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Streamlining operations management by classifying methods and concepts of *Lean* and *Ergonomics* within a sociotechnical framework

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Abstract

Companies have implemented *Lean* to increase efficiency and competitiveness. However, the importance of *Ergonomics* is often neglected, resulting in ergonomic problems and lower profitability and acceptance of *Lean*. This study presents a comprehensive approach to Operations and Production Management (OPM) considering sociotechnical synergies. For *Lean* and *Ergonomics*, literature-based main methodologies and categories are defined. These main methodologies/categories are used as search-term combinations in a further literature search. This literature is divided into “Production worker” (PW), “Physical environment” (PE), “Industry 4.0 technology” (i4.0), “Company culture” (CC), and “Manufacturing methods” (MM) based on a metric, the sociotechnical system (STS) concept. This makes it possible to determine the percentage of participation in *Lean* and *Ergonomics* articles by STS category. The main differences can be seen in PE (Lean: 10%; Ergonomics: 24%) and i4.0 (Lean: 29%; Ergonomics: 15%). However, for PW (Lean: 18%; Ergonomics: 21%), CC (Lean: 19%; Ergonomics: 20%), and MM (Lean: 26%; Ergonomics: 20%), there are similarities between *Lean* and *Ergonomics*. The OPM user should manage the PW, CC, and MM factors equally with *Lean* and *Ergonomics*, as the objective is the same. For PW, CC, and MM measures, a professional separation into *Lean*/OPM and *Ergonomics*/Occupational Medicine does not make sense. Concerning i4.0, there is a danger that the human factor in (especially innovation-oriented) OPM will be unjustly neglected and that too much emphasis will be placed on supposedly human-free technology.

Keywords Operations management · Production management · Lean ergonomics · Lean management · Human factors engineering · Operational excellence

1 Introduction

Operations management and production management (OPM) have evolved from Industry 1.0 to the current phase of Industry 4.0, focusing on the driving forces of change and the market, as well as existing or newly developed methods and technologies (Choi et al. 2022). The risk is that an OPM focused on innovation will neglect existing and equally essential players in a manufacturing enterprise. Disruptive technologies such as artificial intelligence, mobile robotics, 3D printing, digital twins, virtual reality, and others are

emerging individually and collectively, providing data for OPM and exploiting other capabilities (Vinitha et al. 2020). A neglected aspect behind the system- and techno-centric methods and technologies of OPM is the user of these tools, the employee, who is directly exposed to the framework of OPM and must be taken into account for strategic decisions of top management (Brunner et al. 2022; Chen et al. 2023). Industry 4.0 methods and technologies act as facilitators of the effects of lean production processes on improving operational performance (Blanco et al. 2023; Ding et al. 2023). The necessary framework for this cause-and-effect relationship is created through holistic OPM (Tortorella et al. 2019). This seems only logical since *Lean*, in the form of lean production/management, is the gold standard of manufacturing companies in the 21st century, and the specifications and principles of a lean production concept should not only be prepared but also enabled by OPM (Hardcopf et al. 2021).

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Ergonomics is the scientific discipline focused on understanding and optimizing human interactions with a (technical) system to provide wellbeing for the human and performance for the system (Dul et al. 2012). Similar to OPM, the discipline developed in response to megatrends and the great industrial revolutions but has always been human-centered. As a result, extreme working hours of up to 16 hours, high accident rates, and complete absence of social security are things of the past (Luczak et al. 2018). However, just as the OPM lacks a connection to the human factor, the significant developments in Ergonomics lack the reference to business science and OPM that would make Ergonomics indispensable for a rational company (Dul and Neumann 2009; Sobhani et al. 2016).

According to Chen et al. (2023), holistic OPM must consider the user of all operational methods and technologies, primarily the OPM manager/engineer. However, according to Brunner et al. (2022), more is needed because the end effector in this decision cascade is the production worker, who usually does not participate in OPM decisions but is directly affected by them. This means that there are two sociotechnical levels on which OPM operates (Dworschak and Zaiser 2014); usually, only the level of the production worker is associated with direct productivity and value creation on the one hand, and with classical production ergonomics on the other (Battini et al. 2011; Neumann and Dul 2010).

Production ergonomics is often seen as a cost rather than a success factor (Zare et al. 2016). A generalized management approach such as “management by measurement,” on which OPM and the Lean philosophy are based, is not widely used in Ergonomics (Greig et al. 2023), although there are measures and parameters to link production ergonomics to Lean and OPM (Kolus et al. 2018; Yung et al. 2020).

As OPM plays a vital role in operational and strategic decisions or prepares them for top management, a comprehensive understanding of lean production and lean management on the one hand and production ergonomics on the other hand is crucial. Therefore, OPM managers and practitioners must understand how Lean as a production and management concept and Ergonomics as a human-centered counterpart work together, alongside each other or against each other. The research question is: In which categories of the sociotechnical system “factory” do Lean and Ergonomics differ?

This paper examines the similarities and differences between Lean and Ergonomics using an evaluation system that provides evidence. The paper defines the same standardized evaluation categories for methods and concepts of both Lean and Ergonomics. A literature review then examines which categories of Lean and Ergonomics measures and domains are synergistic or antagonistic. This is important for OPM users because the application of OPM/Lean affects not only productivity and profitability but also an entire sociotechnical system. By „Lean,” we mean the philosophy and discipline derived

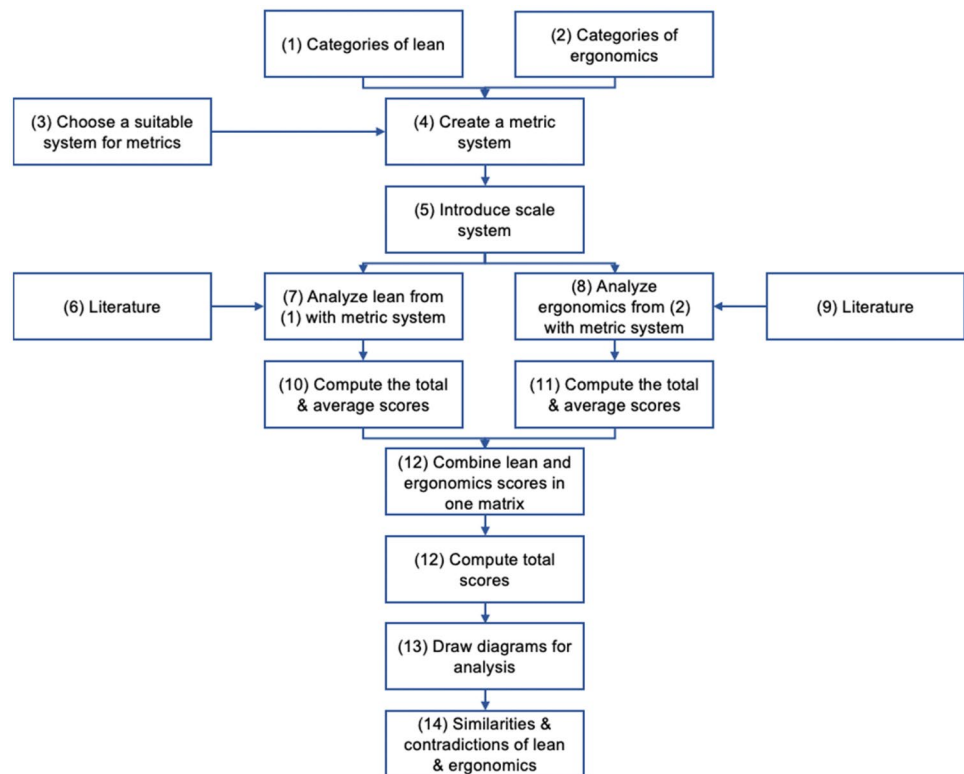
from lean management, lean production, lean manufacturing, and the Toyota Production System. When it is specified, we write „lean [...]” By „Ergonomics,” we mean the discipline. When it is specified, we write „[...] ergonomics.”

