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Review

Applications and future perspectives of integrating Lean Six Sigma and Ergonomics

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ABSTRACT

Organisations seek to adopt strategies to increase their productivity and quality in highly competitive markets. For this purpose, Lean Six Sigma (LSS) is often used. It is frequently combined with other scientific areas such as Ergonomics. Integrating LSS and Ergonomics may improve productivity while preserving workers' health and safety. This study presents a systematic literature review to clarify the impacts of integrating LSS and Ergonomics on organisations. Also, it seeks to assess the main limitations while answering the defined research questions. The research was conducted in Scopus and Web of Science. From the 74 results, 16 articles were included based on the eligibility criteria. The results show that few scientific studies report the application of both areas. As for integrating LSS and Ergonomics, no pattern is observed in the methods and tools to be applied, highlighting that the most common were the DMAIC cycle and the Value Stream Mapping tool. Nevertheless, this review evidences many positive effects of this integration, both for organisations and workers. In general, the topic of this review has the potential to be further studied through conceptual studies and case studies in organisations from different sectors to provide broader conclusions and show the relevance of this theme.

1. Introduction

The increase in competitiveness, internationalisation, and the economic environment that makes consumers more demanding regarding purchase cost and product/service quality forces many organisations worldwide to seek operational and service excellence. For this, it is crucial to increase productivity and efficiency while reducing waste, production costs, delivery times, and defective products. In this sense, there is a growing need to adjust management strategies and continuously improve the performance of organisations, focusing on reducing variability and waste that do not add value while increasing the flow of the processes. To achieve the abovementioned goals, many organisations bet on implementing continuous improvement (Nunes, 2015).

Continuous improvement is an improvement culture that aims to eliminate waste in all work systems and processes, which implies that the work involves all participants within the organisation. Continuous improvement can be evolutionary when improvements result from regular, incremental changes or revolutionary when significant changes occur due to an innovative idea or new technology (Bhuiyan & Baghel, 2005). Nowadays, Lean and Six Sigma are the two most popular continuous improvement strategies in organisations in the industry and service sectors (Bhuiyan et al., 2006; Citybabu and Yamini, 2023).

Lean methodology is a production philosophy that evolved from the Toyota Production System and has the fundamental principle of eliminating sources of waste and non-value-added activities to promote a continuous process flow. The goal of Lean is to improve the performance of the production system and help organisations to promote the delivery of the right product at the right time and in the correct quantity to satisfy customer demand, increasing competitiveness in various sectors. One of the fundamentals of Lean is to "do more with less", that is, to use the least amount of capital and investment to produce the most significant possible gain (Alsaffar & Ketan, 2018b; Nunes, 2015; Putri et al., 2018; Thomas et al., 2009).

Six Sigma was developed by Motorola to improve product quality and productivity in organisations by reducing process variability and is defined as a metric and methodology. One of the priorities of Six Sigma is customer focus, and therefore, the improvements to be implemented are determined by their impact on customer satisfaction and value

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(Gleeson et al., 2019; Putri et al., 2018; Thomas et al., 2009).

Today, the two methodologies mentioned in the previous paragraphs are often used in a single approach called Lean Six Sigma (LSS) (Carnell et al., 2003; George et al., 2005; Salah et al., 2010). This merging of Lean and Six Sigma is crucial since Lean cannot bring a process under statistical control, and, on the other hand, Six Sigma alone cannot dramatically improve process speed or reduce capital investment (Bhat & Jnanesh, 2014; Gleeson et al., 2019). These two methodologies have common grounds and goals regarding dedication to achieving customer satisfaction. The LSS methodology creates added customer value by reducing defects and waste to streamline the value stream and improve product delivery time.

The advantages of using LSS to improve the productivity and efficiency of organisations are remarkable; however, since its objective is to maximise production by minimising resources, the interventions suggested by this methodology can compromise workers' health due to the higher levels of physiological and psychological stress (Koukoulaki, 2014). Thus, it is commonly said that LSS focuses mainly on external productivity, that is, what directly influences the organisation, and does not value internal productivity in the same way, which concerns the ability of workers to produce more without increasing the risk of developing musculoskeletal disorders (MSDs) or the number of errors (Holden et al., 2015; Nunes, 2015). It is crucial to note that LSS, as an evolved framework, incorporates tools such as poka-yoke and jidoka, among others, which indirectly contribute to the well-being of workers. These tools focus on error prevention and detection, thereby reducing the likelihood of errors that could lead to increased strain on workers, potentially causing musculoskeletal disorders. The foundation mentioned above is one of the critical concerns of Ergonomics.

Ergonomics is a field that focuses on understanding the interactions between humans and other elements of the work system to optimise both human well-being (ensuring the health and safety of workers) and system performance (IEA Council, 2000). This scientific area has two main objectives, one at the social level (health and well-being) and the other at the economic level (total system performance). It always considers the physical and psychological aspects of the human being, focusing on adjusting work demands and conditions to workers' capabilities (Dul & Neumann, 2009).

LSS methodology and Ergonomics have common goals: waste reduction, process improvement and increased efficiency. However, these two areas act differently to achieve these goals (Monroe et al., 2012). Therefore, a solution that maximises performance and efficiency while focusing on external and internal productivity is an integration of LSS and Ergonomics since they complement each other and can have a synergistic effect (Nunes, 2015; Nunes & Cruz-Machado, 2007).

Over the years, the impact of Lean methodology on ergonomics have divided scientific opinion because positive and negative aspects have been identified (Arezes et al., 2015). In addition, there are scientific studies that only focus on the disadvantages for workplace ergonomics (Cirjaliu & Draghici, 2016; Kumar et al.,2021). Following a different approach, Stimec and Grima highlighted the negative consequences of Lean for occupational stress (Stimec & Grima, 2019).

