Arturo Realyvásquez Vargas
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Jorge Luis García Alcaraz *Editors*

Automation and Innovation with Computational Techniques for Futuristic Smart, Safe and Sustainable Manufacturing Processes

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Preface

Sustainability is a variable that many companies want to achieve in three dimensions: social, environmental, and economic. It is well known that Ergonomics and Safety can contribute to the sustainability of companies. To achieve this, several computational techniques can be applied to solve mathematical, scientific, engineering, geometrical, geographical, and statistical problems, which in turn facilitate the sustainability of companies.

Currently, the processes of solving problems in computational techniques are mostly stepwise and methodical, and they are used in all fields of engineering. Therefore, soft computing methods are used to resolve all innovative research problems in engineering, manufacturing, and business management.

Many innovative designs and sustainable solutions have been resolved using IoT and A.I. techniques. Any troublesome work without hard labor and with easy approaches can be resolved by the IoT, which is safer and can be learned quickly. This will help research and find a significant replacement with innovative solutions to technical and business-related problems. Safety and sustainability are major problems for most industries and emerging sectors. Sustainability mainly deals with the environmental parameters that impact industries and social life. Without safety practices, the highly productive industrial sectors will fail. Therefore, safety is an essential criterion and is often addressed by framing and following safety policies.

This book is divided into three parts. Part I, called Sustainability in Manufacturing, comprises Chaps. 1–5. Chapter 1 presents a bilbiometric review of sustainable and intelligent manufacturing, innovation, industry, and safety. The authors used 376 documents on these topics that were analyzed using VOSviewer and Bibliometrix software. The authors report the most-cited authors, countries, and documents.

Chapter 2 presents a systematic literature review regarding the main challenges associated with Industry 4.0 technologies implementation in managing the supply chain in the context of sustainability. The review comprised 45 articles showing trends toward challenges related to labor competency, the costs of implementing 4.0 technologies, organizational culture, and computer security.

Chapter 3 reports a structural equation model integrating three latent variables, with poka-yoke as the independent variable, jidoka as the mediator variable, and social sustainability as the dependent variable. The variables were related using three hypotheses validated using information from 411 responses to a survey. The authors use the partial least squares technique to test the hypotheses, and the findings indicate that poka-yoke has a direct and positive effect on jidoka and social sustainability, since they improve working conditions and safety for employees.

Chapter 4 aims to determine the importance of barriers to intelligent manufacturing systems in plastic sector companies operating in the providence of Samsun (Turkey) and select the best innovation management model. While the Neutrosophic AHP method was used to weigh the criteria as barriers to intelligent manufacturing systems, the Neutrosophic MARCOS method ranked alternatives as an innovation management model.

Finally, Chap. 5 presents the critical success factors (CSF) in Six Sigma (S.S.) deployment and their relationship to long-term sustainable benefits (S.B.). Using structural modeling, three factors were found: senior management commitment, relationships with clients and suppliers, and training and education. The originality of this study is that these factors predicted 56% of the S.B. derived from the application of S.S. projects for environmental improvement.

Chapters 6–11 deal with different cases of Ergonomics and Safety in manufacturing companies. Chapter 6 provides a case study on the impact of noise on human health. The case study is conducted on Bhubaneswar-based manufacturing, textiles, auto shops, and small-scale industries, where people work continuously from 7 to 8 h daily. The study used three questionnaires to examine labor-related health issues at clinical and workplace levels. Then, an assessment was conducted to evaluate the noise, suggesting a few noise-control devices and soundproofing materials.

Chapter 7 comprises a case study that clarifies occupational health safety as an essential concern for workers engaged in loading and unloading jobs. Moreover, in this case study, people worked near high temperatures to melt the metals or pour them into a frame to fabricate utensils. Subsequently, they were exposed to danger. Finally, ergonomic posture was assessed to determine discomfort in the workplace.

In Chap. 8, we discuss the impact of noise pollution on human hearing capability. To do this, they used the Simulation Annealing optimization method, prioritizing the risk associated with noise using the WASPAS multi-criterion decision-making method.

Chapter 9 discusses the inclusion of ergonomics in autonomous vehicles (A.V.s). First, the components of human-driven vehicle ergonomics, such as "vehicle ergonomics", "warehouse ergonomics", "training and education", and "research and profession", are explained. Second, the discussion focuses on the features of A.V.s used in both "on and off-highway" situations, such as agriculture and mining. Considering these two factors will help decide how much ergonomics are still required for A.V.s and whether they are essential.

Chapter 10 describes a study conducted to assess the postural risk of workers who perform the task of installing paneled walls. Based on the results obtained, a mechanical device was designed and simulated. The findings of this study suggest that the proposed design may be able to improve the postural load levels of workers during the installation of paneled walls.

Finally, Chap. 11 analyzes the Kano Model and Factor Analysis to determine and classify the design attributes for an ergonomic factor tester product for office chairs. Consequently, nine ergonomic attributes for the chairs and eight design attributes for the product were obtained, which were classified as attractive attributes for the user. In turn, they were grouped into three and two groups.

Finally, Part III contains Chaps. 12–14. These chapters cover computational techniques applied in manufacturing. For instance, Chap. 12 raised the problem of vegetable waste in India. Therefore, this chapter focuses on discovering the problems and difficulties of the vegetable production network and finding an answer to the problem in a production network. As a solution, the authors developed an intelligent device that tracks food based on its freshness by flashing green, red, or orange light. In this way, food with preserved natural freshness can be sold to customers.

Chapter 13 presents a technology transfer model for the Autonomous University of Ciudad Juarez based on the essential managerial, linkage, technological, and research elements required for university-industry technology transfer. Taking advantage of the accumulated capabilities in the city allows for the improvement of products and processes developed in manufacturing firms, which could lead to the economic and technological development of the region.

Finally, Chap. 14 presents System Dynamics (S.D.) and its applications in various disciplines; simple considerations in drawing causal loop diagrams; stock and flow diagrams; and safety management systems. Thus, this chapter reveals the application of S.D. as a modeling and computational technique useful in manufacturing safety systems for intervention strategy allocations.

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Part I
Sustainability in Manufacturing

Chapter 1
Innovation, Safe and Smart Sustainable Manufacturing—A Bibliometric Review

Jorge Luis García-Alcaraz, Arturo Realyvásquez Vargas, and Suchismita Satapathy

Abstract This chapter presents a bibliometric review of 376 documents related to sustainable manufacturing, innovation, industrial safety, and intelligent manufacturing. The information was obtained from the Scopus database on January 12, 2023, and analyzed using VOSviewer 1.6.18 and Bibliometrix software. The results indicate that sustainable manufacturing is of growing academic and scientific interest, with the United States, China, the United Kingdom, and India being the most productive countries. In addition, the most produced documents were articles and conference papers, although there were some reviews and book chapters. The main application areas are engineering and computer science, as manufacturing is studied in the former and hardware and software integration in the latter. The main agencies sponsoring this type of research are the National Natural Science Foundation of China and the National Science Foundation of the USA. The Journals that publish on sustainable manufacturing are Procedia CIRP and Sustainability, although they are not the most cited journals. After observing the trend in the number of publications and the number of institutions from which they originate, it is concluded that this topic will continue to grow in future years, given the trends towards Industry 4.0 and Industry 5.0, where environmentally and human-friendly production processes are required.

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1.1 Introduction

Manufacturing is defined as the transformation of raw materials into a finished product through the hands or with the help of machines, and its objective is to put a product on the market in such a way that it generates economic income (Campana and Cimatti 2015). Initially, this concept was associated with the artisanal production of the past century; however, over time, the concept has evolved owing to the generation of machines and tools that began to emerge with the industrial revolution.

Several industrial revolutions have modified the manufacturing processes (Hassoun et al. 2023). The first industrial revolution (I.R.) occurred in 1784, with the appearance of mechanical production equipment driven by water and steam power. The second I.R. emerged in 1870 with the introduction of electricity and oil as a source of energy and was characterized by mass production systems, division of labor, and specialization of workers. By 1970, the third I.R. emerged, aimed at the automation of production systems with the help of machines that integrated electronic components and that already interacted with each other through information and communication technologies (ICT), but by 2011 the fourth I.R. appeared, characterized by automated and interconnected production through cybernetic physical systems (Harintoro et al. 2023).

The concepts generated until the fourth industrial revolution and with the birth of Industry 4.0, were focused on productivity, effectiveness, and efficiency of production systems, where many environmental and social aspects were not of vital importance (Mazur 2022). Fortunately, the period between one revolution and another is becoming shorter, evolving rapidly; in 2021 (only two years ago) and during the COVID-19 pandemic, the concept of industry 5.0 has emerged, in which three basic concepts are integrated, such as the resilience that must have productive systems based on agility and flexibility, the human factor and its security, where their talent is recognized and based on this, empowerment is granted (Humayun 2021). The third factor is sustainability, which seeks a balance between human beings, the planet, and its resources. In other words, manufacturing systems are now sought to be human-centered, safe, resilient, and capable of responding to the changes demanded by society, and sustainable and balanced with the environment.

With the emergence of the concept of Industry 5.0, in the fifth industrial revolution, three new concepts are integrated: human factor, resilience, and sustainability, which strengthen the concepts that already existed in the previous ones, such as safety at work and respect for employees, recognition of the talent they possess and the empowerment granted to them, sustainability as the basis of any production process in which environmental impact analysis is required, and resilience that allows a quick response to customers with adaptable technologies (Taj and Jhanjhi 2022). Thus, sustainable manufacturing, smart manufacturing, and industrial safety are becoming increasingly common in this industry.

However, many readers ask: What has allowed the evolution between the different stages of industry and production systems? Although there may be several answers to this question, the innovation of new machines and tools as well as the interconnectivity between them is what has favored it the most, which does not mean that there are no other causes.

1.1.1 Sustainable Manufacturing (SM)

Although sustainable manufacturing has always been important in all industrial revolutions, Industry 5.0, has become essential. SM is defined as the creation of manufactured products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources. This is because of the heightened awareness of climate change, which is reflected in the approach that customers take when making their purchases (Bensassi et al. 2022).

The need for low environmental impact has forced many governments to invest resources in SM process emissions (Gupta and Randhawa 2023), as CO_2 emissions from fossil fuel consumption and industrial processes have increased from 2000 to 2020 by 34,810 million metric tons. For example, in the third semester of 2020, investment in sustainable funds in Europe reached 120,800 million dollars (USMD); in the United States of America, it was 20,500 USMD; in Asia, it was 5,000 USMD; in Japan, it was 3,700 USMD; in Australia and New Zealand, it was 1,200 USMD; and in Canada, it was 1,200 USMD. From the above, it can be observed that European countries invest the most in sustainability.

Some of the objectives and benefits of adopting a sustainability profile in manufacturing processes are as follows (Munshi 2023; Bogue 2014; Trentesaux and Giret 2015):

1. Reduced use of natural resources and energy for the transformation and transportation of raw materials.
2. Manage the carbon footprint in all facilities and quantify the impact generated by all production processes.
3. Implementing technologies and machinery that optimize efficiency, resilience, and sustainability throughout the manufacturing lifecycle, including the supply chain.
4. Encourage building a solid foundation for a global circular economy that integrates the entire company and supply chain members.
5. Seeking to improve operational efficiency by reducing costs and waste through lean manufacturing tools.
6. Generate strategic objectives that indicate viability and business success in the long and medium terms.
7. Encourage the creation of a brand characterized by its commitment to the environment, which differentiates it from its competitors to improve sales and economic income.

SM has been studied using different approaches and covers diverse applications, and is of interest to researchers and academics, so many reports are associated

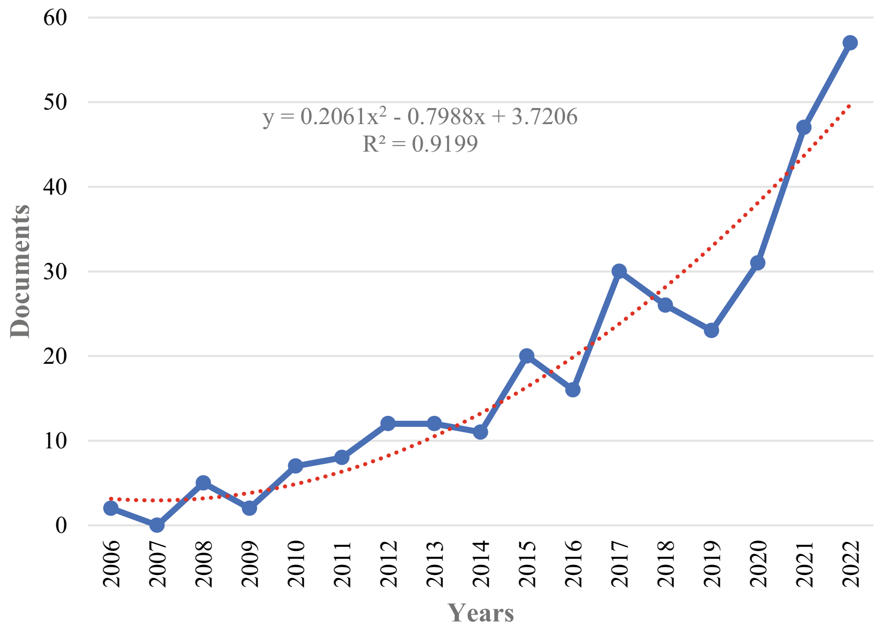

Fig. 1.1 Trends in sustainable manufacturing

with this topic in the literature. For example, Hariastuti and Lukmandono (2022) conducted a literature review indicating the practices that provide the greatest sustainable value to sustainable production systems, whereas Hariyani et al. (2022) focused on identifying organizational and managerial barriers to achieving sustainability through manufacturing processes.

Other authors seek to identify techniques and tools that allow SM; for example, Gupta and Randhawa (2023) proposed using lean manufacturing and Industry 4.0. This is demonstrated by Fuertes et al. (2022), who indicate that Industry 4.0 is a great opportunity to achieve sustainability, but lean manufacturing must be implemented first. Bag and Pretorius (2022) found a direct relationship between Industry 4.0, SM, and the circular economy.

The importance of SM lies in the number of studies on this topic. For example, a quick review of the Scopus database identified 958 papers with the word "sustainable manufacturing" in the title, as indicated in Fig. 1.1, where trends are observed.

1.1.2 Innovation (IN)

Innovation is a process that modifies existing elements, ideas, or protocols, improves them, or creates new ones that have a favorable impact on the market (consumers) and the company (shareholders) (Bagnoli 2014). However, creating new products is also considered disruptive innovation because it breaks previously established paradigms, representing a "great leap" in continuous improvement (Cordero et al. 2002).

Innovation can occur in different areas, such as social, business, organizational, and technological. However, this chapter focuses on industrial processes and product innovation, which are applied to manufacturing and are known as technological innovation. It is also considered a means of achieving sustainable and environmentally friendly manufacturing.

Fortunately, industrial process innovation is seen as a strategy to differentiate companies, which allows them to grow and position themselves in globalized markets due to two main factors (Gu and Xu 2017; Wen et al. 2022):

- Industrial process innovation improves the internal and external operations of all company departments.
- Process innovation allows us to optimize, improve, and consolidate the rest of the organization's strategies: marketing, internationalization, and attracting and retaining new talent, among others.

However, innovation is costly and it is worth asking why companies invest in innovating, improving, and automating their processes. The answer to the above is related to the benefits it offers to productive systems, among which are Liang et al. (2022) and Oumlil et al. (2020):

1. Reduction of production times in the medium and long term
2. Improved productivity and team effectiveness
3. Preventing economic losses due to human error
4. Improved decision-making processes
5. Improved final customer satisfaction.

The application of innovation in the manufacturing industry has been of great academic interest; for example, 2398 documents with the search equation (TITLE (innovation) AND TITLE (manufacturing)) were identified in the Scopus database, and Fig. 1.2 illustrates its evolution. It can be seen that both concepts were combined in 1973, when the first document appeared, but it was not until the year 2000 that the number increased exponentially with an adjustment of 98.05%. This exponential growth shows the importance of innovation in the manufacturing and transformation industry.

1.1.3 Industrial Safety (IS)

The third benefit of innovation is associated with the company's human resources, which need to be safe, and the company is responsible for providing it. Therefore, Industrial Safety in manufacturing processes systematically addresses the prevention of work-related injuries or accidents, which provides greater emotional stability to workers, knowing that their physical integrity is not compromised (Boulanger et al. 2013).

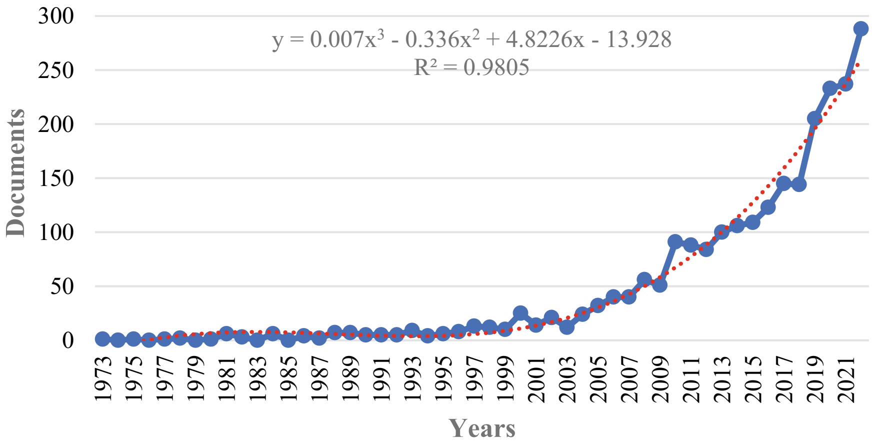

Fig. 1.2 Trends in innovation and manufacturing

The greatest utility of IS consists of minimizing occupational accidents by acting as a preventive rather than a reactive agent; however, it also covers managing and investigating accidents and incidents, should they occur (Simone et al. 2023). Thus, the main objective of this discipline is to achieve zero accident indicators in companies and to avoid government sanctions that affect their economic income and reputation. To achieve this, detailed planning was used to identify hazards in the facilities and processes, and safety and hygiene commissions were created to carry out periodic inspections in all facilities (Lodyany et al. 2022). Thus, based on the results, planning is performed, and monitoring, execution, and control actions are determined to reduce the risk of accidents.

Production activities in an industrial plant are characterized by massive generators of employment, although many operations have been automated owing to technological innovations and the subsequent reduction of personnel. In some cases, manufacturing industries and factories keep a high number of people working; therefore, safety must be an organizational priority (Simone et al. 2023).

The security provided by the company as responsible for the integrity of its workers should focus on the following aspects (Zhang et al. 2022):

- Occupational accidents can result in organic injury, functional disturbances, disability, or death. However, recently, serious damage to plants has also been included in this category.
- Incidents are undesired events that, under slightly different conditions, could cause injuries to people, damage to the facility, or losses to the production process.
- An unsafe or substandard act is any action performed by a worker in an unsafe or inadequate manner, increasing the probability of an occupational accident affecting his physical integrity.
- Unsafe conditions in the workplace are characterized by the presence of uncontrolled risks that can lead to occupational accidents.

Therefore, it is observed that a lack of S.I. affects the social sustainability of companies, generating a bad reputation in the eyes of their workers and society (Rahman et al. 2022). However, economic sustainability is also at risk because accidents represent administrative sanctions, high insurance payments, days not worked, staff turnover, absenteeism, and noncompliance with production rates. To this end, companies must be innovative and intelligently act in their production processes (Kazakova et al. 2020).

The importance of IS has been of interest to many academics from the perspective of the health and integrity of workers as well as the economic losses it generates for the company. A search with TITLE ("industrial safety") in the Scopus database identified 794 documents. This trend is illustrated in Fig. 1.3; however, the concept has been around since 1914. It was not until after 2000 that interest in this topic increased, because there were more automated processes with greater handling of materials and machines. The evolution of the IS concept can be said to have four stages, without a defined trend. The first stage is from 1914 to 1942 (during the Second World War), where a second stage begins and continues until the year 2000 with sporadic publications, but from that date on, it suddenly increases for six years, decreasing again, and currently maintaining a growing trend.

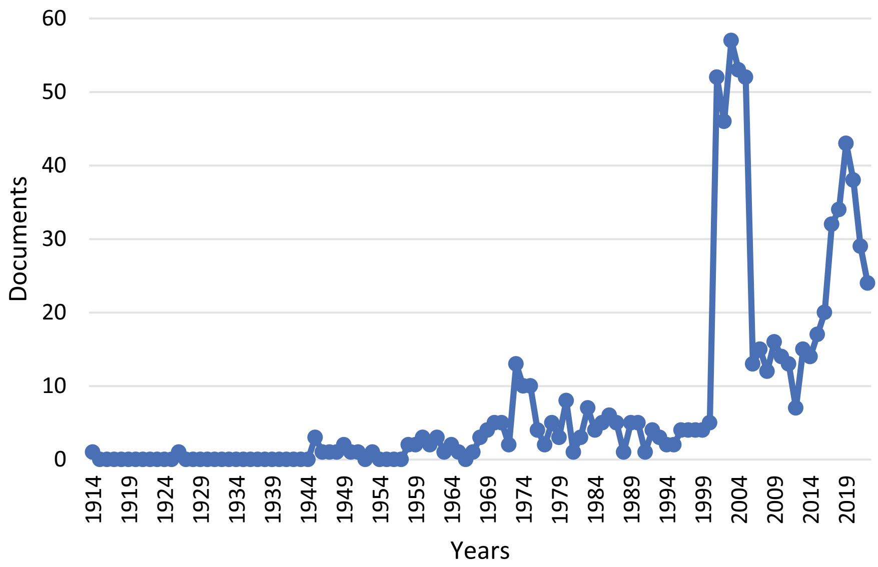

Fig. 1.3 Trends in industrial safety

1.1.4 Smart Manufacturing (SMA)

Technologies have been implemented in production systems, where it is possible to observe innovative machines that perform complex jobs automatically every day, leaving behind traditional manufacturing systems. Many of these machines are capable of making decisions based on collected data, which allows the optimization and streamlining of production processes, so it is said that they perform intelligent manufacturing.

SMA refers to the integration of digital systems in production systems, connecting, through different protocols, every one of the elements that make them up. Data are collected through sensors, stored in physical devices or the cloud, and processed quickly to take action based on the analysis results. Thus, owing to this massive amount of data analysis, valuable information is extracted, and effective and useful decisions are formulated for the company.

From the above, it can be concluded that the integration of hardware and software to collect data through sensors allows the integration of machines to optimize resources. The application of SMA should focus on four main areas in the production process: materials, quality, maintenance, and production. To determine the level of implementation of a company with SMA and whether real-time information on the production process and its automation is available, four important aspects must be analyzed.

1. *The connectivity, data, and computational power* installed equipment, as many of them quickly become obsolete, so the Internet of Things, monitoring, and data storage in the cloud and blockchain are now frequently used.
2. *Analytics and intelligence* are used to analyze the information collected, where Artificial Intelligence, Machine Learning and Deep Learning techniques are applied.
3. A genuine *human–machine interaction*, where we have virtual reality, robotics, and automation at the service of human needs, that is, with ergonomics capable of adjusting machines to humans and not vice versa.
4. *Advanced engineering*, where digital twins or nanoparticles are used in specific processes.

There are many reasons and benefits to applying SMA in production systems (even if it initially requires much investment), and some of these are the following:

- *Resource optimization* allows the centralization of systems and equipment with the most critical activities, allowing greater control over waste generation, reprocessing operations, increased quality, and real-time monitoring for agile decision making. Similarly, the supply of material is done in time, avoiding idle machines, demand follow-up, and global supply chain management.
- *Predictive maintenance.* In SMA, the monitoring of production processes and machines of the production system allows for the identification of possible failures, breakage, wear, and possible incidents that may damage them. Currently, it is common to find applications of Artificial Intelligence and Machine Learning to

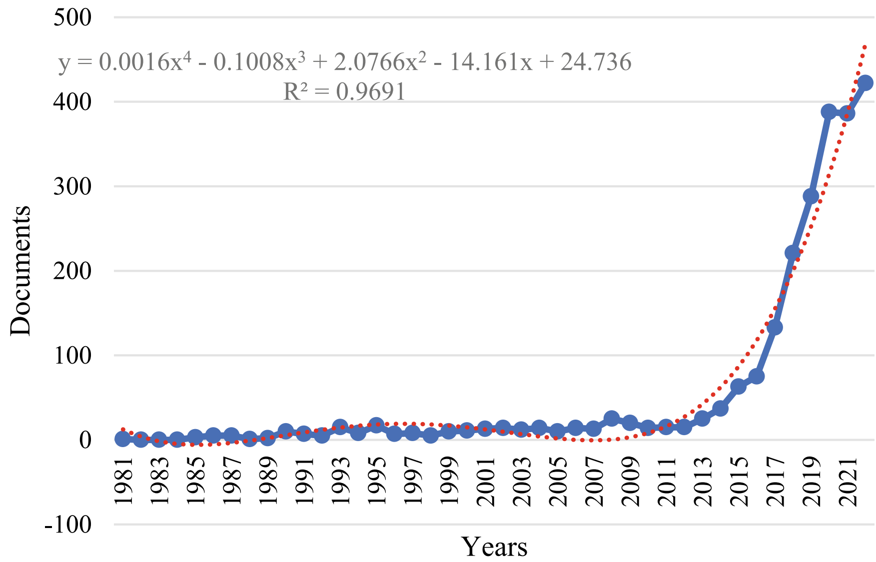

Fig. 1.4 Smart manufacturing trends

predict machinery and equipment failures, which avoids economic losses due to machine downtime.

- *Labor reduction*. With SMA, production processes are optimized and automated, which helps to achieve greater efficiency by avoiding human error attributable to activities performed manually.
- *Increased productivity*. Integrating technologies into the SMA helps increase productivity when properly applied and integrated. This is because functional and well-maintained machines allow for better production planning and less waste and reprocessing. In addition, automation increases product quality by reducing human errors, and processes are standardized without variations.

Smart manufacturing is a new field and has been of academic and scientific interest. A search of the Scopus database using the equation (TITLE (“smart manufacturing”) OR TITLE (“intelligent manufacturing”)) identified 2357 documents. Figure 1.4 illustrates the number of documents per year generated on that topic in the blue line, while the red line indicates an ascending polynomial trend of order 4 with a fit level of 96.91%.

1.1.5 *The Research Problem and Objective*

Previously, concepts related to sustainable manufacturing, innovation, industrial safety, and smart manufacturing have been defined. Lean manufacturing is considered the origin of many of these concepts and the first step towards smart manufacturing because, through automation, we reach the integration of innovations in hardware and software systems that bring benefits associated with the industrial safety and profitability of companies.

It should be understood that the main objective of a company is to increase shareholder profits. For this, it needs to be productive, measured by the quality of its products, defects generated, use of available resources, and customer satisfaction as the main contributors to economic income. Thus, many concepts are merely economic, as they seek to reduce costs to increase profits; that is, a safe company would not pay penalties for accidents, insurance premiums, accidents, or suspension of work due to unhealthy conditions.

Moreover, an innovative company in its production systems and products offered to the market will always analyze the needs of customers and the installed capacities it has to satisfy them. Suppose that operating capacity does not meet the capabilities required by the market for any reason. In this case, it will improve them through innovation processes or replace them with more updated ones.

At this point, the question is whether there are authors who have integrated or associated sustainable manufacturing with innovation, industrial safety, and smart manufacturing in production processes? When have these concepts been integrated? Who are the authors, and where are they affiliated? Currently, there is no answer to these questions, which represents the problem that this chapter addresses to learn more about this area of research. Thus, the objective of this chapter is to present a bibliometric review of these concepts, which will mainly address the identification of the main authors, institutions, and countries in which this topic is the most researched, and the identification of the documents, journals, authors, institutions, and countries that are most cited, among others.

1.2 Methodology

To perform the proposed bibliometric analysis, several activities were conducted, which were integrated into the two stages described below.

1.2.1 Stage 1. Collection of Information

In this stage, all the documents that address the study topics are identified, and we use the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) technique, which has been used in several previous reviews, such as Abusaada and Elshater (2022) in urban planning or Al-Bouwarthan et al. (2022) in health sciences. In addition, Rethlefsen et al. (2021) stated that it is a consolidated and accepted methodology in academia and science.

To identify documents in which sustainable manufacturing is integrated with innovation, industrial safety, and smart manufacturing, the Scopus database was used, performing the search on January 12, 2023, focusing on those that were published in the period from 2006 to 2023, including those that were published or were in press and available. Only articles written in English or Spanish were included.

Based on the above, the search equation is as follows: TITLE-ABS-KEY ("sustainable manufacturing" AND (innovation OR safe OR "smart manufacturing")) AND (LIMIT-TO (PUBSTAGE, "final") OR LIMIT-TO (PUBSTAGE, "aip")) AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "Spanish")), which facilitates the understanding of its content. The list of identified documents was downloaded in the CSV and BIB formats for further analysis.

1.2.2 Stage 2. Analysis with VOSviewer and Bibliometrix

A total of 376 documents were identified using the above search equation, and VOSviewer 1.6.18 and Bibliometrix software were used because they are freely available and have been widely used in scientific articles. For example, VOSviewer has been reported in 3980 documents in Scopus, such as Haba et al. (2023), which analyzes the behavior of green consumers, and Ibda et al. (2023), which analyzes stress in students during the COVID-19 pandemic. Bibliometrix is reported in 628 documents in Scopus, such as Zhong et al. (2023), which discusses trends and challenges in wastewater treatment, and Franco et al. (2023), which studies breast cancer and response to radiation therapy.

The analyses focused on identifying the following.

1. Trends in publications on integrated topics.
2. Authors, institutions, and main sources that publish on topics of interest.
3. Main keywords used by authors and publishers to index documents.
4. The most cited documents, sources, authors, educational institutions, and research centers focus on these topics.

1.3 Results

1.3.1 Identification of Documents

376 papers were identified in the Scopus database on January 12, 2023, which matched the search equation used. All 376 papers were published or in press for the final editing. It is important to mention that four documents associated with this topic, published in 2023, were included.

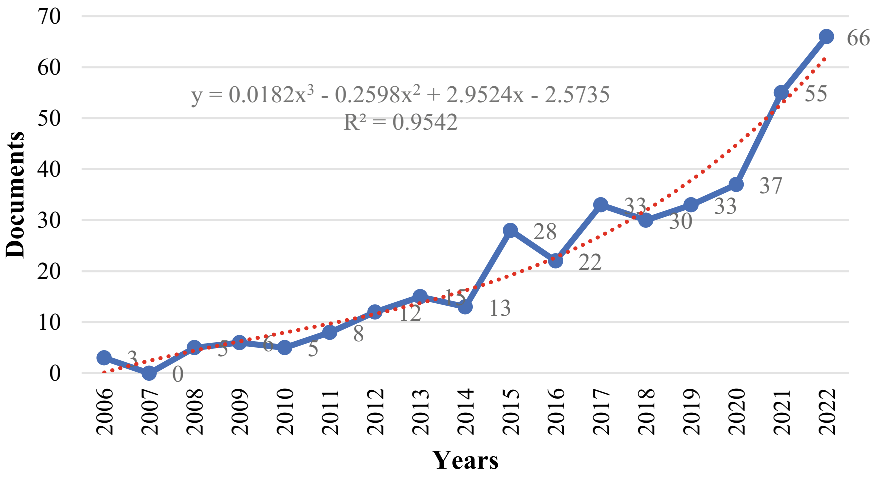

Fig. 1.5 Publication trends

1.3.2 Annual Academic Production

Figure 1.5 illustrates the trend of documents with the word SM in the title and some terms associated with IN, IS, and SMA in the abstract, title, or keywords. It can be seen that it was in 2006 that the concept of SM appeared in combination with some of the other topics, which indicates that it is a new concept that appears as an alternative to traditional manufacturing. However, it is important to note that the concept of SM has a broader approach than green manufacturing because the former includes the environmental, social, and economic dimensions of sustainability, while the latter refers only to the environmental dimension.

The trend of the graph in Fig. 1.5 indicates that it is growing exponentially, increasing year after year. The trend line can be divided into two stages: the first from 2006 to 2014, when there is little pronounced growth, and the second from 2014 to 2022, when there are already 66 documents with a more rapid increase. However, it is important to mention that five documents corresponding to 2023 were eliminated from the analysis to avoid affecting the adjusted trend line.

1.3.3 Main Areas of Application

Figure 1.6 indicates the main topics to which the SM is being applied. It should be mentioned that many of the papers identified are in journals indexed in two or more categories, which is why the sum of all categories is greater than the 376 papers analyzed. It was observed that engineering occupies the first place since manufacturing has been studied in this area.