2 Theoretical background

First, as depicted in Fig. 1, categories of Lean (1) and Ergonomics (2) are selected, filtered, and compiled from research papers and textbooks for later analysis. A metric system including Lean and Ergonomics is selected from the literature (3). Next, the elements of the metric system are further evaluated, and a matrix is created to form a final metric system (4). A scale system is then developed to measure the interdependence between Lean and Ergonomics categories with the metric system (5). After that, the analysis of Lean (7) and Ergonomics (8) with the metric system is carried out using relevant literature (6) and (9). Then, the total and average scores of Lean (10), Ergonomics (11), and the combined characteristics are calculated (12). Lean and Ergonomics are combined in a matrix to compare results and calculate total scores (13). Graphs and charts are drawn for better visualization and analysis (14). Finally, the similarities and differences between Lean and Ergonomics are discussed.

2.1 Categories of lean

First, a literature review in Google Scholar and Scopus is conducted with the following search terms: (lean production OR lean manufacturing OR lean implementation OR Toyota Production System) AND (tools OR principles OR methods) to obtain categories of Lean. This literature search was not limited by time frame but by relevance, citations, and timeliness. Timeliness is essential for this literature as a basis for forming the Lean categories in this article because only the current literature covers the latest developments in Lean. Only English-language peer-reviewed sources were included. Articles from Google Scholar were included only if the search terms appeared in the title. Articles from Scopus were included if the search terms appeared in the title or keywords section of the article. Next, all Lean methodologies are compiled and filtered from research reports to create a list of the seven most commonly used tools in the industry based on the articles in this paper, listed below (Top 7 in bold). Table 1 shows the compilation of different Lean tools with relevant research papers and textbooks. The top Lean tools used in the industry are Kanban, Kaizen, Poka-yoke, 5S (sort, set in order, shine, standardize, sustain), TPM (Total Productive Maintenance), VSM (Value Stream Mapping), and SMED (Single-minute exchange of die) (Dombrowski 2015; Koether and Meier 2017), which are also used in this article.

Fig. 1 Flowchart of the methodology

2.2 Categories of ergonomics

In defining the categories of Ergonomics, we have been guided by the International Ergonomics Association (IEA). The IEA divides Ergonomics into “physical,” “cognitive,” and “organizational” Ergonomics. *Physical ergonomics* includes anatomical, physiological, and biomechanical aspects. It prioritizes the worker's wellbeing, considering environmental factors such as lighting and temperature that affect productivity (Gitahi et al. 2015; McGuire and McLaren 2009). Herzberg's theory emphasizes the role of the environment in worker performance (Herzberg 2008). *Cognitive ergonomics* includes mental aspects such as perception and reasoning that affect human-system interactions (Carayon et al. 2013; IEA 2023). It includes logical reasoning, perception, motor responses, and workplace interactions (IEA 2023). Training is positively correlated with performance (Karimi and Nejad 2018). *Organizational ergonomics* analyzes and optimizes the macroscopic production system by aligning structures, policies, and processes (IEA 2023). It increases efficiency by considering workers' activities, abilities, and constraints (Latip et al. 2022). Organizational ergonomics affects employee motivation and performance, critical to business success (Paais and Pattiruhu 2020).

2.3 Literature search based on defined categories

The literature reviewed for the article was limited to the period from 1990 to January 2023. We chose this period because Lean only became widely known in the West with the publication of Womack et al. (1990). Then, it took several years to establish Lean in manufacturing and OPM (Dombrowski 2015). We also wanted to consider the transition from Industry 3.0 to Industry 4.0 (Sakhapov and Absalyamova 2018). In addition, musculoskeletal work-related disorders manifest themselves with a long time lag, which can result in complaints only appearing 20 to 30 years after the introduction of a production or work-changing measure. Production processes that make people sick have not affected the company's profitability, which means that Ergonomics has not been a must-have from a purely economic point of view. With demographic changes and the increasing number of people with reduced performance, this is changing (Anderson-Connolly et al. 2002; Baur 2013).

We searched for all possible combinations of [Top 7 items of Lean category] AND [three items of Ergonomics category] in Google Scholar and Scopus (title, abstract, keywords). Only articles and textbooks pertinent to the study's context and aim are incorporated. The literature review is

Table 1 Lean tools as categories of Lean used in this paper (Top 7 in bold)

<i>Lean tools</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>	<i>j</i>	<i>k</i>	<i>Total</i>
Poka-Yoke/mistake handling	x	x		x			x	x		x	x	7
Andon								x			x	2
Heijunka/level scheduling	x			x		x				x	x	5
Man-Machine												0
5S	x	x		x			x		x	x	x	7
Pull flow/Kanban	x	x	x	x	x	x	x	x	x	x	x	11
VSM	x	x	x	x			x	x	x		x	8
Standardization	x	x	x	x						x	x	6
TPM	x	x		x	x	x				x	x	7
Visual management	x					x				x	x	4
Kaizen	x	x	x	x		x	x	x	x	x	x	10
JIT (just-in-time)		x			x		x				x	4
Jidoka/Automation	x			x						x	x	4
SMED	x			x			x	x	x	x	x	7
Continuous flow											x	1
PDCA											x	1
Matrix skills										x		1

^a (Andrés-López et al. 2015)^b (Adesta et al. 2018)^c (Nunes 2018)^d (Rewers and Chabowski 2016)^e (Sivaraman et al. 2020)^f (Pakdil and Leonard 2014)^g (Moon et al. 2014)^h (Kolberg and Zühlke 2015)ⁱ (Nunes 2015)^j (Carvalho et al. 2019)^k (Leksic et al. 2020)

not meant to be a thorough and systematic exploration of the literature on OPM, Lean, and Ergonomics. Instead, it aims to summarize their connections, arranged and categorized in new ways to assist OPM users/managers in their decision-making and actions.

