stream mapping, a tool that aims to improve ergonomic conditions without neglecting productive performance indicators. This work aims to provide academics and practitioners with a tool capable of satisfying current needs in manufacturing environments regarding cognitive ergonomics assurance in workplaces. The implementation of ErgoVSM in its cognitive modality is an effort to acknowledge the significance of assessing health risks within each workstation at companies.

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

Seven workstation design considerations – “health and safety,” “work environment, cleanliness and orderliness,” “waste elimination,” “inventory and material logistics,” "flexibility," "visual management" and "quality" – were identified by Gonçalves and Salonitis (2017). These authors developed an evaluation model and a tool to assess each requirement based on lean and ergonomic aspects which was specific for workstation design. This model has the form of a checklist, which 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, were 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 and continuous improvement.

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

A parallel path investigated 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 while considering ergonomic risk assessment and following the principles of lean production.

All of these tools, as well as safety and ergonomics checklists/assessment tools, such as "Ergonomic Workplace Analysis" (Ahonen *et al.*, 1989), Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000), Strain Index (SI) (Moore and Garg, 1995) and Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993) were analyzed in detail and served as input in the construction of the audit tool proposed in this article. Lean concepts, such as 5S, Poka-Yoke, VSM (value stream mapping), Kaizen meetings, Andon, Kanban and TPM (total production maintenance) were also considered during the development of this tool.

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

3. Methodology

The methodology used in this work was exploratory and descriptive to develop the ErgoSafeCI tool; a case study was then used to validate it. 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:

(1) Step 1 – definition of the key requirements in terms of lean, safety and ergonomics with the goal of finding a way to improve the workplace while considering the efficiency and well-being of workers;

(2) Step 2 – development of a checklist to assess each requirement and present the results in a visual, simple and comprehensive way; and
(3) Step 3 – validation of the ErgoSafeCI 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 time constrains of those who will have to use it. The assessment instrument has the format of a checklist with 72 evaluation questions divided into 9 sections: efficiency, continuous improvement, safety, standards, visual management, process and operations, material flow, zero defects, ergonomics and discipline. These questions should be answered in these forms: 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. They (assessment team) should be trained in lean Manufacturing and have the necessary knowledge of the topics used in the checklist, some of them are described in Table I.

Topic	Description
Cellular layout	The arrangement of machines in small cells mostly in U or O shape (Pavnaskar *et al.*, 2003)
VSM	VSM is a graphical tool used to map the as-is situation of the organization, to identify opportunities for waste elimination, and to decide the improvements to be implemented to eliminate the waste (Pavnaskar *et al.*, 2003)
SMED	Single minute exchange of dies assures a quick and efficient change from currently running product to the next one (Karam *et al.*, 2018)
SETUP	The changeover time is the amount of time spent between the last good piece of one product until the first good piece of the next product (Karam *et al.*, 2018)
TPM	The TPM includes practices primarily designed to maximize equipment effectiveness through planned predictive and preventive maintenance of the equipment and using maintenance optimization techniques (Shah and Ward, 2003)
Kanban	In the Kanban System, a form of order card called Kanban is used. Production Kanban is used to order production of the portion withdrawn by the subsequent process (Sugimori *et al.*, 1977)
5S	The 5S practice is a technique used to establish and maintain a quality environment in an organization. The name stands for five Japanese words: *Seiri, Seiton, Seiso, Seiketsu and Shitsuke* (Ho and Cicmil, 1996)
Heijunka	*Heijunka* is a Toyota production method based on mixed-model production and the leveling of production rates in each process through the avoidance of self-imposed large lot production (Jay and Reza, 1994)
Andon	Andon is a manufacturing term referring to a system to notify management, maintenance, and other workers of a quality or process problem (Da Silva and Baranauskas, 2000)
Polyvalence Matrix	Visual tool for versatility management which makes it possible to determine the qualification of each operator for each operation or process (Bau *et al.*, 2012)
Gemba	Japanese term for "actual place." It is used to stress the fact that continuous improvement requires direct observation of current conditions where assembly work is done (Weber, 2018)

Table I. Description of the topics used in the ErgoSafeCI tool

Below are the checklist questions:

- *Performance indicators*: The performance measurement is essential in the management process. Numerous studies have shown that, to adopt the best decisions for the development of the organization, managers must have accurate and current data on the performance of processes taking place within the company (Borsos *et al.*, 2016) (Table II).
- *Continuous improvement (CI)*: CI is one of the core strategies for manufacturing excellence and it is considered vital in today's business environment. A well-known concept related to CI is Kaizen, which originated in Japan and means continuous change for the better through the engagement of all employees (Ahmad *et al.*, 2013) (Table III).
- *Safety*: The tools of risk identification must be useful for the analysis of work contexts in its various aspects.