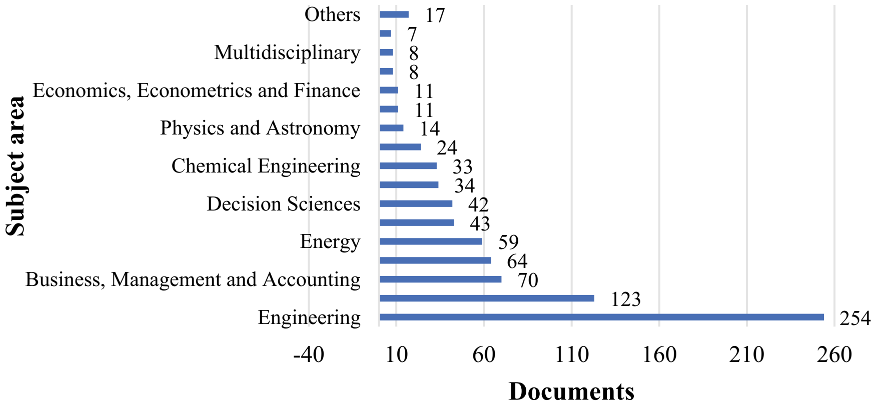

Fig. 1.6 Main areas of application of SM

Other areas, such as computer science, business, and environmental sciences, also stand out. However, the former may be due to the high integration of information and communication technologies used in production processes, where Industry 4.0, concepts are integrated, requiring information collection and analysis knowledge. Concerning business, sustainability is also sold and is a concept that consumers are willing to pay for because of the high levels of environmental awareness that currently exist, and concerning environmental sciences, this is one of the pillars of sustainability.

However, SM study impacts other areas, such as energy, where the aim is to produce more with fewer inputs, including this one. There are also social aspects, since the production processes are less polluting of the cities or regions in which they are established, being more accepted. It is important to mention that in the category Others in Fig. 1.6, the categories of Agricultural and Biological Sciences, Arts and Humanities, Earth and Planetary Sciences, Psychology, Veterinary, Health Professions, and Immunology and Microbiology have been integrated.

1.3.4 Main Sources of Financing

A total of 110 institutions interested in these topics that have funded research associated with SM were identified. Table 1.1 illustrates in the first column the number of documents, and the second column reports the institutions. The National Natural Science Foundation of China and the National Science Foundation of the United States of America occupy first place with nine documents, and the Engineering and Physical Sciences Research Council of the United Kingdom with six documents.

Table 1.1 Main sponsor agencies in SM

Institutions	Documents
National Natural Science Foundation of China, National Science Foundation	9
Engineering and physical sciences research council	6
Agentúra na Podporu Výskumu a Vývoja, European Commission	5
Bundesministerium für Bildung und Forschung, European Regional Development Fund, Fundamental Research Funds for the Central Universities, Ministry of Education and Science of Ukraine, Ministry of Higher Education, Malaysia, Natural Science Foundation of Zhejiang Province, Stiftelsen för Kunskaps-och Kompetensutveckling, U.S. Department of Energy	3
China Scholarship Council, Deanship of Scientific Research, King Saud University, Fundação para a Ciência e a Tecnología, Horizon 2020, Kultúrna a Edukacná Grantová Agentúra MŠVVaŠ SR, Merck, Natural Sciences and Engineering Research Council of Canada, Regione Campania, Sumy State University, Universiti Utara Malaysia, VINNOVA	2

However, 86 institutions have only one product, and the complete list can be found in the Excel sheet as supplementary material, where all the quantitative information in this chapter is presented.

1.3.5 Types of Published Documents and Countries

Table 1.2 illustrates the types of documents published, and fortunately, it can be seen that most of these are journal articles and conference papers that have undergone peer review, which guarantees their quality. These documents come from 57 identified countries, such as the United States of America, India, and the United Kingdom, which are indicated in Fig. 1.7 for the first 15. It is important to mention that it was impossible to identify the origin of 22 documents.

Of the 15 countries in Fig. 1.7, seven European, seven Asian, and Brazil represent South America, the United States represents North America, and Australia represents Oceania. Unfortunately, there are no African countries on the list. Authors interested

Table 1.2 Type of documents

Type of document	Quantity
Article	163
Conference paper	143
Review	31
Book chapter	17
Conference review	17
Book	5

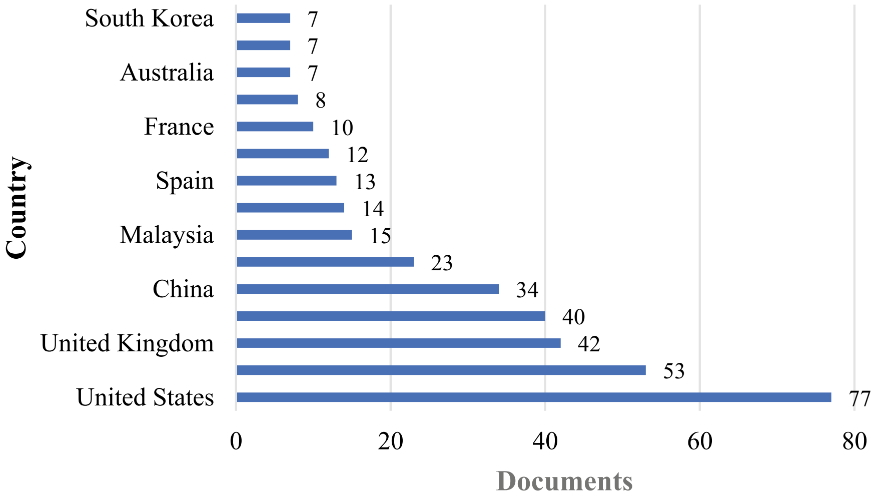

Fig. 1.7 Main countries in which SM is published

in the complete list of countries should consult the supplementary material for this chapter.

Figure 1.8 illustrates the relationships between different countries according to the number of documents published (size of the circle) and the number of years they have been publishing on the topic (color of the circle). Purple indicates the most consolidated countries, such as the United States of America, Malaysia, Japan, Spain, and Norway. The countries represented by green circles are more contemporary and less consolidated, such as China, India, the United Kingdom, Italy, Germany, France, and Brazil, while the countries represented in yellow are those that are beginning to take interest in this topic, such as Poland, Colombia, Slovakia, and Bulgaria, among others.

Specifically, it is observed that authors from the United States of America, China, India, United Kingdom, Italy and France collaborate with authors from other countries (given the large number of links they have), while Chile, Mexico, Bulgaria, Colombia, Iran, Egypt and Slovakia are countries that, because they are just starting, have not had relationships with many colleagues in other countries and have few documents.

One country that has extensive sustainable manufacturing programs is Canada; however, scientific production on this topic is scarce and has only three papers related to authors from China.

Figure 1.9 illustrates the cumulative production of different countries over time. It can be seen that countries such as the United States of America have been pioneers in the generation of documents on SM since 2006, when they held the lead. Countries such as the United Kingdom and Italy, although they were pioneers, are no longer among the most productive because countries such as India and China have displaced them in recent years.

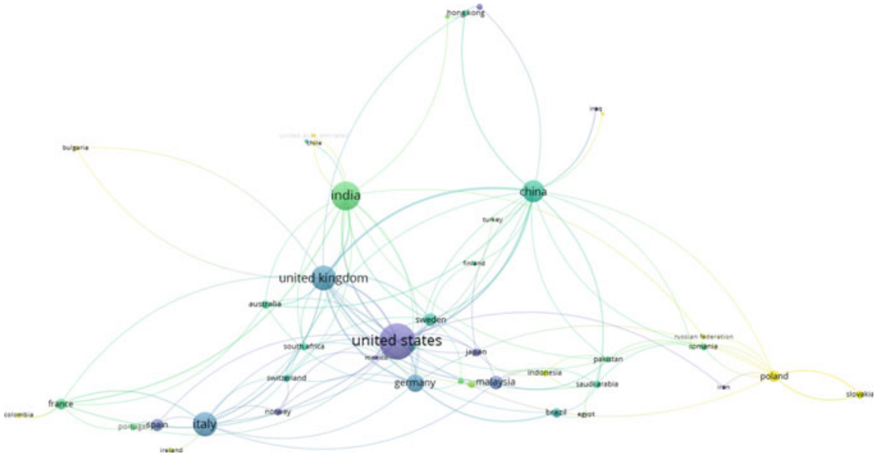

Fig. 1.8 Countries and their relationships

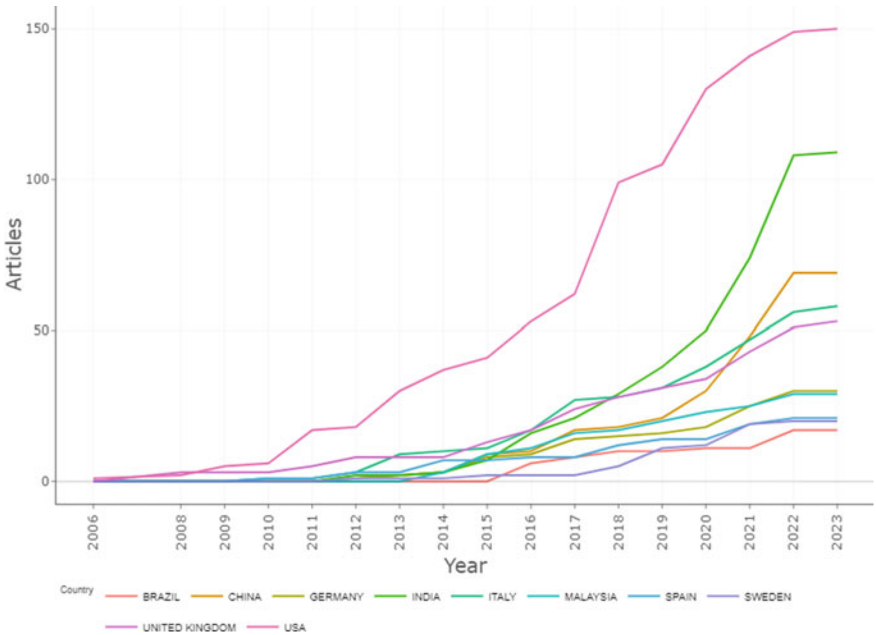

Fig. 1.9 Document production evolution by country

1.3.6 Most Productive Authors

A total of 1134 authors who researched the topics of SM, IN, IS, and SMA were identified. However, because it is a new concept, there are no authors with several

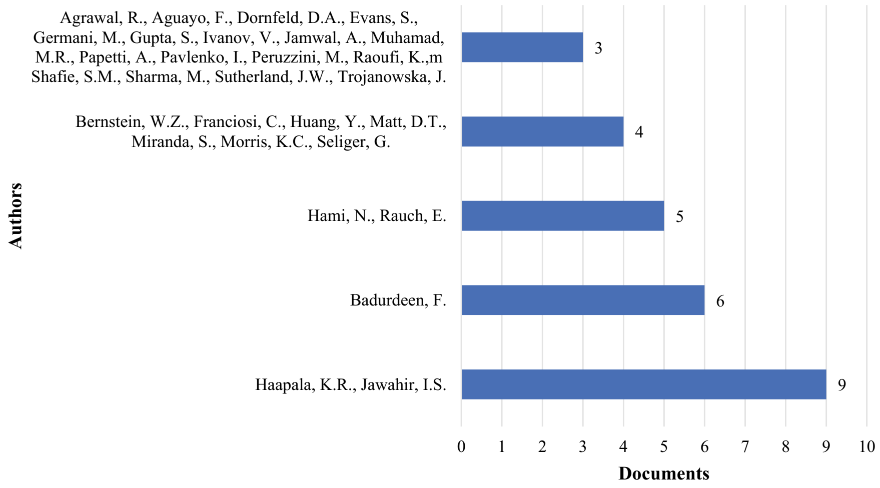

Fig. 1.10 Main authors

documents. The most productive authors are Haapala, K. R. and Jawahir, I. S., with nine papers, and Badurdeen, F. with six papers, among others. Figure 1.10 indicates the main authors with more than three papers; in the supplementary material, the complete list of authors with two and one papers can be found.

Figure 1.11 illustrates the relationships between the different authors and the academic networks in which they collaborate, where the size of the circles indicates the number of documents and the color indicates the level of consolidation. The authors were integrated into 11 clusters, and it can be observed that the authors who initiated research on SM are not those who have generated the most documents. For example, the cluster integrated by Camelio, J., Clarens, A. F., Dornfeld, D. A., Lee, W. J., Mendis, G. P., Rickli, J. L., Skerlos, S. J., Sutherland, J. W., Zhang, H. C., and Zhao, F., are the ones who started writing about SM, since the color that characterizes them is purple; however, according to the size of the circle, Haapala, K. R. and Jawahir, I. S. are the ones who have written the most and have been a reference in many other investigations.

Other clusters are of academic interest, such as the one led by Bernstein, W. Z., Moris, K. C., Seliger, G. and Badurdeen, F., since they have many relationships with other authors. It is also important to mention that most authors on this topic are relatively new, as many of them are represented by yellow circles, indicating that their scientific and academic contributions are recent.

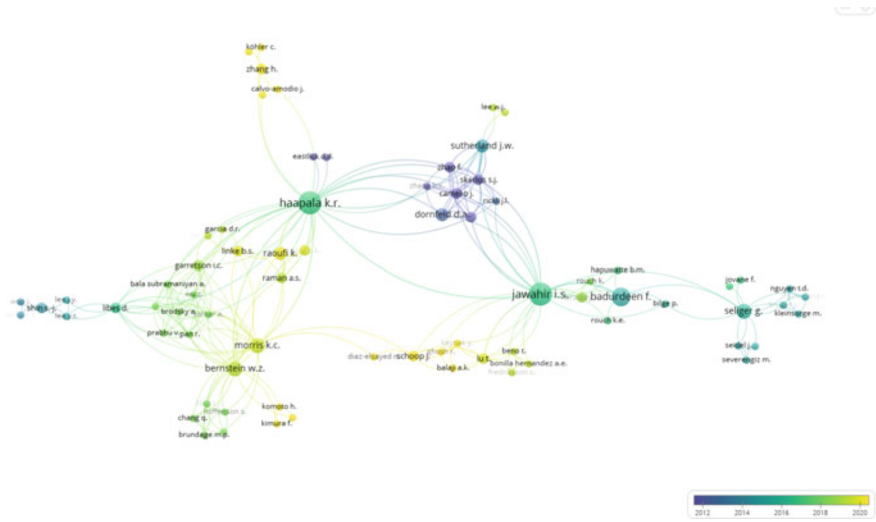

Fig. 1.11 Author clusters

1.3.7 Most Productive Academic Institutions

A total of 752 academic institutions were identified that research topics associated with SM, IN, IS and SMA, among which the Institute for Sustainable Manufacturing (ISM) of the University of Kentucky (Lexington, KY) in the United States of America and the School of Mechanical, Industrial, and Manufacturing Engineering of Oregon State University (Corvallis, OR) in the United States of America stand out with three papers.

Similarly, there are a total of 18 institutions that have two documents, including Wayne State University (Detroit, MI, United States), Auburn University (Auburn, AL, United States), Faculty of Technical Systems and Energy Efficient Technologies, Sumy State University (Sumy, Ukraine), Università Politecnica Delle Marche (Ancona, Italy), Mahidol University (Nakhon Pathom, Thailand), and University of Salerno (Fisciano, Italy). A total of 732 institutions have only one document; therefore, it cannot be said that there are research groups that stand out. However, it is surprising that there is a department specializing in SM at the University of Kentucky, so they may quickly begin publishing papers based on their research results.

Figure 1.12 illustrates the number of documents published by the institution over time, where it is clear that the University of Kentucky and Oregon State University are the pioneers in this topic since they are the ones that have accumulated the most documents. Also noteworthy is the progress made by the Universiti Utara Malaysia, which has a growing trend.

Readers who wish to know the complete list of institutions may consult the supplementary materials associated with this chapter.

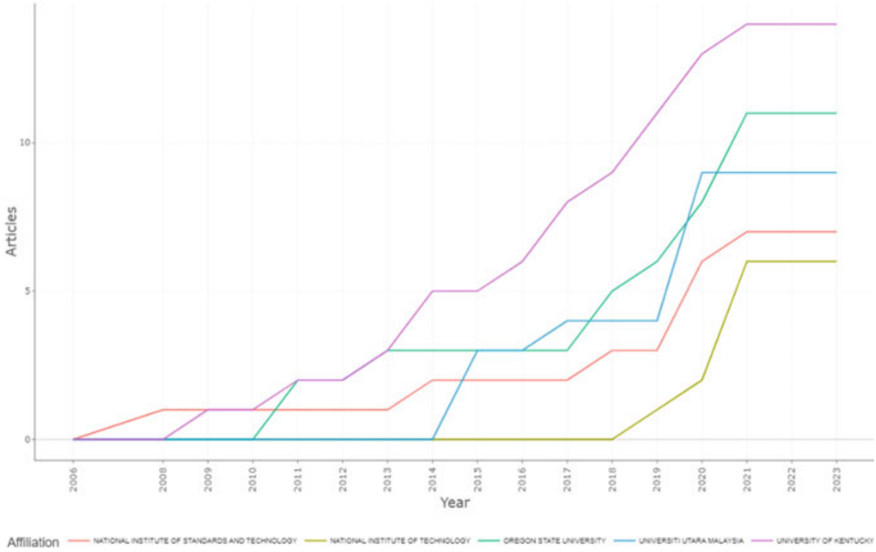

Fig. 1.12 Productivity evolution by academic institutions

1.3.8 Journals that Publish on SM

A total of 115 journals have been identified that publish topics related to SM and Fig. 1.13 illustrates the most important ones. In this case, Procedia CIRP is the one that publishes the most, with 26 papers, which is focused on production and manufacturing systems; in second place is Sustainability Switzerland, with 22 papers focused on sustainability aspects, which are the ones with the highest percentage. This is followed by the Journal of Cleaner Production and Lecture Notes in Mechanical Engineering, which contains only 11 documents.

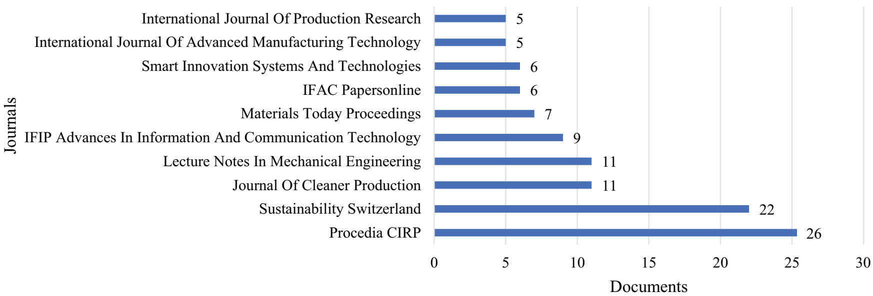

Fig. 1.13 Main journals

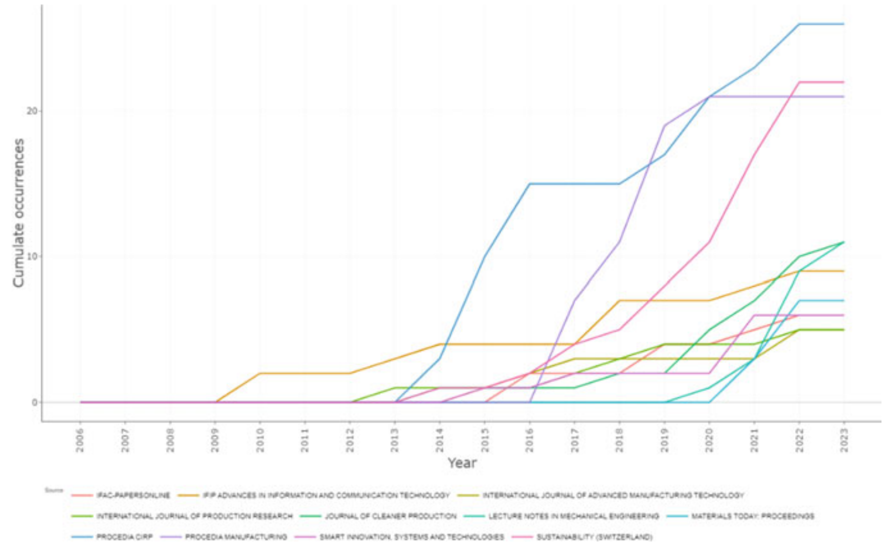

Fig. 1.14 Evolution in the number of publications in journals

We also found three journals that published only three papers and six that published two. The authors wishing to see the complete list can refer to the supplementary material.

Not all Journals have shown the same interest in SM, IN, IS, and SMA over the years. Figure 1.14 illustrates the number of cumulative papers that the top 10 journals publish on these topics and shows that Procedia CIRP is in the lead, followed by Sustainability and Procedia Manufacturing in second and third place.

1.3.9 Most Used Keywords

The most widely used words in the topics of SM, IN, IS, and SMA are of two types: those used by the authors and those used by the editors to index the documents in the different databases. A total of 2875 keywords were identified, and Table 1.3 shows the 15 most important keywords used by the authors and editors together. It can be seen that Sustainable Manufacturing has the highest number, with 245 occurrences, followed by manufacturing and sustainable development, with 132 and 124 occurrences, respectively.

It is also noted that many keywords are related to the industry and type of industry, environmental impact, innovation, and the decision-making process that facilitates the integration of all concepts.

Figure 1.15 indicates the different relationships that the keywords have, as well as their evolution over time. The purple colors indicate that they are older, the green

Table 1.3 Occurrence of keywords

Keywords	Occurrences
Sustainable manufacturing	245
Manufacture	132
Sustainable development	124
Sustainability	79
Manufacturing	51
Smart manufacturing	50
Industrial research	43
Industry 4.0	39
Life cycle	34
Innovation	33
Environmental impact	24
Decision making	22
Manufacturing industries	22
Energy utilization	20
Product design	20

colors are moderately old, and the yellow colors are recent. All words were integrated into 23 clusters, and it was observed that the oldest words referred to energy policies, manufacturing paradigms, printed circuit boards, evaluation metrics, and carbon dioxide. The words in the green circle are more recent and are represented by several factors such as sustainable manufacturing, industrial research, water treatment, renewable energy, and energy utilization. Finally, the words in the yellow circle are more recent and are represented by additives, Pandemic, Covid-19, Advanced manufacturing, 3d printers, among others.

To identify the main keywords that began to be used in the topic of SM and those that are currently used, they were divided into two periods, from 2006 to 2018 and from to 2019–2023 and are illustrated in Fig. 1.16, where it can be seen that the first words that give rise to the topic are related to public policies, agile manufacturing, flow control, sustainable manufacturing, environmental impact, and decision making. However, words such as sustainable manufacturing, knowledge-based systems, material consumption, advanced manufacturing, and environmental aspects are now being used in this topic.

1.3.10 Most Cited Documents

It is important to know which documents have allowed the generation of others, and have been the basis for subsequent research. Table 1.4 illustrates the first 15 most-cited documents and shows that the authors who publish the most are not precisely

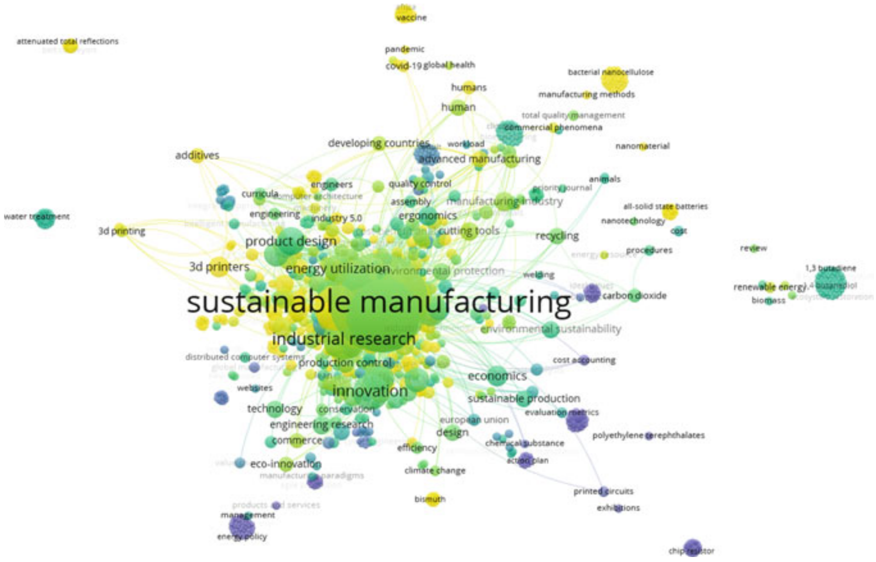

Fig. 1.15 Main keywords

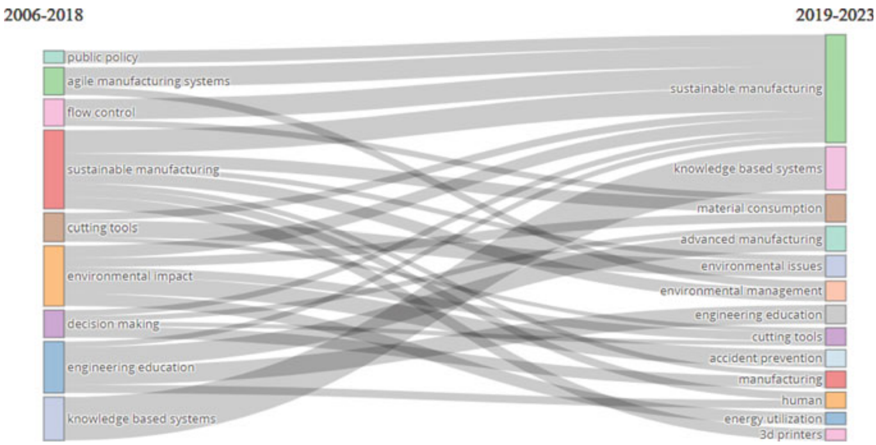

Fig. 1.16 Thematic evolution

those who receive the most citations in their documents. The most cited paper is by Kusiak (2018), which provides the definitions and concepts of smart manufacturing and integrates all electronic devices in the system, a relatively recent document. In this case, the author Haapala has nine papers but ranks third concerning citations received.

Figure 1.17 illustrates the relationships between the documents, and based on the color of the circle that represents them, it can be seen that the pioneers in this topic

Table 1.4 Most cited documents

Authors	Document	Subpoenas
Kusiak (2018)	Smart manufacturing	623
Faulkner and Badurdeen (2014)	Sustainable Value Stream Mapping (Sus-VSM): methodology to visualize and assess manufacturing sustainability performance	281
Haapala et al. (2013)	A review of engineering research in sustainable manufacturing	262
Tan et al. (2020)	From nanoscale interface characterization to sustainable energy storage using all-solid-state batteries	224
Tuptuk and Hailes (2018)	Security of smart manufacturing systems	208
Dornfeld (2014)	Moving towards green and sustainable manufacturing	168
Shen (2014)	Sustainable fashion supply chain: lessons from H&M	157
Cioffi et al. (2020)	Artificial intelligence and machine learning applications in smart production: progress, trends, and directions	134
Clark et al. (2015)	Opportunities for bio-based solvents created as petrochemical and fuel products transition towards renewable resources	133
Jiménez et al. (2019)	Additive manufacturing technologies: an overview about 3D printing methods and future prospects	123
Goodrich et al. (2013)	Assessing the drivers of regional trends in solar photovoltaic manufacturing	111
Waibel et al. (2017)	Investigating the effects of smart production systems on sustainability elements	108
Khorram Niaki and Nonino (2017)	Additive manufacturing management: a review and future research agenda	105
Majeed et al. (2021)	A big data-driven framework for sustainable and smart additive manufacturing	103
Shin et al. (2014)	Predictive analytics model for power consumption in manufacturing	99

are Haapala et al. (2013), Siemieniuch et al. (2015), Shin et al. (2014), Shankar et al. (2016), Malcolm et al. (2006), Dimitrov (2008), among others. Most authors are not old and are represented by green circles as in Meng et al. (2018), Awan (2019), Dimovski et al. (2019) and Abubakr et al. (2020), to name a few. However, many authors are relatively recent, such as Munshi (2023) and Yun and Li (2023), which are from 2023, indicating that a greater number of documents will be published this year.

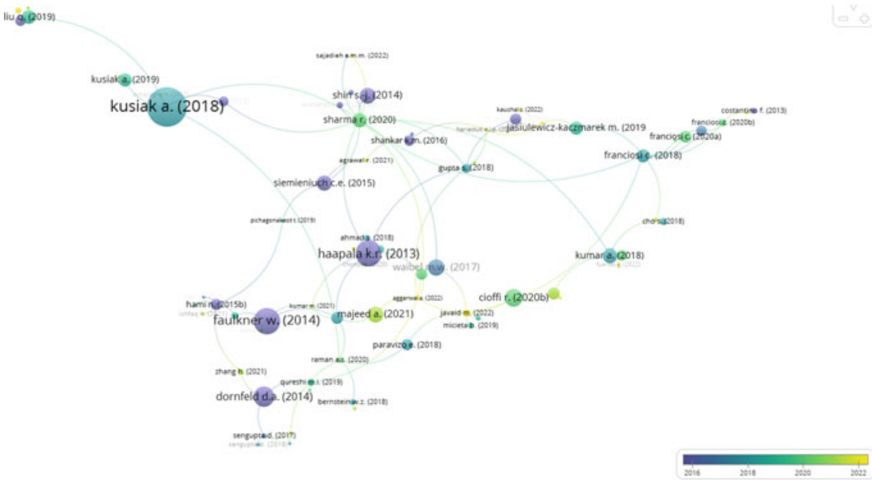

Fig. 1.17 Most cited documents

1.3.11 Most Cited Journals

A total of 196 journals were identified with information related to SM; however, only 49 had citations with others. Table 1.5 illustrates the most cited journals. In this case, it can be observed that the first refers to the study of production systems, the second already integrates the possibility of clean production, and the third focuses on sustainability.

It is important to mention that, in this case, Procedia CIRP publishes the most on this topic of SM with 26 papers, but it is not the one that occupies the first place in citations, since it is in fifth place. The first place is occupied by the International Journal of Production Research, which ranks tenth in production, with only five papers indicating interest from the academic community.

Figure 1.18 indicates the relationships among the 47 journals integrated into 11 clusters. It can be seen that IFIP Advances in Information and Communication Technology and the Journal of Manufacturing Technology Management have the oldest citations, while Procedia Manufacturing, Procedia CIRP and Sustainability (Switzerland) are more recent, as is the Journal of Cleaner Production. However, some journals are very recent and are represented by yellow circles, such as Materials Today: Proceedings, Lecture Notes in Mechanical Engineering and Sustainable Manufacturing, which appears to be a very specialized journal in this topic.

Table 1.5 Most cited journals

Journal	Citations
International journal of production research	854
Journal of cleaner production	618
Sustainability (Switzerland)	596
Procedia manufacturing	451
Procedia CIRP	324
Journal of manufacturing science and engineering	262
Nature nanotechnology	224
Journal of manufacturing systems	208
International journal of precision engineering and manufacturing—green technology	198
Journal of manufacturing technology management	171
International journal of advanced manufacturing technology	151
Energy and environmental science	144
International journal of molecular sciences	133
Robotics and computer-integrated manufacturing	127
Complexity	123

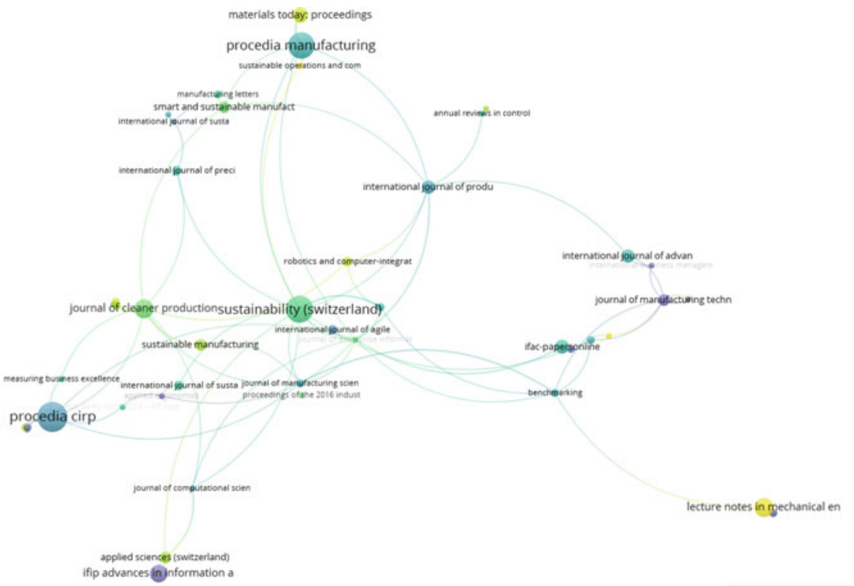

Fig. 1.18 Citations between journals

Table 1.6 Most cited authors

Authors	Documents	Citations
Kusiak A.	2	698
Dornfeld D. A.	3	465
Jawahir I. S.	9	404
Badurdeen F.	6	370
Haapala K. R.	9	363
Sutherland J. W.	3	315
Camelio J.	2	297
Clarens A. F.	2	297
Skerlos S. J.	2	297
Zhao F.	2	297
Faulkner W.	1	281
Rickli J. L.	1	262
Meng Y. S.	1	224
Tan D. H. S.	1	224
Hailes S.	1	208

1.3.12 Most Cited Authors

The most productive authors of a topic are not always the most cited. Table 1.6 illustrates this SM topic's first 15 most-cited authors. It can be seen that Kusiak A., with only two papers, has 698 citations, which indicates an average of 349 citations per paper. However, Jawahir I. S. and Haapala K. R., who both had nine papers and were the most productive, had 404 and 363 citations, respectively. Overall, it can be said that many authors have not been very productive, but with a single paper, they have accumulated many citations, such as Faulkner, Rickli, and Meng, who each have more than 224 citations.