2.4 The socio-technical-system theory

The concept of the socio-technical-system (STS) was first introduced by Leavitt (1965), who categorized organizations into *people*, *task structure*, and *technologies*. In 2011, Clegg & Challenger expanded this using six categories: *goals*, *people*, *infrastructure*, *technology*, *culture*, and *processes*, emphasizing their interconnectedness (Clegg and Challenger 2011). This study's metric framework is derived from Clegg and Challenger (2011) and uses five elements adapted to analyze lean production/manufacturing and Ergonomics synergies and contrasts. Table 2 shows the adapted elements.

The sociotechnical factor “goals” is not included due to industry-specific variations. The remaining five factors are introduced in the following sections.

Table 2 Sociotechnical factors from Clegg and Challenger (2011) (adopted for this article)

Sociotechnical factors from Clegg and Challenger (2011)	Sociotechnical factors used in this article
People	Production worker
Building/ Infrastructure	Physical environment
Technology	Industry 4.0 (i4.0) technology
Culture	Company culture
Procedure/Process	Manufacturing methods
Goals	-

Table 3 Production worker factor (Sakthi et al. 2019)

Production worker category	Subcategory
Physical	Working posture
	Weight/force
	Work intensity
Psychosocial	Job stress
	Job satisfaction
Work design	Job autonomy
	Job clarity
	Time pressure
	Rotation
Managerial factor	Communication
	Supervisor/co-worker support
	Reduction of resources

2.4.1 The production worker

For a more detailed analysis, we subdivide the production worker factor according to Sakthi et al. (2019) into four categories: *physical*, *psychosocial*, *work design*, and *managerial factors*, as shown in Table 3.

2.4.2 Company culture

The company culture factor used in this paper is taken from the concept from Cameron and Quinn (2011), which is further divided into four categories: *hierarchical*, *market*, *clan*, and *adhocracy cultures*, as shown in Table 4 (Cameron and Quinn 2011).

2.4.3 Physical environment

An ideal physical environment of the workplace is where workers' physical and cognitive abilities can perform at their best and thus achieve the objectives and goals of both workers and the company (Chua et al. 2016). The

physical environment factor is further divided into three categories in Table 5 (Schlick et al. 2010; Schmauder and Spanner-Ulmer 2022).

2.4.4 Manufacturing process

The manufacturing process factor for this paper is divided into *labor-intensive* and *capital-intensive* methods. Their descriptions are shown in Table 6.

2.4.5 Technology (i4.0)

In the technology category from Leavitt (1965), i4.0 technology and tools are adopted as our category in the sociotechnical system. Table 7 shows the top i4.0 tools in the industry taken from five research papers. These five articles were used to form the categories, firstly because they are current, which is relevant to technological developments, and secondly because they consider and analyze technology in general in the context of Industry 4.0.

2.5 Hypotheses

Now that STS, as the relevant metric, and the categories of Lean and Ergonomics that are grouped in STS via literature are known, the following hypotheses (H) are proposed (see Tab. 8):

- H1: Industry 4.0 technology is a Lean/OPM category
- H2: Manufacturing process is a Lean/OPM category
- H3: Production worker is an Ergonomics category
- H4: Physical environment is an Ergonomics category
- H5: Company culture is a Lean/OPM category

2.6 Evaluation matrix

Table 9 below shows the matrix used to analyze Lean and Ergonomics. The different scales were sorted in ascending

Table 4 Company culture factor

Company culture category	Description
Hierarchical culture	The hierarchical culture emphasizes the internal environment of the company. Typical characteristics are well-defined and standardized procedures, roles, and work processes (Reis et al. 2016).
Market culture	Market culture focuses on controlling the external environment, in which workers strive to achieve goals to meet customers' demands (Cameron and Quinn 2011).
Clan culture	Clan culture focuses on the internal environment and highlights the human factor, whereby workers are valued and appreciated (Cameron and Quinn 2011).
Adhocracy culture	Adhocracy culture focuses on the external environment and flexibility, whereby workers are encouraged to explore and innovate products (Cameron and Quinn 2011).

Table 5 Physical environment factor (for details, see Luczak et al. 2018; Schmauder and Spanner-Ulmer 2022)

Physical environment category	Description
Temperature	The workplace temperature should be a minimum of 13°C for production workers to work productively.
Lighting	The workplace lighting must be bright enough to prevent eyestrain, stress, and accidents and improve productivity.
Noise	Noise is defined as all the sound in the workplace, either wanted or unwanted. It is one of the most common Occupational Health and Safety (OHS) hazards and is found in different environments (Trebuna et al. 2017).

Table 6 Manufacturing process factor

Manufacturing process categories	Description
Labor-intensive	Manufacturing process has more human labor than production machinery (Kenton 2003).
Capital-intensive	Manufacturing process relies on machinery rather than labor to produce goods and services (Frankenfield 2003).

Table 7 Analysis of the i4.0 technology tools

I4.0 technology tools	a	b	c	d	e	Total
Additive manufacturing (AM)	x	x	x	x	x	5
Machine learning (ML)	x	x	x	x	x	5
Plug and play	x					1
Human-Computer Interaction (HCI)	x	x	x		x	4
Virtual/Augmented reality (VR/AR)	x	x	x	x	x	5
Digital twin	x	x	x		x	4
Big data and analytics	x	x	x	x	x	5
Cloud computing	x	x	x	x	x	5
Blockchain		x			x	2

^a (Mayr et al. 2018)^b (Jiang et al. 2021)^c (Mayr et al. 2017)^d (Vinodh and Wankhede 2021)^e (Chae and Olson 2022)**Table 8** Hypotheses of the category of sociotechnical factors

Hypothesis	
Lean/OPM	I4.0 technology Manufacturing process Company culture
Ergonomics	Production worker Physical environment

and descending order using Microsoft Excel. This way, it is possible to visualize the categories with the highest and lowest degrees.

This analysis employs a binary scale, wherein “X” denotes a positive interdependence, while “blank” indicates a negative or no interdependence. “Negative or no interdependence” was defined as: negative interdependence, no interdependence, and no information. Category headings for

Table 9 Evaluation matrix of Lean and Ergonomics

Sociotechnical factor	Subcategory	Lean or Ergonomics categories			Total score	Average score for each subcategory	Weighted average score for each subcategory
		a	b	...			
Production worker	Working posture						
Production worker	Weight/force						
Production worker	Physical porosity						
Production worker	Job stress						
Production worker	Job satisfaction				(i)	(ii)	(iii)
Production worker	Job autonomy						
Production worker	Job clarity						
Production worker	Rotation						
Production worker	Communication						
Production worker	Supervisor support						
Production worker	Reduction of resources						
Company culture	Hierarchy						
Company culture	Market						
Company culture	Clan						
Company culture	Adhocracy						
Physical environment	Temperature						
...	...						

