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Development of Workplace Design Framework for Manufacturing Small and Medium-Sized Enterprises in Indonesia

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Abstract:

Purpose: This study aims to develop a workplace design framework suitable for manufacturing SMEs in developing countries, particularly in Indonesia, as a guide for manufacturing SME managers.

Design/methodology/approach: The development of workplace design framework in this study was initiated by reviewing the literature on the methodology or framework of workplace design in the manufacturing industry. The methodology or framework of workplace design was then analysed and evaluated based on the characteristics of SMEs to determine the possibility of its implementation in Indonesian manufacturing SMEs. Based on the analysis and evaluation results, a workplace design framework then proposed to assist SME managers in designing their workplaces.

Findings: Two of the five workplace design frameworks introduced by previous researchers have many conformities with the characteristics of manufacturing SMEs in Indonesia and can be implemented with minor adjustments. Finally, a workplace design framework has been developt and proposed to assist managers of manufacturing SMEs in Indonesia in designing their workplaces.

Research limitations/implications: This study offers a workplace design framework that can be applied by managers of manufacturing SMEs in designing their workplaces to obtain a safe, healthy and productive workplace.

Originality/value: This study is the first in developing a workplace design framework for manufacturing SMEs in developing countries, particularly Indonesia. The results of this study will be able to assist manufacturing SME managers in designing their workplaces.

Keywords: ergonomics, framework, methodology, process, workplace design

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1. Introduction

Workplace design in manufacturing small and medium-sized enterprises (SMEs) in developing countries faces many problems such as low productivity (Hermawati, Lawson & Sutarto, 2014), inadequate workspace conditions

(Hermawati et al., 2014), high safety and health risks (Agumba & Haupt, 2012; Işık & Atasoylu, 2017; Reinhold, Järvis & Tint, 2015; Sinclair, Cunningham & Schulte, 2013; Wang, Mei, Liu & Zhang, 2018) and high material handling costs (Mufti, Ikhsan & Putri, 2019; Trisusanto, Bariyah & Kristanto, 2020). This study examines workplace design frameworks in the manufacturing industry and evaluates their compliance with the characteristics of manufacturing SMEs in developing countries, particularly Indonesia. In this study, *manufacturing SMEs* refer to SMEs engaged in manufacturing machinery and other equipment. Furthermore, *manufacturing SME workplace* refers to the workplace in manufacturing SMEs in the form of the production space or area where the production process is performed and materials are transferred from one machine or workstation to another.

In general, the production facilities of SME workplaces in developing countries, particularly Indonesia, suffer from a lack of systematic design (Shikdar & Al-Araimi, 2001). As a result, the machines and production facilities in manufacturing SMEs in Indonesia are located only based on availability of space, and they often disrupt the movement of workers, increase the risk of accidents and hinder material handling activities (Mufti et al., 2019; Trisusanto et al., 2020). Furthermore, the application of ergonomics in SME workplace design has received little attention (Hermawati et al., 2014).

Workplace design can provide many benefits for companies, including increasing work effectiveness, physical and psychological health, performance, satisfaction, comfort, safety and productivity and reducing fatality and work accidents (Al Horr, Arif, Kaushik, Mazroei, Katafygiotou & Elsarrag, 2016; Bangwal & Tiwari, 2018; Candido, Thomas, Haddad, Zhang, Mackey & Ye, 2019; Chim, 2019; Li, Han, Gül & Al-Hussein, 2019; Nag, 2019; Tu'inukuafe, 2016). However, Chim (2019) stated that workplace design must incorporate ergonomic aspects for obtaining such benefits.

Several countries have developed guidelines for workplace design to produce an efficient and comfortable office space and increase productivity (Bakke, 2007; McBain, 2012). In addition, ergonomics has been used to improve occupational safety and health (OSH) and material handling in the manufacturing industry (Scott, Kogi & McPhee, 2010; Tondre & Deshmukh, 2019).

Studies have been performed on workplace design and its evaluation in the manufacturing industry (e.g. Dianat, Molenbroek & Castellucci, 2018; Leskovský, Kucera, Haffner, Matišák, Rosinová & Stark, 2019; Mgbemena, Tiwari, Xu, Prabhue & Hutabarat, 2020; Sanjog, Patel & Karmakar, 2019; Sutalaksana & Widyanti, 2016; Wanniarachchi, Gopura & Punchihewa, 2016). Guidelines for designing workplaces at sewing machine workstations have also been proposed (Tondre & Deshmukh, 2019). However, earlier studies have been performed for improving ergonomic conditions in the workstation area, line balancing in the assembly line, or facility layouts in the production area. Battini, Faccio, Persona and Sgarbossa (2011) stated that isolated efforts to improve ergonomics and layout design resulted in job dissatisfaction and failed to improve productivity.

According to Scott et al. (2010), efforts to improve ergonomics in SMEs, including workplace design, should be carried out in all production areas, given that the size of the production area is relatively small. However, the studies on workplace design integrating ergonomics and layout design into all production areas are still limited.

Designing workplaces in manufacturing SMEs in Indonesia, which is highly dependant on the skills and knowledge of SME managers, has been carried out without a structured process or procedure (Herwanto & Suzianti, 2020). Given the limited quality, knowledge and skills of human resources in Indonesian SMEs (Kurniawati & Yuliando, 2015; Maulina & Fordian, 2018; Meliala, Matondang & Sari, 2014; Supriyanto, 2006; Tambunan, 2011), it is necessary to systematically develop a workplace design guide that managers can use in developing countries, especially in Indonesia.

Thus, we first reviewed the literature on the methodology or framework of workplace design in the manufacturing industry. These methodologies or frameworks were then analysed and evaluated based on the characteristics of SMEs to determine the possibility of implementing the methodology or framework in Indonesian manufacturing SMEs. Based on the analysis and evaluation results, we finally proposed a workplace design framework to assist SME managers in designing their workplaces. Although this study is focused on manufacturing SMEs in Indonesia, we believe that the results can be applied to manufacturing SMEs in other developing countries.

2. Methods

This work aimed to develop a workplace design framework suitable for manufacturing SMEs in developing countries, particularly in Indonesia, as a guide for manufacturing SME managers. We based the preparation of this framework on the progress that earlier studies have made. Thus, we aimed to evaluate the suitability of the proposed workplace design methodologies or frameworks in the manufacturing industry for Indonesian manufacturing SMEs. For this purpose, we conducted a systematic review of the results of research on workplace design. We carried out this systematic review of articles published from 2000 to December 2022 using PRISMA reporting guidelines.

2.1. Eligibility Criteria

The inclusion rules used to select articles from the literature search are as follows:

1. Research articles and review articles written in English and have undergone a peer-review process;
2. Articles published or in-press between 2000 and December 2022;
3. Articles with a framework or methodology regarding workplace design in the manufacturing industry.

2.2. Information Sources

We conducted searches of online databases with large repositories of academic studies, including Crossref, Google Scholar, Microsoft Academic and Scopus. We used the Publish or Perish application software from Harzing.com for harvesting metadata of the articles in the four databases.

Harvesting metadata of the articles began by selecting a database in the Publish or Perish software, followed by entering keywords according to stage 1 in the Study selection section along with the timeframe for article publication according to point 2 in the Eligibility criteria section into the search box. The search results for metadata of the articles from the four databases were extracted into the form as described in the Data collection process section, then combined and selected according to steps 2-6 in the Study selection section.

2.3. Study Selection

The study selection was carried out through six stages:

1. The first stage was to search for literature relevant to the purpose of this paper by using keywords and strings, which are related to workplace design. For this, we use keywords including 'workplace', 'workstation', 'design', 'process', 'framework', 'methodology' and 'ergonomics'. To avoid irrelevant search results, a combined variation of several keywords was carried out using the Boolean operator 'AND'.
2. The search results at the initial stage were then checked for duplication of the paper.
3. The third stage was checking whether the articles have undergone a peer-review process or not. Only the articles that have undergone a peer-review process that we use in this study.
4. The next selection was based on the title of the paper. At this stage, the selected paper was a paper with the topic of workplace design, regardless of the type of workplace.
5. The next stage was to explore the paper based on the abstract and its keywords. At this stage, the selected paper was a paper that discusses the design of workplaces in the manufacturing industry.
6. The last selection was conducted by checking the paper full-text to ensure that the paper used was the paper that provides a framework or methodology for the workplace design process.

The six stages above were carried out collaboratively by the two authors through an iterative process according to the authors' assessment. The assessment was carried out parallelly during the paper screening process, as recommended by Noordzij, Hooft, Dekker, Zoccali and Jager (2009), to ensure that the quality of the paper included for further assessment met the inclusion criteria to minimise the occurrence of selection bias. In addition, we also conducted a quality assessment of all papers that met all inclusion criteria at the end of the sixth stage using the method proposed by Salleh, Mendes and Grundy (2011). Any discrepancies were discussed by the two authors until a mutual agreement was reached.

2.4. Data Collection Process

Data collection was carried out using the Publish or Perish application software to harvest article metadata in each database. The data were extracted into a form containing: author, article title, year, journal name, publisher, type and digital object identifier (DOI) number. The extracted data were then screened based on the steps described in the Study selection section. Any discrepancies that arise were resolved through discussion between the two authors.

2.5. Data Items

The selected articles were assessed regarding the applicability of the framework or methodology for manufacturing SMEs in Indonesia. At the end of the discussion section of this paper, we propose a workplace design framework for Indonesian manufacturing SMEs based on the results of the assessment and evaluation of the existing frameworks.