Although 1134 authors were identified, only 277 were related to each other and were integrated into 15 clusters. Figure 1.19 illustrates the relationships between them. It is interesting to note that Kusiak, A., having only two papers, is very isolated from the others and is only related to Bidanda, B., Haapala, K. R. and Bernstein, W. Z.

1.3.13 Most Cited Academic Institutions

Table 1.7 illustrates the ten most cited institutions (unified since many have campuses in different cities). This list shows that the first nine institutions are based in the United States of America, and that only University College London appears to represent Europe.

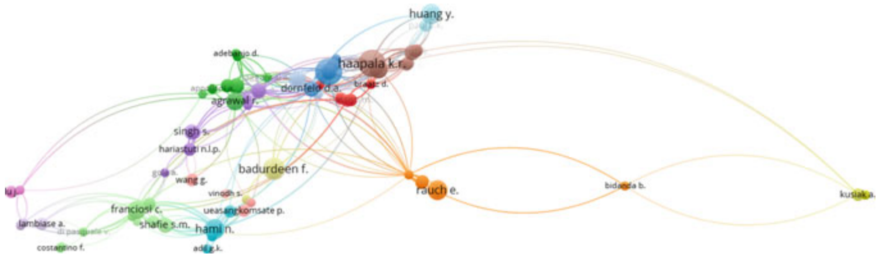

Fig. 1.19 Relationship among most cited authors

Table 1.7 Most cited institutions

University	Citations
University of Iowa	623
University of Kentucky	543
University of Virginia	262
Virginia Polytechnic Institute	262
University of California	486
University of Kentucky	262
University of Michigan	262
Purdue University	262
Oregon State University	262
University College London	208

It is important to mention that by unifying the different campuses of American universities, it has been observed that there are academic departments focused on this area of research, such as the Institute for Sustainable Manufacturing at the University of Kentucky in Lexington, the Laboratory for Manufacturing and Sustainability at the University of California in Berkeley, and the Sustainable Power and Energy Center (SPEC) at the University of California in San Diego, all of them in the United States of America.

See the supplementary material for a complete list of institutions, and the number of citations and documents.

1.3.14 Most Cited Countries

Previously, it has been indicated that the most cited universities were established in the United States of America, which is why Fig. 1.16 shows that this country is the most cited, followed by the United Kingdom, India, Italy, and China. This indicates that the research groups established in these countries are a reference in research beginning to be carried out on this topic.

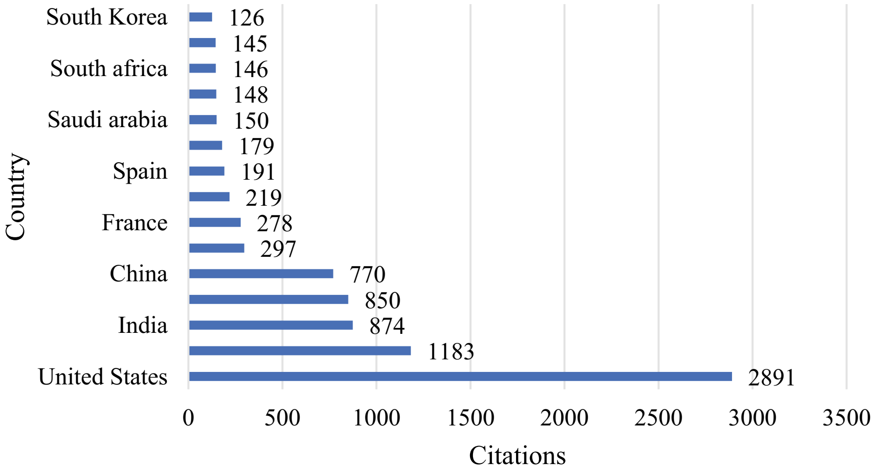

Fig. 1.20 Most cited countries

It is also important to mention that of the 15 countries shown in Fig. 1.20, six are European, including Italy, France, and Germany, indicating that consolidated research groups also exist in these countries. In addition, five Asian countries appear in this list: India, China, Saudi Arabia, Malaysia, and South Korea. In this case, South America is represented by Brazil. Readers interested in the complete list of citations by country can refer to the supplementary material.

Although 57 countries were identified, only 31 maintain some mutual citation, which is integrated into six clusters and Fig. 1.21 illustrates the relationships between them. It is clear that the United States of America, the United Kingdom, China, India, and Italy are the most cited countries because of the size of their circles; however, the United States of America, Malaysia, Japan, and Spain have the oldest citations, while countries with emerging economies are more recent, such as China, India, Portugal, and Sweden. Some countries have few high-quality documents, such as Poland, which has several citations and is beginning to research these topics.

1.3.15 Level of Cooperation Between Countries

Figure 1.22 illustrates the relationships between countries to measure the level of academic collaboration. It can be seen that China is the country with the greatest collaboration and is related to 19 countries, followed by the United States of America with 18, India with 13 and the United Kingdom with 13. However, Italy and Poland have also published documents in collaboration with other countries, with 8 and 6, respectively. It is important to mention that some countries are related to only one

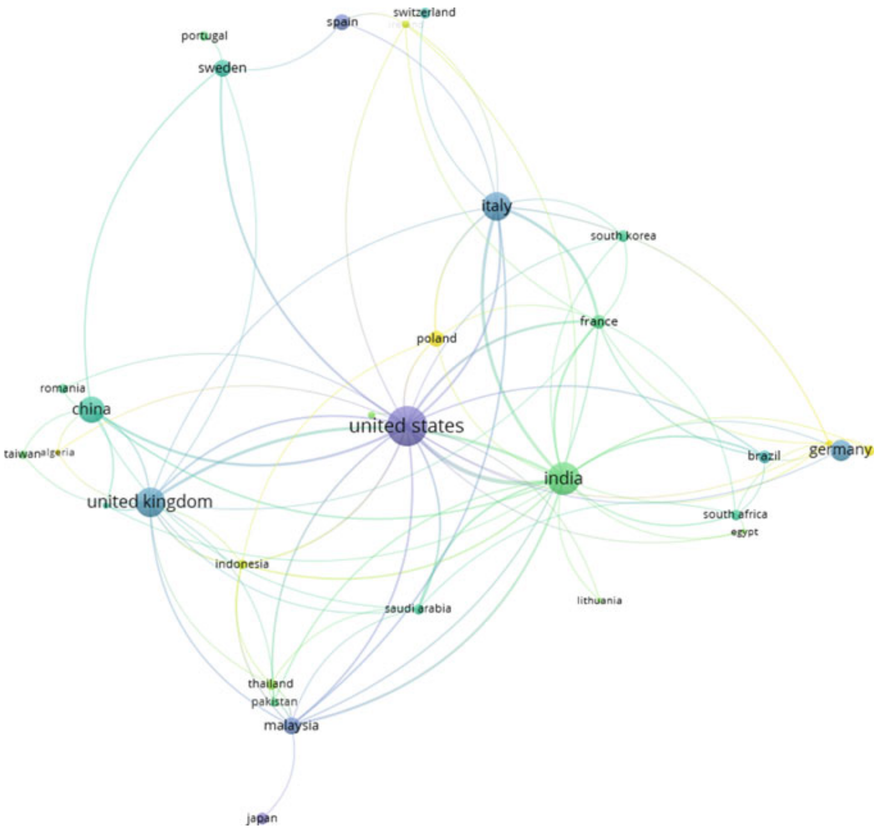

Fig. 1.21 Most cited countries

country, such as Japan, South Korea, Slovenia and Ukraine. For country relationships, please refer to the supplementary materials in this chapter.

1.4 Conclusions

From the bibliometric analysis of 376 documents published on the topic of SM, IN, IS, and SMA, it is concluded that this is an area of academic and scientific interest because the number of publications is continuously growing in the areas of engineering and computational sciences, with articles and conference papers being the most widely disseminated. It has been found that the institutions established in the United States of America are the ones that produce the most documents and the most cited, such as the University of Kentucky and Oregon State University, which are the authors of these institutions and are also the most productive.

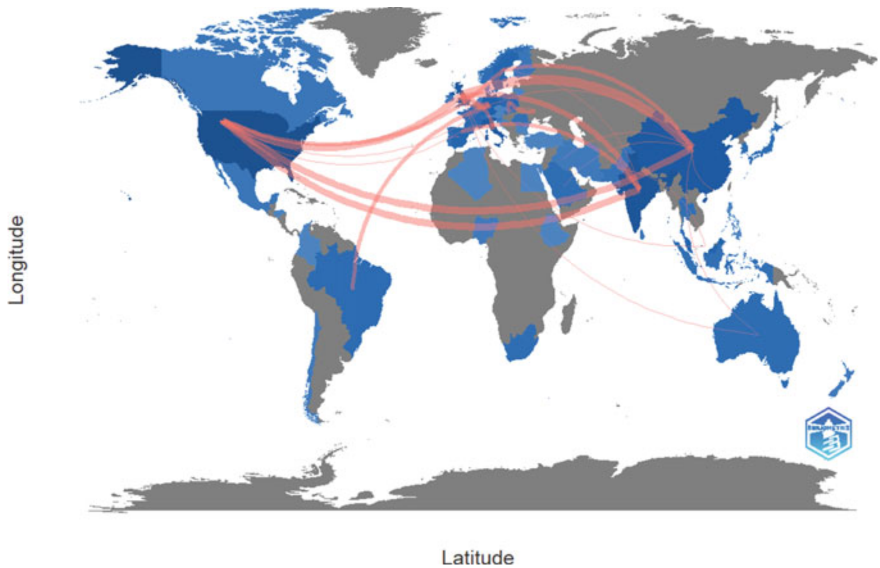

Fig. 1.22 Level of collaboration between countries

However, this topic is also of interest in European countries, since seven of the fifteen countries that publish the most on this topic are from that continent, and Asian countries such as China and India, with emerging economies, are also beginning to conduct their research. The most productive authors are few, and only Haapala, K. R. and Jawahir, I. S. have nine papers; although they are not the most cited, currently, it can be said that they lead the research on this topic.

It has been identified that the Journals Procedia CIRP, focused on production and manufacturing systems, is the leading publication on SM, followed by Sustainability Switzerland and the Journal of Cleaner Production, focusing on environmental issues and measuring the impact of production processes. However, these last two journals have accumulated the largest number of documents in recent years, and therefore, it is expected that they will lead to the dissemination of this topic.

Of the 376 documents identified, 245 contained the word sustainable manufacturing, 132 contained manufacturing, and 124 contained sustainable development, the most relevant. However, at present, other keywords have been added to meet the needs of this type of research, such as material consumption, advanced manufacturing, environmental aspects, and engineering education.

The most cited paper on this topic is smart manufacturing by Kusiak (2018), because it focuses on integrating all SM, IN, and IS concepts, which has 623 citations, even though it was published in 2018. Other papers have attracted attention, such as Tan et al. (2020), which is based on energy optimization and storage and has 224 citations, even though it was published in 2020.

The author with the highest number of citations is Kusiak A., with only two papers, has accumulated 698 citations, compared to others such as Jawahir, I. S. and Haapala,

K. R., who have nine papers each, but only 404 and 363 citations, respectively. Of vital importance are the papers by Faulkner, W., Rickli, J. L., Meng, Y. S., Tan, D. H. S. and Hailes, S., who with only one paper have managed to obtain more than 200 citations each.

Finally, the analysis of relations between countries shows that countries such as China, the United States of America, and India collaborate the most internationally with other countries. Fortunately, Brazil represents South America, in collaboration with European and Asian countries. The United Kingdom has the most international collaboration in its academic production on this topic.

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Chapter 2
Review of the Challenges in Implementing Industry 4.0 Technologies in the Context of Sustainable Supply Chains

José Sánchez Velasco, Karina Cecilia Arredondo-Soto, and Marco A. Miranda-Ackerman

Abstract Since Germany presented the so-called Industry 4.0 in 2011, there has been an increasing number of studies related to this concept, seeking to cover different perspectives, from supply chain management to harmonizing production systems in sustainability. However, when exploring the risks associated with implementing Industry 4.0, it is observed that there are still research gaps in combining these perspectives. In this sense, this work is a systematic literature review of the possible challenges that organizations face and are associated with implementing Industry 4.0 technologies in managing the Supply Chain in a Sustainability context. A review of 45 papers was conducted based on a filter process for 103 initial publications to categorize the main challenges presented in the literature. The results show a tendency towards challenges involved with labor competence followed by those challenges related to the costs of implementing 4.0 technologies, organizational culture, and computer security, so that knowledge of this condition will allow the formulation of a strategy according to the situation. The document's analysis and findings section should highlight the general perception of opportunities a company can consider once challenges related to Industry 4.0 are shown.

Keywords Industry 4.0 · Sustainability · Supply chain

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2.1 Introduction

Currently, there is a fully globalized market in which the performance of specific disciplines is critical in a context in which organizations essentially need to achieve two goals: survival and later growth. In this sense, logistics performance is one of the key disciplines for achieving any of these goals because, according to Sun et al. (2022), the diversification of clients, global competition, government intervention oriented towards environmental compliance, and the organization's weaknesses do not represent an easy path in the operation of any company. Specifically, managing a logistics system (effectiveness of actions related to its fundamental functions, such as storage, transportation, and information management) will achieve competitiveness for organizations. According to Bosman et al. (2019), the trend of economic growth that drags the development of society, including its markets of action, is due to the advances in products and services driven by technology that reach the commercialization processes, so a new commercial relationship between organizations is presented in the production chain.

To guide the understanding of this work, the document uses a diagram that links three research axes: Industry 4.0, Supply Chain, and Sustainability (Fig. 2.1).

The intersection areas of the three main topics of the study are currently and will continue to be relevant research subjects in future work. An exploratory survey before this document showed sufficient references to relate the supply chain to sustainability or Industry 4.0. However, this work delves into the challenges that, according to recent publications, are latent in the triple intersection of themes.

Although there are several articles about systematic reviews of the literature, this paper focuses on the intersection of the topics described in Fig. 2.1 to generate a better understanding of the implementation conditions in practice and answers the question: So, what challenges must an organization consider in implementing Industry 4.0 technologies to sustainably optimize Supply Chain Management?

Fig. 2.1 Study of implementation challenges diagram (own source)

Section 2.2 describes the background of 4.0 technologies, supply chain, sustainability, and how the study topics are intertwined. Section 2.3 describes the methodology used, followed by a systematic review of the literature in Sect. 2.4. Section 2.5 discusses the relevant findings. Finally, Sect. 2.6 concludes the paper, highlights opportunities to understand the risks associated with implementing Industry 4.0, and describes the limitations of this study.

2.2 Background

In a market with a high level of complexity and globality, new technologies are necessary for decisions, resource planning, and even for the sustainability of operations to meet the massive demands and responsiveness demanded by customers, as well as sudden market changes. According to Čater et al. (2021), the main advantages of introducing new technology are as follows:

- Increased productivity
- Resource savings
- Process transparency
- Higher product quality and better working conditions.

However, integrating disruptive technology can place a small business at greater power, and adopting technology is not a simple process. A poor implementation strategy can result in loss of competitiveness. A similar idea is presented by Ghadge et al. (2020) for companies that intervene disruptively in the market. Ali (2019) expressed that the advantages of implementing new technology are flexibility and efficiency in the production and distribution system, but it must be done under a process approach. According to Winkelhaus and Grosse (2020), the key to involving new technology in the face of the demands of the current conditions lies in generating value for the client by satisfying personalized needs through logistics operations with a high level of digitization, connectivity, integration, and timely response capacity.

2.2.1 Industry 4.0

A digital transformation requires the integration of different technologies and intelligent systems that will generate sustainable added value for the companies (Sun et al. 2022); in this sense, Bosman et al. (2019) ensure that greater access to information and connectivity of products and processes should be seen as a new operating paradigm now known as Industry 4.0

Industry 4.0 was presented at the Hannover Industrial Fair in 2011 (Germany). The natural sequence of the first three industrial revolutions considers mechanization, mass production, and automated production. However, the difference between this latest industrial revolution is exponential by combining Internet-based technologies, digitization, the use of information, and manufacturing technology to provide products and services, as well as intelligent processes (Sun et al. 2022), Simultaneously to the promotion of the “German” Industry 4.0 term; there were similar initiatives around the world according to Culot et al. (2020) for example the so-called Advanced Manufacturing in the US, Manufacturing 3.0 in South Korea, Made in China 2025 or Society 5.0 in Japan; however, the label that prevailed worldwide was Industry 4.0. In Chiarini (2021), Industry 4.0 refers to Cyber-Physical Systems (CPS) and smart technologies capable of integrating machines, processes, customers, and supply chains as a single entity. Moreover, smart technologies and CPS allow processes and machines to function autonomously, exchange information, perform actions or make decisions, and control themselves independently. According to Hossain and Thakur (2020), Industry 4.0 influences the industrial environment at four levels: digital data, automation, networks, and digital customer integration. Thus, it has the potential to result in efficient transportation and communication services, improved logistics processes, and reduced operating costs.

According to Kusiak (2018), the essence of manufacturing consists of six pillars: advanced technologies, innovative materials, data mining, technological evaluation in the manufacturing and transportation system, manufacturing sustainability, creation of logistics networks, and resource sharing. The smart factory, which integrates these technologies into factory processes (Chen et al. 2018), is at the heart of Industry 4.0. This business model integrates data from the production floor for use in the supply chain, which is managed across different levels of the business and considers the end-to-end path of the entire product lifecycle. According to Deja et al. (2021), smart manufacturing is a product of modern technologies that automatically collect and process data at all stages of the product life cycle to quickly adapt production and logistics processes to emerging uncertainties within the framework of the strict requirements of consumers and the changing competitive environment.

According to Sun et al. (2022), the technologies associated with Industry 4.0, which are considered the most important, are as follows:

1. Internet of Things (IoT).
2. Blockchain.
3. Big Data.
4. Additive Manufacturing (AM), also known as 3D printing.
5. Virtual Technology (Digital Twin) and Simulation.
6. Artificial Intelligence (AI).
7. Cyberphysical system (CPS).
8. Cybersecurity.
9. Autonomous Robots.
10. Unmanned Aerial Vehicle (UAV).
11. Augmented Reality (AR).
12. Cloud Technology.

The major problem is determining which technology to implement in the logistics processes of those available by Industry 4.0, that is, despite the advantages of this technology, how they should be integrated is not entirely convincing. They necessitate empirical research (Ar et al. 2020); in this regard, Deja et al. (2021) stated that the most important criteria for logistics facilities 4.0 are digital information platforms, intelligent transport systems, and intelligent mobility.

The technologies with the greatest mention in this study are described below. Table 2.2 includes the definitions of the technologies briefly mentioned in the research.

2.2.2 Internet of Things (IoT)

The IoT aims to integrate physical objects by communicating over the Internet to achieve beneficial actions; it securely facilitates the exchange of information in a supply chain (Haddud et al. 2017).

From a Supply Chain perspective, IoT integrates Information and Communication Technologies (ICT), sensor networks, and machine-to-machine systems, among others, to provide visibility to each item within the supply chain. The benefits of the IoT coincide with the relevant factors when evaluating a supply chain, logistics synchronization, information exchange with members of the supply chain, demand forecasting, flexibility in the production system, and growth, among other factors (Haddud et al. 2017). One of the main advantages of the IoT in supply chain management is the predictive ability of the organization to "gain" with this technology. This gain will make organizations highly competitive, as they will improve their operational performance through effective production supply chain management.

The IoT has its most significant challenges in effective adoption and in measuring its impact on organizations to recognize if it is as decisive as intended. According to Majeed and Rupasinghe (2017), most companies fail because of poor supply chain integration into IoT technology, which is based on the impossibility of having employees with the necessary knowledge. Moreover, companies and societies are not prepared for this change in technology and lack the required architecture.

2.2.3 Blockchain

Blockchain technology is a database structured as a list of immutable systematic blocks; thus, the information is protected from the most relevant events: elimination, modification, and distribution, which are achieved through cryptographic elements. A fundamental characteristic is that it operates with fully shared information but with certainty. The blockchain network shows where the data come from, who the owner is, and the operations carried out, which makes the system a transparent option (and in reliable consequence) in supply chains (Ar et al. 2020).

Blockchain is a means of building fully collaborative ecosystems (given the confidence in making secure transactions). Although supply networks are difficult to map, blockchain technology increases visibility, transparency, and traceability using ledger technology to drive trust and openness (Cole et al. 2019).

Ar et al. (2020) express what they consider to be four essential characteristics of the Blockchain:

- It was accessible to all participants.
- System data cannot be distorted once they are entered.
- The data circulate without the need for an intermediary.
- All participants had access to the same data.

To Cole et al. (2019), Blockchain technology has been considered for solving the problem of end-to-end traceability of the supply chain since it is essentially a data structure that combines blocks (data records) in a chain in such a way that it originates a database system of transactions protected and governed by a consensus mechanism, these characteristics grant the advantage that no "party" in the transaction has control, which provides transparency because it provides everyone with timely visibility into what is going on in the network and facilitates accountability when the parties to a transaction are not necessarily aligned.

There are four essential characteristics of the Blockchain:

1. This encourages companies to share their data.
2. The Blockchain contains smart contracts by which negotiated terms are digitized, verified, and fulfilled with greater transparency.
3. It is built using P2P networks; therefore, inaccurate or fraudulent transactions are excluded from the database.
4. The immutability of the data builds confidence, knowing that agreed transactions are recorded and not altered.

Blockchain provides data on the origin of materials, inventory levels, and invoices received or sent to the network, and the conditions of the agreements can be verified and acted upon accordingly. For example, once a product delivery is confirmed, payment is activated, this trigger forms autonomous transactions upon completion of specific key "milestones" potential uses of blockchain technology include:

- Product safety and security can be improved by providing safety test records.
- It improves quality management by providing visible information and is easily accessible; however, it is unalterable.
- Reduce illegal forgery when providing the origin of the data.
- Automate contracts by reducing the need to develop supply chain relationships.
- Reduce transaction costs through automation and real-time auditing using timestamps.

2.2.4 Big Data

To Bai et al. (2020) Big Data refers to the strategy of analyzing large volumes of data from the interaction with current or potential customers that would not be possible to discover with traditional extraction techniques, because of the need to align the commercial strategy and use the meaning of the information collected as business opportunities are easily identified in a multi-data context. A principle of the study of Big Data is to consider that data are constantly changing and that organizations that can react quickly to these changes will have a competitive advantage. The interest in data has led companies to develop the ability to analyze data; however, having the ability to analyze them does not guarantee an impact on profitability through Big data; this idea is reinforced by the works by Akter et al. (2016) that defines Big Data as massive amounts of observation data that support decision-making based on technological capacity (for example, connectivity, the flexibility of the data platform work, compatibility with other technologies), in the capacity of the staff (for example, translate into analysis capacity, theoretical knowledge, technology management) and in the data management capacity, in this sense (Bag et al. 2020) propose five characteristics of big data; Volume, veracity, variety, speed, and value.

2.2.5 Additive Manufacturing

Additive manufacturing, also known as 3D manufacturing, is transforming the vision of personalization of production, heralding a trend towards shorter value chains but also more collaborative and with a focus on sustainability by dedicating itself to the manufacture of what is consumed without generating "additional portions" (Ford and Despeisse 2016) for example, Fig. 2.2 shows the difference between waste resulting from a traditional process compared to 3D printing. Additive manufacturing should be considered a manufacturing technology that creates three-dimensional objects based on the development of a series of layers (Bai et al. 2020).

In addition to the lower generation of material waste, the contributions of additive manufacturing are as follows.

- Production batches based on demand.
- Reduced initial investment costs.
- Lower production costs in the first run.
- It takes advantage of a higher strength or lower material consumption design, regardless of whether the design becomes more geometrically complex.
- Better integration of coupling mechanisms.

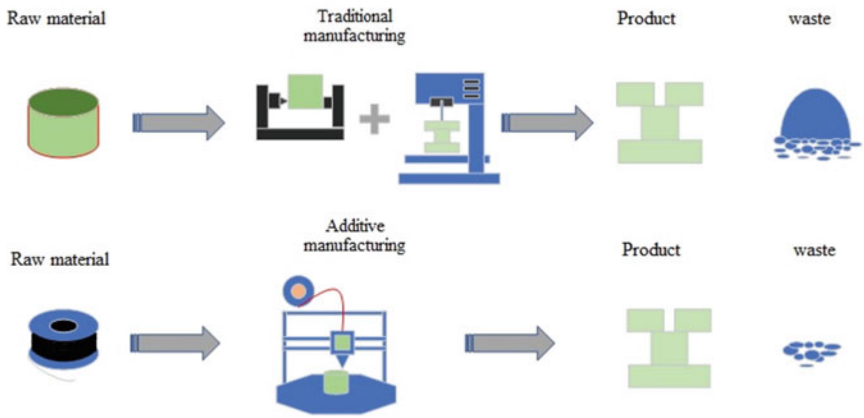

Fig. 2.2 Waste in traditional process versus additive manufacturing

2.2.6 Digital Twin

In the work by Negri et al. (2017), the role of technology is linked to CPS and extended to the physical-virtual connection and interconnection of elements that give rise to digital twins. Conceived as the virtual counterpart of a physical system, emphasis is placed on synchronizing in real time with data from the field, typically collected by a sensor. Perhaps the main advantage of the digital twin is the possibility of synchronization in real time with the physical system so that the autonomous system makes the right decision in time for this to happen, and a metadata model that exhaustively describes the characteristics of the natural environment is essential. Given the complexity of obtaining a unified definition for this technology, some definitions found in the literature are presented in Table 2.1.

2.2.7 Artificial Intelligence

The definition created in the '90 s conceived of artificial intelligence as the science and engineering of intelligent machines. However, the term Artificial Intelligence (AI) is used when a machine simulates functions associated with human minds, as in the case of learning, pattern recognition, or problem-solving, the imitation of the behavior of the human mind can improve iteratively (Cioffi et al. 2020; Bai et al. 2020), manifesting itself in the understanding of the problems or needs of clients, the recommendations provided according to the habits of use and consumption of the users of this technology, and the analysis of large volumes of information for decision making in complex situations. Artificial intelligence (AI) has become more valuable because it provides more information, and its ability to adapt increases.

Table 2.1 Digital twin definitions

Authors	Definition
E. Glassgen, D Stargel (2012) cited in Negri et al. (2017)	Physics and multi-scale probabilistic simulation of a system that uses the best available physical models, sensor updates, fleet history, to reflect and predict the behavior of its physical twin
M. Schluse, J. Rossmann (2016) cited in Negri et al. (2017)	Virtual substitutes for real-world objects consist of virtual representations and communication capabilities that form smart objects that act as smart nodes within the IoT
M. Bajaj, D. Zwemer, B. Cole (2012) cited in Negri et al. (2017)	A unified system model that can coordinate specific architecture, mechanical, electrical, software, verification, and other discipline models throughout the system lifecycle
Gabor et al. (2016) cited in Tao et al. (2019)	Particular simulation is built based on expert knowledge and real data collected from the existing system to perform a more accurate simulation on different time and space scales

The applications of this technology are as versatile as those listed below.

1. Personalized service recommendations.
2. Automation of services (for example, through chatbots).
3. Voice or image recognition.
4. Market segmentation, audiences, and customers.
5. Product/service customization.
6. Personalization of content.
7. Smart search (for relevance, interest, etc.).

2.2.8 Cyber-Physical Systems

It is the name given to the fusion between the physical system and digital level, where the actual condition of the system results from the physical state. However, these parameters are linked to digital processes (Lasi et al. 2014; Negri et al. 2017). These cyber-physical systems behave as intelligent systems integrated into networks in production systems. However, their operation controls physical devices that detect real-world conditions (Fig. 2.3); their performance lies in their capacity to store and communicate the data they collect and translate into information. Cyber-physical systems can interact with physical objects to monitor or control them and use the information available from the virtual world.

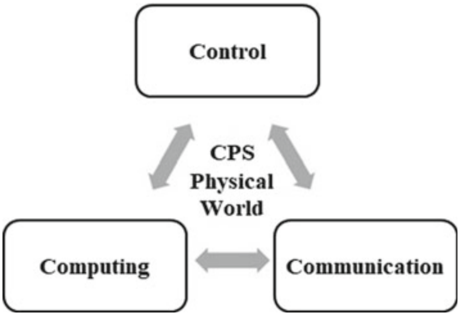

Fig. 2.3 CPS interaction (own source)

2.2.9 Cybersecurity

Bai et al. (2020) define Cybersecurity as the preventive method to protect information. The use of cyberspace as a new dimension for social and commercial interaction justifies the development of Cybersecurity in the face of risks such as theft and publication of secret information, attacks against networks and information systems, attacks against Internet services, infection with malware, digital identity theft, and fraud.

2.2.10 Other Technologies

Other technologies linked to Industry 4.0 have focused on environments and conditions that are not necessarily manufacturing. For example, Table 2.2. defines four additional technologies.

Table 2.2 Definitions of other Industry 4.0 technologies

Technology	Definition
Autonomous robots	Robots are used to replicate human actions in manufacturing
Unmanned Aerial Vehicle (UAV)	Known as a drone, the vehicle work without a human pilot on board (Drone)
Augmented Reality (AR)	Technologies that allow a user to interact through a device with graphic information that complements the real-world experience
Cloud technology	It is a technology that allows remote access to data processing, file storage, and computing services in general through the Internet

2.2.11 Industry 4.0 and Supply Chain

According to Sun et al. (2022), the most important features of a sustainable logistics system for Industry 4.0 are proactive planning based on data, real-time decision-making, and autonomous operations, which can be summed up in more data: more connectivity, more flexibility, more shared resources, and more intelligence. There is an increasing interest in the manufacturing and logistics problems of sustainable cities using Industry 4.0. The sustainable development of manufacturing and the city in a smart city have been evaluated by simultaneously considering the environmental, economic, and social aspects. The complexity of sustainability assessments has led to the development of specific indicators. Deja et al. (2021) introduced the concept of logistics nodes in cities (NLC) and megalopolises and their assessment in terms of their results; the efficiency of an NLC determines the operation of city clusters in conditions of uncertainty concerning supply chains.

Smart and sustainable city logistics technologies are common to cyber-physical systems (CPS), cloud-based manufacturing, cloud-based material handling, IoT, digital twins, Big Data, data mining, AI, and Blockchain. These technologies link manufacturing logistics and cyber-physical systems in sustainable smart manufacturing based on city logistics.

Deja et al. (2021) evaluated the logistics of a smart and sustainable city; indicators such as load compatibility, transport performance, empty routes, gas emissions, and friendly transport infrastructure were used in real time with the environment.

The transportation system provides smart and sustainable urban logistics within a cluster with elements such as AGVs, Autonomous Vehicle Robots (AMR), light electronic pathways, and a Delivery Service Platform (DSP), whose function is to provide a link between urban IoT systems and data-driven logistics planning technologies for the governance and management of smart and sustainable cities. The main activity of the NLC is related to traditional logistics operations, such as reception, storage, classification, and cargo shipment in appropriate directions using modern technologies. For manufacturing 4.0, it is necessary to implement four activities in the logistics facility: handling, information, transportation, and warehouse management. Additionally, 12 critical criteria must be considered.

1. Smart handling.
2. Zero emissions.
3. Smart mobility.
4. Freight exchange platforms.
5. Digital information platforms.
6. Intelligent Transportation Systems.
7. Security of Information.
8. Real-time location systems.
9. Autonomous vehicles.
10. Smart warehouses.
11. Logistics Center Alliances.
12. Digital connectivity.