Lean or Ergonomics in Table 9 are denoted by letters “a,” “b,” and so on and are marked in blue. For Lean, these categories may include Poka-Yoke, Kaizen, and so on, while for Ergonomics, they include physical, cognitive, and organizational Ergonomics. Table 10 shows the formulas to compute the values required for further evaluation. The association between Lean and Ergonomics with the sociotechnical factor is evaluated using the binary scale in the blue-shaded cells. Then, the cumulative score of each subcategory of the Lean and Ergonomics evaluations is ascertained in the red-shaded cells. The analysis of (i) is done by calculating (ii), (iii), and (iv) (Table 10).

(ii) The average Lean or Ergonomics score of a subcategory of sociotechnical factors shows the correlation of each subcategory of sociotechnical factors with Lean or Ergonomics. The scores in the green cells are calculated using (i) the sum of all Lean or Ergonomics categories scores in each sociotechnical subcategory divided by the percentage of the number of Lean or Ergonomics categories. (iii) The weighted average Lean or Ergonomics score of each sociotechnical factor subcategory is the same as (ii) with additional weighting. (iii) The scores in the purple cells are calculated by taking the average Lean or Ergonomics scores in (ii) and dividing by the number of

Table 10 Mathematical formulas used in the analysis

Variable	Formula (with sample entries)
i Total score of each sociotechnical subcategory	Total score of each sociotechnical subcategory $= \sum_{n=\text{Poka-Yoke or physical ergonomics}}^{\text{SMED or organizational ergonomics}} \text{Lean or Ergonomics in binary (n)}$
ii Average Lean or Ergonomics score of a subcategory of sociotechnical factor	The average score of each subcategory of the sociotechnical factor $= \frac{\sum_{n=\text{Poka-Yoke or physical ergonomics}}^{\text{SMED or organizational ergonomics}} \text{score of each subcategory (n)}}{\text{\#of Lean or Ergonomics categories}} * 100\%$
iii Weighted average Lean or Ergonomics score of each subcategory of sociotechnical factor	Weighted average score $= \frac{\text{Average Lean or Ergonomics score of each subcategory}}{\text{\#of subcategories of a sociotechnical factor}}$
iv Score of sociotechnical factor (%)	Score of sociotechnical factor $= \sum_{n=\text{Poka-Yoke or physical ergonomics}}^{\text{SMED or organizational ergonomics}} \text{Weighted average score of subcategory}$

Table 11 Summary of Lean and Ergonomics score using the sociotechnical metrics

Sociotechnical factor	Average Lean score	Average Ergonomics score	Weighted Lean score	Weighted Ergonomics score
Physical environment	24%	100%	9%	24%
Production worker	44%	86%	17%	21%
Company culture	46%	83%	21%	20%
Manufacturing process	64%	83%	25%	20%
Technology (i4.0)	71%	67%	28%	15%
Total	/	/	100%	100%

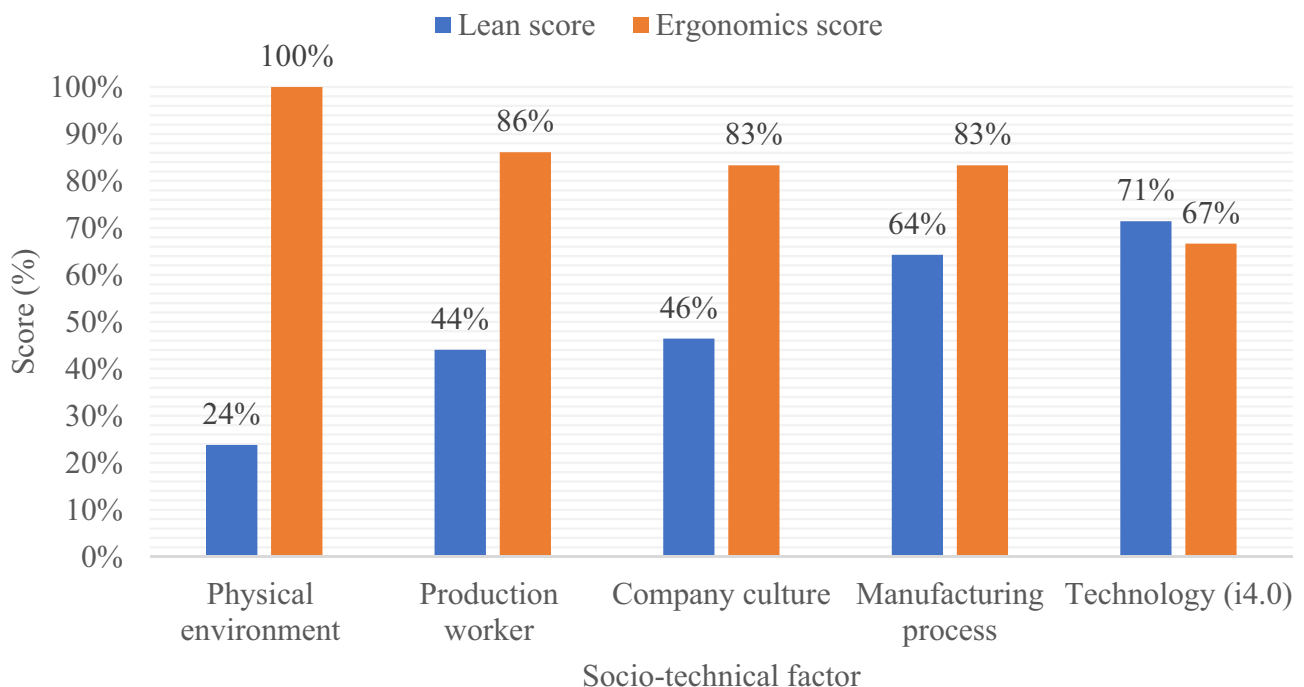
subcategories of a sociotechnical factor. The Lean or Ergonomics scores of the sociotechnical factors (iv) determine the correlation between Lean or Ergonomics and the socio-technical metrics and are calculated using the sum of (iv).

3 Results

Table 11 shows the results of Lean and Ergonomics scores on the sociotechnical metrics. Average and weighted Lean and Ergonomics scores are computed using the formula in Table 10 (see appendix for single evaluation matrix).