3. Results

3.1. Study Selection

The process of searching and screening literature carried out in this study is shown in Figure 1. Harvesting of article metadata using the Publish or Perish application software resulted in 13,607 studies written in English from 2000 to 2022 that matched the specified keywords or keyword combinations. The article duplication cheque yielded 11,116 articles for further screening. Based on the type of article, we removed 3,909 articles that have not undergone a peer-review process. The papers checking based on their titles resulted in 136 articles discussing workplace design, regardless of the type of workplace. Screening based on abstracts and keywords resulted in 59 articles discussing workplace design in the manufacturing industry for full-text checking (see Appendix A). Finally, a total of five articles that included the workplace design framework or methodology were assessed for quality to minimise selection bias. Based on the quality assessment result using the method proposed by Salleh et al. (2011), the five articles had "good" quality and were then selected for further assessment. The list of five articles including their authors, title, publication year, journal name, journal publisher and number of citations is reported in Table 1.

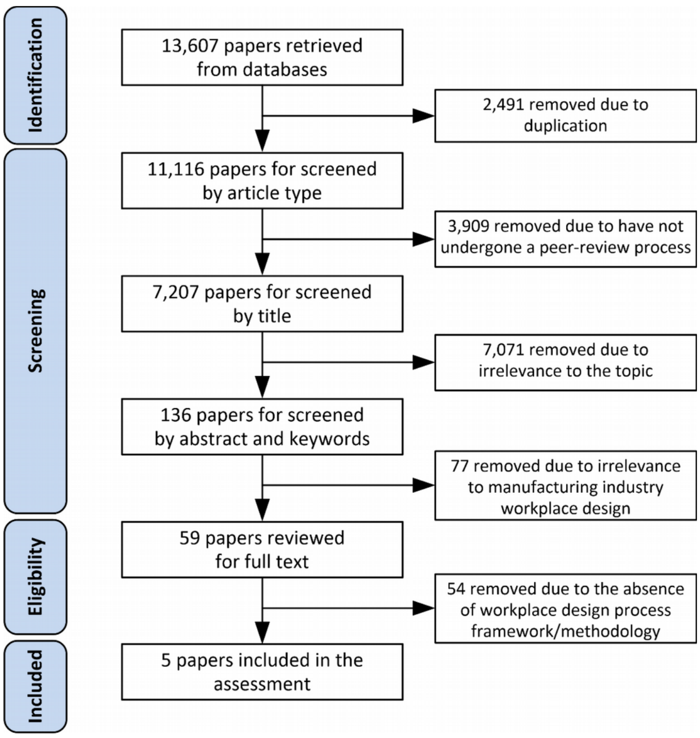

Figure 1. Flow diagram of the search strategy and exclusion criteria

#	Authors	Article title	Year	Journal	Publisher	Number of citations*
1	Battini et al.	New methodological framework to improve productivity and ergonomics in assembly system design	2011	*International Journal of Industrial Ergonomics*	Elsevier	311
2	Vilas, Longo & Monteil	A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach	2013	*Simulation*	Sage	40
3	Harari, Bechar, Raschke & Riemer	Automated simulation-based workplace design that considers ergonomics and productivity	2017	*International Journal of Simulation Modelling*	DAAAM International	30
4	Mateus, Claeys, Limère, Cottyn & Aghezzaf	A structured methodology for the design of a human-robot collaborative assembly workplace	2019	*International Journal of Advanced Manufacturing Technology*	Springer	62
5	Caputo, Greco, Fera & Macchiaroli	Digital twins to enhance the integration of ergonomics in the workplace design	2019	*International Journal of Industrial Ergonomics*	Elsevier	95

*number of citations until December 2022

Table 1. Selected papers for further assessment

Table 1 shows that two of five articles (20%) that included workplace design framework or methodology published in the International Journal of Industrial Ergonomics. In addition, the article from Battini et al. (2011) is the most cited article, with 311 citations (until December 2022).

The next section discusses each of these five frameworks. Henceforth, we mention the name of the framework discussed following the name of the author.

3.2. Framework 1: Assembly System Design by Battini et al.

Battini et al. (2011) proposed a methodological framework to design workplaces in assembly systems or lines. This framework was developed by considering technological and environmental variables and ergonomics evaluation to improve productivity and ergonomics in the assembly system or line.

Technological variables considered by Battini et al. (2011) are divided into four groups: (1) variables related to market needs, including production volume, production mix and flexibility in volume and production mix; (2) variables related to the product, including product life cycle and product components; (3) variables related to the assembly process, including assembly tasks, assembly cycle and precedence diagram configuration and process setup times; and (4) variables related to space availability.

Environmental variables include two groups of variables: (1) variables related to labour, including labour turnover, absenteeism, worker allocation, worker union involvement and psychosocial factors; and (2) variables related to occupational ergonomics and safety, including repetitive work, movement length, body posture, maximum and normal work area, weight handled, anthropometric data, worker diversity and level of automation.

Workplace design in the framework of Battini et al. (2011) integrates fourteen steps, which are grouped into three phases:

1. The preliminary design phase consisting of four steps (Steps 1-4) is focused on analysing the product family and creating a schematic of the assembly process, including the layout or process sequence. The four steps in this preliminary design phase are (1) product family analysis, (2) assembly cycle definition, (3) assembly time estimation and (4) production flow strategy selection, including system layout, cycle time, workstation type, automation level and rough-cut capacity planning.

2. The detailed design phase consists of six steps (Steps 5-10) with a focus on time analysis to identify bottlenecks and time losses due to material flow and ergonomics. The six steps in the detailed design phase include (1) assembly time measurement, (2) ergonomics evaluation, (3) ergonomics improvements, (4) optimal workplace design, (5) system balancing and (6) system sequencing.
3. The management and improvement phase consists of four steps (Steps 11-14) and aims to find the best assembly system configuration that allows maximising productivity and leveraging the physical and psychosocial conditions of workers. The four steps include (1) incentives and incremental improvements, (2) performance monitoring, (3) final output realised reporting and (4) standard times definition.

Battini et al. (2011) provided two case studies by implementing the proposed framework in two assembly lines at two different manufacturing companies to validate the procedures and methodology. Their results showed that implementing this framework can improve ergonomic conditions and productivity in the assembly line.

3.3. Framework 2: Manufacturing Workstation Design by Vilas et al.

Vilas et al. (2013) provided recommendations in the form of a general framework in designing and redesigning manufacturing workstations based on Digital Human Modelling and Simulation (DHMS) by combining ergonomic aspects with operational optimisation approaches. The framework was structured based on three key elements: (1) methodologies for data collection to support workstation analysis, (2) application of multiple ergonomic and time methodologies to analyse current (or proposed) manufacturing workstation design and (3) experimentation methodologies for design optimisation.

In the framework proposed by Vilas et al. (2013), data needed to design or redesign a workstation, such as worker characteristics, object dimensions and work methods, were collected from the real system by various observation-based methods and motion capture technology (MoCap) and then used to analyse the existing or proposed workstation design based on ergonomic methodologies and working time measurement through DHMS. Furthermore, an experimental simulation model was developed for improving workplace design in a virtual environment using DHMS. Finally, simulation model experiments were carried out to obtain the optimal alternative for workplace improvement.

At the end of the article, Vilas et al. (2013) provided two examples of implementing the framework in two manufacturing companies in Italy and Spain. These examples proved the validity of the proposed framework.

3.4. Framework 3: Automated Simulation-Based Workplace Design by Harari et al.

Harari et al. (2017) proposed a methodology for an automated workplace design process, considering production and ergonomics for manual material handling work involving objects with a mass of up to 23 kg.

Harari et al. (2017) developed the workplace design process involved multiobjective optimisation combined with DHMS using Jack software, which resulted in ergonomic and production measures. The work cycle times in the current DHMS were based on predetermined motion-time systems (PMTS).

To ensure the accuracy of the working time prediction through PMTS, Harari et al. (2017) developed a time prediction model, considering the weight of the load to be handled. The proposed model was evaluated in a case study involving moving product boxes to develop a workplace design.

3.5. Framework 4: Human-Robot Collaborative Assembly Design by Mateus et al.

Mateus et al. (2019) introduced a framework to design collaborative workstations between humans and robots (human-robot collaborative workplace, HRCW) based on the idaea that increasing worker age is deemed necessary to improve ergonomic conditions in the workplace.

The framework introduced by Mateus et al. (2019) consisted of several steps grouped into four blocks: (1) product extraction and production process sequence based on information from the computer-aided design (CAD) model, (2) job disaggregation to specify the work that needs to be done and identify the functional requirements needed, (3) measurement of the ability of resources (human and machine/robot) to determine the possibility of safe collaboration between humans and machines/robots and (4) identification of HRCW building blocks for generating and evaluating possible collaborative assembly sequences.

The advantage of the framework proposed by Mateus et al. (2019) is that it can produce an ergonomic and safe HRCW and balance work between humans and robots.

3.6. Framework 5: Assembly Line Design with Digital Twins by Caputo et al.

Caputo et al. (2019a) developed the workplace design process framework to improve ergonomic performance in the workplace, especially in workplaces with complex systems, such as assembly lines in the automotive industry. Caputo et al. (2019a) proposed a workplace design framework to reduce the time for developing and designing assembly lines with digital twin stations based on the concurrent engineering approach.

The framework introduced by Caputo et al. (2019a) had an iterative procedure, consisting of ten steps divided into five macro-steps:

1. Analysis of technological variables and preliminary design consists of the following steps (1) assembly line layout definition, (2) standard operating procedure (SOP) definition and time estimation and (3) preliminary design. The first three steps were executed by considering four technological variables: (1) variables related to market needs, including investigating market needs and product mix and volume; (2) variables related to product feasibility, including product and component analysis, product life and product customisation; (3) variables related to the work environment, including plant analysis, equipment definition and assembly line settings; and (4) variables related to work tasks, including workers and time and variability of tasks.

2. Analysis of ergonomic variables and workplace detailed design, which is the fourth step of designing the proposed workplace. The ergonomic variables considered in this step include (1) anthropometry, (2) worker allocation, (3) body posture analysis, (4) force analysis, (5) manual handling analysis, (6) repetitive task analysis, (7) biomechanical loads and (8) work organisation.

3. Ergonomic assessment and workplace design validation consisting of: (5) ergonomic evaluation and (6) design validation. The ergonomic evaluation was performed in two ways: experimentally through laboratory testing and numerically through DHMS.