Despite the apparent benefits of "intelligent" lean manufacturing from a new technology, the impact of Industry 4.0, on business, is still unclear (Čater et al. 2021). However, Industry 4.0 is on digital technology-based solutions. This changes how companies create value and the extensive interconnection of physical and virtual worlds. This reinforces the idea of considering that the Industry 4.0 paradigm is techno-centric, so that the potential of Industry 4.0 is exploitable in the value chains of multiple organizations and not in the isolated environment of a company. The role of Industry 4.0 is to reduce supply chain risks and minimize negative consequences if the risk cannot be resolved. However, it is not a static role but rather a dynamic one because the current environment is also dynamic (Ali 2019). The present challenges are focused on the security of information technology and data protection, the organization of work, the lack of skills, the training of qualified workers, and the development of standards required in the digitized economy. However, the intention to using 4.0 technologies to translate their use into a real aspect is still a question. Čater et al. (2021) propose an internal driver strategically oriented to using these new technologies of Industry 4.0 that defines the advantage expected to be competitive. His study analyzes five groups of reasons that influence the actual use of Industry 4.0 technology and lists them as follows:

1. Competitive pressure.
2. Supplier pressure.
3. Customer pressure.
4. Expected efficiency.
5. Expected competitive advantage.

2.2.12 Industry 4.0 Under a Sustainability Context

Industrial production is the primary source of global pollution, and the only way to continue the current trend and pace of production is to transform conventional practices into sustainable systems. Ecological practices can simultaneously face environmental, social, and economic adversities (Umar et al. 2022).

At a time of high industrialization, the concern about sustainability is global. Sustainability refers to the development by which the current generation is satisfied without compromising the availability of resources for future generations (Umar 2021, citing WCED 1987). On the other hand, sustainable development means meeting the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development is driven by the following goals: economic prosperity, respect for the environment, and social justice. At the beginning of this century, the concept of green logistics was proposed to reduce environmental impacts through strategic improvement and operational planning.

Umar et al. (2021) assume that the circular economy can contribute to sustainability by setting objectives such as improving the product's usability and reducing the waste of resources. However, adopting these challenges means dealing with high costs, skill gaps, lack of information for decision-making, and supply chain complexities (Jaeger and Upadhyay 2020). Green practices are vital in achieving environmental efficiency while improving economic performance to ensure that the production system fulfills the most basic function for which it was created while at the same time facing new ecological adversities. Thus, green manufacturing practices focus on resource utilization, waste reduction, remanufacturing, and pollution prevention technologies.

Environmental issues such as environmental sustainability (Bag et al. 2018), the circular economy, and green processes (de Sousa Jabbour et al. 2018) have the potential to be addressed by Industry 4.0.

According to Chiarini (2021), the main problem is that smart factories use electronic equipment in a "massive" manner, which generates more energy and resources than traditional methods. Another line of work highlights that waste disposal based on sensors, RFID, and other technologies can help to track and control such waste. According to the author's study, the "friendliest" technologies to the environment turned out to be AI, while traditional robots were at the opposite extreme.

However, according to Sun et al. (2022), the inclusion of Industry 4.0 in the sustainable logistics sector faces challenges inherent to the technological gap, such as.

- There is a lack of sustainable indicators that use a holistic approach.
- The economic benefits do not always translate directly into benefits from the implementation of Industry 4.0
- The environmental footprint is generated by additional technological elements such as sensors and robots.
- Unskilled worker unemployment (similar to the first industrial revolution)
- Inequity in the sector (companies such as DHL have a great advantage over their small competitors) due to economic resources.
- Lack of general guidelines. These efforts are unitary and without systematic guidelines to implement the different tools of Industry 4.0.
- Data security.

According to Chiarini (2021), since its appearance in Germany, Industry 4.0 is considered the future to which each productive sector must have access, as happened with previous industrial revolutions. However, each industrial revolution has incorporated an environmental danger from carbon emissions into the residues of new synthetic materials. Although the reduction of costs, the improvement of quality, the optimization of delivery and service times, and other additional benefits are not in doubt, there are also "cons" in the adoption of these technologies, especially considering that their basis lies in the direct or indirect use of electronic components. These substances are usually harmful to the environment. This leads to an assessment of the environmental performance of companies with experience in using these technologies.

For Umar et al. (2022), Industry 4.0 technologies may be the appropriate tools given their ability to improve the life cycle of equipment, improve resource consumption, reduce waste, and even create opportunities for reuse and recycling with the consequent acceleration of commercial transition. The problem lies in the lack of empirical evidence on the association between these technologies and the implementation of green practices within the production system.

2.2.13 Adoption of Industry 4.0 Practices

For a company's openness to adopting Industry 4.0, practices can be measured in terms of breadth (when assessing the number of technologies adopted) and depth (when the focus is on the number of stages in the value chain implemented). However, the literature does not differentiate between levels of importance, hierarchy, or complexity for the various Industry 4.0 technologies; however, Ghobakhloo and Ching (2019) distinguish these technologies into the first and second levels, given a moderation effect of three elements: availability funding, employee competency, and organizational fit. If adopting a new technology is not tailored to the specifics of a company's organization, synchronizing it with existing teams, structures, and processes can become complex and costly. This can be challenging for smaller companies.

According to Čater et al. (2021), the reasons why companies use 4.0 technology are influenced by internal and external factors, leading them to conclude that companies act proactively (instead of reactively) before the introduction of 4.0 technology initiatives, which means that companies consider the search for technology that offers the highest profit margin in the face of current market opportunities. Winkelhaus and Grosse (2020) state that although investment in Industry 4.0 is not within the reach of many companies, the most complex process of adopting this technology lies in the human factor. Although it is strong in its assimilation capacity, knowledge management, and translation of that knowledge to the logistics sector, it is even more complex if a sustainable approach that will allow long-term competitiveness is considered.

2.3 Methodology

This work aims to collect information related to the challenges of applying technologies associated with Industry 4.0 in the context of sustainability for supply chain management, for which it is necessary to select and evaluate existing contributions to synthesize and translate data. The document uses a systematic review of literature, such as the work of Beltrán (2005), which raises the idea that there should be a specific research question, a series of primary studies, and a gap or uncertainty in the answer investigated for this work. The development of a systematic review requires the following steps:

(a) We defined the trigger question.
(b) Definition of inclusion criteria: Exclusion of articles.
(c) Literature search plan.

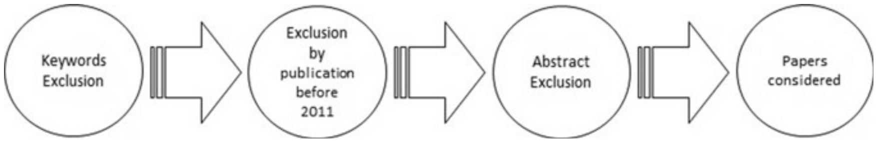

Fig. 2.4 Selection of review publications

(d) Data recording and evaluation of quality of selected studies.
(e) Analysis and synthesis of data: Interpretation of information.
(f) Results presentation.

The triggering question is defined as follows:

What risks must an organization consider in implementing Industry 4.0 technologies to optimize the management of the Supply Chain sustainably?

The exclusion criteria were as follows.

– Date before 2011 (the year in which the Industry 4.0 concept was presented)
– Articles not published in academic journals.
– Articles whose summaries were not based on the application of any Industry 4.0 tool.
– Articles that did not include the terms Industry 4.0, Sustainability, or Supply Chain in the keywords.

Figure 2.4 outlines the methodology used for this document in terms of the selection of papers to be reviewed and proposes the literature search strategy from the Scopus platform, intending to quantify the existing information in such a way that it shows the sequence used for filtering jobs according to the mentioned criteria:

The challenges exposed in each publication were obtained from the reviewed articles. This work is an exploratory study, and the challenges encountered are categorized following the line of research of Chauhan et al. (2021), which considers two major aspects: those with intrinsic and extrinsic characteristics. The results are linked to descriptive statistics that characterize the current situation.

2.4 Literature Review

The literature search plan exhaustively collected information from the keywords, avoiding publication bias in English or multiple publications (by the same author). For this study, the Scopus platform was chosen (www.scopus.com) when considering a database that covers more than 5,000 peer-reviewed journals in the field of interest. Precisely with these data, the VOSviewer application was used to build publication networks and graphically show peer collaboration. Figure 2.5 depicts the results, which confirm the close relationship between the keywords in this document, as well as a variable that, due to the magnitude of its representation, should be considered in work futures (Sun et al. 2022). Logistics deals with the pre-production, production, and post-production cycles to satisfy the needs of different clients. Since logistics is now considered an expression of "material movement" in a commercial context, it has its performance measures in terms of costs, customer satisfaction, and profitability throughout the supply chain. It should be noted that the color code included in the figure also helps to visualize the future trend of the research field, as variables such as Sustainability, Sustainable Development, Electronic Data Interchange, Additive Manufacturing, or Digital Twins shown in yellow are subject to a recent study.

To document the challenges of the selected literature, a tabular format was chosen to present the information collected from the reviewed publications, which led to records of the main items on which to quantify the information relevant to the challenges of technology implementation. Industry 4.0, summarized in Table 2.3, is described below.

1. The legal framework includes government policies and conditions related to trade agreements, and local and regional laws.
2. Implementation Strategy refers to the vision and implementation of an organization's scope.
3. Labor competition: also refers to the technical capacity of the personnel of the organizations and their current knowledge about technology 4.0.
4. Infrastructure: refers to the conditions of the organization involved with the possibility of adopting new technology, having the ability to acquire and manage large volumes of data, and competent technology, among other items.

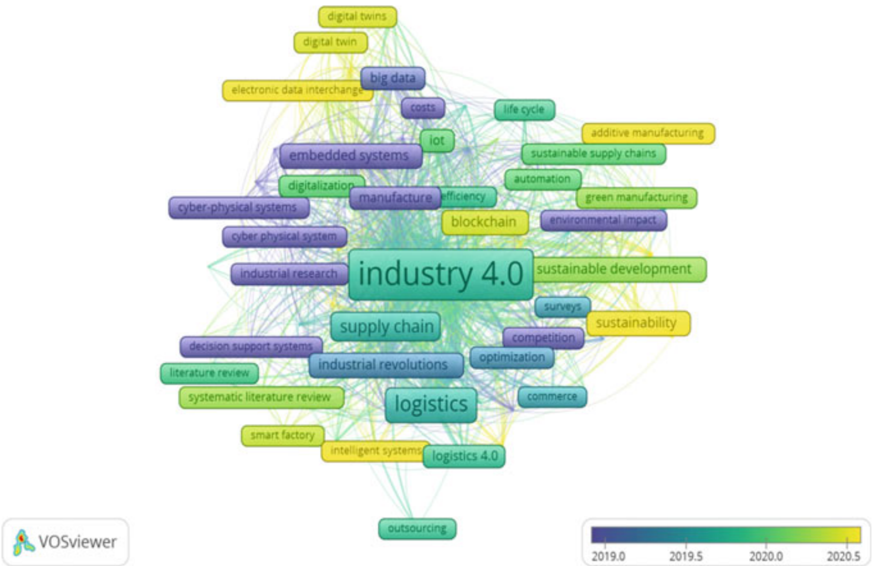

Fig. 2.5 Scopus-based publishing networks

Table 2.3 List of implementation challenges according to the reviewed publications

No	Authors	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Bauer et al. (2015)			x						x				
2	Bag et al. (2018)		x					x			x			
3	El Hamdi and Abouabdellah (2022)			x		x		x		x				
4	Akter et al. (2016)							x						
5	Ortt et al. (2020)			x		x				x				
6	Correia et al. (2021)		x											
7	Moshood et al. (2021)			x	x					x		x		
8	Pfohl et al. (n.d)								x	x				
9	Oláh et al. (2020)	x		x										
10	Stanisławski and Szymonik (2021)							x						
11	Bigliardi et al. (2021)										x			
12	Lasi et al. (2014)					x								
13	Dobrowolski (2021)	x					x			x				
14	Kuteyi and Winkler (2022)	x		x	x						x			
15	Müller et al. (2018)			x			x	x	x					
16	Ng et al. (2022)	x	x	x	x								x	
17	Uhlemann et al. (2017)			x	x	x			x					
18	Soni et al. (2022)				x									
19	de Sousa Jabbour et al. (2018)		x	x				x						x
20	Horváth and Szabó (2019)			x	x				x	x				
21	Han and Trimi (2022)				x	x		x						
22	Bag et al. (2021)					x			x	x				x
23	Hofmann and Rüsch (2017)			x					x	x				
24	Masood and Sonntag (2020a)			x	x		x	x			x			
25	Bag et al. (2020)									x				
26	Kumar et al. (2021)	x		x										x
27	Bai et al. (2020)									x	x			
28	Luthra and Mangla (2018)	x	x	x	x	x		x	x	x			x	x
29	Ford and Despeisse (2016)			x	x							x	x	
30	Khanzode et al. (2021)	x		x	x					x	x			
31	Chauhan et al. (2021)			x	x			x						
32	Kumar et al. (2021)	x		x	x	x		x						
33	Mastos et al. (2021)								x				x	
34	Ghobakhloo et al. (2021)							x		x	x			
35	Verma et al. (2022a)		x	x	x	x	x		x					x
36	Dalmarco et al. (2019)			x		x					x			
37	Hecklau et al. (2016)			x	x			x						

(continued)

Table 2.3 (continued)

No	Authors	1	2	3	4	5	6	7	8	9	10	11	12	13
38	Machado et al. (2019)		*x*	*x*							*x*			
39	Toktaş-Palut (2022)				*x*									*x*
40	Birkel and Hartmann (2019)				*x*	*x*					*x*			
41	Bag et al. (2022)			*x*		*x*								
42	Agostini et al. (2019)			*x*				*x*	*x*					
43	Pfeiffer et al. (2019)			*x*										
44	Furstenau et al. (2020)		*x*	*x*				*x*		*x*				
45	Müller et al. (2018)			*x*				*x*					*x*	

5. Internet: The existence of the Internet in the company, the region, or even the country.
6. Organizational culture: includes fear of change on the part of employees, education to share information within the company and with supplier and customer networks, fear of the expectation of a new labor market.
7. Standardization: refers to the ability (or possibility) of current operations to properly migrate to a new process model.
8. Security: refers to security in information and communication processes.
9. Technological awareness: refers to the proper identification of technologies for each situation and knowledge of Industry 4.0
10. Intellectual Property: refers to the due protection of new models, prototypes (speaking of additive manufacturing), or work systems that can be easily replicated.
11. An innovative market refers to changes in products and services that positively or negatively affect supply chains and future competitiveness.
12. Leadership: refers to the commitment of the management to solve some of the challenges described above.

Figure 2.6 shows the frequency with which the publications expose the different challenges for implementation; the competence of the labor force is the most mentioned factor within the literature, while the capacity of the Internet and the industrial protection environment are exposed less frequently.

The articles have been divided in Fig. 2.7 by the year of publication. Although the restriction was to consider articles published in 2011, the date in which the literature proposes the presentation of the concept in Hannover, it is worth noting that, following the process of filters, the vast majority of the resulting articles were from the last four years at the beginning of this research. This reflects the current nature of the issues involved in this study.

Figure 2.8 shows the percentage of publications that were classified; given the characteristics of this research, it is not strange to have one of the highest percentages in publications with a methodology dedicated to the bibliographic field and literature review. However, it should be noted that a similar percentage of investigations express

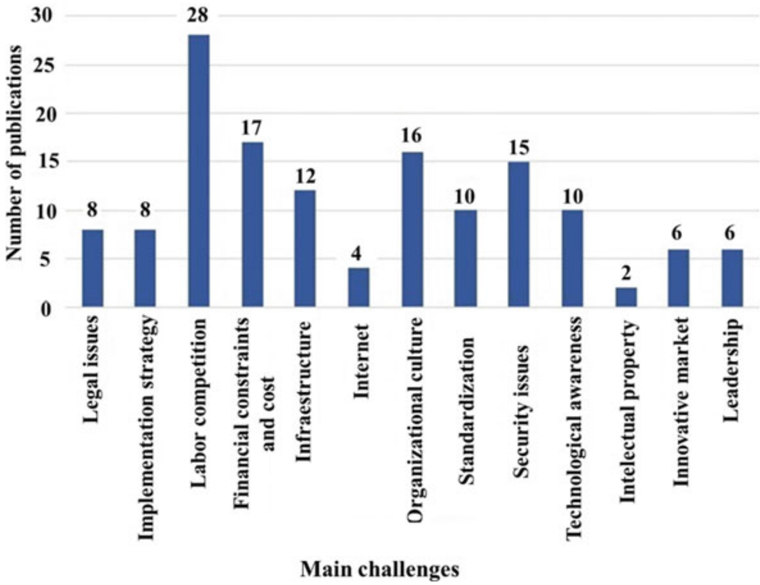

Fig. 2.6 Frequency of the main challenges presented in the literature

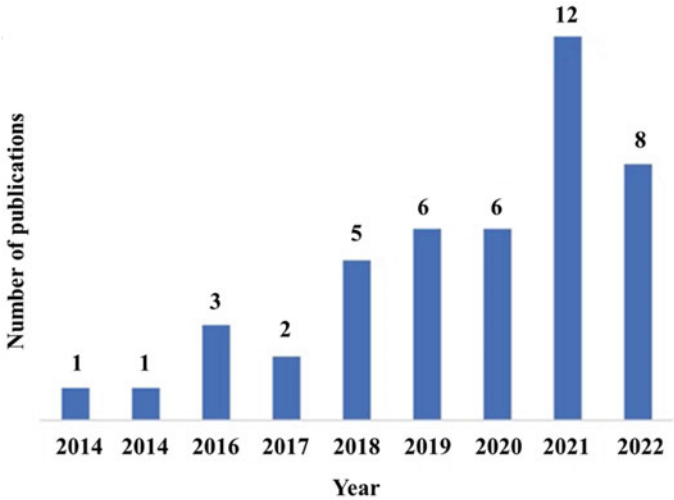

Fig. 2.7 Number of publications by year

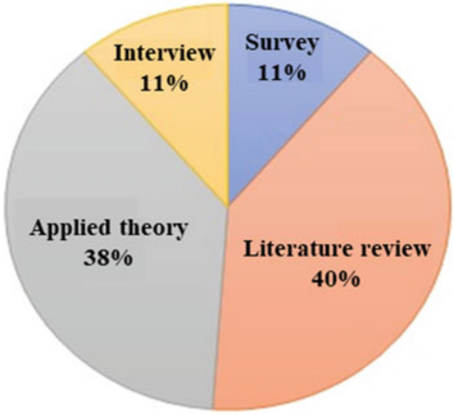

Fig. 2.8 Type of investigations of publications

the challenges organizations face from adopting (or verifying) a specific theory, which extends the limit of knowledge with this type of exploratory study.

As the concept of Industry 4.0 still generates differences of opinion among the academic community, Fig. 2.9 presents a diagram of words to show the nationality from which the first authors published the works, which does not necessarily allude to the place where it was investigated. For example, in the work of Bag et al. (2022), the first author is associated with a South African institution; however, in part of the document, he mentions implementation challenges in the Latin American region. In this sense, given that there are different labels for what the community generally refers to as the fourth industrial revolution, it is understandable that the country promoting Industry 4.0 appears first. It is notable that the low presence of European countries given the technological influence of Germany, and the case of countries such as the USA, China, or Japan can respond to the use of the label above for this type of technology; for example, the equivalent of Industry 4.0 is the "Made in China 2025."

2.5 Analysis and Findings

The chosen publications, directly and indirectly, raise the idea that implementing Industry 4.0 technologies exposes organizations to a change in operating dynamics and not only in paradigm or organizational vision, the challenges with the greatest presence in the reviewed literature. Draw attention to the qualification of the labor force (very similar to the First Industrial Revolution), followed by information security, the acquisition costs of new technology with all the peripheral elements that it implies, and, in a fourth place, organizational behavior and culture. However, they also face the same challenges. Organizations that do not have a favorable environment may be more difficult to overcome. For example, if the organization is located

Fig. 2.9 Nationality of the institution from which the first author conducted this research

in a developing region (whether country or city), some authors agree that the adverse conditions in the region are mainly reflected in the qualifications of the workforce.

Although this document considers many publications of European origin, it is difficult to consider the hypothetical situation in which developing countries find themselves, where technological updating opens an even more significant gap. There is a second block of challenges that appear with the same frequency, and that concerns the legal framework, infrastructure and standardization, which, according to the literature, have a greater link with the sustainability factors raised in this same document; for example, for Ghobakhloo (2020), the impact of Industry 4.0 technologies can be contradictory on the "helix" of environmental development if operations such as automation do not conform to a legal framework that prevents a disturbance in the labor market.

Alternatively, as proposed by Kamble et al. (2018), intelligent production systems require studies to demonstrate their ability to deal with the generation of electronic waste. This opens the door to a technology adoption criterion (not only of Industry 4.0, but of the general industry) that is based on sustainability and involves issues such as job reduction, electronic waste, and the circular economy; for example, Kunkel et al. (2022) mention the environmental risk caused by an increase in efficiency, creating rebound effects, for instance, in the rate of return of products or the consumption of batteries.

This paradox was also mentioned by Beltrami et al. (2021), who found that an attempt to find a balance between economic, social, and environmental performance can lead to efficient production systems that lead to significant waste generation and a greater demand for resources. At the third level, other implementation challenges are mentioned, which should not be minimized because of their frequency but rather consider specific actions to face them, such as the case of intellectual property, the capacity of the Internet, or the conditions of the innovative market. In fact, Chauhan et al. (2021) state that implementation challenges can be considered intrinsic and extrinsic, and that the former is perceived as more critical by organizations because it is within their scope of action to solve them.

In the case where the quality and capacity of the Internet exists in the region where an organization is located, it can be thought that the company can only resign itself to regional conditions. It is the same case of an innovative market in which the trends of change in products and services are frequent and not planned by a single institution but respond to a “collective intelligence.“ The lack of an implementation strategy and organizational leadership is also highlighted at this level. According to the literature, both elements converge in organizational transformation and in leading said transformation towards sustainability. If there is a lack of understanding of the capabilities of Technology 4.0, then the opportunity to achieve a sustainable business model can be lost and only limited to mass manufacturing. Enyoghasi and Badurdeen (2021) mention that the understanding of Industry 4.0 offers better capabilities for a circular economy based on the 6Rs (reduce, reuse, recycle, redesign, recover, and remanufacture) of sustainable manufacturing.

In summary, it can be said that many organizations cannot implement Industry 4.0 technologies due to the presence of multiple challenges. Changes in processes without a framework of performance indicators or aligning strategies with sustainable objectives are similar to building a blindfolded machine. Furthermore, if the risk of imbalance in the supply and demand chain focuses on the variability of the process, then the difficulty of forecasting accurately can cause supply shortages and the inability to satisfy customers or excess inventory with consequences already known (Ali 2019). In addition to the risk of imbalance that poses financial risks and delivery delays, losses can focus on labor, the acquisition of inputs to the process, maintenance in the warehouse, and depreciation, which means that the cost and scarcity of qualified labor should be considered as one of the main evaluation factors. According to Müller et al. (2018), until 2017, the literature did not provide a perspective on the impact of adopting Industry 4.0 in organizations or society. For example, when discussing the increase or decrease in the number of jobs in recent years (see Fig. 2.5), the perspectives described in Table 2.4 were obtained.

2.6 Conclusions

This document aimed to investigate the challenges organizations face in implementing Industry 4.0 technologies in their transformation towards the so-called fourth industrial revolution; the research was carried out through a systematic review of the literature, where 45 articles were analyzed under the methodology described in Sect. 2.3. The results indicate that the main challenges faced by organizations are the competition of the workforce, computer security, and the costs associated with the implementation of 4.0 technologies; Through graphic elements, the characterization of the documents reviewed was observed, finding a trend toward research on the type of literature review, a greater number of authors with affiliation to European

Table 2.4 Future scenario of challenge

Challenge	Future scenario	Authors
Legal issues	The threat of unauthorized use of technology and the legal framework associated with achieving sustainability goals	Dobrowolski (2021), Bag et al. (2020), Luthra and Mangla (2018)
Strategy	Align strategies towards obtaining competitive advantages, but also sustainable ones	Correia et al. (2021), Akter et al. (2016), de Sousa Jabbour et al. (2018), Verma et al. (2022b)
Labor competition	Higher-skilled, more expensive, hard-to-find labor with a high level of specialization. New worker profile	Müller et al. (2018), Ortt et al. (2020), Akter et al. (2016), El Hamdi and Abouabdellah (2022), Bag et al. (2018), Bauer et al. (2015), Birkel and Müller (2021), Horváth and Szabó (2019), Chauhan et al. (2021d)
Financial constraints and cost	Financial access is increasingly difficult for smaller companies	Bag et al. (2018), Ng et al. (2022), Uhlemann et al. (2017), Kamble et al. (2018), Masood & Sonntag (2020b), Khanzode et al. (2021)
Infrastructure	Need for updating, the gradual elimination of obsolete technology, and acquisition of equipment with great data handling capacity	Oláh et al. (2020), Akter et al. (2016), Han and Trimi (2022), Bai et al. (2020)
Internet	Large-scale interconnected systems	Oláh et al. (2020), Bauer et al. (2015)
Organizational culture	A new paradigm that links sustainability, the creation of value through the vision of the chain from end to end, and the permanent presence of resistance to digital transformation	El Hamdi and Abouabdellah (2022), Bag et al. (2018), de Sousa Jabbour et al. (2018), Horváth and Szabó (2019), Luthra and Mangla (2018), Chauhan et al. (2021), Müller et al. (2018)
Standardization	Companies will have a slow process of standardization and could always be behind the changes in Industry 4.0	Uhlemann et al. (2017), Bag et al. (2021), Agostini and Nosella (2019)
Security issues	Increased possibility of cyber-attacks	Kuteyi and Winkler (2022), Dobrowolski (2021), Moshood et al. (2021)
Technological awareness	Awareness of the greatest benefit of technology, emphasis on selecting technology from numerous alternatives	Kuteyi and Winkler (2022), Bag et al. (2018), de Sousa Jabbour et al. (2018), Bai et al. (2020)

(continued)

Table 2.4 (continued)

Challenge	Future scenario	Authors
Intellectual property	Massive generation of models, prototypes (3D), and products that will require intellectual protection	Ford and Despeisse (2016)
Innovative market	More consumers of innovative systems and products, disruptive and personalized innovations	Stanisławski and Szymonik (2021), Pfohl et al. (n.d), Correia et al. (2021), Ortt et al. (2020), Ng et al. (2022), Bag et al. (2020), Chauhan et al. (2021)
Leadership	A greater presence of senior management and leaders in digital transformation	Bag et al. (2021), Kumar et al. (2021)

institutions (mainly from Germany), and a greater number of publications related to the keywords key from the year 2020.

Although the Fourth Industrial Revolution refers to the integration of modern technologies within a production system, these systems have incorporated a new objective to achieve sustainability, in which new technologies provide advantages from digitization capabilities, service orientation, decentralization, and interoperability, which translate into adaptation to changes in demand and supply to improve the recycling characteristics of the product. The common denominator of Industry 4.0 technologies from the green perspective is to develop productive capacities to reduce waste and pollution (Umar et al. 2021).

For this reason, this document is useful because knowledge of the challenges studied allows us to recognize the new paradigm of the supply chain, in which changes towards sustainable production are related to the traceability (or visibility) of the entire supply chain, adapting business models that include new ways of creating value, a new form of collaboration with partners involved both vertically (suppliers and customers) and horizontally (competition and institutions), and new technology adoption skills. Strengthening the technological adoption capacity guarantees greater control of supply chain administration because, according to the perspectives presented in Table 3, for an organization to remain competitive, it must increase the flexibility of its technical, strategic, and distribution elements to associate them with sustainable objectives.

Finally, the findings will provide intellectual capital to professionals in the field of Industry 4.0 to develop strategies that minimize the negative impact of the challenges studied. Since the lack of a holistic approach was commented on by more than one author, this document can be referred to address the concept of Industry 4.0 not only from a technical aspect but also considering the importance of socioeconomic and environmental factors, and the findings will serve to identify the opportunities offered by 4.0 technologies such as IoT, Big data, Digital Twins, and 3D printing.

2.6.1 Future Research Directions

This study suggests the challenges in implementing 4.0 technology in a sustainable context. It provides an opportunity for future research, such as a study that identifies the causes of each main challenge. Future studies can take the counterpart of the challenges and address the initiatives or situations conducive to implementing Technology 4.0. Finally, an opportunity for future work is to determine the impact of adopting technology in quantifiable terms, as the numerical factors can be decisive in decision-making by top management.

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Chapter 3
Impact of Human Error Prevention and Automation on Social Sustainability

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Abstract This chapter presents a structural equation model that relates two Lean Manufacturing tools to the Social sustainability of Maquiladora companies in northern Mexico. These tools are Poka-Yoke and Jidoka, which help to reduce human error when performing any activity to transform a product within a manufacturing process and reduce waste. In this model, three hypotheses were proposed and validated using information collected from 411 questionnaires obtained from the maquiladora industry to quantify the relationship between Poka-Yoke, Jidoka, and Social sustainability. The model was run using the WarpPLS 8.0 software. The results show that Poka-Yoke has a direct and positive effect on Jidoka and Social sustainability, just as Jidoka has a direct and positive effect on Social sustainability. In this sense, using devices that help minimize errors facilitates the implementation and use of tools such as Jidoka through machine stops when a defect is detected through visual control and the power of members to obtain specific information to continue progress within the program. Similarly, Poka Yoke and Jidoka contributed

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to improving working conditions through workers' safety and health by reducing work pressure.

Keywords Human error · Autonomation · Social sustainability · Maquiladora industry · SEM

3.1 Introduction

Human error (HE) is defined by Swain (1989) as "any set of actions or activities that exceed some limit of acceptability; that is, an out-of-tolerance action in which the performance limits defined by the system." However, Hollnagel (2005) states that the HE is "an identifiable human action that, in retrospect, is considered the cause of an undesired result"; that is, the HE must be identified, performed involuntarily, and its impact quantified concerning the system's efficiency indices, where the deviations from the expected result are evident. Consequently, a new research area called human reliability (HR) has emerged.

Thus, HR refers to a person's ability to perform a task or activity consistently and accurately in different circumstances and contexts. That is, HR is the extent to which a person can perform reliably, meeting the expectations and requirements of their job (Li et al. 2023). HR is important in industry, medicine, aviation, and other fields that require high accuracy and consistency in performance because errors can involve the loss of human lives (Aalipour et al. 2016).

People who are reliable in their work are seen as professional and competent, and can generate trust and respect from colleagues and customers. However, HR is influenced by factors such as experience, training, motivation, and working conditions (Sun et al. 2022). Therefore, employers must provide the necessary support and resources to help workers develop trustworthiness at work.

HE has been studied in various industrial sectors. Grosse et al. (2013) indicated that transport and HE in the automotive sector represent 65%, heavy traffic 80%, aviation 70–80%, air traffic 90%, chemical industry 60–90%, and nuclear power plants 50–70%, which indicates the importance of analyzing it or looking for strategies to prevent it.

Regarding the economic cost of HE, a report by the Orange County Chamber of Commerce indicated that 10% of small- and medium-sized companies stated that the downtime cost associated with an HE was $50,000 per hour. For 13% of the respondents, the cost was between $40,001 and $50,000. For 25% of the SMEs, the cost was between $20,001 and $40,000. A slightly higher percentage (26%) said that the loss hovered between $10,000 and $20,000, while 27% said their cost per hour of downtime was less than $10,000 (Computer 2022).

In addition, the European Foundation for the Improvement of Living and Working Conditions states that the direct and indirect costs of workplace accidents caused by human error in Europe amount to more than 476 billion euros per year. This includes medical expenses, lost productivity, compensation, and education and training expenses to prevent future errors (Eurofound 2022).

Regarding the integrity of human beings, according to the World Health Organization (WHO), it is estimated that medical errors cause the death of at least 2.6 million people each year worldwide (WHO 2022). According to the National Highway Traffic Safety Administration (NHTSA) of the United States, approximately 94,000 traffic accidents in the country are caused by HE, resulting in approximately 35,000 deaths annually.

Because of the high economic and health costs associated with HE, many researchers have focused on analyzing HR in different sectors, such as machine and tool maintenance (Zhao et al. 2019; Tavakoli and Nafar 2021), nuclear facilities (Alzbutas and Voronov 2019 ; Rasmussen and Boring 2017), facility design and siting (Hogenboom et al. 2020), surgical and orthopedic interventions (Di Pasquale et al. 2018), petroleum industry (Li et al. 2014), railways (Vanderhaegen 2012), and radiotherapy (Chadwick and Fallon 2012). In summary, a search of the Scopus database revealed 1,113 documents with the word "human reliability" in the title, indicating their academic and scientific importance.

Specifically, in the manufacturing industry, HE costs affect the entire supply chain and can be:

- Production costs: Human errors can cause production delays, leading to additional costs associated with overtime pay, storage costs, and shipping costs, among others.
- Repair costs: Human error can damage equipment or products, which may require costly repair.
- Compensation costs: The company may face legal claims and compensation payments if a human error causes property damage or employee injury.
- Reputational costs: Human error can affect a company's reputation and its ability to attract and retain customers.