Technology (i4.0) and manufacturing process, with 71% and 64%, respectively, are the highest-scoring sociotechnical factors for Lean categories (blue bars) (Fig. 2). The third highest Lean score is the company culture factor,

which has an average Lean score of 46%. Figure 3 also shows the evaluation of Ergonomics with the sociotechnical metrics (orange bars); the physical environment category has the highest Ergonomics score, which is 100%. All three categories of Ergonomics are positively correlated with the physical environment factors such as temperature, sound, and noise. The second-highest Ergonomics score is in the category of production workers, with a score of 86%. At first glance, cognitive Ergonomics is not correlated with the physical characteristics of production workers: posture, weight or force, and porosity. Two categories that score 83% are company culture and manufacturing process factors, considered both Lean and Ergonomics. Hierarchy and clan cultures are strongly associated with Ergonomics, while adhocracy and market cultures are less correlated. Despite being more specific than categories

**Fig. 2** Bar chart of the comparison of Lean and Ergonomics using the sociotechnical metrics

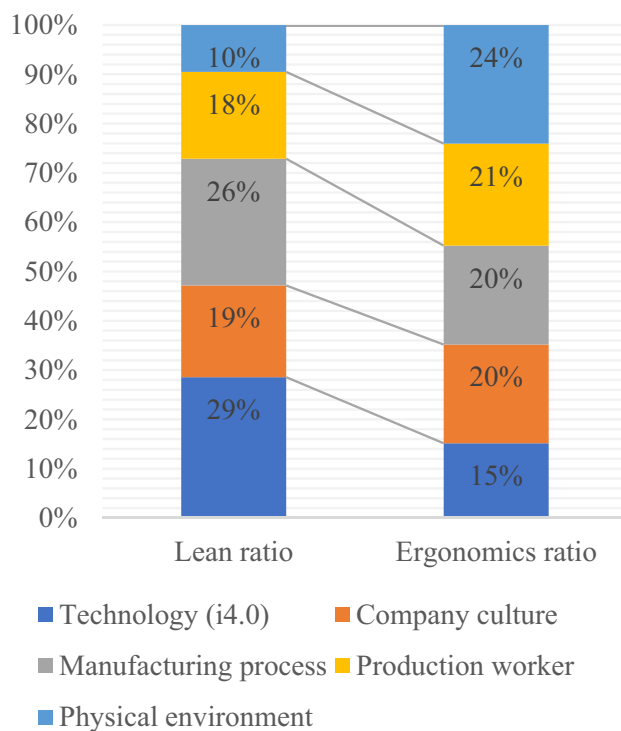


Fig. 3 Stacked chart of the comparison of Lean and Ergonomics with the sociotechnical metrics

of Ergonomics, Lean tools still encompass the same principles. Therefore, it is considered plausible and accurate to utilize the ratio of the weighted average of Lean and Ergonomics scores, as presented in Fig. 3's stacked chart. This approach allows for effective comparison and analysis of similarities and differences.

From the stacked chart in Fig. 3, the significant contradictions between Lean and Ergonomics are the physical environment and technology (i4.0). The factors that exhibit more remarkable similarities than contradictions between Lean and Ergonomics comprise company culture, production worker, and manufacturing process. These factors are expected to hold features of both Lean and Ergonomics, which explains the resulting higher number of similarities compared to contradictions.

4 Discussion, recommendations for the OPM user, and limitations

4.1 Discussion

The highest-scoring sociotechnical factors for Lean categories (blue bars) are technology (i4.0) and manufacturing process, with 71% and 64%, respectively (Fig. 3). Schumacher et al. explain that technology i4.0 tools play an essential role in today's manufacturing sector where manufacturers compete to produce high-quality products, increase productivity, and reduce costs (Schumacher et al. 2016). The development of i4.0 technology allows production to be flexible and modular, supporting companies in the mass production of customized products, thus supporting the Lean principles of reducing waste and increasing efficiency (Fettermann et al. 2018; Huang et al. 2021). In the manufacturing process factor, the higher Lean score in manufacturing processes explains that lean manufacturing supports labor-intensive manufacturing by identifying bottlenecks and increasing quality proofing and throughput (Comm and Mathaisel 2005). The third highest Lean score is the company culture factor, with an average Lean score of 46%. Most of the Lean tools in our study support the hierarchical culture, and none support the adhocracy culture. This is because hierarchical culture focuses on control, standardization, and predictable performance outcomes, which promotes effective Lean processes compared to other organizational cultures (Pakdil and Leonard 2015). Finally, the production workers and physical environment factors are the lowest among the five factors, with 44% and 24%, respectively.

The reason for the low Lean score in the production workers factor is that worker ergonomics and safety should be addressed in lean manufacturing because the focus is on increasing productivity and reducing waste (Cirjaliu and Draghici 2016). Finally, more research needs to be done on the relationship between the physical environment and concrete Lean tools. From the literature review, only a few studies mentioned the importance of good lighting and temperature on worker performance, and none mentioned noise.

Company culture and manufacturing process factors, classified as *Lean* and *Ergonomics*, score 83%. Hierarchy and clan cultures are strongly associated with *Ergonomics*, while adhocracy and market cultures show modest correlations. This may be because clan and hierarchical cultures support workers' quality of life and wellbeing, leading to job satisfaction and cognitive *Ergonomics* (Paz et al. 2020). In capital-intensive manufacturing, many machines are ergonomically designed to support workers with mental and physical workloads (Karwowski and Marras 1999). Similarly, *Ergonomics* is positively correlated with labor-intensive manufacturing, but only if workers' wellbeing is well taken care of – for example, if workers' workloads match their capacities. Finally, technology i4.0 has the lowest *Ergonomics* score of all the sociotechnical factors, at 67%. This supports the assumption made at the beginning that there is a danger that the human factor in innovation-oriented OPM will be unjustly neglected and that too much emphasis will be placed on pure, supposedly human-free technology in the development of Industry 4.0 (Chen et al. 2023; Tripathi et al. 2023).

Figure 2 shows that the *Ergonomics* ratings are generally higher at the initial inspection than the *Lean* ratings. The difference may be due to the different categories chosen for *Lean* and *Ergonomics*. The *Lean* categories are taken from *Lean* tools, while the *Ergonomics* categories are taken from the three pillars of *Ergonomics*. *Ergonomics* tools were first used to analyze the sociotechnical factors before the three pillars of *Ergonomics*. However, most results showed no correlation between *Ergonomics* and sociotechnical factors, which did not yield an acceptable result. This is because *Ergonomics* tools are rigid and inflexible and exist primarily in assessment forms, measurement methods, or measuring tools (Brunner et al. 2023). *Lean* tools such as Kaizen or Poka-Yoke are based on principles and are more flexible and comprehensive, making them more suitable for analysis. As Brunner et al. (2022) described, *Lean Ergonomics* can help production ergonomics achieve “lean-like” principles. *Ergonomics* needs more content that has been prepared in a dogma-like manner like that of the *Lean* philosophy and thus can find many more supporters in companies than, for example, the complex operation of a motion-capturing system.

This was also indirectly confirmed by the attempt to create similar categories based on shared principles.