On the other hand, some studies provide a different perspective by focusing on the synergies of the integration of Ergonomics and Lean methodology. First, Lean's 3Ms, as claimed by (Radin Umar et al., 2023), encompassing waste (MUDA), overburden (MURI), and inconsistency (MURA), can have negative impacts on both physical and mental well-being of workers. Therefore, a handful of studies claim that Lean tools could improve ergonomic conditions of workers. For example, in 2019, the Early Human Resources Management (EHRM) model was suggested to improve the performance of Lean approaches by encouraging active participation in the training and education of the employees (Vukadinovic et al., 2019). In 2021, a scientific study analysed the industrial implementation of a collaborative robotic workstation in a Portuguese organisation. They assessed three parameters: workstation performance before and after implementing changes, musculoskeletal risk before and after implementing changes, and finally the wellbeing and acceptance indicators. Results evidenced that it is possible to improve ergonomic conditions and work cycle times through the synergistic integration of the two areas (Colim et al., 2021). Another example is the combination of Ergonomics and Lean approaches to improve workers' well being and productivity in a steel springs industrial unit (Afonso et al., 2022). Nevertheless, LSS is a current and integrated methodology. As so, continuous improvement processes should be executed by simultaneously applying LSS and ergonomic approaches in a coherent and integrated manner to ensure productivity gains and better working conditions, bridging the existing conflicts between production and occupational health and safety (Nunes, 2015). Moreover, integrating these areas addresses the need to value workers and recognise their importance in responding to the significant evolution of the technological world and automated processes.

On the other hand, disregarding Ergonomics in LSS processes will result in costs to workers (such as adopting forced postures and performing excessive forces) that, in many cases, are financed with the organisation's profits obtained from LSS implementation (Wilson, 2005). In this sense, restructuring processes to implement LSS in the production system should focus on the human factor to avoid an excessive reduction in cycle times and an increase in improper postures and repetitive movements (Nunes & Cruz-Machado, 2007).

This paper presents a systematic review of the literature on the integration of LSS and Ergonomics. It is noteworthy that, in a first approach, authors aimed to focus in the integration of Six Sigma and Ergonomics only. They considered a new research opportunity within this area and aimed to explore the positive and negative aspects of the integration. However, a research in many scientific databases (e.g: Scopus, Web of Science, Springer, and Science Direct) idenfied a lack in scientific studies developed within both areas (which encourage the idea of a new research opportunity). To proceed the investigation and find more relevant studies, authors decided to include Lean because Six Sigma is often used together with Lean as we have mentioned before. Nevertheless, the integration between Lean and Ergonomics (without Six Sigma) was not the focus since it has been studied along the years. Also, it is the topic of other reviews (Arezes et al., 2015; Pereira et al., 2023; Al-Zuheri et al., 2023), so, performing another literature review on the topic would harm the originality of this work.

As so, the present study highlight how Lean Six Sigma, through its comprehensive approach, can lead to improvements in productivity, product quality, and, importantly, the well-being of workers. The paper consists of an analysis of the studies that apply the LSS methodology and present, simultaneously, a concern with Ergonomics, either to improve aspects related to the productivity of organisations or to the health and safety of workers..Therefore, this study seeks to understand the LSS methodologies and the ergonomic assessment methods most used in integrating these two areas and the main sectors where this synergy is applied. Additionally, it is intended to evaluate the advantages of this integration for organisations and workers and the main limitations to its implementation. Finally, this paper represents a scientific basis that aims to encourage and support further studies and research on integrating continuous improvement through the LSS methodology and Ergonomics.

The paper is organised into four sections. Section 2, Research Methodology, presents the research methodology followed throughout the systematic literature review. It contains an explanation of the approach adopted and the various steps performed at each stage of it. Section 3 presents the study results and its critical analysis, and Section 4, Conclusions, summarises the paper's main contributions, discusses the study's limitations, and presents recommendations for future work.

2. Research methodology

The present systematic literature review followed the step-by-step approach proposed by Denyer and Tranfield (2009). It suggests a

structured, systematic literature review process that includes five steps with several tasks each (Fig. 1), all well-defined and easy to understand (Denyer & Tranfield, 2009; Torreglosa et al., 2016). Also, it promotes a holistic point of view since it encourages the inclusion of theoretical and practical references (conceptual and case studies), contributing to a global and embracing perspective of the topic (Yalcin et al., 2022).

The first stage consists of establishing the study's objectives, which implicitly includes contextualisation of the problem and framing the subject under study. Additionally, the research questions are defined, which are intended to guide the review:

QI1: What are the most common LSS and Ergonomics tools applied integrated?

QI2: What benefits arise from the integration of LSS and Ergonomics?

QI3: Are there any limitations/barriers to the application of this integration?

QI4: What will be the evolution trend of LSS and Ergonomics integration?

The next step corresponds to the research phase, that is, the identification of the scientific publications presented in the literature related to the topic. For this purpose, Scopus and Web of Science were selected since they are multidisciplinary database covering published material in the humanities and sciences (Pranckute, 2021; Kumpulainen and Seppänen, 2022). Also, in this step the most appropriate keyword combination was defined to be used in the literature search: (((“Lean” AND “Six Sigma”) OR “Lean Six Sigma”) AND (“Ergonomics” OR “Human Factors”)).The selection of the keywords was based on the main objective of the study, namely, identify as many studies as possible regarding the integration of Six Sigma and Ergonomics. Then, the search was performed, noting that in Scopus, the option chosen was “Article title, Abstract, Keywords”, while in Web of Science, it was chosen “All fields”. It is important to note that the research period was between October and November 2022.

Once the previous aspects have been defined, the third stage consisted of establishing the eligibility criteria for this study, that is, the inclusion and exclusion criteria. For the inclusion criteria, it was defined that the studies to be included in the review must meet the following requirements:

a) Written in English;

b) Whose study type is classified as case studies or conceptual studies;

c) Present relevant information about integrating the two areas under study, LSS and Ergonomics.

It is noteworthy that criteria b was defined because some relevant scientific articles may result from theory and have not been implemented as case studies. In addition, criteria c will ensure that only studies describing LSS and Ergonomics will be selected since this research aims to clarify the integration of the three areas.