In summary, the economic and health benefits of HE can affect profitability and sustainability. Therefore, many companies invest in employee education and training to reduce the likelihood of HEs, and in automated technologies and systems that minimize the possibility of human error.

To increase HR, employers turn to tools they can implement on their production lines, such as Poka Yoke (POY) and Jidoka (JID). POY is a lean manufacturing (LM) tool used to avoid errors or defects, and is a Japanese word meaning "mistake-proof". POY focuses on designing processes and systems that avoid human errors and generate low-quality products or services. It can be any device or mechanism designed to prevent errors or defects during production. Thus, its objective is to simplify and streamline production processes, avoid errors, and reduce costs.

The second tool is JID, a Japanese term used in the industry to describe a process that stops automatically when a problem or anomaly is detected. JID is a key concept in Toyota's production system, and has been developed to improve automobile manufacturing efficiency, quality, and safety. JID seeks to ensure that any problems in the production process are detected quickly and addressed immediately to prevent them from spreading or causing further problems. The idea is that by automatically stopping the process when a problem is detected, defective or low-quality parts are avoided, which in turn helps improve efficiency and reduce costs.

The application of POY in the industry and its association with safety and error detection have been widely reported. For example, Manivannan (2007) relates it directly to a company's productivity, whereas Tommelein (2008) relates it to quality. Given the success of POY in production lines, Saurin et al. (2012) reported a conceptual framework describing its implementation in a standardized process. However, it is safe and prevents errors and accidents, where it is most often found.

Likewise, the application of JID is widely reported in the industry, for example, for quality improvement (Berk and Toy 2009), automation of hazardous processes (Da Silva 2016), error detection using sensors (Abed and Ibrahim 2018), the establishment of working parameters and compliance limits (Tri et al. 2018), and software design and development (Danovaro et al. 2008). However, JID has been combined with other tools to facilitate the decision-making process, such as lean management (Deuse et al. 2020) and CNC machine simulation tools (Villalba-Diez et al. 2021), including 5S and total productive maintenance (TPM) (Rojas-Castro et al. 2022).

As can be seen, human errors in the industry occur in production processes in which there is significant personnel intervention (Zarei et al. 2021), such as in Mexican maquiladora industries. The term maquiladora originated in Mexico and referred to subsidiaries of foreign companies established in the country, mainly engaged in labor-intensive assembly activities and characterized by importing raw materials and exporting finished products (García Alcaraz et al. 2022a). These maquiladoras in Mexico take advantage of Mexico's low wages, proximity to the United States and Canada, and the free trade agreements between the two countries, which favor them with preferential tariffs (Avelar-Sosa et al. 2014).

The maquiladora industry in Mexico currently employs 2,938,160 people, of which 502,009 are located in Chihuahua and, more specifically, 331,180 in Ciudad Juarez, indicating the social importance of this industrial sector. The total number of maquiladora companies in Mexico is 5,160, of which 486 are established in the state of Chihuahua and 322 are located in Ciudad Juarez. These maquiladoras use many lean manufacturing tools in their production lines, including JID (García Alcaraz et al. 2022, 2022b) and POY (García-Alcaraz et al. 2022, 2021).

However, many reports in the literature on POY and JID applications have analyzed both tools in isolation. They analyzed only one tool, although both focused on detecting and eliminating errors that impair the quality of generated products. To contribute to this gap in the literature, this chapter aims to analyze the relationship between POY and JID and how they affect the Social sustainability of companies.

In other words, although POY and JID have an impact on the operating rates of companies, as previously reported, this chapter analyzes the implications of the application of these tools in the improvement of employee working conditions, employee health, labor relations with colleagues and managers, morale, and work pressure, which could generate burnout and, consequently, more significant errors in the execution of their activities.

The results of this study will allow managers and those responsible for the physical and emotional health of workers to understand the impact of the simultaneous implementation of these lean manufacturing tools on production lines, which will allow them to take actions aimed at preserving the integrity and morale of their workers, reducing the level of HE, and increasing RH.

The chapter is organized as follows: section two presents the methodology for describing the activities developed to achieve this objective. Section three presents the results obtained from the analysis; section four discusses the results and their theoretical and industrial implications; section five reports the study's conclusions. Finally, limitations and future research directions are discussed.

3.2 Hypothesis and Literature Review

3.2.1 Relationship Between Poka-Yoke and Jidoka

POY and JID are two concepts in Toyota's production methodology; however, both require efficiency and waste elimination (Vinod et al. 2015). A POY is a device or process designed to prevent errors in the production process; therefore, its objective is to detect and correct them before they can cause significant problems. On the other hand, Jidoka refers to the ability of a machine or process to stop automatically in case of any problem in production (Rubio-Romero et al. 2019). This allows operators to detect and correct a problem before it spreads, causing major problems.

Some managers consider POY a component of JID because integrating a mechanism that prevents errors in a process semi-automates the process, prevents reoccurrence, and increases quality (Arevalo-Barrera et al. 2019). In other words, if a machine can separate defective parts, this is because it has already been detected using a device or sensor. Then, a POY favors JID to specify that the production line must stop, which applies to production systems and other industrial sectors such as healthcare (Grout and Toussaint 2010).

Often, the POY does not stop the machines. However, it does indicate a deviation from the standards and specifications of the product, so the operator can decide whether to stop production, depending on the level of severity incurred (Da Silva 2016). This type of POY requires sufficient training for the operator to decide whether to stop production based on previously established criteria (Cassidy 1991; Consul 2015). Many of these POYs can refer to lights and sounds that indicate malfunctions so that JID can be applied.

In summary, POY implementation can positively impact JID implementation in a productive system by allowing workers to spend more time on problem detection and less on error correction (Baseer et al. 2015; Yusuf and Halim 2023). This improves the efficiency of the production process and ensures that high-quality products with fewer defects are produced (Rajendra et al. 2013; Puvanasvaran et al. 2014). Therefore, we propose the following hypothesis:

H_1. Poka-yoke has a direct and positive effect on Jidoka.

3.2.2 Relationship of Poka-Yoke with Social Sustainability

The implementation of POY is not only analyzed from the point of view of operational and productivity-related indices but also has a social impact on workers. For example, by preventing errors in the production process, POY reduces the amount of waste materials and resources by discarding or reworking defective products (Mesones-Guillén et al. 2021). This increases workers' morale, knowing that they do not cause economic loss to the company. In addition, many of these irreparable products are sent to local landfills, increasing the environmental impact and generating pollutants, and the carbon footprint of the manufacturing process, which generates a dirty city that no one wants (Sundaramali et al. 2018).

In addition, by designing products and processes that make mistakes difficult, POYs can help reduce workers' exposure to the risks of injury and illness related to their tasks (Ahmad et al. 2017). This can improve worker safety, reduce healthcare costs and workers' compensation for workers who feel protected by their company, and increase their sense of belonging (Rubio-Romero et al. 2019).

In addition, by preventing errors in the production process, POYs improve the quality of manufactured products, increasing their pride, morale, and sense of belonging to a company, which is synonymous with quality in society (Erlandson et al. 1998). In addition, quality improvement improves customer satisfaction and enhances a company's reputation, leading to higher revenues and profits in the long run, as reflected in reward systems (Berk and Toy 2009; Abed and Ibrahim 2018).

Likewise, SMEs can foster worker empowerment as they participate in identifying and solving problems, giving them a greater sense of responsibility and control in their work, which can improve their job satisfaction by being taken into account (Médico et al. 2018). These POYs also reduce frustration levels in workers as their productivity and efficiency levels increase, and they do not have to work on fixing their mistakes, which improves their motivation and job satisfaction (Lazarevic et al. 2019). Finally, it is essential to mention that POYs improve the quality of work life because fewer errors represent less overtime on the workday, as they meet planned production standards and reduce workplace pressure and stress (Solke and Sur 2021).

In summary, implementing Poka yokes can positively impact Social sustainability by empowering workers, reducing frustration, improving the quality of work life, and fostering creativity and innovation in the production process. POY helps improve employee retention and long-term success by improving motivation and job satisfaction. Therefore, we propose the following hypothesis:

H_2. The Poka yoke has a direct and positive effect on Social sustainability.

3.2.3 Relationship Between Jidoka and Social Sustainability

Jidoka is a key concept in the Toyota Production System (TPS). This refers to automation with a human touch that emphasizes the detection and prevention of problems in the production process, allowing workers to take action to fix them before they become defects.

The relationship between JID and Social sustainability can be observed from several perspectives, including waste reduction that pollutes the work area and local landfills, which impacts the carbon footprint associated with the production process (Arevalo-Barrera et al. 2019). However, by preventing the continuation of production with defects, the quality of products and customer satisfaction are improved because they prevent them from reaching the market without meeting specifications, which increases the reputation of the company and represents higher revenues and profits in the long term (Berk and Toy 2009).

However, JID focuses on identifying quality problems and risks that affect workers' safety and quality of work life (Deuse et al. 2020). It allows production to stop if the integrity of employees is compromised, which reduces the number of injuries and occupational illnesses and improves motivation and job satisfaction. Additionally, JID improves the efficiency of production systems and reduces the costs associated with correcting errors and defects (Romero et al. 2019). This can improve a company's profitability and enhance its ability to invest in sustainable socially responsible practices.

In summary, JID can positively affect Social sustainability by empowering workers and integrating them into decision-making, reducing waste, improving product quality, worker safety and quality of work life, efficiency and profitability, and promoting more responsibility and sustainable practices. In other words, by implementing JID, companies can improve their ability to meet social and environmental challenges and achieve long-term sustainability. Therefore, we propose the following hypothesis:

H_3. Jidoka has a direct and positive impact on Social sustainability.

Figure 3.1 graphically shows the proposed hypotheses.

3.3 Methodology

This section describes the activities involved in developing this research and achieving the proposed objective.

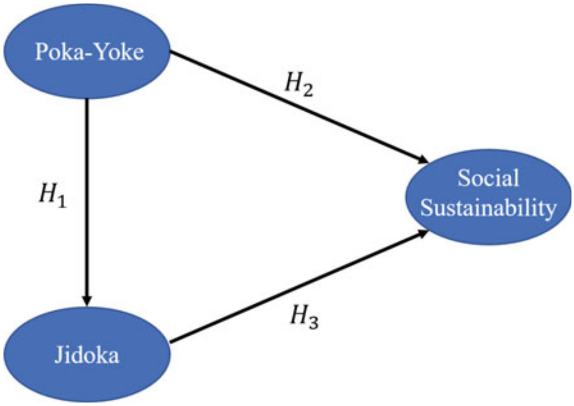

Fig. 3.1 Proposed model

3.3.1 Questionnaire Development

A questionnaire was constructed based on a literature review conducted using different databases to collect data and validate the hypotheses proposed in Fig. 3.1. The most important activities were identified when implementing the different Lean Manufacturing tools and methodologies. Additionally, a search was conducted to identify the sustainability benefits (social, environmental, and economic) of implementing these tools in the Maquiladora industry.

The questionnaire contained three sections. The first section sought to collect demographic information using questions about the company's size and line of business, its position in the organizational structure or position held by each respondent, years of experience, and gender. However, this section was optional, and the questionnaire allowed us to continue without answering them.

The second section presents the 25 lean manufacturing tools used in the proposed model, including POY and JID. The third section refers to the benefits of achieving sustainability in three dimensions (environmental, social, and economic). To answer each question in sections two and three, a 5-point Likert-type scale was used (Likert 1932), where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly disagree.

The preliminary questionnaire was presented to five academics and seven managers working in the industry for judges' validation, seeking to adapt and contextualize it to the maquiladora industry. The judges evaluated the clarity of the content and application of the item in the regional environment. Once reviewed, a questionnaire with 207 items comprised 37 lean manufacturing tools related to quality, planning, control, and material resources. In addition, 27 environmental, social, and economic sustainability benefits were identified.

3.3.2 Questionnaire Administration

Due to the COVID-19 contingency, access to many companies is restricted; therefore, the questionnaire was integrated into the Google Forms platform for online applications. Each question in sections two and three was configured to be mandatory to avoid missing values. A link to the questionnaire was then generated and shared via email with participants.

To administer the questionnaire, the sample was first identified with the help of the Manufacturing, Maquiladora, and Export Service Industry (IMMEX) program, which encompasses sectors such as automotive, aerospace, medical, and metal mechanics. This sample includes managers, engineers, supervisors, and personnel responsible for the production lines in the Maquiladora industry.

The questionnaire link was emailed to all potential participants, as proposed by IMMEX. If the email was not answered within 15 days, a second invitation was sent; if a potential participant did not respond, the case was discarded from the analysis. The questionnaire was open from June 15 to August 15, 2022.

3.3.3 Database Debugging

Once the questionnaire administration period was completed, an xls file was downloaded from all collected information (Excel file). Using this information, a database was created using SPSS 24® software for debugging, which consisted of the following steps:

The standard deviation was calculated for each questionnaire or case. If it was less than 0.5, the questionnaire was eliminated from the analysis because it was considered that the participant was not committed to answering the questionnaire correctly, that is, the participant answered the same in each of the questions to perform the process faster and uncommitted.

The items or questions were standardized to identify the extreme values for each case. Any value greater than 4 in absolute value is considered extreme and replaced by the median since the responses were given on an ordinal scale.

3.3.4 Descriptive Analysis of the Sample and the Items

Cross-tables were created to compare the demographic data from the first section of the questionnaire to identify the origin of the information. In this sense, the industrial sector was related to respondents' position and experience with gender. The size of each company was also included.

Concerning the items, a descriptive analysis was performed for each variable to identify the level of implementation of each LM tool in the companies and the

Table 3.1 Validation indices of the latent variables and their acceptable values

Test	Coefficient	Acceptable values
Parametric predictive validity	R^2 and Adj R^2	≥0.02
Non-parametric predictive validity	Q^2	≥0.02 and similar to R^2
Internal validity	Cronbach's alpha and composite reliability	≥0.70
Convergent validity	Average variance extracted (AVE)	≥0.50
Collinearity	Variance inflation factor	≤5; ideally ≤3.3

benefits obtained from such implementation when administering the questionnaire. To determine this, the median was used to measure the central tendency, and the interquartile range (IQR) was used to measure dispersion. High median values indicated a consensus toward good tool implementation practices, while low values indicated the opposite. Regarding the IQR, high values indicated that the responses varied, and there was no consensus among the participants. This means that there are companies with a high degree of implementation, and others without. However, low IQR values indicated a consensus among the participants.

3.3.5 Validation of Latent Variables

Before validating the hypotheses in Fig. 3.1, it is important to individually validate the variables by using the indices presented in Table 3.1. The indices R^2 and Adj R^2, whose minimum acceptable values are 0.02, were used to validate the variables from predictive and parametric points of view. To measure non-parametric predictive validity, index Q^2 was used, whose values must be greater than zero and similar to R^2.

To measure the internal reliability of each variable, Cronbach's alpha indices were used (Cronbach 1951) along with composite reliability, whose minimum acceptable values should be greater than 0.7. We used the AVE index (Fornell and Larcker 1981) to analyze convergent validity, with a minimum value of 0.50. Finally, the variance inflation factor was used to analyze collinearity within each variable, and the maximum acceptable value was five (Kock 2021a).

3.3.6 Structural Equation Modeling

The hypotheses proposed in Fig. 3.1 were validated by structural equation modeling (SEM) using the partial least squares (PLS) technique. SEM is a set of statistical techniques that allows the examination of a set of relationships between one or several independent variables (IV), continuous or discrete, and one or several dependent variables (DV), continuous or discrete (Ullman and Bentler 2012), where they play the roles of dependent and independent variables simultaneously (MacCallum and Austin 2000).

The SEM methodology was chosen because it allows us to understand the correlation/covariance patterns between variables and explain as much of their variance as possible using the specified model (Kline 2015). In addition, PLS-SEM is a multivariate analysis technique used to test structural models that mainly aim at causal-predictive analysis, especially in complex problems where theoretical knowledge may be scarce (Lévy and Varela 2006). In this case, the PLS-SEM technique and WarpPLS v.8.0 software were used because they are suitable for small samples and information collected on a Likert scale, where normal data distribution cannot be guaranteed.

Before interpreting the SEM, specific indices of quality and model fit proposed by Kock (2021b), such as the Average Path Coefficient (APC), Average R-Squared (ARS) and Average, Adjusted R-Squared (AARS), Average block VIF (AVIF), Average Full collinearity VIF (AFVIF) and Tenenhaus GoF (GoF) are illustrated in Table 3.2.

APC is the average sum of all the hypotheses' coefficients. By contrast, the ARS and AARS coefficients are the averages of the variance explained by the latent independent variables. These indices were used to measure the predictive validity of the model. They are validated using a hypothesis with a confidence level of 95%, so it is sought that they have an associated p-value of less than 0.05.

To identify collinearity between the variables, the values of the AVIF and AFVIF indices were calculated; if their value was greater than five, it was concluded that collinearity existed. Adjustments were made by eliminating the items, and these indices were obtained iteratively. The Tenenhaus GoF index was used to measure the fit of the data to the model; values greater than 0.36 were accepted.

Table 3.2 Model fit and quality index

Index	Validation	Acceptable value
Average Path Coefficient (APC)	Predictive	$p < 0.05$
Average R-Squared (ARS) and Average Adjusted R-Squared (AARS)	Predictive	$p < 0.05$
Average block VIF (AVIF)	Collinearity	Acceptable if ≤ 5, ideally ≤ 3.3
Average Full collinearity VIF (AFVIF)	Collinearity	Acceptable if ≤ 5, ideally ≤ 3.3
Tenenhaus GoF (GoF)	Data model fit	≥ 0.36

3.3.6.1 Effects on SEM

The SEM reports three different effects between the variables. Direct effects are relationships between measured and latent variables, indicated graphically by one-way arrows, whose coefficients are generated to describe the strength of these relationships and are interpreted in the same way as the regression weights (Weston and Gore 2006). Indirect effects are the relationship between an independent latent variable and a dependent latent variable, mediated by one or more latent variables (Baron and Kenny 1986). Finally, the total effect was obtained as the sum of direct and indirect effects.

The β coefficient measures each effect, and a hypothesis test was performed to measure the statistical significance of each parameter. The null hypothesis was H_0: $\beta = 0$, and the alternative hypothesis was H_1: $\beta \neq 0$, , which was tested with a confidence level of 95%. In addition, the direct and indirect effects of each of the latent independent variables explain part of the variance of each of the latent dependent variables, called effect size (ES), and the sum of all of them is equal to the value of R^2

3.3.7 Sensitivity Analysis

A sensitivity analysis was carried out as the final step to analyze the risks that companies are exposed to when implementing each tool. To do this, conditional probabilities were calculated because the analysis suggests that two variables are causally linked, yielding a path coefficient of 0.25 (Kock 2021a); which means that an increase in the independent variable leads to an increase in the conditional probability that the dependent variable will be above a specific value.

This study reports the probabilities of different occurrence combinations for the latent variables. These combinations are related to scenarios in which the tools are properly implemented (+) and those in which they are not adequately implemented (−). In this sense, probabilities are calculated for each tool individually, jointly (&) and conditionally (If). The scenarios to be analyzed are as follows:

1. The probability that a latent variable is present in isolation in an idealized scenario $P(Z > 1)$ and in a non-idealized scenario $P(Z < -1)$.
2. The probability of both variables occurring jointly in different scenarios, that is, $P(Z_i > 1 \text{ and } Z_d > 1)$, $P(Z_i > 1 \text{ and } Z_d < -1)$, $P(Z_i < -1 \text{ and } Z_d > 1)$, and $P(Z_i < -1 \text{ and } Z_d < -1)$.
3. The conditional probability that the implementation activities of one LM tool will occur ideally or non-ideally, given that the other has been implemented ideally or non-ideally, that is, $P(Z_i > 1/Z_d > 1)$, $P(Z_i > 1/Z_d < -1)$, $P(Z_i < -1/Z_d > 1)$, and $P(Z_i < -1/Z_d < -1)$.

Table 3.3 Sample description

Years of experience	Job position					Total
	Manager	Engineer	Supervisor	Technician	Other	
0 to <1	1	6	0	3	13	23
1 to <2	3	22	4	15	16	60
2 to <5	4	61	25	26	23	139
5 to <10	17	44	21	6	15	103
≥10	25	23	10	8	20	86
Total	50	156	60	58	87	411

3.4 Results

3.4.1 Description of the Sample

After information was collected, 411 responses to the questionnaire were obtained. Table 3.3 shows that 78.9% of the participants had more than 2 years and less than 5 years of experience in their job, 46% had more than 5 years and less than 10 years of experience, and 21% had more than 10 years of experience. Therefore, the answers obtained were considered reliable. In addition, it was observed that engineers had greater participation.

Table 3.4 shows the industrial sector and size of the companies in which the participants worked. The automotive sector was the most participating sector, followed by the medical and electronics sectors. In addition, most companies have between 1,000 and 5,000 workers.

3.4.2 Validation of Latent Variables and Their Descriptives

Table 3.5 lists the validation indices for the latent variables. According to the R-squared and Adj. R-squared values, the latent dependent variables have sufficient predictive validity from a parametric point of view because the values are above 0.02. Concerning Composite Reliability and Cronbach's alpha values, it was concluded that the model had sufficient predictive validity and measured what it intended to measure. In addition, the AVE values were greater than 0.5, indicating that the variables had sufficient convergent validity.

Finally, the Full Coll and VIF values indicate no collinearity problems because they are less than 3.3. The predictive validity from a non-parametric point of view is adequate because the Q-squared value is similar to the R-squared value. Thus, we conclude that the variables were included in the model and analyzed (Table 3.5).

Table 3.4 Company size versus industry sector

Industrial sector	Company size						Total
	<50	50 to <300	300 to <1000	1000 to <5000	5000 to <1000	>10,000	
Automotive	1	8	29	70	18	22	148
Aeronautics	0	1	1	2	0	1	5
Electric	0	4	3	7	2	0	16
Electronics	1	4	13	23	9	6	56
Logistics	2	3	6	3	0	1	15
Machining	3	3	3	3	0	1	13
Medical	1	8	10	21	20	12	72
Rubber and plastics	0	1	4	3	0	0	8
Textiles and clothing	1	0	1	1	0	0	3
Other	18	14	19	14	5	5	75
Total	27	46	89	147	54	48	411

Table 3.5 Validation of latent variables

	Poka-Yoke	Jidoka	Social sustainability
R-Squared		0.519	0.347
Adj. R-squared		0.518	0.344
Composite reliability	0.906	0.928	0.956
Cronbach's alpha	0.861	0.903	0.947
AVE	0.707	0.72	0.758
Full Collin. VIF	2.252	2.13	1.525
Q-squared		0.519	0.347

Table 3.6 shows the items for each latent variable, with their respective medians and interquartile ranges. Concerning Jidoka, there is a consensus among most respondents since they consider that visual control is used in companies to evaluate the state of the production processes, given that it is the item with the largest median and lowest interquartile range. Concerning Poka Yoke, the respondents considered that sounds, lights, or other warning signals were used within the companies to indicate that an error had occurred, since it had a median of 4.143. Furthermore, they agreed that the companies had used error-proof devices.

Finally, there was consensus among respondents that social sustainability was improved through improved workplace safety, with a median of 4.234 and an IQR of 1.378. Table 3.6 shows the items with the highest median values in bold font.

Table 3.6 Descriptive analysis of the items

Latent variable	Items	Median	IQR
Jidoka	Does the machinery warn when a piece does not meet the requirements?	4.021	1.685
	Does the machinery stop automatically when it detects an error in the process?	4.007	1.700
	Are small machines used to ensure a fast and uniform flow of materials?	3.863	1.746
	Is visual control used to assess the status of production processes?	4.203	1.442
	When a failure occurs, can each member obtain specific information to continue progressing within the program schedule?	4.076	1.524
Poka-Yoke	Does used machinery separate good parts from bad ones?	3.820	1.946
	Does the machinery avoid making mistakes?	3.966	1.628
	Are poka-yokes used to prevent errors?	4.077	1.526
	Is use made of sounds, lamps or another warning signal to inform about the occurrence of an error?	4.143	1.554
Social sustainability	Improved working conditions	4.230	1.423
	Improved safety in the workplace	4.243	1.378
	Improved employee health	4.232	1.464
	Decrease in working pressure	4.102	1.592
	Improved community health and safety	4.159	1.480
	Incentives have been provided to engage local employment	4.194	1.517
	Social programs are in place to support local society	4.219	1.500

3.4.3 Structural Equation Modeling

Once the latent variables have been validated, it is possible to integrate them into the SEM for analysis in the WarpPLS software; however, it is important to validate the model using the quality and fit indices before interpreting it, and in this case, the results are as follows:

- Average path coefficient (APC) = 0.451, $p < 0.001$

- Average R-squared (ARS) = 0.433, $p < 0.001$
- Average adjusted R-squared (AARS) = 0.431, $p < 0.001$
- Average block VIF (AVIF) = 2.135, acceptable if ≤ 5, ideally ≤ 3.3
- Average full collinearity VIF (AFVIF) = 1.969, acceptable if ≤ 5, ideally ≤ 3.3
- Tenenhaus GoF (GoF) = 0.561, small ≥ 0.1, medium ≥ 0.25, large ≥ 0.36

The APC value (0.451) indicates that the hypotheses are statistically significant on average. In contrast, the ARS (0.433) and AARS (0.431) values indicated that the variance of the latent independent variables explained was statistically significant because the associated p-value was less than 0.05. Concerning the VIF and AFVIF indices, it was concluded that the model was free of collinearity problems because both were less than 3.3. Finally, the value of the Tenenhaus index reflects that the obtained data fit the model adequately, as it was greater than 0.36. Therefore, the model was interpreted.

3.4.3.1 Effects

Figure 3.2 shows the results of the SEM evaluation. According to the p-values associated with the β-parameters of each hypothesis, it can be concluded that all three hypotheses are statistically significant. The largest model effect is presented from the Poka-Yoke tool towards Jidoka with a value of β = 0.720, which means that Poka-Yoke has a direct and positive effect on Jidoka. This indicates that if Poka-yoke increases its standard deviation by one unit, Jidoka increases its standard deviation by 0.720 units.

This means that Poka-Yoke is an enabler of Jidoka within the maquiladora firms. Likewise, Poka-Yoke facilitates social sustainability within firms as it has a positive direct effect size of β = 0.378. Likewise, Jidoka facilitates social sustainability within firms as it has a direct and positive effect of β = 0.254. Furthermore, in the model, an indirect effect is given from Poka-Yoke to Social Sustainability through Jidoka of

Fig. 3.2 Model evaluated

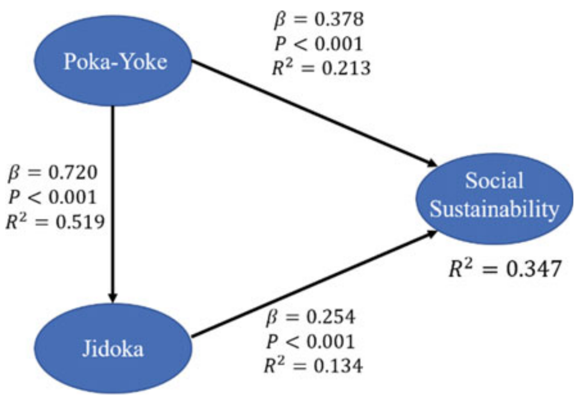

Table 3.7 Total effects

	Poka-Yoke	Jidoka
Jidoka	$\beta = 0.720$ $P < 0.001$ ES = 0.519	
Social sustainability	$\beta = 0.561$ $P < 0.001$ ES = 0.316	$\beta = 0.254$ $P < 0.001$ ES = 0.134

size $\beta = 0.182$, which means that the influence of Poka-Yoke on Jidoka positively affects the Social Sustainability of companies.

Table 3.7 presents the total effects, which are the sum of direct and indirect effects. In this case, Poka Yoke directly affects Social sustainability of size $\beta = 0.378$ and an indirect effect of size 0.183, resulting in the total effect of $\beta = 0.561$. Importantly, all total effects were statistically significant.

3.4.4 Sensitivity Analysis

Table 3.8 presents the sensitivity analysis of the evaluated model. Different scenarios that analyze the risks involved in implementing an LM tool are presented. The probabilities that each LM tool and social sustainability are presented in isolation in ideal and non-ideal scenarios are shown.

For example, the probabilities that Poka-Yoke, Jidoka and Social sustainability are present in their ideal scenarios in isolation are 0.197, 0.207, and 0.195, respectively. By contrast, when they are at a low level of implementation, the probabilities are 0.136, 0.139, and 0.170, respectively.

In this case, high levels are represented by the " + " sign, while the "−" sign represents low levels. In addition, joint probabilities are represented by "&" and conditional probabilities by "IF."

Table 3.8 Sensitivity analysis

Level		Poka-Yoke+	Poka-Yoke−	Jidoka+	Jidoka−
	Probability	0.197	0.136	0.207	0.139
Jidoka+	0.207	& = 0.134 IF = 0.679	& = 0.002 IF = 0.018		
Jidoka−	0.139	& = 0.002 IF = 0.012	& = 0.080 IF = 0.589		
Social sustainability +	0.195	& = 0.107 IF = 0.543	& = 0.017 IF = 0.125	& = 0.112 IF = 0.541	& = 0.012 IF = 0.088
Social sustainability	0.170	& = 0.005 IF = 0.025	& = 0.063 IF = 0.464	& = 0.010 IF = 0.047	& = 0.068 IF = 0.491

3.5 Discussion of Results

For SEM, the following can be inferred.

For H_1. There is sufficient statistical evidence to state that Poka-Yoke directly and positively affects Jidoka in the Mexican maquiladora industry because when the former variable increases by one unit, the latter by 0.720 units. In practical terms, this result indicates that using error-proofing devices within companies will facilitate the implementation of Jidoka, as machinery can alert when a part does not meet quality specifications and automatically stop when it detects an error. However, this also indicates that the status of the production processes can be evaluated through visual monitoring.

For H_2. There is sufficient statistical evidence to state that Poka-Yoke has a direct and positive effect on the social sustainability of Mexican maquiladora companies since when the first variable increases its standard deviation by one unit, the second increases it by 0.378 units. In practical terms, these results indicate that implementing error-proofing devices improves working conditions and that health in the work area improves workers' health. In addition, it decreases work pressure and improves the health and safety of the community because these devices avoid errors that can alter the physical and mental integrity of workers knowing that they do not commit them.

For H_3. There is sufficient statistical evidence to state that implementing the Jidoka Program directly and positively affects social sustainability, as when the first variable increases by one unit, the second increases by 0.254 units. This result indicates that implementing tools such as Jidoka within companies facilitates social sustainability by improving working conditions and that health in the work area improves workers' health. However, it also reduces work pressure and improves the health and safety of the community. Above all, it avoids feelings of guilt in workers, knowing that they do not generate waste for the company, and represents an economic loss.

Several variable behaviors were observed in the sensitivity analysis. For example, the probabilities of POY+ and POY− occurring in isolation were 0.197 and 0.136, respectively, whereas those of JID+ and JID− were 0.207 and 0.139, respectively. Finally, SOS+ and SOS− can occur in isolation, with probabilities of 0.195 and 0.170, respectively. These values indicate that the variables analyzed are more likely to be found at higher than lower levels, representing a risk for managers.

However, the essential analysis probabilities are conditional probabilities. In this regard, POY+ is a strong predecessor of JID+ and SOS+ because it favors them with conditional probabilities of 0.679 and 0.543, respectively. This indicates that investments in devices focused on reducing operator errors favor the automation of processes and generation of products without defects, which results in less risk to the physical integrity of workers and greater motivation. This is demonstrated by the fact that POY+ is only weakly associated with JID+ and SOS because the conditional probabilities are 0.012 and 0.025, respectively. In other words, high investment in POY is not associated with employee labor dissatisfaction or the generation of low-quality products.

It is also observed that POY− represents a risk for managers because it favors the occurrence of JID− and SOS− with probabilities of 0.589 and 0.464, respectively. These results indicate that if POY devices are not implemented, errors that affect the quality of products are generated, and it is difficult to identify them before delivery to customers. Furthermore, POY− is not associated with JID+ or SOS+ because the conditional probabilities are 0.018 and 0.063, respectively, which are very low.

It was also observed that JID+ is a precursor of SOS+ because it favors it with a conditional probability of 0.541; however, JID+ is only weakly associated with SOS because it favors it by only 0.047. These results indicate that automatic processes that identify errors in the production process increase job satisfaction, safety, and hygiene. Therefore, they should be encouraged. However, JID− is a risk factor because it favors SOS− with a probability of 0.491 and is associated only with SOS+ with a probability of 0.088.