4. Line balancing, which is the seventh step of improving line balance and work order.

5. Continuous improvement step, including (8) productivity analysis, (9) standard time optimisation and (10) optimisation of the production process.

Caputo et al. (2019a) applied this framework in a digital twin workstation to the assembly line of Fiat Chrysler Automobiles and validated the proposed numerical procedure.

4. Assessment and Evaluation of the Existing Frameworks

This section discusses the applicability of the five workplace design frameworks for manufacturing SMEs in developing countries, especially in Indonesia. Based on the characteristics of manufacturing SMEs and the results obtained, at the end of this section, we proposed the framework applied to manufacturing SMEs in Indonesia. Table 2 shows some of the characteristics of SMEs in developing countries, particularly Indonesia.

We performed further analysis to determine the variables and steps of the workplace design process that are appropriate and can be applied to develop a workplace design framework in Indonesian manufacturing SMEs, mainly manufacturing SMEs producing machinery products and other equipment components.

Before analysing the possibility of implementing a workplace design framework, first, we compared the five workplace design frameworks for the manufacturing industry, as shown in Table 3.

These frameworks were aimed at designing and improving workplaces in the assembly line and workstation area. Scott et al. (2010) stated that efforts to improve ergonomics in small industries, including workplace design, should include all production areas instead of a particular workstation or assembly line because the size of the production area in small industries is relatively small.

Apart from workspace coverage, only three of the five frameworks were applied to manual production, while two were applied to both robotic and digital workplaces. In reality, production processes in most small industries in Indonesia and other developing countries are performed using manual machines (Mittal et al., 2018; Saputro et al., 2010; Supyuenyong et al., 2009; Zocca et al., 2019).

#	Characteristics	Source(s)
1	The relatively small size of the production area	Scott et al. (2010)
2	Usually manual/traditional or less complex operations	Kurniawati and Yuliando (2015), Mittal, Khan, Romero and Wuest (2018), Supyuenyong, Islam and Kulkarni (2009), Saputro, Handayani, Hidayanto and Budi (2010), Zocca, Lima and Gaspar (2019)
3	Limited quality, knowledge and skills of human resources	Kurniawati and Yuliando (2015), Lekhanya (2016), Maulina and Fordian (2018), Meliala et al. (2014), Shikdar and Al-Araimi (2001), Supyuenyong et al. (2009), Supriyanto (2006), Tambunan (2011)
4	Limited financial resources	Kurniawati and Yuliando (2015), Martdianty (2020), Maulina and Fordian (2018), Meliala et al. (2014), Mittal et al. (2018), Saputro et al. (2010), Suci (2017), Supriyanto (2006), Tambunan (2011), Zocca et al. (2019)
5	Various product weights, even above 23 kg	Al-Haq, Antara and Hartiati (2015), Ariyanti, Widodo, Zulkarnain and Timotius (2019), Jaya, Nuryati and Audinawati (2017), Oktiarso and Loekito (2017), Rahaju and Dewi (2012), Wati and Singgih (2019)
6	The make-to-order production system of most SMEs	Kalijaga, Restiana and Fadhlurrohman (2018), Pranata and Setyorini (2020), Rajak (2018), Syarif and Bedros (2017), Wahyudin (2009)
7	Lack of trade unions in most SMEs	Martdianty (2020)
8	Less complex and more informal organisational culture and structure	Baskoro and Wardana (2017), Martdianty (2020), Mittal et al. (2018), Supyuenyong et al. (2009), Sutalaksana, Anggawisastra and Tjakraatmadja (2006)
9	Job shop (process) layout of most SMEs	Budi, Mulyono and Dewi (2014), Rahaju and Dewi (2012), Rajak (2018), Wahyudin (2009)
10	No worker specialisation	Forsman (2008), Wahyuningrum, Sukmawati and Kartika (2016)
11	Most located in residential areas	Rodhiyah (2015)

Table 2. Characteristics of SMEs in developing countries, mainly Indonesia

Study	Workplace area	Types of the production process	Improvement area(s)	Degree of detail	
				Variables	Process steps
Battini et al. (2011)	Assembly line	Manual	Ergonomics, productivity	Detailed	Detailed
Vilas et al. (2013)	Workstation	Manual	Ergonomics	Not detailed	Not detailed
Harari et al. (2017)	Workstation	Manual	Ergonomics	Not detailed	Detailed
Mateus et al. (2019)	Workstation	Human-robot collaborative	Ergonomics, safety	Not detailed	Detailed
Caputo et al. (2019a)	Assembly line	Twin digital	Ergonomics, line balancing, productivity	Detailed	Detailed

Table 3. Summary of industrial manufacturing workplace design framework

We conducted the following assessment to determine the degree of applicability of the five workplace design frameworks to Indonesian manufacturing SMEs.

4.1. Framework 1: Assembly System Design by Battini et al.

The framework developed by Battini et al. (2011) describes the variables and design process in detail. Given the characteristic #4 (see Table 2), this detailed workplace design process can help manufacturing SME managers stepwise follow workplace design. However, considering that the framework was intended to design a workplace in the form of an assembly system, the variables and processes in this framework must be evaluated to ascertain which variables and processes can be applied to Indonesian manufacturing SMEs.

4.2. Framework 2: Manufacturing Workstation Design by Vilas et al.

The framework developed by Vilas et al. (2013) utilises a real-time simulation approach to improve workstation design during the design process to improve ergonomic conditions and production operations. Although the results obtained via this framework are optimal, it requires technology (hardware and software), which is relatively expensive for SMEs in Indonesia. In addition, characteristics #3 and #4 (see Table 2), can prevent Indonesian SMEs from implementing this framework. Thus, we recommend against implementing this framework in Indonesian manufacturing SMEs.

4.3. Framework 3: Automated Simulation-Based Workplace Design by Harari et al.

This framework was developed to design workplaces with manual material handling tasks with a load mass of up to 23 kg and merge optimisation and DHMS to enable ergonomic and productive material handling operations. The steps of the design process are described in detail. The work performed in manufacturing SMEs in Indonesia involves products with a variety of loads (sometimes > 23 kg) (Al-Haq et al., 2015; Ariyanti et al., 2019; Jaya et al., 2017; Oktiarso & Loekito, 2017; Rahaju & Dewi, 2012; Wati & Singgih, 2019); and a variety of work tasks, not just material handling tasks. Thus, we recommend against using the framework by Harari et al. (2017) for workplace design in manufacturing SMEs in Indonesia.

4.4. Framework 4: HRC Assembly Workplace Design by Mateus et al.

This framework was specifically developed for HRC workplaces to obtain a safe and ergonomic workplace, considering human and machine/robot coexistence. One of the advantages of this framework is that the steps of the process are described in detail. However, this framework is unsuitable for Indonesian manufacturing SMEs as they do not currently use robotics in their production processes (Kurniawati & Yuliando, 2015; Saputro et al., 2010).

4.5. Framework 5: Line Assembly Workplace Design with Digital Twins by Caputo et al.

This framework has similarities to the framework proposed by Battini et al. (2011); however, it is devoted to assembly lines in automotive companies by utilising digital twins. Variables and process steps in this framework are described more concisely compared to those in the framework by Battini et al. (2011). Although it is devoted to automotive assembly lines, most of the variables and steps in this framework can be applied to Indonesian manufacturing SMEs with minor adjustments.

The results of the assessment show that not all frameworks introduced by previous researchers can be recommended for workplace design in Indonesian manufacturing SMEs. According to the characteristics of manufacturing SMEs in Indonesia, two of the five frameworks can be recommended: those proposed by Battini et al. (2011) and Caputo et al. (2019a).

However, the frameworks proposed by Battini et al. (2011) and Caputo et al. (2019a) must be further studied to investigate the suitable variables and steps from the two frameworks that can be applied to design workplaces in Indonesian manufacturing SMEs. Thus, as a first step, we examined the variables considered in the two frameworks and, consequently, the workplace design process steps.

Study	Description	Degree of applicability in SMEs
Battini et al. (2011)	Framework for designing assembly lines, with detailed descriptions of the variables and steps of the workplace design process. This framework can be applied to Indonesian manufacturing SMEs after minor adjustments.	Applicable with adjustments
Vilas et al. (2013)	Framework for designing workstations through a real-time simulation approach. This framework requires relatively expensive technology; thus, it can be a burden for SMEs to implement.	Not applicable
Harari et al. (2017)	Framework for designing workplaces with manual material handling, based on optimisation and DHMS. Considering that work in SMEs is not only material handling, this framework is not recommended for SMEs.	Not applicable
Mateus et al. (2019)	Framework for designing HRCW. This framework is not recommended, considering that the machines used in SMEs are manual.	Not applicable
Caputo et al. (2019a)	Framework for designing assembly lines, using digital twins. Although designed specifically for automotive assembly lines, this framework can be implemented in SMEs with minor adjustments.	Applicable with adjustments

Table 4. Degree of applicability of workplace design framework for SMEs

Given the relatively narrow area of production in small industries, efforts to improve ergonomics, including workplace design, in small industries should be implemented in all production areas (Scott et al., 2010), not just in one workstation or assembly line. Thus, the variables 'assembly tasks' and 'assembly cycle' (Battini et al., 2011) need to be converted into 'production tasks' and 'production cycle' to be used in the process of designing workplaces in SMEs.

Most manufacturing SMEs in Indonesia manufacture their products using a make-to-order system, where products are manufactured only after receiving orders from customers (Kalijaga et al., 2018; Pranata & Setyorini, 2020; Rajak, 2018; Syarif & Bedros, 2017; Wahyudin, 2009). This signifies that the products manufactured by SMEs are in accordance with customer demands. Therefore, we recommend against using the variables 'product lifetime' (Battini et al., 2011; Caputo et al., 2019a), 'product components (number/commonality/modularity)' (Battini et al., 2011) and 'product feasibility' (Caputo et al., 2019a) for workplace design in Indonesian manufacturing SMEs.