#	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 past six months?			
5	Are there any workers with occupational diseases associated with tasks performed at the workstations/production area under analysis?			

Notes: * Not applicable; **numbers according to the company's objectives

Table II. Evaluation questions on performance indicators

#	2 – continuous improvement	Yes	No	NA*
6	Have all the performance indicators plus lead time been improving since the past month?			
7	Are the standards revised and improved monthly?			
8	Is there a current and future 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 past six** months?			
10	Does the worker, or team, have lean knowledge (does he/she recognize, at least, the difference between value task and no value task and is he/she able to identify the 5S)?			
11	Do all workers feel responsible for continuous improvement, actively and participate frequently (more than once every six** months) in giving ideas for it?			
12	Is there a specific time, on a daily basis, dedicated to continuous improvement (e.g. 10 min Kaizen meetings) and does this time involve all workers?			

Notes: * Not applicable; **numbers according to the company's objectives

Table III. Evaluation questions on continuous improvement

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

- *Standards and visual management*. The visual management system is a key theme in a lean operation and essential to ensure standardization (Gonçalves and Salonitis, 2017).

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

- *Work organization*: Process improvements, layout arrangement and work organization were considered as the main dimensions to encourage the implementation of lean production practices (Yusup *et al.*, 2016) (Table VI).
- *Product and material flow*: This 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 quickly responding to customers' demands (Liua *et al.*, 2017) (Table VII).
- *Quality/zero defects*: The major principles of the lean process improvement methodology include the concepts of value, value streams, flow, pull and perfection. One of the basic lean tools is the concept of zero defects and mistake proofing (Glenn and Blackmore, 2013) (Table VIII).

#	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 (is it properly placed, is it stable, does the operator's eye 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/is it 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 (e.g. work tool slippery or difficult to grasp, etc.)?			

Note: * Not applicable

Table IV. Evaluation questions on safety

#	4 – standards and visual management	Yes	No	NA*
22	Are all standards documents required in the production area in place (work instructions, cleaning plan, maintenance plan, 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? Etc.)?			
29	Is all the information about the daily production targets (quantities to be produced, quantities already produced, stoppages, team performance, etc) visible (e.g. 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?			

Note: *Not applicable

Table V. Evaluation questions on standards and visual management

#	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 (e.g. supplying the line, setups, overprocessing)?			
38	Do the setup times exceed 10** min or are there internal tasks (e.g. 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)?			

Notes: *Not applicable; ** numbers according to the company's objectives

Table VI. Evaluation questions on work organization

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 MSDs lead to significant losses of productivity because of higher absenteeism and injury rates (Cheshmehgaz *et al.*, 2012). Ergonomics comprises three main areas: physical (posture, load handling, repetitive movements, MSDs, workstation design, safety and health); cognitive (mental workload, decision-making, human computer interaction, stress, and training); and

#	6 – product and material flow	Yes	No	NA*
40	Is the layout organized in a way which makes it possible to have product and materials flow (e.g. 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?			
44	Does the plant or production line produce only what the next process needs and when it needs it (Is information given through Kanban cards)?			
45	Is only one piece at a time produced and sent to the next process (one-piece flow)?			
46	Are supermarkets used where continuous flow is not possible (e.g. high setups, distant processes)?			
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 (e.g. through Kanban, timetable, route)?			

Notes: *Not applicable; ** numbers according to the company's objectives

Table VII. Evaluation questions on product and material flow

#	7 – quality	Yes	No	NA*
50	Is it the worker the person in charge of performing 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 (e.g. 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?			

Note: *Not applicable

Table VIII. Evaluation questions on quality/zero defects

organizational (communications, design and programming work, cooperative work, organizational culture, quality management) (IEA [International Ergonomics Association], 2000) (Table IX).