3.6 Conclusions

This study reports a structural equation model integrating two LM tools (POY and JID) associated with the SOS. The model was statistically validated, and the following conclusions were drawn:

The proper implementation of POY in the production systems of Mexican maquiladora industries favors automation, which allows the detection of errors before they spread and generate low-quality products. However, it also favors SOS because it prevents errors that could put the physical integrity of workers at risk but avoid feelings of guilt and consequent economic losses.

The proper implementation of JID favors SOS because it prevents products that do not meet quality specifications from being sent to the market, which results in extended product warranties, repairs of defective products, and delays in administrative processes and costs.

Therefore, managers should pay special attention to LM tools to avoid errors in production processes and their propagation. This is because errors represent a lack of quality planning, which can decrease a company's reputation.

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Chapter 4
The Barriers Related to Smart Manufacturing Systems and an Application for the Selection of Innovation Management Model: The Case of Samsun Province

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Abstract More productive processes and innovation management have gained popularity due to technological advancements enabling flexible manufacturing, cost-effectiveness, and business process optimization. In the information age, Industry 4.0 has strengthened the relevance of smart systems, and the smart concept is emphasized for innovative production processes. In other words, integrated innovative automation and digitalized solutions provide businesses with a competitive advantage. Consequently, smart manufacturing technologies that enable effective and quick production processes can be regarded as key elements for businesses. However, businesses face many barriers when transitioning to and adopting smart manufacturing systems. To increase production and efficiency, businesses must remove or reduce barriers to the lowest possible level. However, in both service and manufacturing organizations, innovation management and innovation management models are critical indicators for enhancing competitiveness and providing a cost advantage. This is also beneficial for technology and smart management practices. In this context, this chapter aims to determine the importance of barriers to smart manufacturing systems in plastic sector companies operating in Samsun and select the best innovation management model. While the Neutrosophic AHP method was used to weigh the criteria, the Neutrosophic MARCOS method was utilized to rank the alternatives consisting of linear, balanced, interactive, and learning-integrated system models. According to the study,

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the most significant barriers to smart production systems are "Smart manufacturing system expenses" and "Insufficient technical infrastructure." The integrated learning systems model was chosen as the best model for innovation management.

Keywords Smart manufacturing systems · Barriers related to smart manufacturing systems · Innovation management and models · Single valued neutrosophic AHP · Single valued neutrosophic MARCOS

4.1 Introduction

Efficiency, which is defined as the effective use of raw materials, capital, energy, land, and information resources required for the introduction of various goods and services in enterprises, is the most often used performance indicator in manufacturing enterprises, as well as in all sectors (Prokopenko 2011). Efficiency is defined as getting more with a given input quantity or obtaining a specified output with less input (Korucuk 2019). Smart manufacturing (SM) systems are a sign of better business efficiency and performance, and this manufacturing system has strong potential for value-added output. In other words, SM boosts employment, added value, resource efficiency, competitiveness, trade, financial stability, and economic well-being (Association 2013).

According to Duman and Karğın (2021), SM has a structure that substantially affects the manufacturing processes in Industry 4.0. This transition was made feasible by Industry 4.0. Smart factories have been modernized with these technologies, and the production achieved with these technologies is known as production achieved with these technologies.

In contrast, SM systems connect all production elements, including the supply chain, production, product, logistics, and service (Choi et al. 2015). Owing to sophisticated automation, SM systems provide high efficiency and adaptability to production processes (Kagermann et al. 2013). Simultaneously, SM processes provide enhanced data access across the entire supply chain network.

SM systems aid in increasing productivity and decreasing costs. Prices have another effect of lowering costs. SM systems allow for transparent and adaptable manufacturing systems. From a macroeconomic perspective, it can be concluded that an innovative manufacturing style based on SM benefits long-term development. SM systems can aid in reducing the waste of raw materials and resources. Simultaneously, companies that provide environmentally friendly products recognize this as a strategic value and alter their marketing strategies to reflect this (Duman 2019).

However, companies face several barriers to the adoption of SM systems. These barriers are generally expressed as the problem of leaving the traditional manufacturing method, a lack of technological infrastructure, a negative perspective of senior management on smart systems, unemployment problems that may arise, the cost of SM systems, the problem of technology-intensive business process planning, anxiety against SM systems (such as cyber-attacks), scarcity of skilled labor for SM systems, and the presence of unexpected stops and failures in smart devices (Duman 2019; Banger 2017).

On the other hand, innovation management/innovation management models are essential indicators in enhancing competitiveness and delivering a cost advantage in service and manufacturing organizations. In this view, innovation management has been defined as managing the entire innovation process, from new idea development to product or process development/market adaptation (Ojasalo 2008). According to White and Bruton (2010), this concept requires the organization's CEO to encourage employees to be creative and take risks. In this context, innovation models are divided into demand-and supply side models. Similarly, innovation theories are divided into two categories: linear and systemic. These two classifications have numerous analogies and logical links.

On the one hand, the linear innovation model portrays the invention process as a supply-side activity. However, it has been suggested that the demand-side perspective is more efficient in models that systematically examine innovation (Edquist and Hommen 1999). Various studies have focused on innovation management models, particular since the 1950. R&D, the market environment, customer expectations, cost reduction, and design and engineering projects all contribute to the value of these models. The most common types of innovation management models include linear, balance, interactive, and learning integrated system models (Güleş and Bülbül 2004; Maylor 2001).

In this context, the authors are motivated to research this subject for various reasons. According to the decision-maker's expertise, experience, and knowledge, this study is regarded as one of the most promising solutions for ensuring efficiency and effectiveness in manufacturing enterprises for smart production systems and innovation management models, as well as for activating competitiveness. Furthermore, this study is expected to significantly contribute to providing an effective and relevant solution to the decision-making problem involving the selection of smart production systems and an innovation management model in a critical sector such as the manufacturing sector. This study provides a roadmap for effective cost and technology management practices because it includes an innovation management model and smart systems in the manufacturing sector. The study also examines the similarities and differences between SM systems and innovation management practices in businesses in the relevant industry, and how they can be reflected. Thus, this study provides a practical roadmap for selecting SM systems and innovation management models for the manufacturing sector.

This study also includes a comprehensive, robust, and practical decision-making model that can deal with uncertainty. As a result, in addition to contributing to the long-term solution of the relevant decision-making problem for the manufacturing sector, this study is expected to provide a robust methodological framework to fill theoretical gaps in the literature. This study aims to identify the barriers to smart production systems in plastic sector firms operating in Samsun and to select the best innovation management model.

The factors collected from the literature review were analyzed using single-valued neutrosophic AHP (SVN-AHP) and single-valued neutrosophic MARCOS (SVN-MARCOS), which are multi-criteria decision-making methods. A literature review on the barriers to smart production systems and innovation management models is presented in the following section. Theoretical explanations of the study's methodology are then provided. The findings section presents an analysis of the study's problem in the context of expert evaluations. As a result, the study was completed by providing recommendations regarding its limitations and future research.

4.2 Literature Review

Below is a detailed literature review of smart production systems/barriers and an innovation management model.

- Marinova and Phillimore (2003) classify innovation models and examine the theoretical framework of public R&D policy based on innovation models.
- Ortt and van der Duin (2008) investigated the innovation approach phases in innovation management from the past to the present and identified the differences between them.
- Erden (2009) sought to determine which innovation model could be used as a foundation for the design and legitimation of public policies.
- Güneş (2011) analyzed four value-creation innovation models and evaluated them in terms of corporate economics and transaction costs.
- Milić (2013) studies the strategic implications of innovation management during an economic crisis.
- Ritala and Huizingh (2014) integrate an overview of innovation management with a strategic assessment of business and network models for innovation.
- Murphy et al. (2015) develop an innovation management model to continually apply product innovation to building projects.
- According to Lu et al. (2016), there are no applicable standards on which future SM systems will be based, and current standards should be evaluated for a better understanding.
- Tidd and Thuriaux-Alemán (2016) assessed the cross-sectoral adoption, variety, and efficiency of innovation management practices.
- Kang et al. (2016) studied the concept of SM and basic technologies using time-series analysis, and included multiple definitions of SM systems.
- Ventura and Soyuer (2016) studied innovation management and knowledge-based innovation approaches in R&D and marketing-production integration in businesses. Based on the perspectives of several scientists and firm examples,
- Nizharadze (2017) analyzed aspects of creative process management, dynamics of government financial support, and new innovation management models.

- Crnjac et al. (2017) defined SM as factories in which humans, machines, and resources can readily communicate with one another, and items in the virtual and real worlds can be connected.
- According to Chen (2017), Industry 4.0 is a new manufacturing paradigm characterized by two fundamental elements: integrated and SM.
- Wiktorsson et al. (2018) investigated how SMEs and major enterprises in South Korea and Sweden implemented the concept of SM.
- Zartha et al. (2018) consolidate the results of analyzing and evaluating organizations using the tools and techniques used in the Delphi method, innovation strategy, and innovation management models.
- Frank et al. (2019) studied the application of SM, cloud services, big data, and analytics, and discovered that Industry 4.0 is essential to SM.
- Furdui et al. (2019) examined the fundamental characteristics of approaches to technological entrepreneurship growth that can be interconnected within the context of innovation management.
- Öncül and Ateş (2020) outlined the obstacles organizations faced when moving to the SM strategy.
- Duman and Karğın (2021) evaluated the impact of SM on company performance, which was implemented using Industry 4.0.
- Idris and Durmuşoğlu (2021) conducted a systematic literature review on innovation management systems and standards and concluded that the findings would guide future research.
- Villacís and Crespo (2022) investigated the drivers of innovation management in the manufacturing industry in Pichincha, Ecuador.
- Sağbaş and Özdil (2022) proposed an SM system integration model for textile businesses in Industry 4.0.

According to the literature, studies on SM systems for enterprises producing plastic products are limited. However, SM systems are prominent in terms of providing sustainability and cost advantages. In addition, considering the dimensions of technology management, competitiveness, customer satisfaction, and innovative business management, the fact that no other study in this field has been found makes this study valuable and differentiates it. Furthermore, there is no quantitative research in the literature examining the barriers to smart production systems and the adoption of new management models for the Samsun province. The mathematical model developed in this study was considered valuable in terms of revealing the significance of the study, as it can provide solutions to the obstacles in smart production systems and innovation management models in the problem of varying importance levels to be determined by decision-makers for each criterion and alternative.

4.3 Methodology

4.3.1 Neutrosophic Set

Neutrosophic Sets (NS) were proposed by Smarandache (1998), which have the independent degree of truth, indeterminacy, and falsity membership functions. Suppose U as universal set with $\forall \mathrm{x} \in \mathrm{U}, 0^{-} \leq \mathrm{T_N(x)} + \mathrm{I_N(x)} + \mathrm{F_N(x)} \leq 3^{+}$. N as NS in U is defined with the functions of $\mathrm{T_N} : \mathrm{U} \rightarrow \left]^{-}0, 1^{+}\right[$, $\mathrm{I_N} : \mathrm{U} \rightarrow \left]^{-}0, 1^{+}\right[$ and $\mathrm{F_N} : \mathrm{U} \rightarrow \left]^{-}0, 1^{+}\right[$ as shown in Eq. (4.1).

$$\mathrm{N} = \{\langle \mathrm{x}, \mathrm{T_N(x)}, \mathrm{I_N(x)}, \mathrm{F_N(x)} \rangle : \mathrm{x} \in \mathrm{U}\} \tag{4.1}$$

where $T_N(x)$, $I_N(x)$, and $F_N(x)$ are the truth, indeterminacy, and falsity membership functions, respectively.

Wang et al. (2010) arranged the definition of NS to apply to real-life problems with inconsistent, indeterminate and vague information and proposed single-valued neutrosophic sets (SVNS). The interval of [0, 1] is considered rather than]0^{-},1^{+}[. Let U a universal set with $\forall \mathrm{x} \in \mathrm{U}, 0 \leq \mathrm{T_N(x)} + \mathrm{I_N(x)} + \mathrm{F_N(x)} \leq 3$. N as SVNS in U is considered with the functions of $\mathrm{T_N} : \mathrm{U} \rightarrow [0, 1]$, $\mathrm{I_N} : \mathrm{U} \rightarrow [0, 1]$ and $\mathrm{F_N} : \mathrm{U} \rightarrow [0, 1]$.

Let a single-valued neutrosophic triangular number $\tilde{c} =< (c_1, c_2, c_3); \alpha_{\tilde{c}}, \theta_{\tilde{c}}, \beta_{\tilde{c}} >$ is a particular neutrosophic set on R. In addition $\alpha_{\tilde{c}}, \theta_{\tilde{c}}, \beta_{\tilde{c}} \in [0, 1]$ and $c_1, c_2, c_3 \in R$ where $c_1 \leq c_2 \leq c_3$. The truth, indeterminacy, and falsity membership functions for this number can be obtained as follows (Abdel-Basset et al. 2017; Karamaşa et al. 2021; Stanujkic et al. 2017):

$$T_{\tilde{c}}(x) = \begin{cases} \alpha_{\tilde{c}}\left(\dfrac{\mathrm{x} - c_1}{c_2 - c_1}\right) & (c_1 \leq x \leq c_2) \\ \alpha_{\tilde{c}} & (\mathrm{X} = c_2) \\ \alpha_{\tilde{c}}\left(\dfrac{c_3 - x}{c_3 - c_2}\right) & (c_2 < x \leq c_3) \\ 0 & \text{otherwise} \end{cases} \tag{4.2}$$

$$\mathrm{I}_{\tilde{c}}(x) = \begin{cases} \left(\dfrac{c_2 - \mathrm{x} + \theta_{\tilde{c}}(\mathrm{x} - c_1)}{c_2 - c_1}\right) & (c_1 \leq x \leq c_2) \\ \theta_{\tilde{c}} & (\mathrm{x} = c_2) \\ \left(\dfrac{x - c_2 + \theta_{\tilde{c}}(c_3 - x)}{c_3 - c_2}\right) & (c_2 < x \leq c_3) \\ 1 & \text{otherwise} \end{cases} \tag{4.3}$$

$$\mathrm{F}_{\tilde{\boldsymbol{c}}}(\boldsymbol{x}) = \begin{cases} \left(\frac{c_2 - \mathrm{x} + \beta_{\tilde{c}}(\mathrm{x} - c_1)}{c_2 - c_1}\right) & (c_1 \le x \le c_2) \\ \beta_{\tilde{\boldsymbol{c}}} & (\mathrm{x} = c_2) \\ \left(\frac{x - c_2 + \beta_{\tilde{c}}(c_3 - x)}{c_3 - c_2}\right) & (c_2 < x \le c_3) \\ 1 & \text{otherwise} \end{cases} \tag{4.4}$$

Maximum truth, minimum indeterminacy and minimum falsity membership degrees are indicated by $\alpha_{\tilde{c}}$, $\theta_{\tilde{c}}$ and $\beta_{\tilde{c}}$ respectively according to the Eqs. (4.2)–(4.4).

4.3.2 *Neutrosophic AHP*

The steps of the single-valued neutrosophic AHP (SVN-AHP) can be summarized as follows (Abdel-Basset et al. 2017; Karamaşa et al. 2021; Stanujkic et al. 2017).

1. A decision problem is constructed based on a hierarchical view consisting of goals, criteria, sub-criteria, and alternatives.
2. A neutrosophic matrix comprising a triangular neutrosophic number was formed with regard to pairwise comparisons. Neutrosophic pairwise comparison matrix $\left(\tilde{P}\right)$ is given as follows:

$$\tilde{P} = \begin{bmatrix} \tilde{1} & \tilde{p}_{12} & \cdots & \tilde{p}_{1n} \\ \vdots & \vdots & & \vdots\vdots \\ \tilde{p}_{n1} & \tilde{p}_{n2} & \cdots & \tilde{1} \end{bmatrix} \tag{4.5}$$

   where $\tilde{p}_{ji} = \left(\tilde{p}_{ij}\right)^{-1}$ is valid for Eq. (4.5).
3. The neutrosophic pairwise comparison matrix was obtained via the scale in Table 4.1 (Karamaşa et al. 2021; Radwan et al. 2016).
4. The neutrosophic pairwise comparison matrix is transformed into a deterministic pairwise comparison matrix for computing the weights of the criteria, as shown below:

   Suppose $\tilde{p}_{ij} =< (f_1, g_1, h_1); \alpha_{\tilde{p}}, \theta_{\tilde{p}}, \beta_{\tilde{p}} >$ as a single-valued neutrosophic number, then the score and accuracy degrees for $\tilde{p}_{ij}$ are obtained according to Eqs. (4.6) and (4.7):

$$S\left(\tilde{p}_{ij}\right) = \frac{1}{16}[f_1 + g_1 + h_1]x\left(2 + \alpha_{\tilde{p}} - \theta_{\tilde{p}} - \beta_{\tilde{p}}\right) \tag{4.6}$$

$$A\left(\tilde{p}_{ij}\right) = \frac{1}{16}[f_1 + g_1 + h_1]x\left(2 + \alpha_{\tilde{p}} - \theta_{\tilde{p}} + \beta_{\tilde{p}}\right) \tag{4.7}$$

   The score and accuracy degree of $\tilde{p}_{ij}$ are obtained via Eqs. (4.8) and (4.9):

Table 4.1 Linguistic terms for SVN-AHP

Saaty fundamental scale	Linguistic terms for importance levels	Neutrosophic triangular set with reciprocals
1	Equally influential	< (1,1,1);0.5,0.5,0.5 >
2	Intermediate value	< (1,2,3); 0.4,0.65,0.6 >
3	Slightly influential	< (2,3,4); 0.3,0.75,0.7 >
4	Intermediate value	< (3,4,5); 0.6,0.35,0.4 >
5	Strongly influential	< (4,5,6); 0.8,0.15,0.2 >
6	Intermediate value	< (5,6,7); 0.7,0.25,0.3 >
7	Very strongly influential	< (6,7,8); 0.9,0.1,0.1 >
8	Intermediate value	< (7,8,9); 0.85,0.1,0.15 >
9	Absolutely influential	< (9,9,9); 1,0,0 >

$$S\left(\tilde{p}_{ji}\right) = 1/S(\tilde{p}_{ij}) \tag{4.8}$$

$$A\left(\tilde{p}_{ji}\right) = 1/A(\tilde{p}_{ij}) \tag{4.9}$$

Then, the deterministic pairwise comparison matrix is obtained as follows:

$$P = \begin{bmatrix} 1 & p_{12} & \cdots & p_{1n} \\ \vdots & \vdots & & \vdots\,\vdots \\ p_{n1} & p_{n2} & \cdots & 1 \end{bmatrix} \tag{4.10}$$

To obtain the ranking of priorities, we first divide each entry by the sum of columns and then sum the row averages.

5. The consistency index (CI) and consistency ratio (CR) were computed to verify the consistency of pairwise comparisons. If the CR is greater than 0.1, pairwise comparisons are reviewed and renewed. Each element in the first column of the pairwise comparison matrix was multiplied by the ranking priority of the first criterion, and this process was applied to all columns. A weighted sum vector was acquired by summing the values across rows. Following that, the average of values (λ_{max}) is handled by dividing the weighted sum vector by the related priority for each criterion.

   The CI was obtained using Eq. (4.11):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4.11}$$

where n is the number of compared components.

Then, the CR is acquired using Eq. (4.12):

$$CR = \frac{CI}{RI} \tag{4.12}$$

where RI is the consistency index related to a randomly generated pairwise comparison matrix.

6. The ranking of alternatives was obtained based on the overall priority values.

4.3.3 Neutrosophic MARCOS

Tang et al. (2021) proposed single-valued neutrosophic MARCOS (SVN-MARCOS) for ranking and selection problems. The linguistic terms in Table 4.2 can be used to evaluate the alternatives (Şahin and Yiğider 2016).

SVN-MARCOS was applied according to the steps defined below (Stević et al. 2020; Tang et al. 2021).

1. The decision problem is then defined. The criteria, alternatives, and decision makers or experts seeking their opinions are defined in this context.
2. Experts evaluated the alternatives using the linguistic terms in Table 4.2.
3. A single decision matrix was constructed by combining the expert evaluations. Experts can then be evaluated using aggregation tools. However, if experts are given equal weights, it is possible to obtain an integrated decision matrix by averaging the evaluations. The average was used because the experts' evaluations were given equal weights in this study. Thus, the integrated SVN decision matrix $X = \left[x_{ij}\right]_{m \times n}$ is constructed, where $x_{ij} = (d_{ij}, e_{ij}, f_{ij})$ and d, e, f refer to Truth, Indeterminacy, and Falsity values, respectively.
4. Positive crisp values were obtained using Eq. (4.13). Thus, an integrated crisp decision matrix, Y, was constructed (Tang et al. 2021).

Table 4.2 Linguistic terms for evaluating alternatives

Linguistic terms	Codes	T	I	F
Extremely high	EH	1	0	0
Very very high	VVH	0, 9	0, 1	0, 1
Very high	VH	0, 8	0, 15	0, 2
High	H	0, 7	0, 25	0, 3
Above average (Medium good)	AA	0, 6	0, 35	0, 4
Average (Fair)	A	0, 5	0, 5	0, 5
Below average (Medium low)	BA	0, 4	0, 65	0, 6
Low	L	0, 3	0, 75	0, 7
Very low	VL	0, 2	0, 85	0, 8
Very very low	VVL	0, 1	0, 9	0, 9
Extremely low	EL	0	1	1

$$y_{ij} = \frac{2 + d_{ij} + e_{ij} + f_{ij}}{3} \tag{4.13}$$

5. The ideal solution and anti-ideal solution are defined based on y_{ij} values. For this purpose, Eq. (4.14) is used for the ideal solution, and Eq. (4.15) for the anti-ideal solution, where J^+ depicts benefit-criteria, and J^- denotes cost-criteria.

$$\begin{aligned} A^* &= \left\{ \left(\underset{i}{maks}\, y_{ij} | j \in J^+ \right), \left(\underset{i}{min}\, y_{ij} | j \in J^- \right) | i = 1, \ldots, m \right\} \\ &= \left\{ y_{01}^*, \ldots, y_{0j}^*, \ldots, y_{0n}^* \right\} \end{aligned} \tag{4.14}$$

$$\begin{aligned} A^- &= \left\{ \left(\underset{i}{min}\, y_{ij} | j \in J^+ \right), \left(\underset{i}{maks}\, y_{ij} | j \in J^- \right) | i = 1, \ldots, m \right\} \\ &= \left\{ y_{01}^-, \ldots, y_{0j}^-, \ldots, y_{0n}^- \right\} \end{aligned} \tag{4.15}$$

As a result, the extended decision matrix Υ is constructed by adding the A^* and A^- vectors to the Y matrix, as stated in Eq. (4.16).

$$\Upsilon = \begin{bmatrix} y_{01}^- & y_{02}^- & \cdots & y_{0n}^- \\ y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \\ y_{01}^* & y_{02}^* & \cdots & y_{0n}^* \end{bmatrix} \tag{4.16}$$

6. The extended decision matrix was normalized using Eq. (4.17).

$$n_{ij} = \begin{cases} \frac{y_{0j}^*}{y_{ij}}, & j \in J^- \\ \frac{y_{ij}}{y_{0j}^*}, & j \in J^+ \end{cases} \tag{4.17}$$

7. Using Eq. (4.18), weighted normalized matrix elements were obtained.

$$v_{ij} = n_{ij} w_j \tag{4.18}$$

8. The degree of utility for each alternative is determined by comparing it with the ideal solution using Eq. (4.19) and an anti-ideal solution with Eq. (4.20). Equations (4.19) and (4.20) show that the ideal solution is represented by the S_* value, while the anti-ideal solution is shown by the S_- value.

$$K_i^+ = \frac{S_i}{S_*} \tag{4.19}$$

$$K_i^- = \frac{S_i}{S_-} \tag{4.20}$$

9. S_i values are calculated using Eq. (4.21) while considering the elements of the weighted normalized matrix V.

$$S_i = \sum_{j=1}^{n} v_{ij} \tag{4.21}$$

10. The utility function $f\left(K_i^+\right)$ related to the ideal solution is computed using Eq. (4.22). Besides, the utility function $f\left(K_i^-\right)$ related to the anti-ideal solution can be obtained using Eq. (4.23). Then, Eq. (4.24) is used to create the overall utility function $f(K_i)$ for each alternative.

$$f\left(K_i^+\right) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{4.22}$$

$$f\left(K_i^-\right) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{4.23}$$

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1-f\left(K_i^-\right)}{f\left(K_i^-\right)}} \tag{4.24}$$

11. The problem is resolved by ranking the alternatives according to their $f(K_i)$ values in descending order.

In addition, a flowchart showing the main activities or stages of the proposed methodology is designed and illustrated in Fig. 4.1.

4.4 Results

Individuals with ten years or more of field and managerial experience in related disciplines were interviewed as experts in the scope of the study. Five experts, including production staff (4) and business managers (1), provided face-to-face evaluations. The databases used in this study were “Web of Science” and “Scopus,” which are widely regarded as the most reputable scientific journals. Furthermore, the “Dergipark” database was used to analyze Turkish publications. First, literature was used to determine the study’s criteria and alternatives. Thus, the first list was formed, including many criteria and alternatives. The final list of criteria and alternatives was then defined following an assessment with the manufacturing staff (1) and the business manager (1).

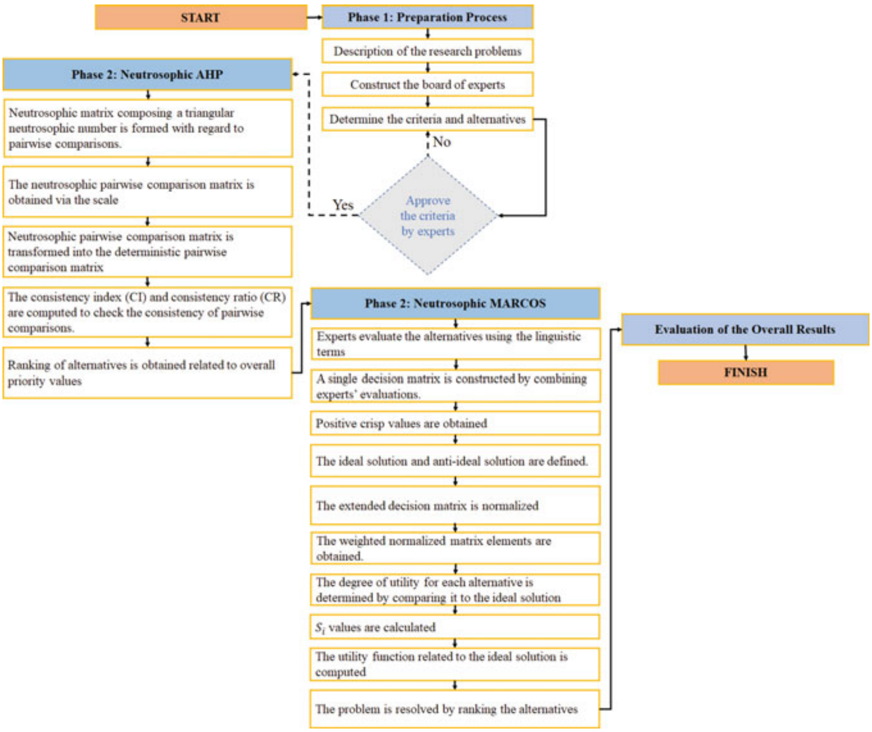

Fig. 4.1 Flowchart showing the main activities or stages in the proposed methodology

Five experts evaluated nine criteria for analyzing barriers to SM systems. Because of the ease of representation, the expert evaluations (E1,…, E5) regarding the criteria are presented in Table 4.3 using Saaty's Fundamental Scale values.

By integrating the experts' assessments and completing the other steps, the crisp values for SVN-AHP are obtained in Table 4.4.

Finally, the weight values for the criteria were determined as listed in Table 4.5.

As seen in Table 4.5, the most important barrier related to SM systems is "SM systems costs". Also, the importance order of criteria is determined as C5≻C2≻C9≻C6≻C1≻C8≻C7≻C4≻C3. Table 4.6 presents the expert evaluations of the alternatives based on the linguistic terms listed in Table 4.2.

In Table 4.4.6, A1 is "Linear Models", A2 is "Balance Models", A3 is "Interactive Models" and A4 is "Learning Integrated Systems Models". The geometric mean of the expert evaluations was used to construct the integrated SVN decision matrix shown in Table 4.7. In addition, Table 4.7 includes the optimization orientation of criteria.

The steps described in the methodology section for SVN-MARCOS were used to obtain the results shown in Table 4.8.

As seen in Table 4.8, the ranking order of the alternatives is A4≻A3≻A2≻A1.

Table 4.3 Evaluations of experts for SVN-AHP

E1	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	1/5	5	3	1	1/3	1/4	1/3	4
C2	5	1	7	6	3	1/3	3	3	4
C3	1/5	1/7	1	3	1/4	1/3	3	3	2
C4	1/3	1/6	1/3	1	1/6	3	3	1/3	1/4
C5	1	1/3	4	6	1	4	6	5	7
C6	3	3	3	1/3	1/4	1	5	4	5
C7	4	1/3	1/3	1/3	1/6	1/5	1	1/6	1/5
C8	3	1/3	1/3	3	1/5	1/4	6	1	1/3
C9	1/4	1/4	1/2	4	1/7	1/5	5	3	1
E2	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	1/5	5	3	1/5	1/5	1/5	5	1/3
C2	5	1	5	5	1/5	4	5	5	5
C3	1/5	1/5	1	5	1/5	1/3	1/3	1/3	1/6
C4	1/3	1/5	1/5	1	1/7	1/6	1/4	6	1/3
C5	5	5	5	7	1	6	7	8	8
C6	5	1/4	3	6	1/6	1	3	4	1/3
C7	5	1/5	3	4	1/7	1/3	1	1/3	1/4
C8	1/5	1/5	3	1/6	1/8	1/4	3	1	1/4
C9	3	1/5	6	3	1/8	3	4	4	1
E3	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	1/5	1/3	1	1/3	1/3	1/5	1/3	3
C2	5	1	6	7	1/3	1/3	1/3	3	6
C3	3	1/6	1	1/3	1/7	1/7	1/7	1/6	1/7
C4	1	1/7	3	1	1/7	1/5	1/3	1/3	1/3
C5	3	3	7	7	1	3	7	5	8
C6	3	3	7	5	1/3	1	4	1/4	1
C7	5	3	7	3	1/7	1/4	1	1	1
C8	3	1/3	6	3	1/5	4	1	1	2
C9	1/3	1/6	7	3	1/8	1	1	1/2	1
E4	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	1/7	6	5	1/4	1/5	1/4	4	1/3
C2	7	1	7	4	1/4	4	4	4	1
C3	1/6	1/7	1	5	1/7	1/5	1/3	1/2	1/2
C4	1/5	1/4	1/5	1	1/7	1/6	3	2	1/4
C5	4	4	7	7	1	9	5	8	8
C6	5	1/4	5	6	1/9	1	4	4	1/5
C7	4	1/4	3	1/3	1/5	1/4	1	1/2	1/6

(continued)

Table 4.3 (continued)

E1	C1	C2	C3	C4	C5	C6	C7	C8	C9
C8	1/4	1/4	2	1/2	1/8	1/4	2	1	1/6
C9	3	1	2	4	1/8	5	6	6	1
E5	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	3	2	1/2	3	1/3	1/3	1/2	3
C2	1/3	1	6	4	3	1/3	1/2	1/6	1/4
C3	1/2	1/6	1	4	2	1/5	1/3	1/5	1/4
C4	2	1/4	1/4	1	2	1	1/2	6	2
C5	1/3	1/3	1/2	1/2	1	4	4	4	4
C6	3	3	5	1	1/4	1	2	3	1/3
C7	3	2	3	2	1/4	1/2	1	1/5	3
C8	2	6	5	1/6	1/4	1/3	5	1	1/4
C9	1/3	4	4	1/2	1/4	3	1/3	4	1

Table 4.4 Deterministic pairwise comparison matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1.00	0.41	1.63	0.81	0.62	1.12	0.73	2.00	1.07
C2	2.46	1.00	2.79	2.07	0.68	1.77	1.62	0.79	1.09
C3	0.61	0.36	1.00	1.49	0.40	0.75	1.04	0.84	0.61
C4	1.24	0.48	0.67	1.00	0.33	0.40	0.96	1.62	1.00
C5	1.63	1.46	2.47	3.02	1.00	1.62	2.50	2.57	3.83
C6	0.90	0.56	1.34	2.51	0.62	1.00	0.98	0.98	1.04
C7	1.37	0.62	0.96	1.05	0.40	1.02	1.00	0.76	0.44
C8	0.50	1.27	1.19	0.62	0.39	1.02	1.32	1.00	0.72
C9	0.94	0.91	1.64	1.00	0.26	0.96	2.25	1.39	1.00

Table 4.5 Weights of criteria

Code	Criteria	Weight	Importance ranking
C1	The problem of giving up traditional manufacturing methods	0.1002	5
C2	Insufficient technical infrastructure	0.1506	2
C3	Senior management's negative view of SM systems	0.0739	9
C4	Unemployment issues that may occur because of the use of SM systems	0.0804	8
C5	SM systems cost	0.2126	1
C6	Technology-intensive business process planning problem	0.1044	4
C7	Anxiety about SM systems (such as cyber-attack)	0.0821	7
C8	The problem of a skilled workforce for SM systems	0.0894	6
C9	The presence of sudden stops and malfunctions in smart devices	0.1063	3

Table 4.6 Linguistic evaluations for alternatives

		C1	C2	C3	C4	C5	C6	C7	C8	C9
E1	A1	AA	AA	BA	BA	L	L	L	L	L
	A2	AA	AA	H	L	AA	H	AA	BA	BA
	A3	H	H	H	H	AA	H	H	H	VH
	A4	AA	AA	AA	H	H	H	AA	VH	VH
E2	A1	L	L	BA	BA	L	L	L	L	VL
	A2	BA	L	L	L	BA	VL	VL	BA	A
	A3	H	H	H	VH	H	H	H	H	H
	A4	AA	H	H	H	VH	VH	VH	H	VVH
E3	A1	VL	VL	VL	L	L	L	L	BA	L
	A2	AA	H	VH	VH	L	L	L	L	L
	A3	H	VH	VH	H	AA	H	VH	H	H
	A4	H	H	H	H	H	VH	VH	VVH	VVH
E4	A1	BA	BA	L	L	BA	VL	VL	A	A
	A2	A	A	AA	A	L	L	L	L	L
	A3	VH	H	H	H	BA	A	A	A	H
	A4	VH	VH	H	H	H	H	H	AA	AA
E5	A1	VVH	AA	H	A	AA	A	BA	A	A
	A2	AA	AA	AA	A	L	L	L	AA	H
	A3	AA	AA	H	H	H	AA	VH	H	H
	A4	H	H	H	H	H	AA	VH	VH	AA

4.5 Conclusions and Implications

Modern innovative technologies, including SM systems, are used in practically all sectors of the economy and are rapidly gaining global attention. It is common knowledge that new technological developments have a favorable effect on how well businesses perform. Moreover, it improves customer satisfaction while simultaneously increasing competitive power through a cost advantage for businesses. However, many barriers, problems, and challenges arise with the implementation of SM technology in business.