In the stacked chart, the biggest contradiction between *Lean* and *Ergonomics* is the physical environment factor (Fig. 3). *Lean* has a physical environment score of 10%, while *Ergonomics* has a score of 24%. Numerous studies have shown that an optimal physical environment improves *Ergonomics* and enables workers to achieve higher overall productivity and efficiency (Kamarulzaman et al. 2011; Zare et al. 2016). However, some studies suggest that lean manufacturing has a negative impact on the physical work environment and the wellbeing of workers, especially in manual work (Anderson-Connolly et al. 2002; Hasle et al. 2012). It was also noted that *Lean* views employees more quantitatively, not qualitatively, in its holistic application in OPM. We suspect this is due to a ‘deterrent function’ of complex, expensive ergonomic studies. In the literature review, we identified mainly *Ergonomics* measurement methods and expert tools rather than practitioner-oriented guidelines or concepts as they exist in *Lean* – and are known down to the shop floor level. This also needs to be further discussed by *Ergonomics* as to how the meso level between the system-centered macro level of OPM and the human-centered micro level of *Ergonomics* can be served. The second largest contradiction between *Lean* and *Ergonomics* is the technology (i4.0) factor, which scores 29% and 16% for *Lean* and *Ergonomics*, respectively. Some studies mentioned in the above section, such as Neumann et al. (2021), concluded that there needs to be more focus on the *Ergonomics* aspect in the study and development of i4.0. Both lean manufacturing and i4.0 focus on increasing quality, productivity, and efficiency of production, waste reduction, and customer-centric systems (Buer et al. 2018). Both *Lean* and *Ergonomics* place a high value on employees in labor-intensive manufacturing settings that require significant investment. Labor-intensive manufacturing increases overall process efficiency and reduces labor waste (King et al. 2008; Tanner and Roncarti 1994). In capital-intensive manufacturing, new machine technology assists workers with mental and physical workloads (Karwowski and Marras 1999). From the corporate culture factor results, hierarchical and clan cultures support both *Lean* and *Ergonomics*.

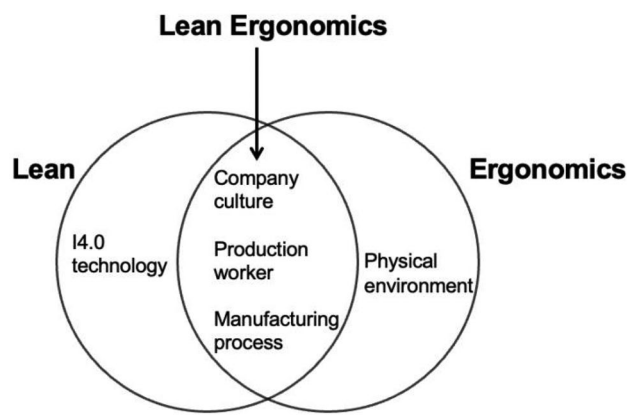


Fig. 4 Results of the categories of sociotechnical factors

In contrast, market culture is considered to have more Lean aspects, and adhocracy culture has more ergonomic aspects than Lean aspects. The surprising result is the production worker factor. While it was expected to tend toward Ergonomics, the results show that production workers support both Lean and Ergonomics. The analysis shows that Lean and Ergonomics share the same goals of increasing employee job satisfaction, reducing waste, and achieving efficiency, which supports Brunner et al.'s (2022) concept of Lean Ergonomics and thus calls for the consideration of the human factor in OPM systems.

Based on the results and the literature discussion, the hypotheses are processed in the following way.

H1: Industry 4.0 technology is a Lean/OPM category
→ accepted

H2: Manufacturing methods is a Lean/OPM category
→ rejected

H3: Production worker is an Ergonomics category

→ rejected

H4: Physical environment is an Ergonomics category

→ accepted

H5: Company culture is a Lean/OPM category

→ rejected

Hypotheses H2, H3, and H5 are rejected based on our results. The STS elements are therefore arranged as follows (Fig. 4 and Table 12). Because of the significant overlap between Lean and Ergonomics in the areas of “Company culture,” “Production worker,” and “Manufacturing process,” an additional category – Lean Ergonomics – is suggested (according to Brunner et al. 2022).

4.2 Recommendations for the OPM user

Based on the literature reviewed for this article and the findings based on the methodology presented, implications for OPM users are summarized.

- **Company Culture:** Among company culture factors, hierarchical and clan cultures support Lean and Ergonomics. Therefore, companies should pay special attention to Ergonomics and OPM in hierarchical/clan organizational structures.
- **Employee Productivity and Satisfaction:** Lean and Ergonomics have similar goals, such as increasing employee satisfaction and efficiency, and reducing waste.
- **Integrating Ergonomics into OPM/Lean:** Integrating Ergonomics into Lean benefits workplace efficiency and cost reduction. Ergonomic studies do not have to be expensive and time-consuming. There are Lean-like approaches that combine Ergonomics and OPM using a modular methodology system.
- **Importance of Ergonomics:** Ergonomics is an essential element of operational performance management efforts, especially in labor-intensive environments with manual tasks.
- **Technology (i4.0):** Introducing technology (i4.0) risks unjustifiably neglecting ergonomic aspects. This leads to ergonomic challenges, which in turn conflict with the profitability of the technological measure.
- **Organizational Structure and Responsibilities:** Neither Lean/OPM departments nor occupational Health/Ergonomics departments should be solely responsible for actions affecting production workers, company culture, and manufacturing methods.

Table 12 Comparison of the hypotheses and results of the categories of sociotechnical factors

	Hypothesis	Results of this paper
Lean/OPM	i4.0 technology Manufacturing process Company culture	i4.0 technology
Lean Ergonomics	/	Company culture Manufacturing process Production worker
Ergonomics	Production worker Physical environment	Physical environment

4.3 Limitations and future research

As a limitation, this study does not claim comprehensiveness of the literature review due to several factors, which can lead to biases. The seven most important Lean methods were selected from the literature and compared to Ergonomics. The categorical classification of Lean tools and methods is based on 11 selected articles, each dealing with several Lean methods per se. At the same time, these methods were qualitatively compared with those from standard works on Lean (Bertagnoli 2022; Bhasin 2015; Davim 2018; Monden 1983; Shingō and Dillon 2006; Womack et al. 1990), and congruence was identified. Other Lean methods may address Ergonomics differently. Other classifications for Ergonomics were examined, but none was found to be more appropriate than the IEA's. "Goals" from the STS theory were not considered because Lean and Ergonomics have different goals depending on the company's size and the industry. Further research should consider "goals" and how company size and industry influence them. The authors have classified technologies, methods, and principles to the best of their knowledge, but these may need to be clarified for reasons of binarity or classification. This study provides a starting point for evaluating and understanding the synergies and differences between Lean and Ergonomics. However, it is limited to sociotechnical factors and does not address all aspects, such as cost.

The binary system used here does not distinguish between negative interdependence, no interdependence, and no information available. All these three aspects are understood as the binary counterpart of "positive interdependence." Further research could start here and expand the binary system into a fourfold division. Web of Science could be included as a search engine in further research. The abandonment of Google Scholar due to reduced search options must be considered.

Overall, this paper has methodically deduced that three factors – company culture, manufacturing process, and production worker – have more commonalities than differences in Lean and Ergonomics and can indeed be categorized as "Lean Ergonomics" in the category shown in Fig. 4. For those factors that have more similarities than contradictions, such as company culture, manufacturing

processes, and production workers, it is recommended that they be studied in more detail so that the information can be used to improve both worker wellbeing and workplace performance.