- Discipline: sustaining improvements. The aim of this section is to measure if the implemented standards are being respected. It is sometimes easy to implement new procedures but it then proves hard to sustain them (Table X).

#	8 – physical ergonomics	Yes	No	NA*
58	Does the layout allow for social contacts?			
59	Does the worker adopt a static posture most of the time?			
60	Does the worker have enough space (Analyze whether the worker has any 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 full 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 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, raised and/or abducted shoulder, elbow away from the body, twisting and/or flexion of the torso 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?			

Note: * Not applicable

Table IX.
Evaluation questions on ergonomic aspects

#	9 – discipline	Yes	No	NA
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			

Table X.
Evaluation questions on discipline

After the evaluation of each item, the score of the workstation/production area assessed was given in the form of a percentage, which represented the level of lean implementation considering safety and ergonomic aspects. The final percentage was calculated from the average of the percentages of each item, according to the answers given: 100 per cent if it was OK, 0 per cent if it was NOK. In case of a not applicable question, this question was ignored for the calculation.

The ErgoSafeCI tool was then validated in a metallurgical industry that produces bath and kitchen taps, door handles, locks, access controls and other bath accessories. This metallurgical company has 12 production areas which deal with different difficulties and needs. These areas were in different stages regarding ergonomic conditions and performance indicators. Therefore, it was necessary to apply this tool to help the team prioritize the most critical areas in what concerns lean, safety and ergonomics.

4. Case study method

The assessment instrument proposed in this paper was validated through the application of a case study. The approval of the tool underwent several interactions, according to this type of methodology (Figure 1).

After several iterations, the team responsible for the tool development, composed by continuous improvement management, industrial engineers, production management and safety engineers defined a flowchart to implement which was then validated it in the production.

The first step was the choice of the system to be assessed and then the election of the team members. The choice of the system was based on strategic goals previously defined by the management team and/or based on workers' complaints to supervisors. This type of complaint was not formalized but most of the time resulted in absenteeism on the part of the worker. The assessment team was composed of production operators, a quality engineer, a production supervisor, an industrial/process engineer, a safety engineer and continuous improvement management members. In some cases, others were required to join the team, for instance members of the maintenance and development department.

The next step was to train the team members in the ErgoSafeCI tool and then the system was assessed. The last step was the analysis of the results, followed by the action plan opening/monitoring.

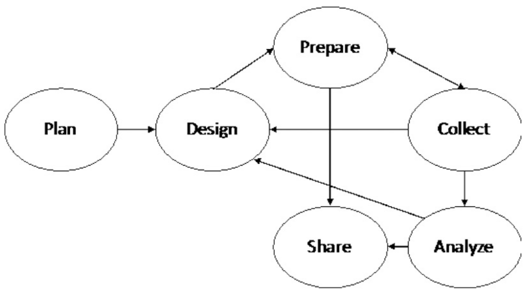
The continuous improvement management members were responsible for following up on the action plan and setting a date to re-evaluate the system. It may be in the interest of the company to pass this responsibility to the owner of the process under assessment.

These steps are described in Figure 2.

Using this tool, four production areas of the metallurgical company were identified as the most critical; afterwards, several studies were conducted in these areas. The main objective of this tool is to contribute to the continuous improvement, so it is a never-ending process, which means that it should be used periodically. Typically, the evaluation to a production system takes 1.5-3 h, depending of the complexity of the area under assessment.

5. Case study results

Assessments in all workstations and production areas of the company were performed using the proposed tool, such as the tuning production area, sanding and polishing workstations, physical vapor deposition (PVD) coating, packaging and assembling production areas. Table X shows some of the results of these assessments. The calculation of the percentages is explained in the final of the Section 3 Table XI.