On the other hand, studies are excluded from the review if they present the following characteristics, defined as exclusion criteria:

a) Studies that do not present any contribution to the discussion of the integrating LSS and Ergonomics;

b) Articles whose present philosophy is not LSS, but only Lean philosophy or Six Sigma methodology, used as individual methodologies throughout the study;

c) Publications from which only the abstract referring to the proceedings of a conference was obtained instead of the full article.

After searching the two scientific databases, 74 publications were identified, of which 28 were in the Web of Science and 46 in Scopus. Note that this number already excludes the eight publications that present only the abstract of the conference proceedings instead of the abstract of the relevant studies.

Subsequently, a careful document selection process was performed based on the methodology proposed by Denyer and Tanfield. First, it was observed that 18 studies were repeated in the two databases, so duplicates were excluded, reducing the studies to 56. Then, studies were excluded by reading their abstract, considering the abovementioned criteria, which reduced the number of studies to 44.

At last, it was considered essential to read the full text of the 44 studies in order to obtain a detailed view of their contribution, or not, to this study. After reading, 28 of the 44 studies were excluded because they did not meet inclusion criterion c), which requires relevant information about the integration of LSS and Ergonomics. Thus, this literature review includes 16 articles, of which four are from Scopus, four from Web of Science, and the remaining 8 in both. Fig. 2 presents a flowchart that summarises the document selection phase.

Once the third step was completed and the studies included in the review were obtained, each one was analysed and organising them in an informative table (presented in the next section) to present, in a synthesised manner, the relevant information of each article selected for this systematic review.

Finally, the fifth step is the documentation of the results, which corresponds to the development of the systematic literature review report. This report corresponds to this document, which follows a structure with the following topics: introduction, research methodology adopted, analysis of results, discussion of results, and conclusions of the study, which includes the limitations found and suggestions for future work.

3. Results and discussion

The results of this study represent the 16 publications included in the systematic literature review and their main findings. After reading the full text of all studies, the relevant information from each study was broken down into an informative table (Table 1). This table contains information about each selected publication, such as the year of publication, the country where the study was conducted, the type of study, the objectives of the study, the method(s) adopted in the study, including the tools used, and the main results and conclusions drawn from each study.

As for the type of study, two groups were defined: conceptual studies, which consist, for example, of model proposals, literature reviews, and/or comparative analyses, and case studies, which are conducted in several different organisations, belonging to both the industrial and service sectors, namely the health sector. In this study, the difference between the number of case studies and conceptual studies is quite significant, with case studies accounting for 11 of the 16 studies included in the review. The existence of fewer conceptual studies shows the need to better understand these two areas, for example, by conducting literature reviews.

3.1. Bibliometric analysis

Reports about integrating LSS and Ergonomics began in 2006. Thus it can be considered a relatively recent topic. Only eight years later (in

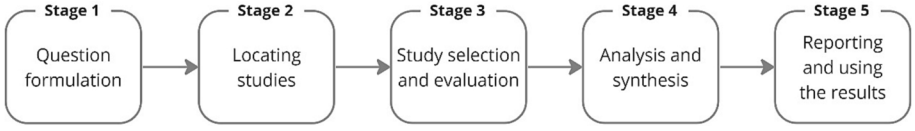

Fig. 1. Schematic of the steps proposed by Denyer and Tranfield (2009). .
Adapted from Torreglosa et al., 2016

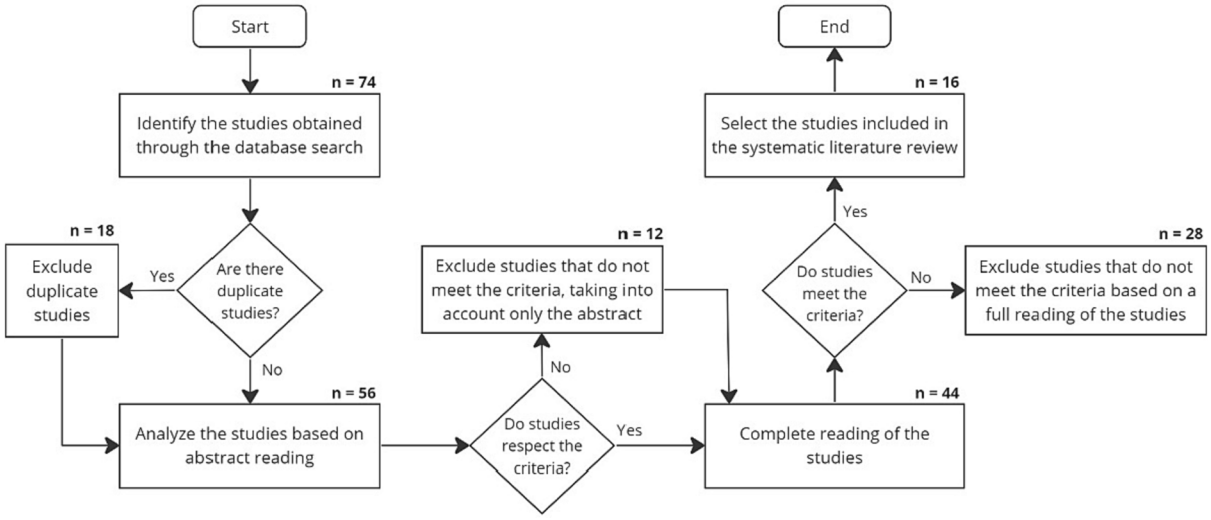

Fig. 2. Flowchart of selecting relevant studies for the systematic literature review.

2014), another study was published regarding this topic; therefore, it can be seen that this theme only gained popularity about ten years ago, when researchers began to recognise the potential benefits of this combination (Bhat & Jnanesh, 2014; Dahlgaard and Mi Dahlgaard-Park, 2006; Nunes, 2015). An analysis of the publication trend of articles can be seen in Fig. 3.