Although regulations in Indonesia allow the formation of trade unions by a minimum of 10 workers, in reality, there are no trade unions in most SMEs (Martdianty, 2020). With a small number of workers, the relationship between workers and company leaders can be intimate and informal (Baskoro & Wardana, 2017; Martdianty, 2020; Sutalaksana et al., 2006), thereby providing job satisfaction for employees and reducing employee turnover (Baskoro & Wardana, 2017). Most SMEs in Indonesia do not apply a specific division of tasks to each worker so that each worker must have a multiskill about all the processes in the SMEs (Forsman, 2008; Wahyuningrum et al., 2016). Therefore, the variables 'work allocation' and its subvariables (Battini et al., 2011), 'trade union involvement' (Battini et al., 2011), 'psychosocial factors' (Battini et al., 2011), 'worker allocation' (Caputo et al., 2019a), 'force analysis' (Caputo et al., 2019a) and 'work organisation' (Caputo et al., 2019a) do not need to be considered in the workplace design of Indonesian manufacturing SMEs.

The production process in manufacturing SMEs is generally performed manually (Kurniawati & Yuliando, 2015; Saputro et al., 2010). Therefore, the variable 'automation level required to prevent injuries/diseases' (Battini et al., 2011) should not be used in the workplace design process in Indonesian manufacturing SMEs.

Table 5 provides a summary of the variables for workplace design proposed by Battini et al. (2011) and Caputo et al. (2019a) that have to be applied based on the characteristics of Indonesian manufacturing SMEs.

One of the advantages of the frameworks proposed by Battini et al. (2011) and Caputo et al. (2019a) is that they include a detailed workplace design process that is easy to understand. However, both frameworks are devoted to designing workplaces with the assembly line. Most manufacturing SMEs in Indonesia are 'parts producer' or 'vertically integrated plant' and not 'assembly plant', according to Groover (2015). 'Parts producer' is a plant that only makes components without assembling them, while a 'vertically integrated plant' is a plant that makes components and assembles them into a final product (Groover, 2015). Therefore, the steps of the workplace design process in the two frameworks need to be adjusted so that they can be applied in manufacturing SMEs in Indonesia.

Study	Variables	Degree of applicability in SMEs
Battini et al. (2011)	*Variables linked to market demand*	
	1) Production volume	Applicable
	2) Production mix	Applicable
	3) Flexibility required in production mix and production volume	Applicable
	Variables linked to product	
	1) Product lifetime (flexibility to products variations and changes)	Not applicable
	2) Product components	
	• Number/commonality/modularity	Not applicable
	• Physical dimension and weight	Applicable
	Variables linked to the assembly process	
	1) Assembly tasks	
	• Time length	Applicable with adjustments
	• Time variability	Applicable with adjustments
	2) Assembly cycle and precedence diagram configuration	Applicable with adjustments
	3) Process setup times	Applicable
	Variables linked to space	
	1) Space availability, for:	
	• assembly system	Applicable
	• material inventories	Applicable
	• human resources	Applicable
	• material handling/lifting devices	Applicable
	Variables linked to workforce	
	1) Labour turnover and replacement strategies	Not applicable
	2) Absenteeism	Not applicable
	3) Work allocation	
	• Maximum length of sustainable workload per operator	Not applicable
	• Job enlargement/assembly content	Not applicable
	• Physical human diversity	Not applicable
	• Learning curve	Not applicable
	• Task repetitiveness	Not applicable
	4) Trade union involvement	Not applicable
	5) Psychosocial factors	
	• Influence on and control overwork	Not applicable
	• Stimulus from the work itself	Not applicable

Study	Variables	Degree of applicability in SMEs
	• Supervisor climate	Not applicable
	• Relations with fellow workers	Not applicable
	• Psychological workload	Not applicable
	Variables linked to ergonomics and safety	
	1) Tasks repetitiveness	Applicable
	2) Movements length/muscular load	Applicable
	3) Body posture	Applicable
	4) Maximum and normal work area	Applicable
	5) Weight handled	Applicable
	6) Anthropometrics data	Applicable
	7) Human diversity	Applicable
	8) Automation level required to prevent injuries/diseases	Not applicable
Caputo et al. (2019a)	*Market demand variables*	
	1) Product demand investigation	Not applicable
	2) Production volume and mix	Applicable
	Product feasibility variables	
	1) Product analysis	Not applicable
	2) Components analysis	Not applicable
	3) Product lifetime	Not applicable
	4) Product customisation	Not applicable
	Environmental variables	
	1) Plant analysis	Applicable
	2) Equipment definition	Applicable
	3) Assembly line set	Applicable with adjustments
	Work task variables	
	1) Human resource	Applicable
	2) Time analysis	Applicable
	3) Task variability	Applicable
	Ergonomic variables	
	1) Anthropometry	Applicable
	2) Worker allocation	Not applicable
	3) Body posture analysis	Applicable
	4) Force analysis	Not applicable
	5) Manual handling analysis	Applicable
	6) Repetitive task analysis	Applicable
	7) Biomechanical loads	Applicable
	8) Work organisation	Not applicable

Table 5. Degree of applicability of variables in workplace design for SMEs

Study	Steps	Degree of applicability in SMEs
Battini et al. (2011)	1) Product family analysis	Applicable
	2) Assembly cycle definition	Applicable with adjustments
	3) Assembly time estimation	Applicable with adjustments
	4) Production flow strategy selection	
	a) System layout	Applicable with adjustments
	b) Cycle time (paced/un-paced)	Applicable with adjustments
	c) Workstation type (i.e. open/closed, parallel/serial, two-sided, ...)	Applicable with adjustments
	d) Automation level	Not applicable
	e) Rough-cut capacity planning	Not applicable
	1) Assembly times measurement	Applicable with adjustments
	2) Ergonomics evaluation	Applicable
	3) Ergonomics improvements	Applicable
	4) Optimal workplace design	Applicable
	5) System balancing	Not applicable
	6) System sequencing	Not applicable
	7) Incentives and incremental improvements	Not applicable
	8) Performance monitoring	Not applicable
	9) Final output realised reporting	Not applicable
	10) Standard times definition	Applicable
Caputo et al. (2019a)	1) Assembly line layout definition	Applicable with adjustments
	2) Standard operating procedure (SOP) definition and times estimation	Applicable
	3) Preliminary design	Not applicable
	4) Workplace design	Applicable
	5) Ergonomic evaluation	Applicable
	6) Design validation	Not applicable
	7) Assembly line balancing and sequences	Not applicable
	8) Cheque productivity	Applicable
	9) Standard times optimisation	Applicable
	10) Production process optimisation	Applicable

Table 6. Degree of applicability of workplace design process steps for SMEs

Given that the design of workplaces in SMEs must be implemented in all production areas, all steps related to the assembly line need to be adjusted. Therefore, the steps 'assembly cycle definition' (Battini et al., 2011), 'assembly time estimation' (Battini et al., 2011), 'assembly time measurement' (Battini et al., 2011) and 'assembly line layout definition' (Caputo et al., 2019a) must be adjusted to 'product cycle definition', 'production time estimation', 'production time measurement' and 'production room layout definition'.

Heragu (2016) stated that material handling is one of the problems often occur in production processes that utilise the process layout, as characteristic #9 of Indonesian manufacturing SMEs (see Table 2), while line balancing problems occur more frequently in production processes that utilise the product layout. Therefore, 'system balancing' (Battini et al., 2011), 'system sequencing' (Battini et al., 2011) and 'assembly line balancing and sequences' (Caputo et al., 2019a) are not recommended in the workplace design process in Indonesian manufacturing SMEs and should be replaced with 'material handling evaluation'.

Limited financial resources and the uncertainty of business and profit make it difficult for SMEs in Indonesia to increase employee wages (Martdianty, 2020). Therefore, we do not recommend the step 'incentives and incremental improvements' (Battini et al., 2011) in the workplace design process in manufacturing SMEs in Indonesia. Therefore, the two steps related to the step 'incentives and incremental improvements' (Battini et al., 2011) (i.e., 'performance monitoring' and 'final output realised reporting') are also not recommended.

A summary of the recommended steps in the workplace design frameworks proposed by Battini et al. (2011) and Caputo et al. (2019a) provided in Table 6.

The workplace design process in manufacturing SMEs should be aimed at improving work productivity, OSH, as well as working space conditions. This is following the press release put forward by the International Labour Organization (ILO) (2014), which states that one of the challenges faced by SMEs in Indonesia is to increase productivity while improving OSH and working conditions.

Dianat, Vahedi and Dehnavi (2016) stated that environmental conditions (temperature, lighting and noise) in the manufacturing industry are generally unsatisfactory and thus need to be considered in designing workplaces in the manufacturing industry. The setting of environmental conditions (temperature, lighting and noise) in the manufacturing industry needs to be carried out by taking into account the applicable regulations regarding the threshold for the environmental conditions. There are at least two ministerial regulations about the threshold value of industrial environmental conditions in Indonesia, namely the Minister of Health Regulation Number 70 of 2016 and Minister of Manpower Regulation Number 5 of 2018.

Therefore, apart from the need to consider the variables and steps previously discussed, the process of designing workplaces in manufacturing SMEs in Indonesia needs to be performed by paying attention to OSH aspects as well as physical environmental conditions (temperature, lighting and noise) in the workplace so that a more productive, safe, comfortable and healthy workplace can be achieved. In addition, considering the relatively narrow size of the production space, the design of workplaces in Indonesian manufacturing SMEs needs to be carried out on all production floors, including workstation design and production facility layout design.

5. Proposed Workplace Design Framework

Following the results of the assessment and evaluation above, we propose a workplace design framework that can be used for manufacturing SMEs in Indonesia, as shown in Figure 2. This proposed framework is predominantly based on the framework introduced by Battini et al. (2011) and Caputo et al. (2019a), as well as adapted to the characteristics of manufacturing SMEs in Indonesia as shown in Table 2. The following section describes each of the variables and stages used in the proposed framework to provide a comprehensive understanding.