5 Conclusion

This paper proposes a sociotechnical metric system based on Clegg and Challenger (2011) that includes both human and technological factors to analyze the similarities and contradictions of Lean and Ergonomics. Company culture, production worker, physical environment, manufacturing process, and technology (i4.0) are included as factors in the metric system, and a binary scale is used for the analysis. The analysis shows that measures and decisions focusing on Ergonomics should be combined with those on Lean because there are more similarities than contradictions between Lean and Ergonomics. Lean and Ergonomics have remarkable synergies in manufacturing processes, company culture, and production worker factors but less so in the physical environment and technology, which is essential for OPM to know. This study also helps to answer the general question: Are Lean and Ergonomics compatible? Although the total score for Ergonomics in each sociotechnical factor is higher than that for Lean, the results are considered valid when converted to the ratio of the scores. It is also interesting to note that the production worker factor, previously thought to be Ergonomics rather than Lean, contains both Lean and Ergonomics aspects. Introducing and exploring new technologies is usually separated from the human factor, even though the human is involved as both the designer and the user. Neglecting Ergonomics in this process jeopardizes profitability and can cause unexpected stress to employees. In conclusion, the advantages of combining Lean and Ergonomics in an OPM system outweigh the disadvantages.

Appendix 1: Lean evaluation

See Tables 13, 14, 15, 16, and 17.

Table 13 Lean score of the production worker factor

Production worker category	Subcategory	Poka-Yoke	5S	Kanban	VSM	TPM	Kaizen	SMED
Physical	Working posture		X ^a					
Physical	Weight/force		X ^a					
Physical	Physical porosity							
Psychosocial	Job stress	X ^c	X ^a	X ^b	X ^c		X ^d	
Psychosocial	Job satisfaction	X ^c	X ^{a,f}	X ^{f,b,g,h}	X ⁱ	X ^j	X ^{k,d,l}	X ^m
Work design	Job autonomy			X ^{n,o,p}			X ^{e,q,u}	
Work design	Job clarity			X ^r		X ^{s,t}	X ^u	X ^{gg}
Work design	Time pressure	X ^e						
Work design	Rotation			X ^{v,w}			X ^x	
Managerial factor	Communication	X ^{y,z}	X ^{aa}	X ^{bb}		X ^{cc}	X ^{aa,dd}	X ^{ee}
Managerial factor	Supervisor support		X ^{a,aa}			X ^{i,ff}	X ^{u,aa}	X ^{gg}
Managerial factor	Reduction of resources	X ^{q,hh}	X ^{q,hh,ii}		X ^c	X ^{jj}		X ^{kk}

^a (Pinitchan and Pinitchan 2008)^b (Laanti 2013)^c (Riezebos and Huisman 2021)^d (Hagos 2016)^e (Erlandson et al. 1998)^f (Brkic and Tomic 2016)^g (Aguilar-Escobar et al. 2015)^h (Murrells et al. 2005)ⁱ (Lindskog et al. 2016)^j (Brah and Chong 2004)^k (Tomic et al. 2017)^l (Thiele Schwarz et al. 2017)^m (Müller and Leyer 2022)ⁿ (Gilson et al. 2015)^o (Moe et al. 2019)^p (Parker and Wall 2006)^q (Drotz and Poksinska 2014)^r (Ostergaard 2016)^s (Suzuki 2017)^t (Carannte 1995)^u (Bortolotti et al. 2018)^v (Ahmad et al. 2013)^w (Mukhopadhyay and Shanker 2005)^x (Rinehart et al. 1994)^y (Vinod et al. 2015)^z (Shahin and Ghasemaghaei 2010)^{aa} (Gupta and Jain 2014)^{bb} (Zayat and Senvar 2020)^{cc} (Witt 2006)^{dd} (Wickens 1990)^{ee} (Moxham and Greatbanks 2001)^{ff} (Ireland and Dale 2001)^{gg} (Groneberg et al. 2021)^{hh} (Treville and Antonakis 2006)ⁱⁱ (Ghany 2010)^{jj} (Lawrence 1999)^{kk} (Bragança et al. 2013)

Table 14 Lean score of the company culture factor

Company culture category	Poka-Yoke	5S	Kanban	VSM	TPM	Kaizen	SMED
Hierarchy culture	X ^a	X ^{b,c}	X ^c	X ^c	X ^c	X ^c	
Market culture			X ^c	X ^c	X ^c		
Clan culture	X ^{d,e,f}	X ^c	X ^d				
Adhocracy culture						X ^d	

^a (Cameron and Quinn 2011)^b (Gambi et al. 2013)^c (Paro and Gerolamo 2015)^d (Anderson 2010)^e (Stock et al. 2007)^f (Tomic et al. 2017)**Table 15** Lean score of the manufacturing process factor

Manufacturing process category	Poka-Yoke	5S	Kanban	VSM	TPM	Kaizen	SMED
Labor-intensive		X ^a	X ^b		X ^c	X ^{d,e,f}	
Capital-intensive	X ^g			X ^h	X ⁱ	X ^j	X ^{k,l}

^a (Peng and Wei 2010)^b (Jin 2014)^c (Jeong and Phillips 2001)^d (Prošić 2011)^e (Tanner and Roncarti 1994)^f (Brown et al. 2006)^g (Wadhwa 2012)^h (King et al. 2008)ⁱ (Kumar et al. 2014)^j (Boyle 1998)^k (Stapelbroek et al. 2022)^l (Palanisamy and Siddiqui 2013)**Table 16** Lean score of physical environment factor

Physical environment category	Poka-Yoke	5S	Kanban	VSM	TPM	Kaizen	SMED
Temperature			X ^{a,b}	X ^c			
Lightning		X ^d	X ^{a,e}				X ^f
Noise							

^a (Simons and Mason 2003)^b (Carvalho et al. 2019)^c (Chiarini 2014)^d (Carvalho et al. 2019)^e (Hartini et al. 2019)^f (Faulkner and Badurdeen 2014)

Table 17 Lean score of technology (i4.0) factor

I4.0 technology category	Poka-Yoke	5S	Kanban	VSM	TPM	Kaizen	SMED
AM	X ^a				X ^b		X ^{c,e}
ML	X ^{d,e,f}		X ^{f,v}	X ^g	X ^{h,i,b}	X ^j	X ^f
VR/AR	X ^k	X ^{l,o}			X ^{m,n}	X ^o	X ^{p,o}
Big data & analytics	X ^e		X ^q	X ^r	X ^{s,b}	X ^{f,t}	
Cloud computing	X ^{e,u}		X ^v		X ^b		
HCI/HMI	X ^e	X ^{w,x}	X ^y	X ^e	X ^{z,aa}	X ^{bb}	
Digital twin	X ^{e,cc}	X ^{dd}	X ^x	X ^{ee,ff}	X ^{gg}	X ^{f,hh}	X ⁱⁱ