Further analysing the publication trend of articles, it is observed that the most publishing years were 2015 and 2018. A possible reason to explain this could be the fact that in the last decade there has been a greater awareness of the possible consequences of implementing LSS and the importance of Ergonomics to prevent some of the negative impacts since Ergonomics aims to promote safety, well-being and productivity, leading more organisations to incorporate its principles in the design and improvement of their processes (Dalle Mura & Dini, 2019; Lehto & Landry, 2013). In addition, there has been an increase in form programs growth in the resources and tools available to support the integration of LSS and Ergonomics, such as training programs and case studies that show the benefits of this approach (Alsaffar & Ketan, 2018a; Nunes, 2015).

The existence of 4 articles published between 2020 and 2022 proves the current interest in integrating the two mentioned areas and the increasing concern with the organisation's workers. However, the number of studies published per year is lower when compared to 2015 and 2018. It may be related to the emergence of the Covid-19 virus pandemic in 2020, from which it is still recovering, to the extent that it drastically conditioned the studies in the "field". Furthermore, as far as organizations are concerned, some have separate departments for Ergonomics and continuous improvement, which develop their internal studies. These studies may not be disclosed so that competitors do not have access, which is a possible reason for the decrease in publications after 2018.

Concerning the geographical location where the studies were conducted, Fig. 4 shows that the United States stands out significantly since it is the country that contributed the most articles to this review. This prominence was expected since this country is considered one of the world's most significant economic powers and has a large and developed industrial sector with availability (Ha et al., 2016; McFarland, 1971; Schwerha et al., 2020). In addition to these countries, the European and Asian continents are also present, with India, Iraq, and Portugal both presenting 2 studies included in this systematic review.

Regarding the sector where the studies were conducted, of the 16 articles analysed, 6 were conducted in service-providing organisations, with the health sector standing out, given that, of these 6, 5 were in hospitals. In this sector, the existence of errors in the workplace can generate complications with the clinical condition of patients and, therefore, it is crucial to improve processes, reduce errors and increase the quality of care (Ozturkoglu et al., 2021; Rathi et al., 2022). Most of the remaining work is carried out in organisations from various types of industries to improve the efficiency and productivity of processes without overburdening workers and also reducing their exposure to risk factors that put their health at risk (Alsaffar & Ketan, 2018a; Freitas et al., 2015).

3.2. *Ways of integrating LSS and Ergonomics*

The integration of LSS and Ergonomics can happen by several combinations of methods from each area. Detailed analysis of the studies included in the systematic literature review shows no trend in how these two areas should be integrated since the objectives and method(s) used in each study depends on the context, and no pattern was be noticed between the 16 studies analysed.

Within the selected studies, there are case studies that incorporate LSS and ergonomic tools and/or principles into their methodology, conceptual studies about the topic under study, and, for the most part, case studies that use LSS tools to improve aspects related to Ergonomics, both physical, cognitive, and organisational. Of the latter, an example is the study conducted by Wang et al. (2022) that applies a DMAIC-based improvement model together with VSM 4.0 (Fig. 5) to improve employee well-being and employee engagement in organisational processes (Wang et al., 2022).

In studies using LSS approaches to intervene in the organisational domain of Ergonomics, such as improving lighting and thermal comfort in the workplace, the usefulness of the approach has been proven by the realisation that the organisational aspects themselves are integral to sound ergonomic practices, which in turn are critical to the success of any LSS initiative. It ultimately represents a cycle of benefits from integrating these two areas (Hachem et al., 2015).

Although a trend towards integration of LSS and Ergonomics is not seen, it observed the more recurrent use of specific LSS tools, namely the DMAIC cycle. It may be because the DMAIC cycle uses a standardised methodology, with clear steps to follow, for problem-solving and process improvement (Wang et al., 2022). Furthermore, the holistic and efficient approach presented by DMAIC allows for incorporating LSS and ergonomic tools and principles throughout its five stages, as proposed by Nunes (2015).

Besides this, VSM is also used very often in studies that link LSS to Ergonomics in order to map the current processes, analyse their value streams and identify the existing sources of waste/waste (Nabiyouni &

Table 1
Synthesis of the studies included in the systematic literature review.

Ref.	Country	Type of study	Objetctive(s)	Method(s)	Method(s)
(Dahlgaard & Mi Dahlgaard-Park, 2006)	Sweden	Conceptual study	Detailed analysis of Six Sigma, Lean and TQM tools combined with a focus on the human factor and the necessary corporate culture	Literature research and comparative analysis complemented with a Danish case on waste	- High concentration on training tools and techniques - Little focus on understanding the human factor
(Bhat & Jnanesh, 2014)	India	Case study	Implementing LSS methodology to reduce the cycle time of the service of the outpatient department of a rural hospital	. Data collection 2. Use statistical techniques and Gemba to analyse the data 3. Apply the DMAIC method, Kanban, 5S and ergonomic design of workplace layout	- Cycle time decreased by 2.77 min − 97 % reduction in average system wait time and 91 % reduction in queue size - Reduced waste and time in the organisation - Improved efficiency and reduced variability - Improved worker well-being due to reduced movements performed on a task
(Nunes, 2015)	Portugal	Conceptual study	Model of a Framework and Decision Support System	Framework based on the association of an additional ergonomic perspective to the LSS procedures used in each phase of the DMAIC cycle	- Beneficial for the production process and the workers - Significant gains in productivity - Improved working conditions
(Freitas et al., 2015)	Portugal	Case study	Apply an integrated approach that combines Lean, Six Sigma and Ergonomics to increase productivity in a fish processing plant while ensuring adequate levels of health, safety, and well-being for workers	1. Define: Process Diagram and Project Charter 2. Measure: VSM and Working Conditions Questionnaire 3. Analyse: NIOSH equation 4. Improve: Brainstorming	- Improved productivity - Decreased physical demands of the tasks - Decreased number of workers exposed to physical demands, from 10 to 2, in the Defrosting process