The workplace design framework for Indonesian manufacturing SMEs that we propose considers seven variables, including (1) product variables, (2) process variables, (3) space variables, (4) workforce variables, (5) ergonomics variables, (6) material handling variables and (7) physical environment variables.

The product variables consist of two sub-variables, including (1) product type and quantity and (2) the weight and physical dimensions of the product, both raw materials, work-in-process and finished products. The type and quantity of product are needed to determine the type of process to be carried out (Bellgran & Säfsten, 2010; Groover, 2015; Venkataraman & Pinto, 2018). The weight of the product will affect the type of layout that should be used (Kiran, 2019; Tompkins, White, Bozer & Tanchoco, 2010), while the physical dimensions of the product (both raw materials, finished products and work-in-process) are needed to design the workstation (Muther & Hales, 2015; Tompkins et al., 2010).

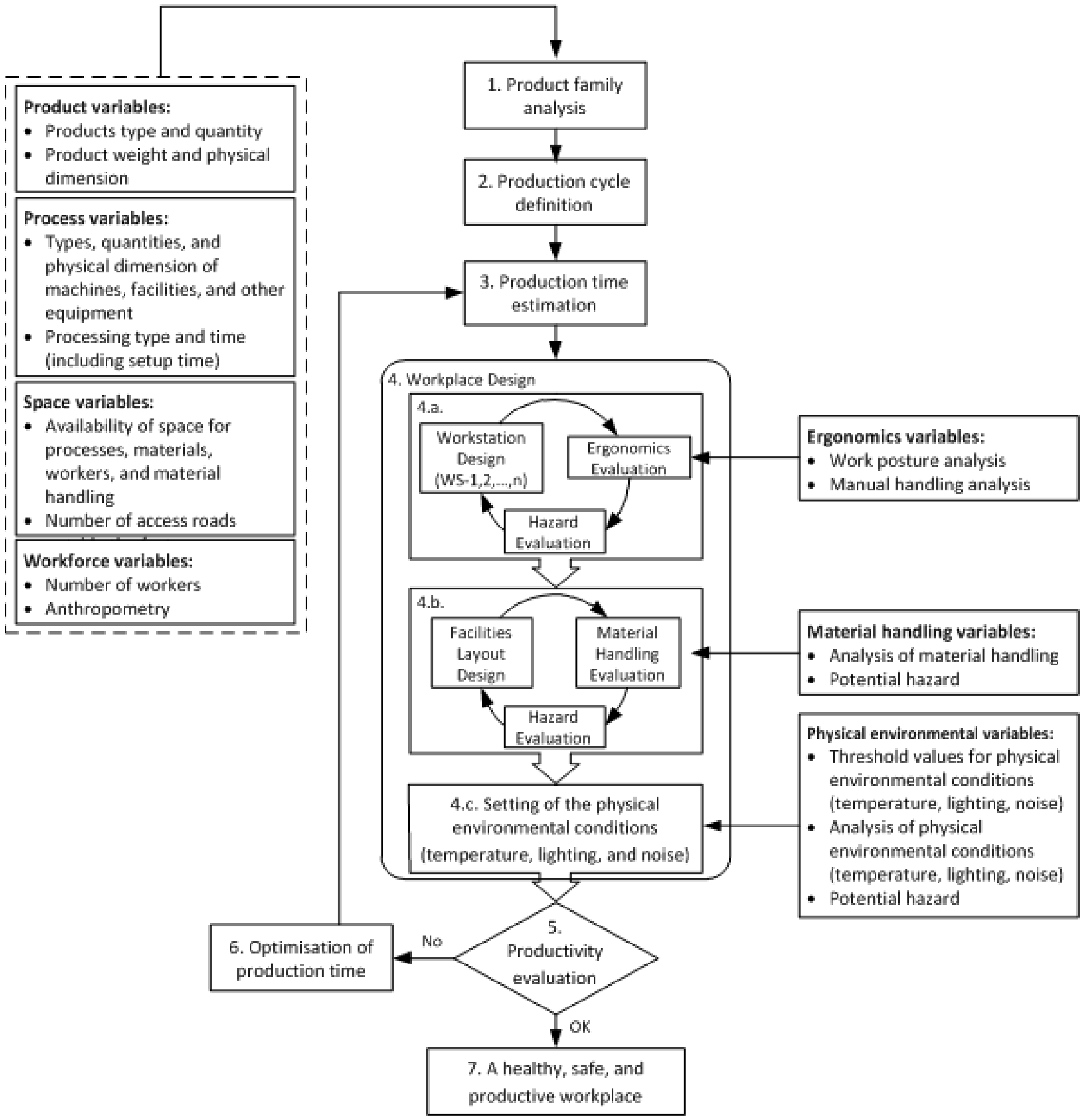

Figure 2. Proposed framework

The process variables consist of two sub-variables, including (1) the type, quantity and physical dimensions of machines, facilities and other equipment; and (2) process type and time, including setup time. The type and number of machines, facilities and other equipment will affect the type of layout that should be used (Kiran, 2019; Tompkins et al., 2010), while the physical dimensions of machines, facilities and other equipment are needed to design workstations (Kiran, 2019; Tompkins et al., 2010). Meanwhile, the type and processing time will affect the selection of the appropriate layout type (Kiran, 2019; Muther & Hales, 2015; Tompkins et al., 2010).

The space variables consist of two sub-variables, namely (1) the availability of space for processes, materials, workers and material handling and (2) the number of available road access outside the factory. The availability of space for processes, materials, workers and material handling will affect the choice of layout type (Kiran, 2019; Tompkins et al., 2010; Wignjosoebroto, 2009). One of the characteristics of SMEs in Indonesia is that most SMEs are established in residential areas so that SMEs often have limited road access. We consider it necessary to consider the limitations of road access in the design of workplaces in SMEs, especially in determining the layout that should be chosen.

The workforce variables consist of two sub-variables, namely (1) the number of workers and (2) the anthropometric size of the workers. The number of workers needs to be considered in selecting the appropriate type of layout (Hunter, 2001; Kiran, 2019), while the anthropometric size of workers is needed to design the workstation (Muther & Hales, 2015; Tompkins et al., 2010).

Ergonomics variables is needed to evaluate whether the designed workstation is ergonomic or not. This variable consists of (1) work posture analysis and (2) manual handling analysis. Work posture analysis is used to assess the work posture shown by workers when performing their tasks. Several methods such as rapid entire body assessment (REBA), rapid upper limb assessment (RULA) and ovako working posture assessment system (OWAS) are very familiar and widely used by previous researchers (e.g. Jadhav, Arunachalam & Salve, 2019; Mali & Vyavahare, 2015; Peruzzini, Pellicciari & Gadaleta, 2019) to analyse work postures. This work posture assessment can also be done manually or with a DHMS software. Manual handling analysis is required on workstations in which there is manual lifting work to assess whether manual handling work is safe or not. The National Institute for Occupational Safety & Health (NIOSH) equation is very familiar and is used by many researchers (e.g. Harari et al., 2017; Kassaneh & Tadesse, 2019; Peruzzini & Pellicciari, 2017) to perform manual handling analysis.

The material handling variables consists of two sub-variables, namely (1) material handling analysis and (2) potential hazards arising from material handling activities. Both of them need to be considered in designing the layout of the production room.

The physical environment variables consist of three sub-variables, namely (1) the threshold value of the physical environment (temperature, lighting and noise), (2) analysis of physical environmental conditions and (3) potential hazards arising from physical environmental conditions. The physical environment threshold value is required to ensure that the physical environmental conditions of the designed workplace do not exceed the applicable standards. Analysis of physical environmental conditions is needed to determine the current condition of the physical environment so that it can be seen what improvements need to be made so that the condition of the physical environment is following the standard. Potential hazards arising from physical environmental conditions also need to be considered so that negative things that arise due to unfavourable physical environmental conditions (not according to standards) can be minimised.

The stages of workplace design that we propose to design workplaces in manufacturing SMEs in Indonesia consist of seven stages, including (1) product family analysis, (2) production cycle definition, (3) production time estimation, (4) workplace design, (5) productivity evaluation, (6) optimisation of production time and (7) a healthy, safe and productive workplace.

The first stage in this proposed framework is 'product family analysis' to determine the group or family of products produced by manufacturing SMEs based on similarities in form or process experienced by these products.

The second stage that we propose in this framework is ‘production cycle definition’. This stage is intended to define the production cycle of the products based on the variables that have been described previously.

The third stage is production time estimation, which is intended to determine the length of time the production process takes, both per process and as a whole. Determination of processing time is needed to determine the number of machines needed in the production process so that it can be seen whether the number of machines currently available is sufficient or not.

The fourth stage is workplace design, which consists of three sub-stages, namely (1) workstation design, (2) facilities layout design and (3) setting of physical environmental conditions.

Workstation design can be carried out following the opinion of Muther and Hales (2015) and Tompkins et al. (2010). The results of the workstation design are then evaluated in terms of ergonomics, in the form of work posture analysis and manual handling analysis. To improve occupational safety and health conditions in SMEs, at the end of the workstation design stage it is necessary to carry out a hazard analysis to ensure that the workstation design has the least risk of OSH. If the hazard analysis shows that the risk of OSH is still high, it is necessary to improve the workstation design. If the hazard analysis shows that the OSH risks are good, then proceed to the next stage, namely the facilities layout design.

To assist SME managers in determining the layout of their facilities, we propose a flowchart for determining the type of facility layout as shown in Figure 3. This flowchart supports stage 4.b in Figure 2, which based on literature reviews and studies on facilities layout design in manufacturing SMEs in Indonesia, as explained in the following section.