^a (Pancha 2022)^b (Tortorella et al. 2021)^c (Feldmann and Gorj 2017)^d (Brunner 2011)^e (Mayr et al. 2018)^f (Ciano et al. 2021)^g (My 2021)^h (Jardine et al. 2006)ⁱ (Lucke et al. 2017)^j (Thakur et al. 2020)^k (Rammelmeier et al. 2012)^l (Pötters et al. 2017)^m (Palmarini et al. 2018)ⁿ (Benbelkacem et al. 2011)^o (Cudney et al. 2011)^p (Tothong et al. 2020)^q (Saltz and Suthrland 2019)^r (Lucke et al. 2017)^s (Kieviet 2016)^t (Varian 2014)^u (Wijaya et al. 2020)^v (Reyes et al. 2023)^w (Neges et al. 2017)^x (Kolberg and Zühlke 2015)^y (El Abbadi et al. 2011)^z (Thakur and Panghal 2021)^{aa} (Kanta Patra et al. 2005)^{bb} (Cavadini and Pedrazzoli 2018)^{cc} (Zhihan et al. 2023)^{dd} (Deng et al. 2022)^{ee} (Trebuna et al. 2019)^{ff} (Lu et al. 2021)^{gg} (Barni et al. 2020)^{hh} (Umeda et al. 2020)ⁱⁱ (Guo et al. 2021)

Appendix 2: Ergonomics evaluation

See Tables 18, 19, 20, 21, and 22.

Table 18 Ergonomics score of production worker factor

Production worker category	Subcategory	Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
Physical	Working posture	X ^{a,b,c,d}		X ^m
Physical	Weight/force	X ^{a,e,f,g}		X ^m
Physical	Physical porosity	X ^{a,b,h}		X ^{m,b}
Psychosocial	Job stress	X ^d	X ^{i,j}	X ^m
Psychosocial	Job satisfaction	X ^d	X ^{k,l}	X ^{m,u,n,o}
Work design	Job autonomy	X ^d	X ^p	X ^q
Work design	Job clarity	X ^r	X ^s	X ^t
Work design	Time pressure	X ^d	X ^u	X ^{v,d}
Work design	Rotation		X ^s	X ⁿ
Managerial factor	Communication	X ^d	X ^w	X ^{w,v,m}
Managerial factor	Supervisor support	X ^d	X ^w	X ^u
Managerial factor	Reduction of resources		X ^w	X ^u

^a (Otto and Battaia 2017)

^b (Jarebrant et al. 2015)

^c (Vincent et al. 2015)

^d (Koukoulaki 2014)

^e (Sakthi et al. 2019)

^f (da Costa and Vieira 2010)

^g (van Rijn et al. 2010)

^h (Jonker et al. 2011)

ⁱ (Jahncke et al. 2011)

^j (Lagomarsino et al. 2022)

^k (Bryson et al. 2017)

^l (Shobe 2018)

^m (Olla 2012)

ⁿ (Bouville and Alis 2014)

^o (Rodríguez et al. 2016)

^p (Chung-Yan 2010)

^q (Hasle et al. 2012)

^r (Edwards 2014)

^s (Falck et al. 2014)

^t (Sprigg and Jackson 2006)

^u (Ehrensberger-Dow and O'Brien 2015)

^v (Bednárová-Gibová 2021)

^w (Berlin and Adams 2017)

Table 19 Ergonomics score of company culture factor

Company culture category	Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
Hierarchy culture	X ^a	X ^{d,f}	X ^{b,c,e}
Market culture		X ^d	X ^e
Clan culture	X ^a	X ^{d,f,g}	X ^h
Adhocracy culture	X ^a	X ^{d,f}	

^a (Paz et al. 2020)^b (Hendrick and Kleiner 2005)^c (Schutz et al. 2007)^d (Zahari and Shurbagi 2012)^e (Dubkēvičs and Barbars 2010)^f (Olynick and Li 2020)^g (Goodman et al. 2001)^h (Olla 2012)**Table 20** Ergonomics score of physical environment factor

Physical environment category	Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
Temperature	X ^{a,b,c}	X ^{d,e}	X ^{f,g}
Lightning	X ^{a,b}	X ^{h,d,i}	X ^{f,g}
Noise	X ^{a,b}	X ^{j,k,l,m}	X ^{f,g,n,o}

^a (Olla 2012)^b (Berlin and Adams 2017)^c (Jaffar et al. 2011)^d (Thaneswer 2013)^e (Vimalanathan et al. 2017)^f (Hendrick and Kleiner 2005)^g (Taghipour 2015)^h (Vischer 2007)ⁱ (Juslén et al. 2007)^j (Jahncke et al. 2011)^k (Couffe and Michael 2017)^l (Jafari et al. 2019)^m (Sundstrom et al. 1994)ⁿ (Stokols and Scharf 1990)^o (Hedge 1986)^p (Oldham 1988)**Table 21** Ergonomics score of manufacturing process factor

Manufacturing process category	Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
Labor-intensive		X ^a	X ^{b,c}
Capital-intensive	X ^{d,e}	X ^{f,g,e}	X ^g

^a (Akca and Küçükoğlu 2020)^b (Latip et al. 2022)^c (Larson et al. 2015)^d (Peruzzini and Pellicciari 2017)^e (Ciccarelli et al. 2022)^f (Morsy et al. 2016)^g (Karwowski and Marras 1998)**Table 22** Ergonomics score of technology (i4.0) factor

I4.0 technology category	Physical ergonomics	Cognitive ergonomics	Organizational ergonomics
AM	X ^{a,b}		X ^c
ML	X ^{d,e}	X ^{f,g}	X ^h
VR/AR	X ^{i,j,k}	X ^l	X ^{m,n,o,h}
Big data & analytics	X ^{p,q}	X ^{r,s}	
Cloud computing	X ^t	X ^{u,v,w}	
HCI/HMI		X ^x	
Digital twin			X ^{h,o}

^a (González et al. 2018)^b (Stoklasek et al. 2016)^c (Da Silva et al. 2020)^d (Hummel et al. 2015)^e (Lee et al. 2021)^f (D'Orazio et al. 2020)^g (Lazarova-Molnar et al. 2017)^h (Longo et al. 2017)ⁱ (Richert et al. 2016)^j (Horváth and Erdős 2017)^k (Scheuermann et al. 2016)^l (Chiabert and Aliev 2020)^m (Kadir et al. 2019)ⁿ (Stern and Becker 2017)^o (Pacaux-Lemoine et al. 2017)^p (Tatić and Tešić 2017)^q (Ahmed 2019)^r (Panagou et al. 2021)^s (Segura et al. 2020)^t (Hou et al. 2021)^u (Montini et al. 2021)^v (Du et al. 2020)^w (Fu et al. 2016)^x (Fatorachian and Kazemi 2018)

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Declarations

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Conflict of interest The authors declare that they have no conflict of interest and no competing interest.

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