Abbreviations: TQM - Total Quality Management; DMAIC – Define, Measure, Analyse, Identify, Control; VSM -Value Stream Mapping; NIOSH - National Institute for Occupational Safety and Health

Ref.	Country	Type of study	Objetctive(s)	Method(s)	Results/Conclusions
(Hachem et al., 2015)	United States	Case study	Apply a systematic multidisciplinary approach focusing on the principles of LSS philosophy to assess thermal comfort (a factor considered in Ergonomics by the organisational domain) in a packaging company	A systematic multidisciplinary approach based on LSS philosophy and principles and a combination of multidisciplinary variables (physiological, biological and environmental) to generate a unique methodology for thermal comfort assessment	The use of this methodology promotes the use of minimal waste of resources and time in non-value-added activities while guiding a detailed study with minimal defect rates
(Hignett et al., 2015)	United Kindgom	Case study	Use a hospital staff/organisation-based approach to discuss how Ergonomics can be applied to managing occupational slips, trips and falls (STF) risks, using quality improvement methods such as Lean and Six Sigma	Project 1: Lean techniques such as process diagram and affinity diagram to standardise work processes involved in STF risk assessment - Project 2: Six Sigma tools (SIPOC, cause and effect diagram, FMEA) applied throughout the phases of the DMAIC cycle to support continuous improvement and redesign processes to investigate the causes of crashes	- Existence of problems such as lack of staff, staff and management turnover, and low-quality medical discharge reports - Project 1: allowed a significant reduction of 34% in total STFs - Project 2: led to no STFs with serious injuries, decreasing their value by 56% - Difficulties experienced in staff involvement and employee turnover
(Clayton & Stuckey, 2016)	United States	Case study	Improve processes to reduce traditional set-up times for Highly Accelerated Stress Screening (HASS) testing	FMEA + Cause and Effect Diagram + Poka-Yoke + reduction of value-added steps + standardisation of process steps + implementation of 5S workplace	- Reduced HASS test set-up time - Decreasing the time when the operator is subjected to high physical demands while performing a particular task

Abbreviations: STF - Slips, trips and falls; SIPOC – Supplier, Inputs, Process, Outputs, Costumer; FMEA – Failure Mode and Effect Analysis; HASS – Highly Accelerated Stress Screening

Ref.	Country	Type of study	Objetctive(	Method(s)	Results/Conclusions
(Barach & Kleinman, 2018)	United States	Conceptual study	Discuss quality improvement strategies and tools used to improve the quality and safety of cardiac care in paediatrics	Tools for continuous quality improvement: - Checklists - Process Diagrams - Cause and effect diagrams - Run charts - Control charts	The tools discussed to provide a starting point for systematic reflection, staff commitment and improvement - The use of checklists improves communication between workers and, as a result, the quality of the work done by them
(Putri et al., 2018)	Indonesia	Conceptual study	Show the link between minimising the seven wastes, using LSS, and the importance of caring for the workers in a bank	DMAIC + Survey questionnaire + Brainstorming + 5Whys + FMEA	Proposal of six recommendations to improve the efficiency of the banking unit without unnecessarily consuming the energy of the workers and also improving their comfort and well-being

(*continued on next page*)

Table 1 (*continued*)

Ref.	Country	Type of study	Objetctive(	Method(s)	Results/Conclusions
					- LSS seeks the perfection of a system by working together with workers
(Alsaffar & Ketan, 2018a)	Iraq	Conceptual study	Propose a model based on integrating LSS and Ergonomics to identify risk levels inherent to workers' postural movements	A computer program to integrate LSS and Ergonomics that includes two structural subsystems used in the Measure and Analyse phases of DMAIC: - Subsystem 1: Process Flow and Time Efficiency, which uses the LSS tools cause and effect diagram and 5Whys - Subsystem 2: Work Condition vs Ergonomics, which uses the RULA ergonomic assessment method	- Estimated reduction of the MSDs risk level from 7 to 3 through workstation reconfiguration and reduced fatigue and discomfort - Predicted increase in assembly line efficiency - Reduced Mura waste levels

Abbreviations: RULA – Rapid Upper Limb Assessment

Ref	Country	Type of Study	Objective(s)	Method(s)	Results/Conclusions
(Alsaffar & Ketan, 2018b)	raq	Case study	Reorganising workstations according to the level of risk of generating harm or negative consequences in order to reduce additional psychological stress for workers in a hydraulic sector organisation	A computerised program designed based on two models involving LSS tools and ergonomic work criteria: - Model 1: Process Flow and Time Efficiency- Model 2: Work Condition vs Ergonomics	- Improved levels of safety and productivity - Reduction of physiological tension, stress, discomfort and muscular fatigue felt by the workers - Increased efficiency of operations - Increased time spent on value-added activities due to the reduction of non-value-adding activities by reducing waste
Nabiyouni & Franchetti, 2019)	United States	Case study	Optimise a hospital's red bag waste management program through the use of LSS methodology, focusing on reducing defects and managing the frequency of disposal	- Analysis and evaluation of the hospital's established regulations and procedures dealing with red bag waste management - Lean 5Principles + VSM	− 85% of existing waste in task performance is related to inadequate training and lack of commitment of workers - Error is considered a significant source of waste - Suggested improvements to reduce waste - Predicted to minimise waste by 55% if appropriate improvements are implemented
(Schwerha et al., 2020)	United States	Case study	System to fill the lack of available tools to allow safety, productivity and quality professionals to work together	Prioritisation Tool + Poka-Yoke + Process Training Document + MOD Tool VSSM (Modular Value Stream Safety Map)	- Reduction in the number of postures with a high risk of causing MSDs - Reduction of forces exerted by workers - Decreasing the risk of MSDs - The use of this system based on LSS tools allows working on the problem considering safety, productivity and quality as a whole