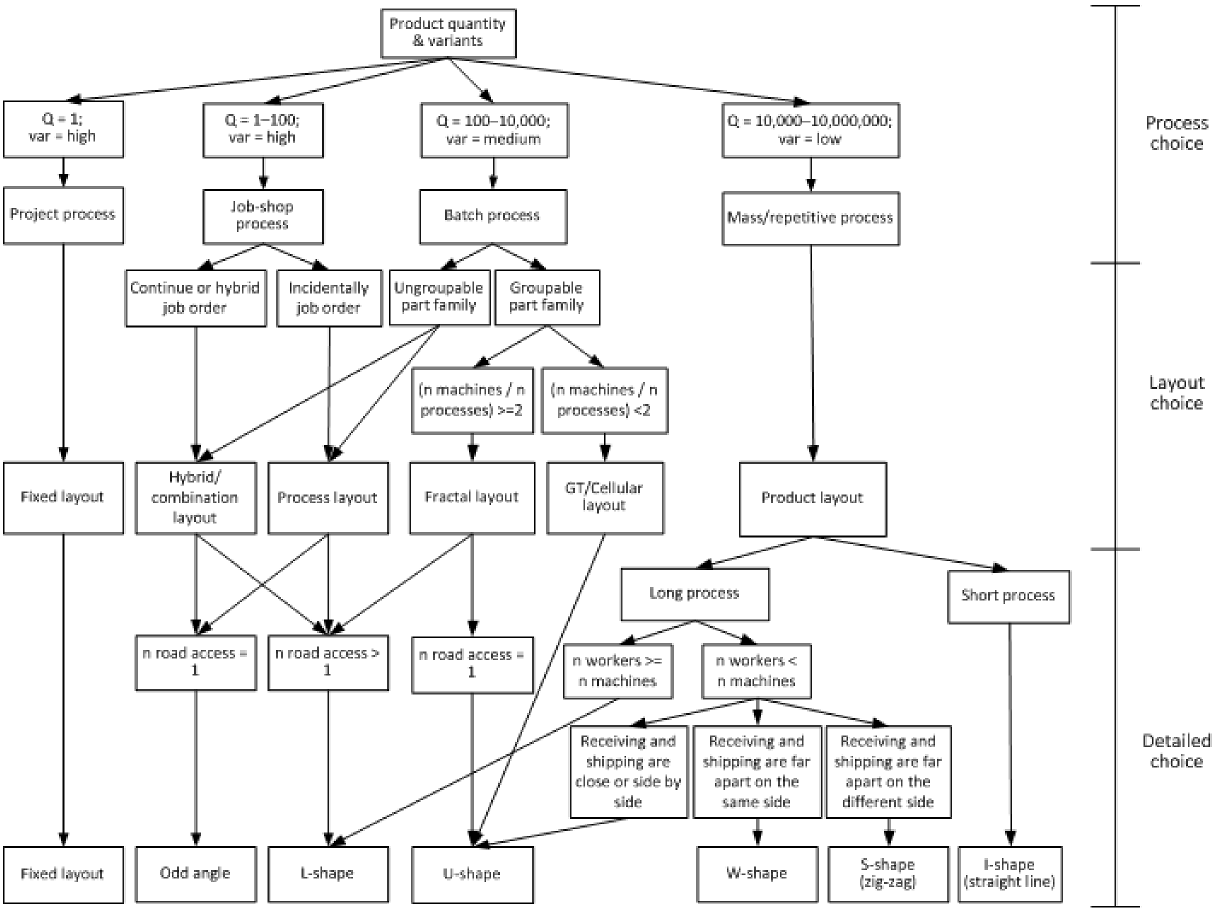

Figure 3. Flowchart of determining the type of facilities layout

In accordance with Bellgran and Säfsten (2010), we divide the stages of determining the type of layout into three stages, namely (1) selecting the type of process (process choice), (2) selecting the general/basic layout (layout choice) and (3) selecting a detailed layout or flow pattern (detailed choice).

Venkataraman and Pinto (2018) divide the types of processes into five, namely project processes, job-shop processes, batch processes, mass/repetitive processes and continuous processes. During the reference search, we did not find any SMEs that operate continuously, so in the future we propose four types of processes that are suitable for SMEs in Indonesia, namely project processes, job shop processes, batch processes and mass/repetitive processes.

The selection of the type of process is carried out based on a comparison between the number of products and the number of product variations made. Several references (e.g. Groover, 2015; Venkataraman & Pinto, 2018) stated that the appropriate type of process based on the ratio between volume and product variation can be summarised as shown in Table 7.

Quantity and product variety ratio	Type of process
Quantity = 1 pcs/year, high variation	Project process
Quantity = 1-100 pcs/year, high variation	Job-shop process
Quantity = 100-10.000 pcs/year, medium variation	Batch process
Quantity = 10.000-1.000.000 pcs/year, low variation	Mass/repetitive process

Table 7. Process type based on product quantity and variety ratio for manufacturing SMEs

There are four basic facilities layouts, namely fixed layout, product layout, process layout and group technology (GT) or cellular layout (Groover, 2015; Heragu, 2016; Kiran, 2019; Muther & Hales, 2015; Tompkins et al., 2010; Wignjosoebroto, 2009). In addition, there are also various further layout developments, such as distributed layout, fractal layout, hybrid layout, spine layout and others (Hasnan, Ab-Aziz, Taip & Zulkifli, 2019; Narayanan, 2007; Santoso & Halim, 2012).

The results of previous research indicate that six types of facilities layouts are widely applied in Indonesian manufacturing SMEs, namely fixed layout, hybrid/combination layout, process layout, fractal layout, GT/cellular layout and product layout (Dewi, Sari, Dewi & Ariyono, 2015; Fahma & Sakinah, 2014; Morena & Siska, 2011; Prasetya & Noya, 2015; Santoso & Halim, 2012). So, the authors propose these six types of facilities layouts in the layout selection flowchart in Indonesian manufacturing SMEs.

Determining the type of general layout can be based on the product's physical size, the number of machine types and the number of machines of each type. The company can use the fixed when running a project process (Singh & Rajamani, 1996) or the product is large and is difficult to move around (Ailing, 2009; Groover, 2015; Kumar & Suresh, 2008; Tompkins et al., 2010).

Hybrid/combination layouts can be applied in companies with a job-shop process and continuous or combination orders (Benjaafar, Heragu & Irani, 2002; Ristyanadi & Orchidiawati, 2019) or in companies with batch process types and ungroupable product families. Process layout can be applied in a company with a job-shop process and incidental orders or a batch process with ungroupable product families.

If the company runs a batch process with groupable product families and the ratio between the number of machines and the number of processes is two or more, then the company can choose a fractal layout (Anggraini & Sunarni, 2019; Santoso & Halim, 2012). If the ratio between the number of machines and the number of processes is less than two, then the company can use a GT/cellular layout. Meanwhile, the product layout is suitable for use in companies with mass/repetitive processes.

Many detailed layouts types can be used, such as L-shape, U-shape, I-shape and so on (Hitomi, 1979; Muther & Hales, 2015; Poch, 2009; Tompkins et al., 2010; Wignjosoebroto, 2009). The selection of the detail layout type can based on the material flow pattern on the production floor.

SMEs in Indonesia are generally categorized as 'parts producer' and 'vertically integrated part', referring to Groover (2015), so the detail layouts or flow patterns that can be selected are fixed layouts, odd angles, L-shape layouts, U-shape layouts, W-shape layouts, S-shape (zig-zag) layouts and I-shape (straight line) layouts.

Most SMEs in Indonesia are located in residential areas (Rodhiyah, 2015) with limited access roads. If the access road is only one with a hybrid/combination layout or process layout, the company can choose the odd angle type as the detailed layout while placing similar machines in the same area. If the facility layout that used is a fractal with one access road, then the detail layout should use a U-shape. If the access road is more than one with a hybrid/combination layout or process layout, the detail layout type should be L-shape. If the company uses a product layout with a long process and the number of workers is more than or equal to the number of existing machines, the company can also apply the L-shape as detail layout.

In a company with a product layout and a long process as well as fewer workers than the number of processes, the detail layout should be: (1) U-shape, if the receiving and shipping areas are close or side by side; (2) W-shape, if the receiving and shipping areas are far apart on the same side; or (3) S-shape or zig-zag, if the receiving and shipping areas are far apart on the different side (Tompkins et al., 2010). Meanwhile, when the company runs a short process, the detailed layout should be an I-shape or straight line.

After the layout design is complete, it is necessary to evaluate the material handling to ensure that the designed layout can provide the most efficient material handling. In addition, it is also necessary to conduct a hazard evaluation to ensure that the results of the layout design do not cause work safety risks, so that workers can work healthily. In this regard, Moatari-Kazerouni, Chinniah and Agard (2015) have proposed the integration of OSH in the design of facilities layouts and can be used in Indonesian manufacturing SMEs.

The third sub-stage of the workplace design stage is the setting of physical environmental conditions, especially temperature, lighting and noise, which aims to ensure that the physical environmental conditions in the production room in manufacturing SMEs meet the standards set by the Indonesian government in the Minister of Health Regulation No. 70 of 2016 and the Minister of Manpower Regulation No. 5 of 2018.

The fifth stage of this workplace design framework is productivity evaluation. Productivity evaluation can be done by comparing the number of products produced before and after the use of this framework, as well as comparing material handling activities between before and after the implementation of the framework.

The sixth stage is the optimisation of production time, which needs to be done if the results of the productivity evaluation show that the productivity of SMEs is not good.

If all the previous stages are carried out well, it can be expected that a healthy, safe and productive workplace can be achieved at the end of this workplace design framework.

6. Conclusion

6.1. Academic Contribution

The workplace design process in manufacturing SMEs in Indonesia is evaluated. The previously introduced frameworks of workplace design can be used to design workplaces in manufacturing SMEs in Indonesia. Our analyses showed that two of the five frameworks introduced by previous researchers, i.e. Battini et al. (2011) and Caputo et al. (2019a), have many conformities with the characteristics of manufacturing SMEs in Indonesia and can be implemented with minor adjustments. Besides, workplace design in Indonesian manufacturing SMEs must be performed by considering ergonomics and OSH as well as environmental conditions (temperature, lighting and noise) in the workplace. Finally, a workplace design framework has been developed and proposed to assist the managers of manufacturing SMEs in Indonesia in designing their workplaces.