Furthermore, the success of the innovation management process and innovations that might provide a competitive advantage to organizations will be feasible by focusing on specific dynamics (Tidd et al. 2020). Technology management models can help shape keeping up with technological developments, establish strategic plans for the future, and achieve sustainable and flexible supply chain management structures.

The results show that "SM Systems Cost" is the biggest obstacle to SM systems. New technologies, such as SM systems, place a heavy financial burden on businesses when they first adopt these technologies.

Table 4.7 Integrated SVN decision matrix

Opt. Or	Max.			Min.			Max.		
	C1			C2			C3		
	T	I	F	T	I	F	T	I	F
A1	0.42	0.43	0.42	0.39	0.55	0.56	0.37	0.58	0.57
A2	0.53	0.43	0.45	0.52	0.41	0.44	0.57	0.32	0.37
A3	0.70	0.24	0.29	0.70	0.24	0.29	0.72	0.23	0.28
A4	0.68	0.26	0.31	0.70	0.24	0.29	0.68	0.27	0.32
Opt. Or	Min.			Min.			Max.		
	C4			C5			C6		
	T	I	F	T	I	F	T	I	F
A1	0.37	0.65	0.62	0.37	0.63	0.61	0.31	0.71	0.67
A2	0.45	0.46	0.48	0.37	0.63	0.61	0.33	0.62	0.61
A3	0.72	0.23	0.28	0.59	0.35	0.39	0.63	0.31	0.35
A4	0.70	0.25	0.30	0.72	0.23	0.28	0.72	0.22	0.27
Opt. Or	Max.			Max.			Min.		
	C7			C8			C9		
	T	I	F	T	I	F	T	I	F
A1	0.29	0.75	0.70	0.39	0.62	0.59	0.34	0.65	0.63
A2	0.32	0.66	0.64	0.39	0.61	0.59	0.42	0.54	0.54
A3	0.69	0.23	0.28	0.65	0.29	0.33	0.72	0.23	0.28
A4	0.74	0.20	0.25	0.75	0.18	0.22	0.75	0.18	0.20

Table 4.8 Results obtained using SVN-MARCOS

Alternatives	$f(K_i)$	Ranking
A1	0.6646	4
A2	0.7880	3
A3	1.1985	2
A4	1.2832	1

However, it is important to emphasize that investing in this resource over the long and medium terms will produce much better returns. Business strategies, plans, and programmes must be used to support these systems. However, this burden will be reduced through publicly supported grants and long-term loans. One of the barriers is the "Lack of Technological Infrastructure." The old technological infrastructure is insufficient, particularly during the transition period of enterprises to new technologies, and eliminating this deficiency is a critical issue in terms of efficiency and productivity. It is evident that the barrier, "Existence of Unexpected Situations and Failures in Smart Devices," can be overcome by increasing the level of trained and qualified personnel in the applications of smart production systems in enterprises.

The ideal innovation management model was selected using the weights of the barriers in the SM systems. The ideal innovation management model is the "Learning Integrated Systems Model." This model employs electronic technology to manage an enterprise's internal and external connections. This requires a more collaborative approach to innovation, such as strategic alliances or joint ventures (Maylor 2001). As a result, this situation can be viewed as proof that the "Learning Integrated Systems Model," the best alternative in plastic sector businesses, is open to learning and makes this situation sustainable.

Each model is critical for defining, implementing, and measuring innovation. Technology, the market environment, customer satisfaction, and competitive advantage increase the need for innovation management models and require integration with SM systems. At this point, in addition to the theoretical contributions of the study, it has important consequences for manufacturing industry decision-makers, practitioners, and individuals interested in the subject. This provides an opportunity to evaluate the barriers related to SM systems. Furthermore, it pioneers a fundamental model for selecting the best alternative for SM system barriers and innovation management models. This study proposed a model that allows for a flexible and structured decision-making environment and the opportunity to consider multiple conflicting viewpoints.

In addition, by implementing the model proposed in this study, decision-makers can track a new path and plan for selecting smart production system barriers and innovation management models while considering globalized market and competition conditions.

4.5.1 Limitations and Future Research

However, this study had some limitations. One of the major limitations of this study was the limited number of expert groups interviewed, which could not be increased due to time constraints. Another limitation is that the study should be conducted in a specific province and sector.

Moreover, some classifications used in this study were subjective. In addition, neither the expert group's perspective on the subject nor the literature review identified any criteria for selecting barriers to smart production systems and innovation management models. This study's fuzzy decision model has been considered valuable because it can help companies overcome barriers that impede them from implementing intelligent manufacturing and innovative management strategies. Future studies could perform comparative analyses using different decision-making environments, such as spherical fuzzy, fermatean fuzzy, and hesitant fuzzy, and methods, such as ARAS, COPRAS, REF, and WASPAS.

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Chapter 5
Predictor Model for Six Sigma Deployment and Its Sustainable Benefits

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Abstract The purpose of this research is to present the critical success factors (CSF) in Six Sigma (SS) deployment and their relationship to long-term sustainable benefits (SB). The method derives from a literature review between the links SS and SB contrasted, conducted in a cross-sectional study in the aerospace industry applying a survey to experts with experience in the subject. Using a structural equation model, three factors are found: senior management commitment, relationship with clients and suppliers, and training and education. The originality of this study shows that these factors predict 56% of the SB derived from the application of SS projects for environmental improvement. These results can guide organizations that are not committed to sustainability to contemplate the sustainable benefits that can be obtained with the implementation of SS, one of the limitations is that the results only apply to the aerospace sector.

Keywords Six sigma · Continuous improvement · Sustainable benefits · Structural model

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5.1 Introduction

The Six Sigma (SS) adoption has increased significantly in organizations looking to apply best practices to increase or maintain competitiveness. Since its introduction, this methodology has become part of quality and project management. It has become the business strategy focused on the customers' needs, whose main objective is the cost reduction in manufacturing, services and variation in the processes until achieving a proportion of non-defective production of 99.999998% or the generation of 3.4 defects per million opportunities (Tlapa et al. 2016). Its definition is found in a statistical methodology for the processes measurement through the analysis of its capacity (Baptista et al. 2020), focusing on the defects reduction and improvement of financial results through the examination of the root causes and focusing on improvement efforts on those causes (Klochkov et al. 2019; Madhani 2020).

The SS term began in 1988 when Motorola won the Malcolm Baldrige National Quality Award due in large part to their initiative called SS, as well as the results they presented, increased quality of various products, and significant money savings (Gastelum-Acosta et al. 2018). Since then, the concept has been widely used worldwide to its proven ability to improve economic performance and increase customer satisfaction by reducing inferior products and services (Gholami et al. 2021). In addition, in the last two decades, SS has been considered an important development in quality management and process improvement tools (Yadav et al. 2019). In addition, SS can help develop skills, improve knowledge, improve employee ethics and give the ability to use a range of improvement tools (Caiado et al. 2018; Abbes et al. 2022).

Although the usefulness and advantages obtained with the implementation and development of SS are widely recognized, some studies report that organizations frequently experience problems when deploying it, and the expected results are not achieved. This results in the idea that the methodology does not provide clearly positive results regarding performance improvement (Näslund 2013; Antosz et al. 2022).

Despite this, companies continue to show a tendency towards continuous process improvement. This is why companies must identify the essential variables during the strategy deployment since this will benefit them. In such a way, by knowing the factors on which you should focus attention, you will know which resources should be managed and how to do it, obtaining a greater capacity to achieve the objectives set. The disagreement found in the literature, as well as the growth of the aerospace industry in the country, justifies the relevance of carrying out this research. Although the literature has been found regarding the Critical Success Factors (CSF), there is not enough evidence on their structural modeling in deploying SS projects and their sustainable benefits (SB).

In another sense, the literature shows the trend that organizations are presenting towards a culture of sustainability, given that environmental concern has become paramount. Regarding the various benefits that can be obtained by adequately deploying the SS strategy, sustainability is one of these, so organizations that implement continuous improvement and *green* principles simultaneously consider better performance (Chugani et al. 2017a, b). In this sense, only a small group of environmental experts and researchers have investigated the relationship between aspects of *green* principles and continuous improvement practices, representing a new current and relevant research gap (Dües et al. 2013).

Sustainability and SS are common continuous improvement management strategies in the manufacturing and service sectors. Companies achieve a competitive advantage when they maintain practices consistent with sustainable development strategies and, as such, control waste and implement practices that are environmentally and socially responsible (Albliwi et al. 2015; Alhuraish et al. 2017; Kaswan and Rathi 2020).

Regarding the link between SS and SB, there is an impression that SS can indirectly influence sustainability through the application of its tools to environmental management systems. SS has been directly related to environmental protection, considering 2096 pollution prevention programs and confirming that SS methodologies were effective in developing pollution reduction strategies and solving problems. In addition, numerous studies have shown the effective compatibility of integrating improvement practices with environmental care (Gholami et al. 2021). However, an essential requirement for the positive results achievement between the link SS and SB is the commitment and collaboration of the employees, for which it is considered necessary that both concepts are understood and adopted (Caiado et al. 2018; Hariyani and Mishra 2023). The growing interest and need to protect the environment is a potential precedent for evaluating the influence of continuous improvement strategies, particularly SS with SB (Francis and Thomas 2020).

Due to the above, it is considered important that organizations measure, monitor, and evaluate their environmental performance on an ongoing basis (Sagnak and Kazancoglu 2016) and adopt strategies that combine system reconfiguration synergies and environmental care, thus seeking cleaner and more sustainable production and developing a relationship between SS and SB (Dias et al. 2019). Within these reconfigurations, it is important to consider the three pillars of sustainability, which are social, economic and environmental (Bianchini and Rossi 2021).

For this research, the manufacturing context was focused on the aerospace industry, considering that Mexico is positioned as an important producer worldwide in the aerospace sector. According to the Mexican Federation of the Aerospace Industry (FEMIA), in 2013, there were 287 companies in the aerospace sector in 18 states of the republic, and one of them corresponds to Baja California, a state considered with the greatest opportunity for the aerospace industry's development. Approximately 300 aerospace companies have been identified, with the largest number concentrated in the northern region of the country, with a total of 198 companies.

The aerospace sector in Mexico has strategic advantages, such as reduced costs, proximity to important markets and qualified personnel, which have driven the sustained growth of this industry. As can be seen, the aerospace industry has become a strategic sector for the country's economic development since it has grown 17.2% on average per year in the last nine years. According to data from the Ministry of

Economy, exports from this sector have been 6366 million dollars, and the average annual growth of its exports has been 20% in the last five years.

In this sense, and considering the importance and growth of the aerospace industry in Mexico and Baja California, this research seeks to contribute to the literature with the identification of the essential variables that occur in the SS strategy deployment and its possible effect on the achievement of benefits in terms of sustainability through a structural model of predictive purpose.

5.2 Literature Review and Hypotheses Statement

5.2.1 Identify in the Literature the CSF of SS

To perform the CSF identification, it is based on the SS strategy conceptual review. In this sense, SS has been defined as one of the most important developments for quality management and process improvement in the last two decades since it focuses on the critical quality characteristics of the product or process that are relevant to customers and mainly seeks to identify and eliminate defects, errors or failures that may affect business processes or systems (Garza-Reyes et al. 2014; Kota et al. 2021; Swarnakar et al. 2020; Rajak et al. 2022).

On the other hand, the authors state that SS has three meanings. First, it is a statistical measure of variation that, when achieved, a process would produce 3.4 defects per million opportunities. Second, it is a management philosophy and strategy that allows organizations to obtain lower costs, guaranteeing competitive operations. Third, it is a problem-solving and improvement methodology that can be applied to all types of processes to eliminate the root cause of defects (Cherrafi et al. 2017; Linderman et al. 2003; Al-agha et al. 2015).

Concerning the critical success factors considered relevant, the literature reports a great variety, highlighting that the most important aspect when deploying the SS methodology is to involve all company employees, considering skills, training, and knowledge of their roles and activities within the project. In addition, interest groups also play an important role in the project's deployment since they are the ones that provide support to the organization (Antony and Karaminas 2016; Elias 2016; Pamfilie et al. 2012; Zaman et al. 2022).

For this research development, several of these factors have been synthesized into three large constructs: *Support and Commitment of senior management, Relationship with Customers and Suppliers, and Formation and Training*, being considered essential to achieve a *Successful Implementation of SS*, which consequently allows obtaining *Sustainable Benefits.*

5.2.2 Develop the Research Instrument

Concerning the developed measurement instrument, it is necessary to support the operationalization of the questionnaire constructs; for this, a literature review of case reports and theoretical studies was performed.

5.2.2.1 Senior Management Support and Commitment

To correctly manage a project, it must start with the participation and commitment of senior management. In this sense, the participation and commitment of senior management is one of the most important factors in the SS implementation because it prevents SS from being weakened. Senior management must act as a critical driver in continuous improvements; therefore, the following is addressed (Dileep and Rau 2009; Paiva et al. 2008; Tlapa et al. 2016):

H1: There is a direct and positive relationship between the senior management construct and the clients' and suppliers' construct.

Senior management involvement is vital in the SS deployment. The implementation process must begin with the employees' training, who learn to apply the tools and techniques of SS to face the complications of its deployment and manage resources in improvement projects aligned with the company's competitive strategy. Thus, it is proposed:

H2: There is a direct and positive relationship between the senior management construct and the formation and training construct.

Management commitment and involvement are the most important CSF of SS deployment. Commitment presents from the beginning of the process to the operation execution (Brones et al. 2014; Shokri et al. 2022). Also, it is proposed that:

H3: The senior management construct has a direct and positive relationship with the implementation of the SS strategy.

5.2.2.2 Customers and Suppliers' Relationship

Organizations that develop SS focus on improving their products, staying within the highest quality standards, and achieving customer satisfaction. In this sense, customer needs and expectations are assessed, customers are involved in quality improvement projects, customer satisfaction is measured, and there is close contact with key customers. To achieve quality, it is essential to understand what customers want and to provide products or services that meet their needs (Zu et al. 2010, 2006).

Concerning suppliers, they are involved in product development and quality improvement projects, which must be evaluated based on quality. The organization must provide training and technical assistance to suppliers; in this sense, a well-developed supplier management system, where the main criteria for selecting suppliers is based on quality aspects, has a positive impact on the SS success, and the processes must be built to monitor the quality performance levels of suppliers (Dileep and Rau 2009; Zu et al. 2010). Therefore, the following hypothesis is proposed:

H4: Customers and suppliers construct has a direct and positive relationship with the strategy implementation.

5.2.2.3 Formation and Training

Regarding formation and training, companies like Samsung consider training the first essential step when preparing for the SS methodology implementation, which allows setting new goals, and asking employees to face change by thinking and acting differently, performing and participating in new tasks. At this point, it is necessary to identify and select the types of training and education that the staff will receive. In this context, a series of studies showed areas of training or continuing education that will be important for the manufacturing professional in the coming years; these include lean manufacturing, SS, quality management, and statistical analysis (Tlapa et al. 2016). The education and training system should provide ongoing courses for employees to equip them with quality-related knowledge and problem-solving skills. Consequently, training is a crucial factor in successfully implementing SS projects (Banuelas-Coronado and Antony 2002; Dileep and Rau 2009; Zu et al. 2006). Based on this, it can be considered that:

H5: Formation and training construct has a direct and positive relationship with the strategy implementation.

5.2.2.4 Strategy Implementation

The strategy implementation for SS implies that the improvement projects are focused on the organization's objectives and business strategy. Also, the organization members have developed project management skills and can list a defined strategy to supervise, control and follow up on project results (Dileep and Rau 2009; Banuelas-Coronado and Antony 2002; Zu et al. 2010).

This construct considers teamwork a fundamental element to confirm that SS implementation happens. Thus, the collaborative team is characterized by the fact that its members master the SS methodology and tools, have the appropriate leadership, are skilled in effective communication, and participate proactively. Undoubtedly, the organizational culture represents a distinctive element to perceive the strategy implementation, and values and beliefs underlying an organization's culture must be described. Another important aspect that characterizes the SS implementation strategy is a structured improvement procedure, which occurs if the planning and implementation of improvement projects are guided by formal, systematic and standardized procedures (Zu et al. 2010).

Another vital element to measure the degree of SS implementation strategy is its alignment with the organization's objectives. Attention should be paid to both short-term and long-term goals. On the other hand, according to the strategy implementation, the project monitoring and review must be considered since the project status and the performance of the SS tools and techniques implemented must be reviewed periodically. These aspects configure the conceptualization of the construct in the SS strategy implementation (Paiva et al. 2008; Tlapa et al. 2016).

In addition to this, the organizational culture influences the social and institutional dimensions, so it is necessary to develop strategies so that the dimensions are considered within the substantive axes within the business culture. Therefore, it is key that companies have a strong, healthy organizational culture that supports these strategies; in such a way that their employees adopt them as part of their values and personal culture, in addition to sharing these beliefs and emphasizing the importance of balancing economic efficiency, social equity and environmental responsibility (Carro-Suárez et al. 2017).

5.2.2.5 Sustainability

The concept of sustainable development was first developed in 1972 at the UN Conference on the Human Environment in Stockholm. The World Commission on Environment and Development (1987) developed the best-known definition of sustainable development: "economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". Taking this definition into account, for companies to achieve sustainable development, they must demonstrate continuous improvement in operational, economic, social and environmental performance (Azapagic 2003; Cherrafi et al. 2016; Moore et al. 2017; Debnath et al. 2023).

Sustainability has become a crucial element, and its evaluation has emerged in many different forms worldwide, allowing profit generation and citizens to live in a healthy environment simultaneously. In that sense, sustainable manufacturing is the creation of manufactured products through economically viable processes that minimize negative environmental impacts while conserving energy and natural resources and improving employee, community, and product safety (Fleith de Medeiros et al. 2022). Likewise, the objective of the SS strategy is the search to obtain products and processes that meet high-quality standards, develop economic processes, seek to reduce waste and decrease the use of energy, bringing with these valuable repercussions in the reduction of environmental impacts (Abbas and Sağsan 2019; Pope et al. 2017; Zhang and Awasthi 2012).

Throughout the last two decades, organizational sustainability has been a constant topic and has increasingly received considerable attention from academia and business because it is relevant to organizational performance. For example, high profitability and improvement of employee work-related attitude or behavior, including job engagement, knowledge sharing, and innovative work behavior, are also crucial for long-term organizational success (Kim and Park 2017).

On the other hand, recent research is beginning to highlight the term educating for sustainability, defining it as a complex and intentional process, like any educational process, which involves the acquisition of conceptual knowledge and values, as well as the development of attitudes, skills and ways to act in social interaction, with what is sought that the term is recognized from the early stages of education and not until the individual is immersed in the labor stage. In other words, upon reaching this stage, the individual already knows and masters the concept to develop strategies focused on the transition or development of companies to sustainable companies committed to environmental care (Álvarez-Lires et al. 2017).

Likewise, eco-technological sustainability tools have been developed, aiming to satisfy human social needs by minimizing environmental impact through knowledge of the structures and processes of ecosystems and society (Gavito et al. 2017). In this sense, researchers have shown interest in linking business techniques and eco-design with a perspective focused on environmental care and sustainability. Also, they argue that corporations are increasingly motivated to proactively integrate sustainability issues into their strategy rather than simply meeting regulatory requirements (Carvalho and Rabechini 2017; Wijethilake 2017).

5.2.2.6 SS with Sustainability Relationship

Sustainability is part of the benefits that can be obtained through a correct SS strategy implementation since the deployment of SS allows to focus on the reduction of the defect to improve the quality of the product, which helps reduce environmental waste (i.e., material, consumption of water and energy, and waste generation). On the other hand, sustainable manufacturing is the creation of manufactured products through economically viable processes that minimize negative environmental impacts while conserving energy and natural resources while improving employee, community, and product safety. For manufacturing companies, developing products with better environmental performance is part of their commitment to sustainable development. In this sense, SS contributes positively to sustainable development because its main objective is to manufacture products with the fewest possible defects, directly benefiting the organization's environmental performance (Mohan et al. 2021). In this way, various multinational companies have implemented SS to improve pollution prevention programs and obtain positive results, for which it is considered necessary to carry out further research to explain how the deployment of SS has a positive impact on programs that prevent pollution (Kaswan and Rathi 2020). Due to this, it is considered to establish the following hypothesis (Alhuraish et al. 2017; Calia et al. 2009; Cherrafi et al. 2016; Faulkner and Badurdeen 2014; Rodrigues et al. 2016; Hariyani and Mishra 2022; Titmarsh et al. 2020):

H6: The strategy implementation construct has a direct and positive relationship with the sustainability.

The relationships established by the hypotheses proposed to evaluate the critical success factors related to the effective implementation of Six Sigma and its impact on sustainability are shown in Fig. 5.1.

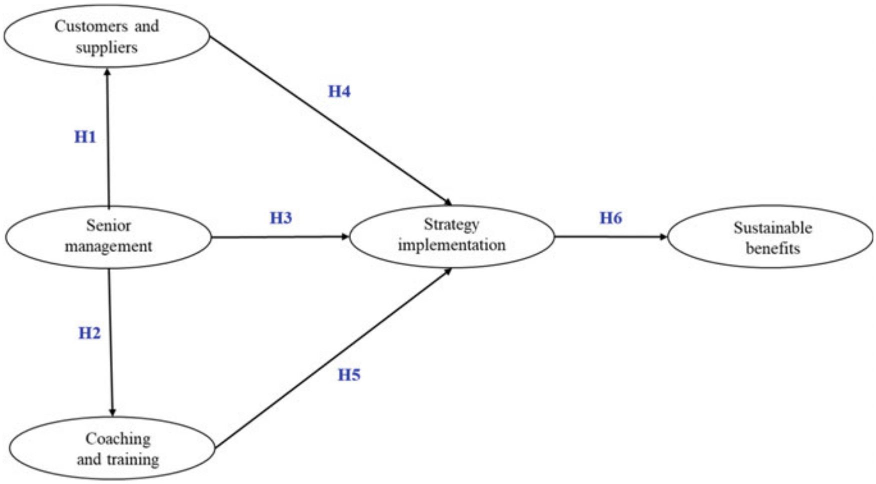

Fig. 5.1 Research conceptual model

According to the initial conceptual model, the questionnaire is divided into sections that represent the constructs to be investigated, which are measured by statements that represent the practices that the theory establishes to develop SS projects, in addition to several items that measure the sustainable benefit obtained by the application of SS. The Likert measurement scale was used to respond to the statements, where number 1 was the lowest value (totally disagree), and the highest was number 5 (totally agree). The 5 constructs were; SI: SS strategy implementation, SM: senior management, CS: customers and suppliers, CT: coaching and training, and SB: sustainable benefits. The instrument begins with a purpose description of the survey and a concept to define sustainability. In addition, it contains a general section to collect data on the person's profile, the respondent's work experience and his or her experience in SS projects to have a vision of the industrial sector from which the information was obtained.

Prior to its application, the instrument was validated through expert judgment. Expert judgment is an informed opinion of people who have experience in the subject, are recognized as experts, and can provide information, evidence, judgments and assessments. In this investigation, the method used was the method of individual aggregates, where the coefficient used for validity is Kendall's W. To obtain validation, values between 0.40 and 0.70 indicate good expert agreement. To carry out this validation, 5 experts on the subject were considered (Escobar and Cuervo 2008).

On the other hand, the instrument's internal consistency is validated, and a question arises regarding what extent the items that make up the instrument represent the universe or trait to be measured. Reliability is essential in estimating validity, as it provides evidence about construct validity and a basis for constructing test forms in a large-scale assessment. An index above 0.70 indicates a strong or high-reliability coefficient; however, the minimum recommended value is 0.75 (Corral 2009; Escobar and Cuervo 2008; Sarstedt et al. 2014). In this validation, 30 experts were considered to integrate the pilot test that allowed the performance validation.

5.3 Methodology

The research design applied in this study is non-experimental, cross-sectional and correlational. Its purpose is to identify possible relationships of associations between intangible variables that predict and relatively quantify the plausible link between the SS strategy and its sustainable benefits in the context of the aerospace industry in Baja California. The profile of the research subjects comprises professionals who have experience and knowledge in the deployment of SS projects and who are aware of the sustainable processes within their companies; in this case, the profile of the companies was aerospace. The data was collected through the survey method. The phenomenon under study is analyzed through the SEM (Structural Equation Model) methodology, described in detail in the following sections (Byrne 2010).

5.3.1 Measurement Instrument Design

A measurement instrument is a questionnaire based on research and literature review. As a result, the instrument was developed, searching through reagents, items or questions associated with each construct to determine those factors considered the most important for the adequate and successful deployment of SS.

This instrument seeks to examine the following aspects:

- Determine the critical success factors in the SS projects application.
- Check the relationship of the SS strategy with the sustainable benefits.

The instrument was initially made up of 39 reagents that measure the degree of agreement on the critical success factors in SS projects and their relationship with sustainable benefits. The constructs that make up the instrument are Senior management support (7 items), Relationship with customers and suppliers (8 items), Training and coaching (3 items), Strategy implementation (15 items), and Sustainable benefits (6 items).

Table 5.1 presents an abstract of the content of the measurement instrument.

5.3.2 Instrument Application

The data collection was performed through the distribution of questionnaires under two distribution channels. The first was done with printed questionnaires, and

Table 5.1 Measuring instrument

Instrument summary
Senior management support
Company managers provide support and are committed to SS projects
Senior management assigns a mentor/supervisor and the necessary tools for SS projects
Company supervisors support SS projects
Relationship with customers and suppliers
Members of the organization seek customer feedback (needs) to determine quality and delivery requirements
SS projects are related to customer demands and satisfaction
There is an effective supplier management system
Suppliers are evaluated based on quality, delivery, performance, and Price
Training and coaching
The organization provides training in SS fundamentals, quality, problem-solving, and teamwork
Training is provided to plant managers and supervisors related to quality
Strategy implementation
SS projects are linked to the strategic objectives of the organization
The expected financial benefits of an SS Project are identified during its planning
Those involved in the Project understand SS methods, techniques, practices, and tools
A structured plan and/or procedure is followed to implement SS
The members of the organization have experience in SS projects
Sustainable benefits
The integration of SS practices has a positive influence and sustainably benefits the company
With the SS implementation, a company's sustainability level can be measured
Adopting SS by the company can be the first stage to becoming a sustainable company

the second was in electronic format for professionals working in the maquiladora aerospace industry based in Baja California, Mexico. Forty-three were sent to companies located in Tijuana, 34 in Mexicali, 5 in Ensenada and Tecate, and, finally, 1 in Rosarito. From this process, 273 valid questionnaires were collected. With the data collection, we proceed with the consecutive stages of the investigation, developing all the phases of the structural model.

5.3.3 Instrument Validation

Before the target population instrument application, it is necessary to verify its validity. For this, the following two main techniques were used.

The first validation is that of content by expert judgment, being an informed opinion of people who have experience in the subject, are recognized as experts, and can provide information, evidence, judgments and assessments. Through expert judgment, it is possible to know the probability of error in the instrument configuration and that it is intended to obtain reasonably good estimates. The coefficient used for this investigation is Kendall's W.

The second technique is the validation of internal consistency, which is sought to measure to what extent the items or reagents of an instrument are representative of the universe and the traits to be measured. It consists of measuring what you have to measure. Reliability is an important component when estimating validity, as it provides evidence about construct validity and provides a basis for constructing parallel forms of a test in large-scale assessment; in this case, the most widely used coefficient is Cronbach's alpha.

5.3.4 Development of Statistical Models

To develop a structural model, a two-stage approach must be followed. The first consists of evaluating the measurement model, and the second, evaluating the structural model (Byrne 2010). Therefore, the following subsections describe the statistical procedure and the recommended metrics to evaluate the model proposed in this research.

5.3.4.1 Measurement Model Evaluation

This phase, a 5-step process was performed: model specification, model identification, parameter estimation, fit evaluation, construct validity, and model modification. The theoretical model specification is based on the conceptual model shown in Fig. 5.1 and consists of a literature review that supports the relationships between the model elements. After having the model identified and specified, the model parameters were estimated using the maximum verisimilitude method, which is relatively robust to samples far from multivariate normality (Hair et al. 2005).

Subsequently, the model's empirical validity was evaluated with various fit indices. Firstly, with the statistical significance (X^2 chi-square) and its corresponding p-value, given that this metric tends to reject models based on the increase in sample size systematically, it suggests using the normed X^2/Degrees of Freedom index, considering a lower value to 2 as adequate (Byrne 2010).

On the other hand, using the root mean square error of approximation (RMSEA) is recommended since this index corrects the tendency of $\chi 2$ to reject models with large size or number of variables. A lower RMSEA value (<0.05) indicates a good fit and is often reported at a 95% confidence level to account for sampling errors associated with the estimated RMSEA. The RMSEA is interpreted using suggested cut-off values that should be considered rules of thumb. RMSEA values less than 0.05 indicate a close fit, values less than 0.08 are considered satisfactory, and values greater than 0.10 indicate a poor fit (Lin et al. 2015).

Other widely used indices are the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), and the Expected Cross-Validation Index (ECVI). The CFI indicates the relative lack of fit of a specific model. It is normalized and ranges from 0 to 1, where values greater than 0.90 indicate a good fit. The CFI is widely used due to its relative insensitivity to model complexity. The TLI compares the adjustment by degrees of proposed model freedom and that with no relationship between the variables. This index tends to be 1 for models with a perfect fit, considering values higher than 0.90 to be acceptable (Hair et al. 2005). Finally, the cross-validation model adequacy remains desirable information in model evaluation. A recommended method to assess the adequacy of cross-validation is the ECVI, under the assumption that the researcher can choose between a set of competing models. The model with the lowest ECVI value will be the model that will have the best cross-validation capacity, for which a proposed model is estimated against a saturated model, which contains more empirical relationships than those that are reasonable in light of theory (Byrne 2010).

To assess construct validity, statistical procedures were applied to check convergent and discriminant validity. Convergent validity measures the degree to which a construct converges on its indicators when explaining the items' variance. It is assessed by the average variance extracted (AVE) for all items associated with each construct. The AVE value is calculated as the mean of the squared loadings for all indicators associated with a construct. An acceptable AVE is 0.50 or higher since it indicates that, on average, the construct explains more than 50% of the variance of its elements. Concerning discriminant validity, the most recommended and used criterion is the Fornell and Larcker criterion in 1981 (Marzagão and Carvalho 2016); this method compares the AVE value of each construct with the squared correlation between constructs (a measure of shared variance). The recommended guideline is that a construct should not exhibit a variance shared with any other construct greater than its AVE value; this allows for verifying that the items associated with the construct belong to it and not to another construct (Henseler et al. 2014).