Abbreviations: MOD VSSM - Modular Value Stream Safety Map

Ref.	Country	Type of Study	Objective(s)	Method(s)	Results/Conclusions
(Kochov & Argilovski, 2020)	Croatia	Case study	Propose a framework to improve the process (or design a new one) involved in performing manual load-handling tasks in a particular organisation	DMEDI cycle + VOC + SIPOC + Project Charter + Process Flow Diagram + 5Whys + KPIs	- Reduction of costs generated due to: maintenance, compensation for injuries and waste (drop) of raw materials during transport - Improvement of Ergonomics-related problems: reduction in the number of worker injuries and illnesses and worker complaints about the working conditions of the task - Decreased time required to produce the final product - Increased competitiveness of the company
(Ozturkoglu et al., 2021)	India	Case study	Investigating the efficiency of LED technology (a factor relative to the organisational domain of Ergonomics) in a hospital operating room using LSS principles and tools	- Lean: Measurement System Analysis (MSA). - Six Sigma: Gage Control Methodology	The variation of the measurement system decreased by about 4% and then showed that calibration helped reduce variability and increased the efficiency of the LED technology, improving workplace conditions
(Wang et al., 2022)	Ireland	Case study	Improvement model based on DMAIC with VSM 4.0 to improve the design of the picking station of a company that manufactures refrigeration systems for trucks, with a human-centric approach	1. Define: VSM 4.0 (current state), Pro-project charter, SIPOC and Gemba. 2. Measure: KPIs and data visualisation. 3. Analyse: 5Whys. 4. Improve: Kaizen events + VSM 4.0 (future state)	- Improved planning capabilities - Increased employee involvement - Improved productivity - Reduced quality-related customer complaints, costs, and delivery time - Suggestion of a human-centric LSS model that could serve as a roadmap

Abbreviations: DMEDI – Define, Measure, Explore, Design, Implement; VOC – Voice of Costumer; KPIs – Key Performance Indicators; MSA - Measurement System Analysis.

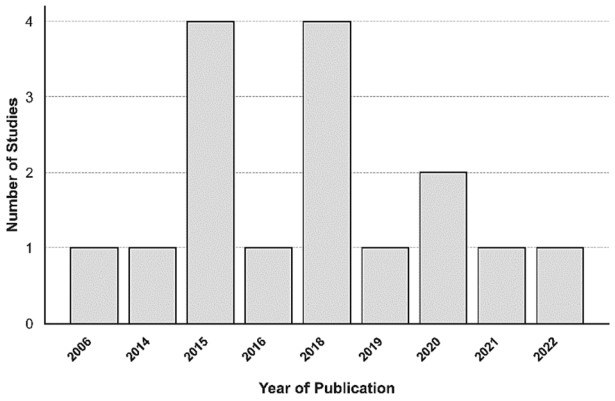

Fig. 3. Study publication trend analysis.

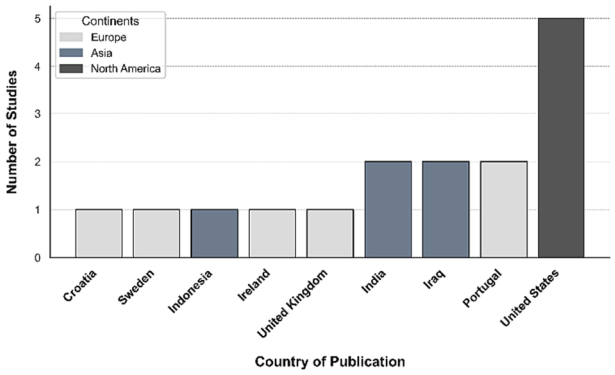

Fig. 4. Number of studies by country of publication.

Franchetti, 2019; Paul-Eric et al., 2020). LSS tools such as VOC, 5S, Kaizen, Gemba Walks, Poka-Yoke, FMEA, SIPOC, Kanban, Brainstorming, 5Whys, Cause and Effect Diagram, Process Diagram, and Project Charter also appear in studies of this type, although less frequently.

As for the tools and principles of Ergonomics, the ergonomic design of the workplace is recognised in studies related to this topic to adapt the work environment to the workers' abilities reducing exposure to risk factors (Hoe et al., 2012). Another frequent ergonomic method used in this integration is checklists, which assess the ergonomic design of a workplace or work task by identifying risk factors for developing MSDs. It helps to understand what can be improved and how to do it.

Regarding ergonomic risk assessment methods, two more were applied in the studies analysed. One of them is RULA, embedded in a study that develops a computer program based on LSS tools and the RULA method, where it was shown that this method has a positive impact on process efficiency and, at the same time, allows for reducing the risk level, as well as decreasing the discomfort and fatigue experienced by workers (Alsaffar & Ketan, 2018a). The other ergonomic assessment method found is the NIOSH equation, applied in a study in the fish production sector. This method allows for assessing the potential risks in a given manual load-handling process, namely analysing whether this process is compromising workers' health (Freitas et al., 2015).

Still, regarding the ways to integrate LSS and Ergonomics, it was observed that the authors Alsaffar and Ketan (2018) conducted two studies where they applied the same computerised program called "LSS + Ergo System". The development of this program was based on tools and principles of LSS and Ergonomics, and it is based on two subsystems (Fig. 6), one related to process flow and efficiency time and the other to working conditions and ergonomic effects. It shows the growth of interest and exploration for this topic since, to develop the referred system, it is essential to have detailed knowledge about the principles of each area and the characteristics of their integration (Alsaffar & Ketan, 2018a, 2018b).

3.3. Importance and benefits of integrating LSS and Ergonomics

Throughout the literature review, it was possible to identify the impact of the integration of LSS and Ergonomics in the continuous improvement of a company. Moreover, the integration of the two areas was analysed, concluding that it is beneficial for the organisation and workers, even though it presents a high level of complexity (Nunes, 2015).