6.2. Implications for Practice

This proposed framework guides SME managers in designing their workplaces to obtain healthy, safe, and productive workplaces. Managers of manufacturing SMEs in Indonesia should follow the steps provided in this proposed framework when designing or re-designing their workplaces.

6.3. Limitations and Future Work

The limitation of this paper is that it is only based on the literature review from the four databases, i.e., Crossref, Google Scholar, Microsoft Academic and Scopus, and there might be other papers not indexed in the four databases that are consistent with the purpose of this paper but not included in this review. Furthermore, all the papers reviewed were limited to only peer-reviewed papers published in English. Papers not written in English and/or not peer-reviewed papers are not taken into consideration in this review.

This paper provides a solid foundation for developing an appropriate workplace design framework for manufacturing SMEs in Indonesia in the near future. However, the evaluation results based on this literature review need to be verified by involving manufacturing SME managers to obtain a workplace design framework that is suitable for manufacturing SMEs in Indonesia. Furthermore, this proposed framework needs to be implemented to determine the usability and performance of this proposed framework in assisting SME managers.

Declaration of Conflicting Interests

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Appendix A

59 articles about the manufacturing industry workplace design for full-text checking

#	Authors (year)	Title	Journal	Link
1	Wang, Rahardjo & Rovira (2022)	Lean six sigma with value stream mapping in industry 4.0 for human-centered workstation design	*Sustainability,* 14(17), 11020. https://10.3390/su141711020	https://www.mdpi.com/2071-1050/14/17/11020
2	Alipour, Daneshmandi, Fararuei & Zamanian (2021)	Ergonomic design of manual assembly workstation using digital human modeling	*Annals of Global Health,* 87(1), 112. https://10.5334/aogh.3256	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8231455/
3	Colim, Faria, Cunha, Oliveira, Sousa & Rocha (2021)	Physical ergonomic improvement and safe design of an assembly workstation through collaborative robotics	*Safety,* 7(1), 14. https://10.3390/safety7010014	https://www.mdpi.com/2313-576X/7/1/14
4	Gualtieri, Palomba, Merati, Rauch & Vidoni (2020)	Design of human-centered collaborative assembly workstations for the improvement of operators' physical ergonomics and production efficiency: A case study	*Sustainability,* 12(9), 3606. https://10.3390/su12093606	https://www.mdpi.com/2071-1050/12/9/3606
5	Herzog & Harih (2020)	Decision support system for designing and assigning ergonomic workplaces to workers with disabilities	*Ergonomics,* 63(2), 225236. https://10.1080/00140139.2019.1686658	https://www.tandfonline.com/doi/abs/10.1080/00140139.2019.1686658
6	Iqbal, Hasanuddin, Hassan, Bin, Soufi & Erwan (2020)	The study on ergonomic performances based on workstation design parameters using virtual manufacturing tool	*International Journal of Integrated Engineering,* 12(5), 124129.	https://publisher.uthm.edu.my/ojs/index.php/ijie/article/view/6092
7	Jadhav, Arunachalam & Salve (2020)	Ergonomics and efficient workplace design for hand-sewn footwear artisans in Kolhapur, India	*Work,* 66(4), 849860. https://10.3233/wor-203230	https://content.iospress.com/articles/work/wor203230
8	Realyvásquez-Vargas, Arredondo-Soto, Blanco-Fernandez, Sandoval-Quintanilla, Jiménez-Macías & García-Alcaraz (2020)	Work standardization and anthropometric workstation design as an integrated approach to sustainable workplaces in the manufacturing industry	*Sustainability,* 12(9), 3728. https://10.3390/su12093728	https://www.mdpi.com/2071-1050/12/9/3728
9	Ariyanti et al. (2019)	Design work station of pipe welding with ergonomic approach	*Sinergi,* 23(2), 107114. https://10.22441/sinergi.2019.2.003	https://publikasi.mercubuana.ac.id/index.php/sinergi/article/view/5422
10	Bligard & Berlin (2019)	ACD 3 as a framework for design of ergonomic workplaces	*Work,* 62(1), 512. https://10.3233/WOR-182836	https://content.iospress.com/articles/work/wor182836
11	Caputo et al. (2019a)	Digital twins to enhance the integration of ergonomics in the workplace design	*International Journal of Industrial Ergonomics,* 71, 2031. https://10.1016/j.ergon.2019.02.001	https://www.sciencedirect.com/science/article/abs/pii/S0169814118303883

#	Authors (year)	Title	Journal	Link
12	Caputo et al. (2019b)	Workplace design ergonomic validation based on multiple human factors assessment methods and simulation	*Production and Manufacturing Research,* 7(1), 195-222. https://10.1080/21693277.2019.1616631	https://www.tandfonline.com/doi/full/10.1080/21693277.2019.1616631
13	Havard, Jeanne, Lacomblez & Baudry (2019)	Digital twin and virtual reality: a co-simulation environment for design and assessment of industrial workstations	*Production & Manufacturing Research,* 7(1), 472489. https://10.1080/21693277.2019.1660283	https://www.tandfonline.com/doi/full/10.1080/21693277.2019.1660283
14	Jadhav et al. (2019)	Ergonomics design and evaluation of the stitching workstation for the hand-crafted Kolhapuri footwear using a digital human modeling approach	*Journal of Industrial and Production Engineering,* 36(8), 563575. https://10.1080/21681015.2019.1702593	https://www.tandfonline.com/doi/abs/10.1080/21681015.2019.1702593
15	Malik, Masood & Bilberg (2020)	Virtual reality in manufacturing: immersive and collaborative artificial-reality in design of human-robot workspace	*International Journal of Computer Integrated Manufacturing,* 33(1), 116. https://10.1080/0951192X.2019.1690685	https://www.tandfonline.com/doi/abs/10.1080/0951192X.2019.1690685
16	Mateus et al. (2019)	A structured methodology for the design of a human-robot collaborative assembly workplace	*International Journal of Advanced Manufacturing Technology,* 102, 26632681. https://10.1007/s00170-019-03356-3	https://link.springer.com/article/10.1007/s00170-019-03356-3
17	Sanjog et al. (2019)	Occupational ergonomics research and applied contextual design implementation for an industrial shop-floor workstation	*International Journal of Industrial Ergonomics,* 72, 188198. https://10.1016/j.ergon.2019.05.009	https://www.sciencedirect.com/science/article/abs/pii/S0169814118300611
18	Tondre & Deshmukh (2019)	Guidelines to sewing machine workstation design for improving working posture of sewing operator	*International Journal of Industrial Ergonomics,* 71, 3746. https://10.1016/j.ergon.2019.02.002	https://www.sciencedirect.com/science/article/abs/pii/S0169814118301835
19	Kumari (2018)	An ergonomic approach for modifying the workstation design of food processing enterprises	*Journal of Ergonomics,* 8(5), 1000241. https://10.4172/2165-7556.1000241	https://www.longdom.org/open-access/an-ergonomic-approach-for-modifying-the-workstation-design-of-food-processing-enterprises-25340.html
20	Diego-Mas, Poveda-Bautista & Garzon-Leal (2017)	Using RGB-D sensors and evolutionary algorithms for the optimization of workstation layouts	*Applied Ergonomics,* 65, 530540. https://10.1016/j.apergo.2017.01.012	https://www.sciencedirect.com/science/article/abs/pii/S0003687017300200
21	Harari et al. (2017)	Automated simulation-based workplace design that considers ergonomics and productivity	*International Journal of Simulation Modelling,* 16(1), 518. https://10.2507/IJSIMM16(1)1.355	http://www.ijsimm.com/Full_Papers/Fulltext2017/text16-1_5-18.pdf
22	Nguyen, Pontonnier, Hilt, Duval & Dumont (2017)	VR-based operating modes and metaphors for collaborative ergonomic design of industrial workstations	*Journal on Multimodal User Interfaces,* 11, 97111. https://10.1007/s12193-016-0231-x	https://link.springer.com/article/10.1007/s12193-016-0231-x