Source: Yin (2003)

Figure 1.
Iterative process of a case study research

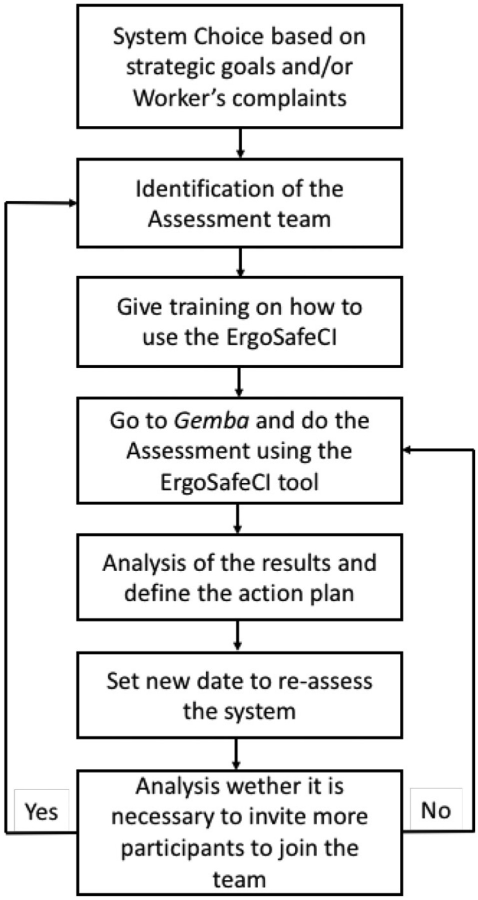


Figure 2.
Case Study steps

Table XI.
Assessment scores

Production area/workstation	Assessment score (%)
PVD coating	26
Packaging	22
Polishing/sanding	21
Tuning	26

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

The members of the assessment team were then invited to analyze the process of these critical production areas in detail and suggest some modifications to improve ergonomics and safety conditions and, at the same time, improve performance indicators using lean principles, such as reducing wastes.

The main problems found in each workstation were:

- *PVD*: ergonomic problems due to awkward postures when performing the tasks, such as an arm flexion higher than 45°;
- *Packaging*: high lead times, transports and WIP. Forceful hand exertions when performing manual tasks, such as the twisting hand/wrist postures needed to perform the selection and dimensional control tasks;
- *Polishing/sanding*: high lead times, transports and WIP due to the layout configuration and awkward postures due to the height of the work plane; and
- *Tuning*: high setup time (around 105 min), and ergonomic problems due to awkward postures and forceful hand exertions to perform manual tasks.

As an example, below are the detailed results of one of the production areas evaluated using the assessment tool proposed in this article, namely the sanding and polishing area. It was one of the worst production areas, with an assessment score of 23 per cent, far below the target set by the company, which was 51 per cent.

Figure 3 shows the assessment results of the sanding and polishing production area.

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

To improve the company's performance, urgent improvements in the identified sections were necessary. The next step was a detailed evaluation of the initial situation; 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, also identified by the team, were handling movements, operator motions and transports of materials between processes. As a result, lead times were considerably high.

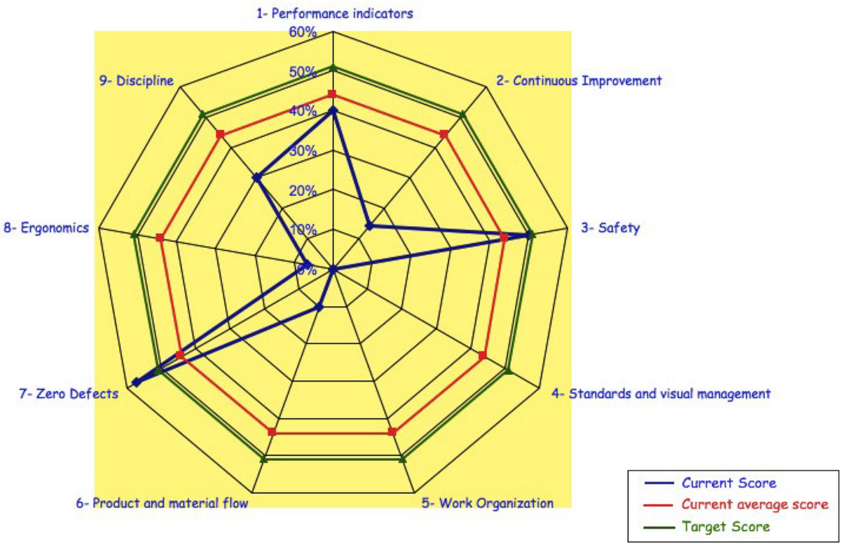


Figure 3.
Results of the assessment tool application in the case study – before intervention

To reduce these kinds of wastes, the team proposed a change to the layout from a process to a cellular configuration. This change was aligned with lean philosophy principles and previous studies which stated that several companies which have implemented cellular manufacturing claimed that the new system resulted in reduced handling time, setups, throughput times and work in process inventories. At the end of the layout change, 5S were implemented to improve visual management and reduce operation motions by bringing the materials closer to the operator.