By itself, the LSS philosophy represents a search for the perfection of the system in that it does not simply demand more from workers but works together with them to seek to innovate and implement improvements to achieve a balance between both parts (Putri et al., 2018). Thus, uniting LSS with Ergonomics, that is, combining the quality of organisational performance with concern for workers, allows for better results given that the well-being of workers is significantly reflected in the efficiency and productivity of the organisation.

This integration enables organisations to demonstrate a commitment to worker well-being while achieving their improvement goals, based on the certainty that solutions are achieved when safety, productivity, and quality are considered as a whole to solve a problem (Schwerha et al., 2020).

The importance of using the integration of LSS and Ergonomics in organisations has been substantiated throughout this paper. It is proven through the benefits provided, such as achieving a safer, more comfortable, and efficient work environment while improving the quality of processes, reducing non-value-added activities, and increasing the organisation's productivity (Alsaffar & Ketan, 2018a; Dul & Neumann, 2009). On the other hand, organisations that do not use their efforts to integrate these two areas may have high numbers of work-related musculoskeletal disorders (WRMSDs) in workers, higher absenteeism, higher defect rates, and lower efficiency (Fernandez, 1995; Nunes & Cruz-Machado, 2007; Afonso et al., 2022).

Thus, simultaneously satisfying the principles of LSS and Ergonomics, the goals of reducing waste, increasing productivity, and preserving workers' health can be achieved. However, it is essential to note that the success of this integration requires careful planning, leadership support, employee involvement, and access to adequate resources (Sordan et al., 2020).

3.4. Limitations and barriers to implementing the integration of LSS and Ergonomics

Despite the benefits of integrating these two areas, their implementation faces challenges and limitations. One of the main limitations relates to resistance to change by organisations and people involved in them, both management and workers. The implementation of LSS integrated with Ergonomics usually requires changes in work processes and/or procedures, and workers often show inertia in accepting improvement proposals, changing their work routines and even learning new skills, so this has an impact on the success of this integration (Melton, 2005; Walder et al., 2007; Bhat et al., 2014; Bhat et al., 2016). However, in some instances, the workers' resistance to change can be mitigated if LSS is implemented naturally, with proper training and communication (Sánchez-Rebull et al., 2022).

Another aspect that creates difficulty is the limited resources in some

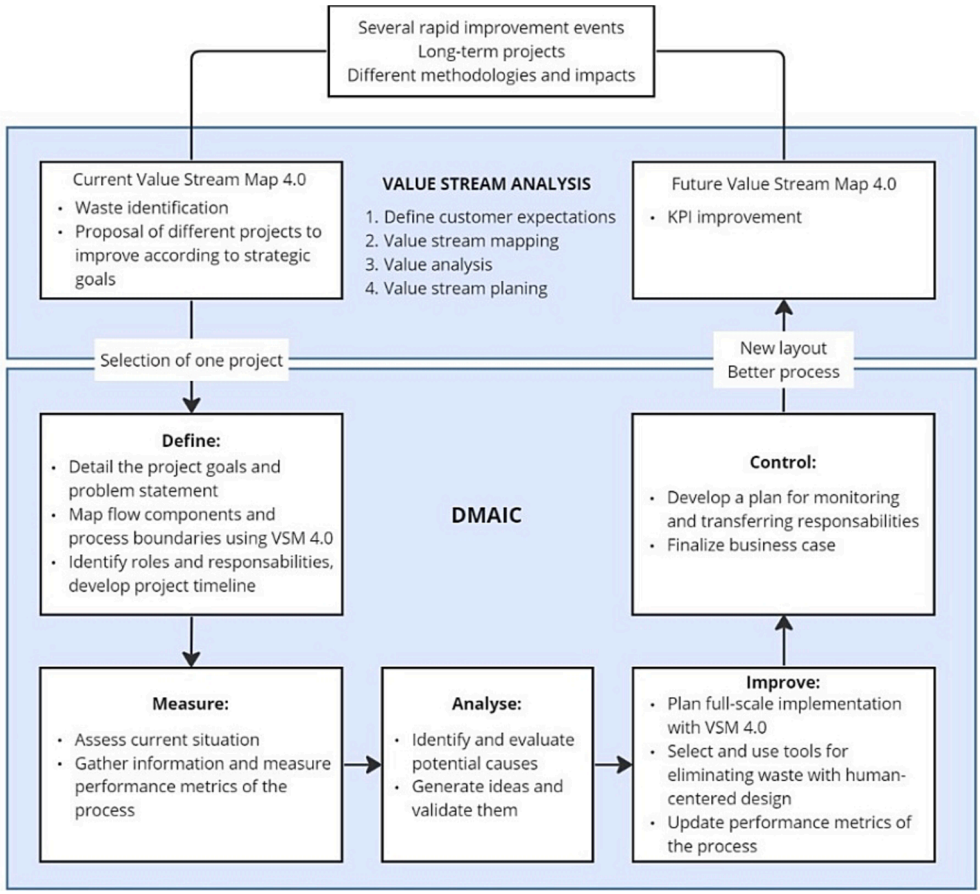

Fig. 5. Improvement model based on DMAIC together with VSM 4.0. .
Adapted from Wang et al. (2022)

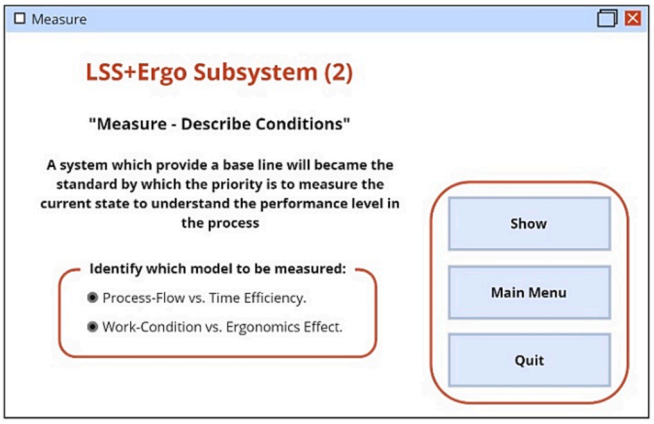

Fig. 6. "LSS + Ergo System" program. .
Adapted from Alsaffar & Ketan (2018b)

organisations, as this integration often requires additional resources, such as equipment, tools, staff, or workers (Albliwi & Antony, 2013; Rowan & Wright, 1994; Schwerha et al., 2020). Allied with this comes the costs of applying the tools used in integrating LSS and Ergonomics, which may also represent a limitation. Moreover, the complexity of this implementation is at the base of another challenge related to the difficulty of quantifying the results and their effectiveness (Carvalho, 2016).