#	Authors (year)	Title	Journal	Link
23	Singh, Meena, Chaudhary & Dangayach (2017)	Ergonomic assessment and prevalence of musculoskeletal disorders among washer-men during carpet washing: guidelines to an effective sustainability in workstation design	*International Journal of Human Factors and Ergonomics,* 5(1), 2243. https://10.1504/IJHFE.2017.088416	https://www.inderscienceonline.com/doi/abs/10.1504/IJHFE.2017.088416
24	Kushwaha & Kane (2016)	Ergonomic assessment and workstation design of shipping crane cabin in steel industry	*International Journal of Industrial Ergonomics,* 52, 2939. https://10.1016/j.ergon.2015.08.003	https://www.sciencedirect.com/science/article/abs/pii/S0169814115300111
25	Sutalaksana & Widyanti (2016)	Anthropometry approach in workplace redesign in Indonesian Sundanese roof tile industries	*International Journal of Industrial Ergonomics,* 53, 299305. https://10.1016/j.ergon.2016.03.002	https://www.sciencedirect.com/science/article/abs/pii/S0169814116300154
26	Usman, Haitao & Ul-Haq (2016)	Design improvement of assembly workplace through ergonomic simulation and analysis using DELMIA	*International Journal of Engineering Research in Africa,* 21, 238246. https://10.4028/www.scientific.net/JERA.21.238	https://www.scientific.net/JERA.21.238
27	Mahoney, Kurczewski & Froede (2015)	Design method for multi-user workstations utilizing anthropometry and preference data	*Applied Ergonomics,* 46, 17. https://10.1016/j.apergo.2014.07.003	https://www.sciencedirect.com/science/article/abs/pii/S000368701400115X
28	Müglich, Sinn-Behrendt, Schaub & Bruder (2015)	Development of a database for capability-appropriate workplace design in the manufacturing industry	*Occupational Ergonomics,* 12(3), 109118. https://10.3233/OER-150228	https://content.iospress.com/articles/occupational-ergonomics/oer228
29	Vagaš, Baláž, Koukolová and Putala (2015)	Methodology for workplace design at food production process	*Journal of Automation and Control,* 3(3), 127130. https://10.12691/automation-3-3-18	http://pubs.sciepub.com/automation/3/3/18/
30	Garbie, 2014	An experimental investigation on ergonomically designed assembly workstation	*International Journal of Industrial and Systems Engineering,* 16(3), 296321. https://10.1504/IJISE.2014.060131	https://www.inderscienceonline.com/doi/abs/10.1504/IJISE.2014.060131
31	Motamedzade, Afshari & Soltanian (2014)	The impact of ergonomically designed workstations on shoulder EMG activity during carpet weaving	*Health Promotion Perspectives,* 4(2), 144150. https://10.5681/hpp.2014.019	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4300439/
32	Pontonnier, Dumont, Samani, Madeleine & Badawi (2014)	Designing and evaluating a workstation in real and virtual environment: toward virtual reality based ergonomic design sessions	*Journal on Multimodal User Interfaces,* 8, 199208. https://10.1007/s12193-013-0138-8	https://link.springer.com/article/10.1007/s12193-013-0138-8?sa_campaign=email%2Fevent%2FarticleAuthor%2FonlineFirst
33	Vilas et al. (2013)	A general framework for the manufacturing workstation design optimization: A combined ergonomic and operational approach	*Simulation,* 89(3), 306-329. https://10.1177/0037549712462862	https://journals.sagepub.com/doi/10.1177/0037549712462862

#	Authors (year)	Title	Journal	Link
34	Neubert, Bruder & Toledo (2012)	The charge of ergonomics – A model according to the influence of ergonomic workplace design for economical and efficient indicators of the automotive industry	*Work,* 41(Suppl.1), 43894395. https://10.3233/WOR-2012-0735-4389	https://content.iospress.com/articles/work/wor0735
35	Rebelo, da Silva & Karwowski (2012)	A whole body postural loading simulation and assessment model for workplace analysis and design	*International Journal of Occupational Safety and Ergonomics,* 18(4), 509519. https://10.1080/10803548.2012.11076948	https://www.tandfonline.com/doi/abs/10.1080/10803548.2012.11076948
36	Shikdar & Hadhrami (2012)	Evaluation of a low-cost ergonomically designed adjustable assembly workstation	*International Journal of Industrial and Systems Engineering,* 10(2), 153166. https://10.1504/IJISE.2012.045178	https://www.inderscienceonline.com/doi/abs/10.1504/IJISE.2012.045178
37	Vitello, Galante, Capoccia & Caragnano (2012)	Ergonomics and workplace design: application of Ergo-UAS System in Fiat Group Automobiles	*Work,* 41(Suppl.1), 44454449. https://10.3233/wor-2012-0744-4445	https://content.iospress.com/articles/work/wor0744
38	Battini et al. (2011)	New methodological framework to improve productivity and ergonomics in assembly system design	*International Journal of Industrial Ergonomics,* 41(1), 3042. https://10.1016/j.ergon.2010.12.001	https://www.sciencedirect.com/science/article/abs/pii/S016981411000106X
39	Deros, Khamis, Ismail, Jamaluddin, Adam & Rosli (2011)	An ergonomics study on assembly line workstation design	*American Journal of Applied Sciences,* 8(11), 11951201. https://10.3844/ajassp.2011.1195.1201	https://thescipub.com/abstract/ajassp.2011.1195.1201
40	Miralles, Holt, Marin-Garcia & Canos-Daros (2011)	Universal design of workplaces through the use of Poka-Yokes: Case study and implications	*Journal of Industrial Engineering and Management,* 4(3), 436452. https://10.3926/jiem.2011.v4n3.p436-452	https://www.jiem.org/index.php/jiem/article/view/420
41	Saptari, Lai & Salleh (2011)	Jig design, assembly line design and work station design and their effect to productivity	*Jordan Journal of Mechanical and Industrial Engineering,* 5(1), 916.	http://jjmie.hu.edu.jo/files/v5n1/JJMIE-2.pdf
42	Broberg (2010)	Workspace design: A case study applying participatory design principles of healthy workplaces in an industrial setting	*International Journal of Technology Management,* 51(1), 3956. https://10.1504/IJTM.2010.033127	https://www.inderscienceonline.com/doi/abs/10.1504/IJTM.2010.033127
43	Eswaramoorthi, John, Rajagopal, Prasad & Mohanram (2010)	Redesigning assembly stations using ergonomic methods as a lean tool	*Work,* 35(2), 231240. https://10.3233/WOR-2010-0975	https://content.iospress.com/articles/work/wor00975
44	Hallbeck, Bosch, Rhijn, Krause, Looze & Vink (2010)	A tool for early workstation design for small and medium enterprises evaluated in five cases	*Human Factors and Ergonomics in Manufacturing & Service Industries,* 20(4), 300315. https://10.1002/hfm.20222	https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20222
45	Seim & Broberg (2010)	Participatory workspace design: A new approach for ergonomists?	*International Journal of Industrial Ergonomics,* 40(1), 2533. https://10.1016/j.ergon.2009.08.013	https://www.sciencedirect.com/science/article/abs/pii/S0169814109001127

#	Authors (year)	Title	Journal	Link
46	Cimino, Longo & Mirabelli (2009)	A multimeasure-based methodology for the ergonomic effective design of manufacturing system workstations	*International Journal of Industrial Ergonomics,* 39(2), 447455. https://10.1016/j.ergon.2008.12.004	https://www.sciencedirect.com/science/article/abs/pii/S0169814108001947
47	Longo & Mirabelli (2009)	Effective design of an assembly line using modelling and simulation	*Journal of Simulation,* 3(1), 5060. https://10.1057/jos.2008.18	https://www.tandfonline.com/doi/abs/10.1057/JOS.2008.18
48	Chaffin (2007)	Human motion simulation for vehicle and workplace design	*Human Factors and Ergonomics in Manufacturing,* 17(5), 475484. https://10.1002/hfm.20087	https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20087
49	Choobineh, Hosseini, Lahmi, Khani-Jazani & Shahnavaz (2007)	Musculoskeletal problems in Iranian hand-woven carpet industry: Guidelines for workstation design	*Applied Ergonomics,* 38(5), 617624. https://10.1016/j.apergo.2006.06.005	https://www.sciencedirect.com/science/article/abs/pii/S0003687006001244
50	Das, Shikdar & Winters (2007)	Workstation redesign for a repetitive drill press operation: A combined work design and ergonomics approach	*Human Factors and Ergonomics in Manufacturing,* 17(4), 395410. https://10.1002/hfm.20060	https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20060
51	Lin & Chan (2007)	Effectiveness of workstation design on reducing musculoskeletal risk factors and symptoms among semiconductor fabrication room workers	*International Journal of Industrial Ergonomics,* 37(1), 3542. https://10.1016/j.ergon.2006.09.015	https://www.sciencedirect.com/science/article/abs/pii/S0169814106001934
52	Shikdar & Hadhrami (2007)	Smart workstation design: An ergonomics and methods engineering approach	*International Journal of Industrial and Systems Engineering,* 2(4), 363374. https://10.1504/ijise.2007.013184	https://www.inderscienceonline.com/doi/abs/10.1504/IJISE.2007.013184
53	Pitt, Goyal, Holt, Ritchie, Day, Simmons et al. (2005)	An innovative approach to facilities management in the workplace design brief: Virtual reality in design	*Facilities,* 23(7/8), 343355. https://10.1108/02632770510600290	https://www.emerald.com/insight/content/doi/10.1108/02632770510600290/full/html
54	Choobineh, Lahmi, Khani-Jazani, Hosseini & Shahnavaz (2004b)	Musculoskeletal symptoms as related to ergonomic factors in Iranian hand-woven carpet industry and general guidelines for workstation design	*International Journal of Occupational Safety and Ergonomics,* 10(2), 157168. https://10.1080/10803548.2004.11076604	https://www.tandfonline.com/doi/abs/10.1080/10803548.2004.11076604
55	Choobineh, Lahmi, Hosseini, Khani-Jazani & Shahnavaz (2004a)	Workstation design in carpet hand-weaving operation: Guidelines for prevention of musculoskeletal disorders	*International Journal of Occupational Safety and Ergonomics,* 10(2), 157168. https://10.1080/10803548.2004.11076604	https://www.tandfonline.com/doi/abs/10.1080/10803548.2004.11076625
56	Zha & Lim (2003)	Intelligent design and planning of manual assembly workstations: A neuro-fuzzy approach	*Computers and Industrial Engineering,* 44(4), 611632. https://10.1016/S0360-8352(02)00238-3	https://www.sciencedirect.com/science/article/abs/pii/S0360835202002383
57	Carey & Gallwey (2002)	Evaluation of human postures with computer aids and virtual workplace designs	*International Journal of Production Research,* 40(4), 825843. https://10.1080/00207540110093927	https://www.tandfonline.com/doi/abs/10.1080/00207540110093927

#	Authors (year)	Title	Journal	Link
58	Feyen, Liu, Chaffin, Jimmerson & Joseph (2000)	Computer-aided ergonomics: A case study of incorporating ergonomics analyses into workplace design	*Applied Ergonomics,* 31, 291300. https://10.1016/S0003-6870(99)00053-8	https://www.sciencedirect.com/science/article/abs/pii/S0003687099000538
59	Sengupta & Das (2000)	Maximum reach envelope for the seated and standing male and female for industrial workstation design	*Ergonomics,* 43(9), 13901404. https://10.1080/001401300421824	https://www.tandfonline.com/doi/abs/10.1080/001401300421824

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