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

The elimination of several *gemba* wastes, such as waiting time, transports and WIP, the new cellular layout, anthropometric studies and enlargement of tasks were the key operational improvements simulated and implemented in the sanding and polishing area. After this improvement intervention, a new assessment was performed whose results are shown in Figure 4.

In spite of the good results, they did not prove 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 per cent after the improvement intervention as a result of the re-layout and the elimination of waiting time and time spent in material transports. The tool helped in the identification of critical areas, which had a lower score on the ErgoSafeCI tool, and an improvement on these sections resulted in a very significant improvement in productivity.

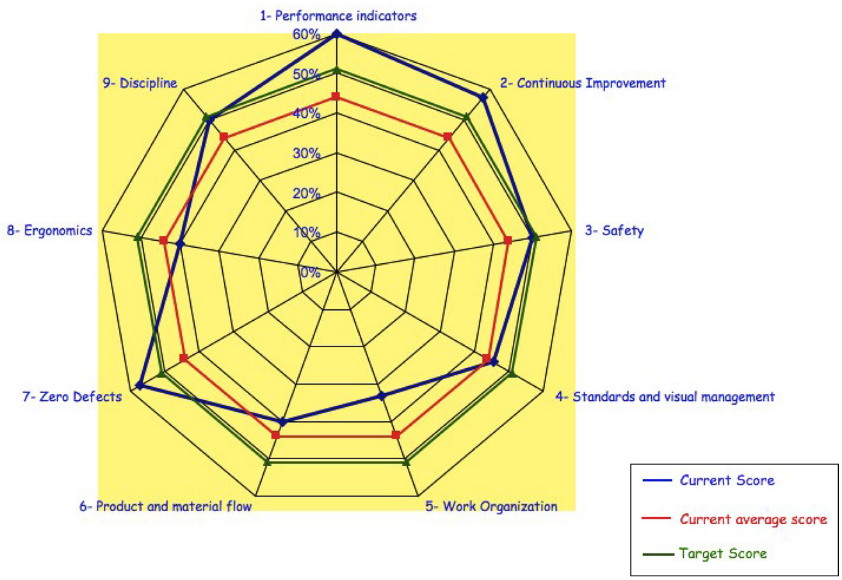


Figure 4.
Results of the assessment tool application in the case study – after intervention

6. Conclusions

To be up-to-date on lean thinking implementation progress, a repetitive evaluation of leanness by frequent assessments becomes a necessity, as it helps in assessing the contribution of the 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 to 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 MSDs and psychological load, and lead to company losses. The use of decision support tools, such as ergonomic risk assessment methods and computer-based simulation, represent a major contribution to the design of lean manufacturing systems, allowing for the application and integration of ergonomics and safety design principles (Nunes and Machado, 2007).

More than 20 researchers have attempted to develop various methods and procedures to quantify leanness. Many quantitative and qualitative studies have been conducted, and a plethora of assessment techniques have been proposed (Narayanamurthy and Gurumurthy, 2015).

Audits have also helped manufacturers sustain lean, and in addition 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. When done well, audits are the ultimate measuring stick. When done poorly, they are next to useless. Often, the tools require in-depth knowledge of the organization and significant resource commitment, including the use of external experts, to be used effectively (Bhasin, 2011).

Not having found a tool which would allow for a detailed and exhaustive analysis of a workstation or production area, linking the three key dimensions of lean, safety and ergonomics, the authors developed the assessment tool proposed in this paper. This instrument allows managers to evaluate their business and identify the priority areas to improve according to previously defined company goals.

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 was too small. It would be important to validate it in different companies and different types of industries, as each has its own characteristics.

The study reveals that high scores are derived from a good interaction between lean, ergonomics and safety. To the authors' 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 ergonomics.

As future work, it would be interesting to include in this tool the service and administrative areas.

According to Shruti *et al.* (2017), there is still a lack of standard in the Leanlean Six Sigma implementation framework. In the authors' opinion it would also be interesting to include Six Sigma approach in this assessment tool.

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