As for conducting studies that apply the integration of the two mentioned areas, the difficulty lies in uniting them without neglecting any of their fundamental principles and, more importantly, thinking of them as complementary and not as individuals (Carvalho, 2016). For this, workers must have the expertise and understand the principles of the two areas involved, especially Ergonomics, since organisations often neglect it (Hendrick, 2008). The lack of knowledge can compromise the success of applying this approach and, therefore, providing workers with training that explicitly the concepts, principles and tools of both areas may represent a solution to overcome this barrier (Brewer & Hsiang, 2002; Mehrjerdi, 2011).

At last, the non-existing of models that combine specific methods of LSS and Ergonomics can also be a barrier. However the methods used must be selected for each specific context (Afonso et al., 2022). As so it is necessary to gather the expertise in both areas to guarantee that the interventions are adequated.

3.5. *Evolution trend*

Although the integration of LSS and Ergonomics is a relatively recent approach, it allows for obtaining better results and more advantages compared to the implementation of the two areas separately, namely improving the efficiency, quality and productivity of organisations and also the safety and well-being of workers (Monroe et al., 2012; Nunes, 2012).

Thus, the integration of these two areas, over time, will become increasingly indispensable as organisations seek to improve their productivity and quality to meet the growing competitiveness of markets and consumer demands. The emergence in recent years of studies that integrate LSS and Ergonomics in various ways supports the prediction that the future of this topic will continue to evolve positively, driven by several factors (Alsaffar & Ketan, 2018a; Ozturkoglu et al., 2021).

One of the main factors is the increasing focus on worker health and

safety related to organisations' demand for reducing the risk of developing WRMSDs and improving the well-being of their workers in order to increase productivity (Grooten & Johansson, 2018; Lehto & Landry, 2013; Wang et al., 2022). In this sense, another factor is related to the reduction of costs associated with the WRMSDs developed by workers and, derived from this, absenteeism in the workplace.

The remarkable recognition of the importance of workers in process improvement represents another aspect that may encourage the increasing application and study of this topic in the future since organisations are likely to seek different ways to integrate LSS and Ergonomics and, for this, the contribution and feedback from workers are fundamental (Dul & Neumann, 2009; Snee, 2010; Taghizadegan, 2006).

On another level, technological advances may encourage the use and implementation of ergonomic principles, for the design of appropriate workstations, along with LSS methodology, to ensure that technology assesses ergonomic risks and maximises productivity (Alsaffar & Ketan, 2018b; Fernandes et al., 2022).

4. Conclusion

In this paper, a systematic literature review on the integration of LSS and Ergonomics was carried out to contribute to a better perception, together with a detailed analysis, of the current situation of this topic in the literature. This systematic review followed a five-step methodical approach, including the document search and selection phase, and had 16 studies as results of this study. The analysis of the results allowed us to understand that this integration can be applied both in industry and in services and that, in the latter, health stands out when it comes to integrating these two areas.

The small number of studies included in this review, 16, allows us to state that research on this subject is still limited and that there is room and potential for evolution, both in terms of case studies and conceptual studies. On the other hand, this systematic literature review has shown the impact of LSS methodology and Ergonomics on the continuous improvement of an organization. Despite its complexity, it is remarkable that implementing this integration provides benefits simultaneously for organizations and their workers, as it allows them to achieve the defined improvement goals while preserving the health and safety of their workers, thus ensuring their quality, efficiency and productivity. This study contribute to emphasize the role of Lean Six Sigma in improving processes to achieve higher efficiency while concurrently addressing ergonomic concerns.

Despite the potential barriers to the implementation of LSS and Ergonomics integration, it is expected that this theme will continue to evolve in the future, driven by several factors, such as the growing interest in involving continuous improvement without compromising the well-being of workers, the cost reduction provided by this integration and the need to respond to advances in technology used in workplaces.

While conducting the systematic literature review, some challenges and limitations were encountered at the research level and related to the selected studies. First, the main obstacle to this systematic review was the few studies in the literature on the integration of LSS and Ergonomics and particularly the integration of SS and Ergonomics. However, more than a limitation, this fact may be faced a new opportunity to support future scientific studies within the topic (e.g.: analyse more case studies in the industry or use the potential benefits of the integration to design/improve working systems in industry 4.0 and 5.0). Another limitation is related to the databases, as they contain only some scientific publications in the literature on the topic under study, so relevant studies may not be included. As for the content of the studies, the challenge arose in analysing the results and, subsequently, in their discussion since the studies present significant variability regarding the applied approach and the ways of integrating LSS and Ergonomics.

Future works should consider do more case studies with concrete objectives and well-defined methodologies where LSS tools are applied in conjunction with ergonomic principles and/or ergonomic assessment methods appropriate to the context under study. In addition, conceptual studies should be conducted to develop models that integrate principles and tools from both areas. It would be beneficial for research on this topic if organizations use metrics to measure the success of applied approaches and also record and monitor the evolution of occupational disease risk factors, especially WRMSDs, to investigate their impact on workers' health in the long term. Also, future studies could also address how LSS can intersects with technologies of Industry 4.0, or the role that it might have on Industry 5.0, where human-centric digital transformation is the main focus.

CRediT authorship contribution statement

Inês Vicente: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Radu Godina:** Writing – review & editing, Supervision, Methodology, Validation. **Ana Teresa Gabriel:** Writing – review & editing, Supervision, Methodology, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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