5.3.4.2 Structural Model Evaluation

To perform the structural model evaluation, the main model fit indices are inspected, the parameters are estimated, and it is evaluated that the minimum recommended criteria are met; subsequently, the global fit indices in the model are examined. In this sense, the absolute fit index $\chi 2$ (chi-square) is evaluated, which evaluates whether the model has been built under an erroneous specification; this suggests to what extent the model fits the data obtained from the sample. The global fit indices in the model are evaluated, considering the most used and reported in the literature, for which CMIN/DF, TLI, CFI and RMSEA are inspected (Rodrigues et al. 2016).

The SEM allows testing multiple relationships simultaneously in a single model, with multiple relationships instead of examining each individually (Hussain et al. 2018; Kaswan and Rathi 2019). Likewise, the standardized regression coefficients estimation is evaluated through the factor loads obtained in the estimation. This allows observing the strength with which the observable variables measure the latent variables in the model. For this, the regression weights are examined, for which the literature suggests values above 0.70. Finally, the explanatory value of the model is determined considering the variance explained proportion, expressed by the coefficient of determination (R^2).

5.3.4.3 Explain the Relationship Between SS and SB

Once the structural model has been evaluated and presented, the acceptable global fit indices and the most significant variables in the model are evaluated in detail. Those that present greater factorial loads in the standardized regression weights allow us to observe which are the CSFs for developing a successful implementation of SS; for this, a table with the most significant variables is presented. Finally, the predictive power of the strategy implementation with the sustainable benefits is discussed, which allows establishing the existing degree in the relationship of SS with SB.

5.4 Results

This section describes the CSF results identified in the literature and the results obtained from the validations obtained for the measurement instrument, the descriptive analysis acquired from the instrument application, the model specification, and, finally, the global results of the structural model.

5.4.1 Sample Description

Derived from the distribution channels used, the analysis of the most important information for the study is presented. In this sense, it is obtained that, from the 273 valid questionnaires, the majority belong to Mexicali and Tijuana since a total of 139 and 113 were collected, respectively, and the rest is divided between Ensenada, Tecate and Rosarito.

Regarding the company size, a total of 202 questionnaires were answered in companies with more than 500 employees, which allows the comparison of the SS strategy deployment. The rest are classified in the ranges between 100 and 300 employees, between 300 and 500 employees, and less than 100 employees.

According to the respondent's profiles, the questionnaire was answered by 41% by continuous improvement engineers, 15% by manufacturing engineers, and the rest by personnel from various areas, without neglecting that everyone had knowledge and experience in developing SS projects.

From the 273 questionnaires obtained, it was found that 96% of the respondents developed SS projects in their companies, and the remaining 4% stated that they did not use them, so they were excluded from further analysis. Finally, 261 cases were considered for model specification and structural modeling.

5.4.2 CSF Reported in the Literature

Concerning the implementation of critical success factors for the SS, the literature reports a great variety, highlighting that the most important aspects when deploying the SS methodology is to involve all company employees, considering the skills and training of "Black Belts", as well as knowing their roles and activities within the project. In addition, the interest groups also perform an important role in the project's deployment since they are the ones that provide support to the organization. The CSFs considered mainly for the SS projects implementation are mentioned below: Support and commitment of senior management, relationship with clients, organizational culture, education and training, organizational infrastructure, communication, project selection and prioritization, use of project management tools, collaborative teams, relationship with suppliers, leadership, resources, incentive programs, project management, participation of all staff, adequate development of a strategic planning system, data analysis, attention to objectives, resistance to change, and development of projects in inappropriate times for the company. They are among the 20 most mentioned in the literature.

5.4.3 Validation of the Research Instrument

The estimation of Kendall's W concordance coefficient is made concerning content validity. Table 5.2 shows the results obtained from the validation.

The value found is within the interval, indicating a good agreement between the evaluators. Thus, the measurement instrument for evaluating reliability through expert judgment is adequate.

On the other hand, because of the internal consistency validation, indices were obtained that were the minimum recommended in the literature. Table 5.3 shows the indices for each construct and the complete instrument.

Table 5.2 Concordance coefficient

Index	Value
Number of experts	5
Kendall's W	0.405
Chi-Square	89.198
df	44
Asymp. Sig	0.000

Table 5.3 Internal consistency validity by construct

Construct to be evaluated	Cronbach's Alpha (α)
Senior management support	0.880
Strategy implementation	0.943
Customers' and suppliers' relationship	0.845
Training and coaching	0.798
Sustainable benefits	0.896
Full instrument	0.959

With the reliability indices obtained, the instrument's internal consistency is validated, which suggests that the indicators evaluated represent the full scale. Otherwise, it is verified that the 30 variables considered to measure the success in the SS implementation and its relationship with sustainable benefits indicate an adequate internal consistency of the instrument.

5.4.4 Measurement Model

The model proposed in this research, after the validations, is made up of 30 observable variables or items and 5 latent variables or constructs that are: Senior Management (SM), which is made up of 6 variables, Customers and Suppliers (CS) by 6, Coaching and Training (CT) by 3, Strategy Implementation (SI) by 9, and Sustainable Benefits (SB) are made up of 6 variables.

With the constructs and variables, the measurement model allows proceeding with the statistical validation. In this sense, the first step to assess the construct validity is to calculate various goodness-of-fit indices and compare them with the values recommended in the literature. By observing Table 5.4, it can be seen that the TLI and CFI fit indices exceed the values suggested in the literature, greater than 0.90, so they present an optimal fit for the proposed model. About X^2/Df and the RMSEA index, it can be seen that there is a satisfactory global fit.

The second step in the model evaluation is to verify that the convergent validity is fulfilled for each construct by verifying that the average variance extracted (AVE) value is greater than 0.50 so that the construct explains the variance of the items that compose it. Table 5.5 shows that the criterion is satisfied for all the constructs evaluated.

Finally, the discriminant validity was evaluated. This criterion is fundamental because it is necessary to verify that each construct is conceptually different (Acuña et al. 2017). When examining Table 5.4, it can be seen that the variances shared

Table 5.4 Global fit indices in the measurement model

CMIN/DF (<2)	TLI (>0.90)	CFI (>0.90)	RMSEA (<0.08)
1.960	0.914	0.923	0.066

Table 5.5 Convergent and discriminant validity

Construct	SI (%)	SM (%)	CS (%)	SB (%)	CT (%)
SI	61.34				
SM	58.52	65.21			
CS	57.46	51.98	58.76		
SB	50.41	41.99	46.51	55.33	
CT	47.06	44.76	36.36	34.69	79.86

between the constructs do not exceed the AVE value, so it is concluded that the constructs have been successfully established.

5.4.5 Structural Model

The structural model corresponds to the statistical model's family that explains the relationships of multiple variables. It examines the structure of interrelationships expressed in a series of equations, similar to multiple regression equations. In that sense, the structural model validity and its corresponding hypothetical, theoretical relationships must be tested. To test the fit of the structural model, a general fit must first be established; secondly, the estimated parameters of the structural relationships are obtained since empirical evidence of the relationships in the structural model is shown.

For the estimation of parameters, the literature suggests values for the minimum factor loads of 0.70; in this sense, the factor loads of the standardized weights in all the variables that make up the model are examined. Figure 5.2 shows values above the recommended minimum. Consequently, it is verified that all the variables adequately measure the constructs of the proposed model.

The values of X^2/Df, TLI, CFI and RMSEA are examined to assess the absolute fit index. As seen in Table 5.6, indices that suggest a good fit in the structural model are obtained for all cases, considering a 90% confidence in the statistical tests.

Finally, it is necessary to determine the explanatory value of the model; for this, the proportion of variance explained is considered, expressed through the coefficient of determination R^2 (Pérez et al. 2013).

As a result of the evaluation, a proportion of the explained variance of 56% was obtained, moderately explaining the SB average variability. This means that the SB construct is explained in 56%. In comparison, the strategy implementation is explained in 78% by the constructs of support from senior management, customers and suppliers, as well as training and coaching. An R^2 value of 0.75, 0.50 and 0.25 is considered substantial, moderate and weak, respectively; however, they should be interpreted according to the context of the study in question (Sarstedt et al. 2014).

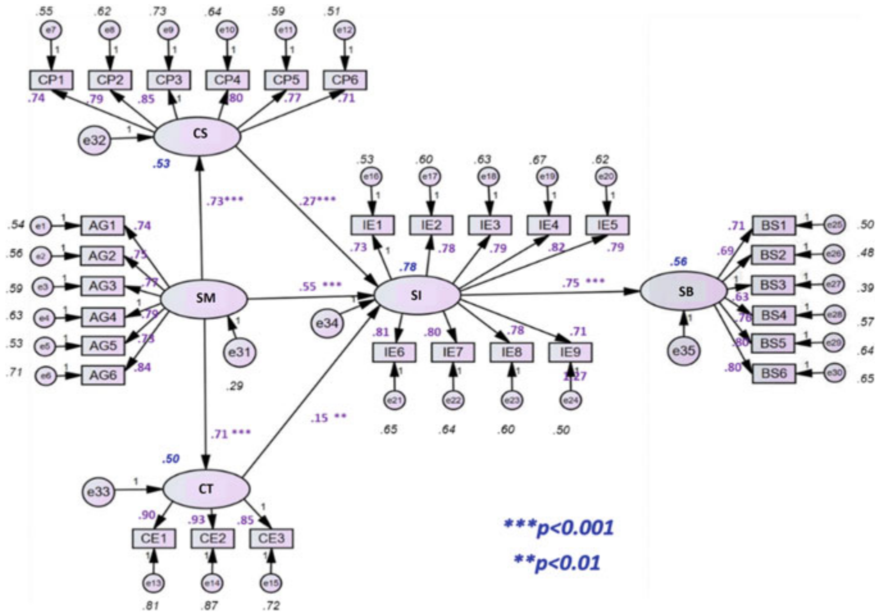

Fig. 5.2 Structural model with standardized weights

Table 5.6 Global adjustment indices in the structural model

Model	CMIN/DF	TLI	CFI	RMSEA
Default model	2.006	0.91	0.918	0.068
Saturated model			1	0.226
Independence model	12.181	0	0	

5.4.6 Relationship Between SS and SB

It has been determined that the main critical factors for the success of the SS implementation are the support of Senior Management, the Relationship with Clients and Suppliers, Coaching and Training, and the Collaborative Team, whose synergistic combination has a favorable effect on the SS strategy implementation. As a result, a structural model composed of an exogenous latent variable, Senior Management and four endogenous latent variables (Customers and Suppliers, Coaching and Training, Strategy Implementation and Sustainable Benefits) was obtained. The model allows quantifying and identifying the interrelationships between these variables and determining the impact of the SS deployment on the sustainable practice in the companies investigated.

From the proposed model, the variables that most strongly represent the model were identified. Concerning senior management, it is identified that it is appropriate that there is good communication during the project execution. The projects must be aligned with the strategic vision of the company. In the same way, it is necessary that the supervisors support the project's deployment and that the main variables concerning the clients and suppliers are identified. In that sense, it is observed that there must be efficient communication between the organization, customers and suppliers. The projects must be focused on customer satisfaction, and the company must have a supplier management system that considers quality standards, response and delivery time, administration and organization of suppliers. Likewise, it is necessary that, prior to the implementation of the strategy, the organization provides training in the fundamentals of SS, quality, skills to solve problems and teamwork so that employees who have different roles obtain knowledge and skills to comply with the assigned responsibilities, so it is recommended that the training is differentiated.

Finally, it is identified that, as a result of a correct implementation of the SS strategy, it minimizes pollution and consequently reduces the negative impact on the environment, which introduces sustainable thinking. And if the collaborative team of SS and all employees collaborate in developing projects, improvements in the environment and, in turn, sustainable benefits will be achieved.

Figure 5.3 shows the relationships between the constructs, indicating the strength with which the variables predict others. In this sense, the results obtained when performing the hypothesis tests in the investigation are presented.

Table 5.7 shows the factor loadings to identify the most significant variables to achieve the success of SS for each of the constructs mentioned above and shown in the measurement model.

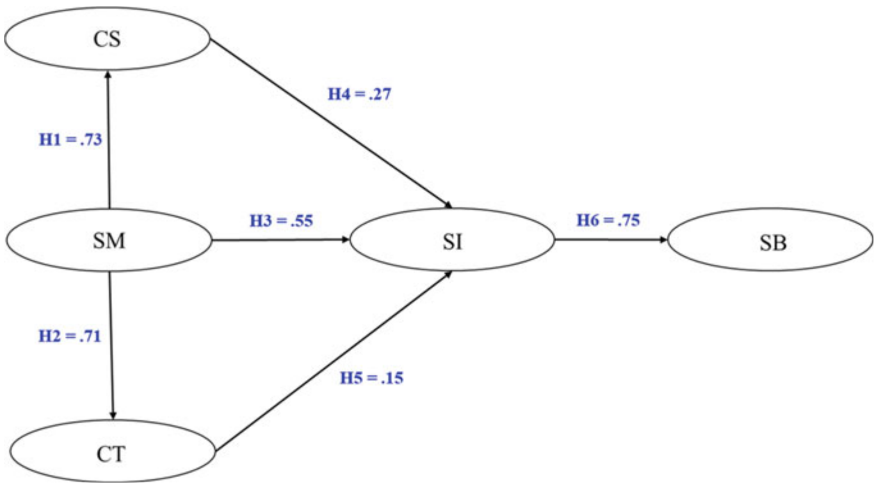

Fig. 5.3 Hypothesis tests in the measurement model

Table 5.7 Most significant variables to achieve the success of SS

Construct	Variable	Factor load	Description
SM	SM6	0.844	It is appropriate that there is good communication between managers and employees during the execution of the Project
	SM4	0.793	The SS Projects must be aligned with the strategic company's vision
	SM3	0.771	It is necessary to support the company's supervisors for SS projects
CS	CS4	0.803	There must be efficient communication between the organization and the suppliers
	CS3	0.853	SS projects must be focused on customer satisfaction
	CS2	0.79	The company must have a customer management system that considers the response and delivery time, customer service, administration and organization of customers
	CS5	0.767	The company must have a supplier management system, which considers quality standards, response and delivery time, administration and organization of suppliers
CT	CT2	0.93	It is necessary that, before the implementation of SS, the organization provides differentiated training, so employees with different roles obtain knowledge and skills to fulfill the assigned responsibilities
	CT3	0.846	Plant managers and supervisors belonging to the quality and/or continuous improvement area must receive training before implementing SS
	CT1	0.902	The organization shall provide continuous training in SS fundamentals, quality, problem-solving, and teamwork
SI	SI4	0.816	During the implementation of SS, a plan and/or structured procedure for the execution of SS must be followed
	SI6	0.806	During the execution of the Project, it is necessary to have someone responsible for managing and documenting the activities carried out prior to and during the implementation of SS
	SI7	0.803	During the implementation of the SS, it is necessary that there is a program of regular audits and that their progress is reported
	SI3	0.793	Those involved in the Project must understand the methods, techniques, practices and tools for SS
	SI5	0.787	The members of the organization must have experience in SS projects
	SI2	0.778	The expected financial benefits of a SS project should be identified during its planning
	SI8	0.777	When implementing SS projects, the objectives set by the organizations must be achieved
SB	SB6	0.806	Correct implementation of the SS strategy introduces sustainable thinking

(continued)

Table 5.7 (continued)

Construct	Variable	Factor load	Description
	SB5	0.802	Successful implementation of the SS strategy results in the minimization of contamination and consequently reduces the negative impact on the environment
	SB4	0.755	The collaborative SS team and all employees must collaborate in the development of projects; with this, they will achieve improvements in the environment and, in turn, sustainable benefits

5.5 Conclusions and Managerial Implications

It is observed that the literature is not finished; it does not objectively and sufficiently explain the SS relationship. Moreover, as for the sustainable benefits, there is an emerging discussion. Although it is widely accepted that environmental deterioration is an alarming problem, there are not enough explanations to reconcile the interests of customers and suppliers and environmental protection.

With the model, it was found that there is a direct and positive relationship between the senior management construct and the relationship with customers and suppliers (H1). Therefore, there must be efficient communication between the organization and suppliers and an understanding of customers' and suppliers' needs and objectives.

The relationship of senior management with coaching and training (H2) is also critical. If senior management provides the proper coaching and training, it will ensure that members of the organization have the necessary skills to manage or participate in the project, including monitoring, control and evaluation, which will promote the success of the SS deployment.

Likewise, the existing relationship between senior management and strategy implementation (H3) was verified. If the deployment of an SS project has the participation and commitment of senior management, correct implementation is promoted, although the project must be aligned with the strategic vision of the organization. The relationship between clients and suppliers in the strategy implementation (H4) is also relevant for successful SS implementation.

It is confirmed that the direct relationship between coaching and training toward strategy implementation (H5) coincides with various studies that have reported that coaching and training should be the first steps for SS implementation.

The relationship between the strategy implementation and the sustainable benefits was verified with H6. For this, it is important to highlight that if in the development and implementation of the SS strategy, the organization considers criteria that allow managers and leaders to understand and solve sustainability problems, the strategy will not be limited only to defects reduction but will be understood that, by improving the quality of the products, the negative impact on the environment can be reduced.

Therefore, the present investigation confirms the research hypotheses regarding the orientation to sustainable profits. Consequently, SS improves resource efficiency and drives sustainability.

There is a new paradigm; the SS strategy introduces sustainable thinking, and with SS projects aimed at reducing pollutants and/or energy savings, added to the efforts of the SS team and the employee's collaboration, the environment can be improved, and there will be a favorable scenario for obtaining sustainable benefits, a new set of values.

As a consequence of the above, the results of this study are important contributions to theories related to technology, organization, administration, strategic planning and continuous improvement. It can trigger the development of a technique that adapts the SS methodology to obtain sustainable benefits, giving rise to the Sustainable Six Sigma concept. Moreover, in practice, the CSF determined in this study constitutes the main contribution of this research. There is evidence that the support of senior management, the relationship with customers and suppliers, and coaching and training lead to a successful SS implementation. This, in addition to achieving the strategic objectives set by the organization, consequently benefits sustainability. The determined factors explain how to manage and focus efforts on SS implementation activities to achieve long-term benefits. It also explains that the SS strategy implementation is a predictor of sustainable benefits and even facilitates an organizational environment that promotes the formulation and achievement of strategic objectives, including objectives related to the environment, such as waste elimination and pollution prevention.

By identifying factors and variables, companies can improve their results in the organizational and environmental fields, linking continuous improvement and sustainable practices, which do not currently occur, because improvement is aimed at increasing quality, efficiency and productivity.

The results of this research help develop continuous improvement models in conjunction with sustainability in simultaneous implementations. It is pertinent to highlight a limitation: although the observation of the relationships between a successful implementation of SS and sustainable benefits derives from punctual analysis in time, without sufficient empirical support, it is a disadvantage; it opens the opportunity for future work, developing methods, tools and techniques with an SS-SUSTAINABLE approach.

As a managerial implication, it is highlighted that the results described in this research may encourage organizations that are not fully committed to sustainability to contemplate the possible benefits towards sustainable benefits, obtain with the correct implementation of SS and guide managers in the design of sustainable projects to reduce the use of raw materials, waste, atmospheric emissions and consequently minimize environmental deterioration. Great commitment from management is required to ensure that continuous improvement projects consider both care for the environment and the sustainable benefits that can be achieved by implementing projects that considerably improve their processes' objectives and products and the environmental benefit.

With the support and commitment of management, the probability of linking continuous improvement with sustainable benefits is increased; thus, these can verify the findings of this investigation. In addition, the findings shown can be useful for academics, for developing continuous improvement models in conjunction with sustainability, seeking simultaneous implementations, and, finally, for qualitative and empirical studies, which are necessary due to the little literature reported.

5.5.1 Limitations

It is important to mention that this study has some limitations. The first has been the number of databases that are freely accessible to the researcher and allow access to all the documents sought and identified as valuable for the investigation. Second, the results only apply to the aerospace sector, and it was impossible to find more empirical studies in the same context. Third, the results of this research must be contextual; that is, the specific characteristics of the companies must be taken into account. Fourth, research of this type is a punctual analysis of time and resources, which is why they present this limitation to continue with the development and go deeper into the research, leaving what has been identified as future work, suggesting the development of more empirical studies, seeking the generalization of the model proposed here in various manufacturing contexts.

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Part II
Ergonomics and Safety

Chapter 6
Assessment and Evaluation of the Effects of Hazardous Noise Produced by the Manufacturing Industry on the Workers

Tushar Kanta Mahapatra and Suchismita Satapathy

Abstract People are becoming more aware of this problem as noise pollution has increased significantly in recent decades owing to the expanding industry. The manufacturing sector provides employment opportunities for workers and produces annoying noise from various sources, particularly machinery. This study aims to pinpoint dangerous loudness in the manufacturing sector, where employees work eight hours daily under sweltering conditions. In addition, a follow-up study may provide a clear image of many noisy situations, such as an auto shop, the textile industry, or a small industrial worker, enabling them to evaluate the effects of noise on their hearing conditions. A quick study of various industries was conducted at the site to categorize the health issues caused by noise pollution in the Bhubaneswar, Odisha area. In this survey, 120 workers were examined by a health expert to determine whether they had health issues owing to high noise. This study used three questionnaires to examine labor-related health issues at clinical and workplace levels. The findings suggest that a significant proportion of the population experiences problems with hearing impairment (26%), acoustic fatigue (18%), and sleep problems (16%). Other problems include a change in behavior towards others, annoyance, decreased success in carrying out routine tasks for industrial workers, and increased hypertension with other cardiovascular conditions. To reduce the detrimental impacts of noise pollution, industries must follow specific suggestions and take preventative measures such as using personal protective equipment (PPE), particle boards, soundproofing barriers, and vibration-proof foundations. Therefore, hearing preservation techniques should be used under noisy conditions.

Keywords Noise pollution · Hearing loss · Decibels · Health problems · Sleeping problem

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6.1 Introduction

An essential element of human existence is sound. Humans cannot communicate their needs and feelings to others without sounds. Nevertheless, when sound turns into noise, it affects society and daily life (Subramaniam et al. 2019). The Latin word for "nausea" is the root of the English term "noise". Noise is a wrong, unpleasant, and distracting sound at the wrong time or place. However, this form of pollution carries risks that cannot be observed. This cannot be observed, even though it exists on land or water. Any undesirable or annoying sound affecting people's health and well-being and other living things is called noise pollution (Goswami et al. 2019). Noise pollution is no longer a new issue for typical people, particularly in most industrial and metropolitan areas. Noise is the most common workplace environmental hazard.

Human activities produce two types of noise, occupational noise and environmental noise, which include noise from traffic, music, and other sources (Khajenasiri et al. 2016). Unwanted or excessive noise can harm the environment and human health, and noise pollution is what this means. Prolonged or recurrent exposure to loud noises that harm the spiral organs can result in high-frequency deafness. In addition, hypertension, is more prevalent due to noise.

Some studies draw on this area of research to learn more about how noise and loud music impact human performance and how music, an everyday activity that frequently incorporates background music, impacts driving (Dalton and Behm, 2007). In addition to adversely affecting a person's capacity for comprehension, attention, and alertness, background noise also affects public health (Oguntunde et al. 2019). Hearing loss, sleep disturbance, heart disease, social impairments, poor productivity, rebellious public behavior, irritable responses, absenteeism, and accidents are all severe public health issues that can be caused by noise.

Numerous studies have shown that 30 million American employees are routinely subjected to loud noise. Noise exposure is one of the most common environmental risks in industrial settings, although its effects vary depending on job and location (Gurjar et al. 2016). Numerous studies have shown that noise pollution negatively affects workers' productivity and effectiveness. One of the major environmental stressors is noise pollution, and contemporary life demands that the noises produced will not disappear overnight.

6.1.1 The Source of Noise Pollution

6.1.1.1 Industrialization

A unit of measurement for sound is "decibels." Most industries employ machines that generate a significant amount of noise. Different equipment contributes to the production of loud noise, such as grinding mills (134 dB), milling machines (104 dB), lathe machines (101 dB), weaving mills (94–99 dB), compressors (95–104 dB), sawmills (95–105 dB), and steam turbines (91 dB). These factors contribute to the excessive noise (Bhosale et al. 2010; Caciari et al. 2013).

6.1.1.2 Bad Urban Planning

Large families living in cramped quarters, disputes over parking, and frequent alterations in necessities contribute to noise pollution, which disturbs the social environment (Pantawane et al. 2017).

6.1.1.3 Public Transport

Many cars are on the road, planes pass over residences, and underground trains generate much noise, making it difficult for people to get used to them. Regular individuals lose hearing capacity because of extreme noise levels.

6.1.1.4 Constructions Work

Construction activities, including mining, building bridges, dams, buildings, stations, highways, and flyovers, are ongoing worldwide. These building and bridge construction activities occur daily because new structures must be created to accommodate more people and ease traffic congestion. However, the negative aspect is the noise of these construction tools (Pantawane et al. 2017).

6.1.1.5 Other Sources

Primary noise sources currently include traffic, building sites, industrial regions, shoddy urban design, social gatherings, housework, and air traffic (Bhosale et al. 2010). There are many different sounds in the environment, such as thunderclaps (120 dB), rustling leaves (20–30 dB), and siren calls (120–140 dB). Loud rock concerts, subway trains, and powerful lawnmowers are sound sources that are louder than this level, between 90 and 115 dB and 110–120 dB (Józwik et al. 2018).

6.1.2 Impact of Noise Pollution

Humans are affected by sound frequency. It is widely known that the human ear can detect frequencies within the range of 0–180 dB. A critical issue is that insufficient number of individuals know how noise pollution at work affects and causes serious health issues (Aluko and Nna 2015). The World Health Organization (WHO) claims that noise pollution is the most significant environmental threat to human health.

The European Environment Agency (EEA) estimates that noise causes more than 72,000 hospital admissions annually and 16,600 premature deaths in Europe (Parma Declaration on Environment and Health 2010).

Loud noise can also cause hearing issues (physical effects), high blood pressure, heart disease, insomnia, stress (physiological effects), a weak nervous system, sleeping issues (psychological effects), and low productivity (effects on work performance). In 1972 Saphiro and Baland two were the first to measure the intensity of noise pollution and then describe it as the "third pollution" after air and water pollution (Shapiro and Berland 1972; Panhwar et al. 2018).

The World Health Organization (WHO) defines noise pollution as louder than 65 decibels (dB). Noise levels greater than 75 dB (in decibels) are harmful and painful. As a result, it is suggested that daytime sound levels are kept under 65 dB and that it is difficult to have a good night's sleep when ambient noise levels at night are higher than 30 dB. Millions of people are affected by daily noise pollution. All of these noise sources impact our daily lives without our knowledge because it is impossible to intentionally close our ears while sleeping to block unwanted aural input (Babisch 2005).

Moreover, noise harms health and can cause auditory issues, such as nerve fatigue, partial hearing loss, and other issues, such as decreased productivity, aggravation, cardiac issues, and high blood pressure. Noise is a stress-mediating factor that reduces mental clarity, interferes with communication, disturbs sleep, alters psychosocial behavior, and generally degrades performance in daily tasks (Kpang and Dollah 2021). Noise-related symptoms include increased heart rate, severe hypertension, physiological disturbances, and peripheral vascular resistance.

The impact of the physical work environment on employee performance was investigated using a theoretical framework. Temperature, sound, air, light, color, and physical workplace space are the five primary elements that affect employee performance. According to industrial safety and health, noise is hazardous to worker health and safety (Kahya 2007), even though hearing is one of the basic senses and is crucial to our ability to comprehend our surroundings.

6.1.3 Health Problems Due to Noise

Excessive noise pollution can harm mental health in public areas, workplaces, construction sites, bars, and homes. Studies have shown a connection between loud environments and aggressive behavior, annoyance, chronic stress, fatigue, sleep problems, and hypertension. Continuous loud noise may cause headaches, upset, and emotional equilibrium (Firdaus and Ahmad 2010).

Figure 6.1 describes the diseases caused by noise pollution, such as hypertension, high cholesterol, and disturbed sleep.

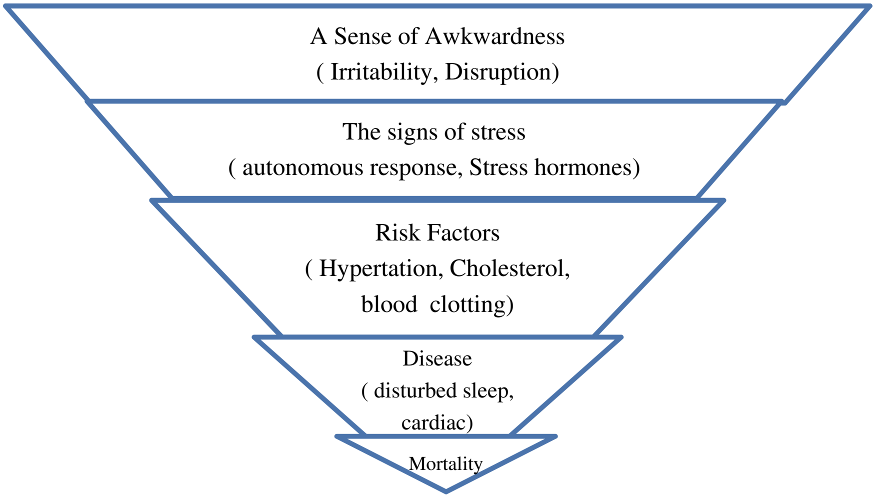

Fig. 6.1 Various forms of diseases have occurred due to the impact of noise pollution

6.1.3.1 Cardiovascular Problems

Numerous studies have shown that noise pollution has both temporary and long-term effects on the autonomic nervous system of humans and other species (Hahad et al. 2019). According to one theory, noise acts as a general biological stressor, activating processes in the body that prepare for a fight-or-flight response (Aluko and Nna 2015). As noise can cause reactions in the hormonal and autonomic nervous systems that affect the circulatory system, it may increase the risk of cardiovascular disease. Long-term repeated exposure to noise levels above 65 dB and quick access to noise levels above 80–85 dB can cause these effects. According to previous studies, high-intensity noise causes high blood pressure and increases the heart rate by disrupting regular blood flow (Berglund and Lindvall 1995).

6.1.3.2 Sleeping Disorder

Adequate sleep is necessary for the proper physiological and psychological performance of healthy individuals. Environmental noise contributes significantly to sleep disruptions (Singh and Davar 2004). Repeated sleep disturbances can lead to changes in mood, poor performance, and other long-term adverse effects on health and wellness. For instance, it is widely recognized that consistent noise levels exceeding 30 dB make sleep challenging.

Sleep deprivation and disrupted sleep cycles have also been linked to decreased attentiveness, which results in mishaps, injuries, and fatalities. This loud noise may make it difficult to sleep, annoy, and create uncomfortable situations. People feel fatigued and perform worse at work and home if they do not sleep well.

Table 6.1 Effects on hearing due to noise

Sound level (dB)	Effects due to noise
10	There is no hearing loss at these volumes
30	
40	
60	
80–85	Hearing the damage after two hours
95	Hearing damage after 50 min
100–105	After 15 min, possible hearing loss
110	Possible hearing loss after 2 min
120	Pain and ear injury
140–150	Pain and ear injury

6.1.3.3 Hearing Issue

Any uncomfortable sounds that our ears are not designed to filter harms our health, and our ears can only handle noise before they are damaged. Constant exposure to loud noises can quickly damage the eardrums and cause hearing loss (Anees et al. 2017). Table 6.1 clearly shows that sound levels above 80 dB begin to damage our ears after continuous exposure to that noise level (Dunne et al. 2017) and shows how our ears respond to different noise levels (in decibels) (Qutubuddin et al. 2012). Below are the data collected from different sources, such as literature, doctor consultations, and informed responses.

According to a report from the National Institute for Occupational Safety and Health (2021), in Fig. 6.2, people are affected by different types of health issues due to the high noise collected and categorized under Employees are at risk of hearing loss, mental health problems, hearing difficulty, and tinnitus. There is no solution for these injuries yet, which means those who are hurt will have to live with the effects for the rest of their lives.

To address this issue, some countries passed different laws, such as Japan in 1972, the United Kingdom enacted the Health and Safety at Work Act in 1974, and the United States of America implemented the Occupational Health and Safety Act in 1970. The Occupational Safety and Health Act (OSHA) was revised in 1994 to address the need for an extensive employee base and dangerous workplace acts. According to the Occupational Safety and Health Act (OSHA), industrial workers should not work for more than eight hours in an environment with noise levels greater than 90 dBA.

6.1.3.4 Disappointment and Negative Human Behavior

Any action or circumstance that a person believes will harm them can irritate them, causing them to feel annoyed. Noise has been utilized as a noxious stimulus in

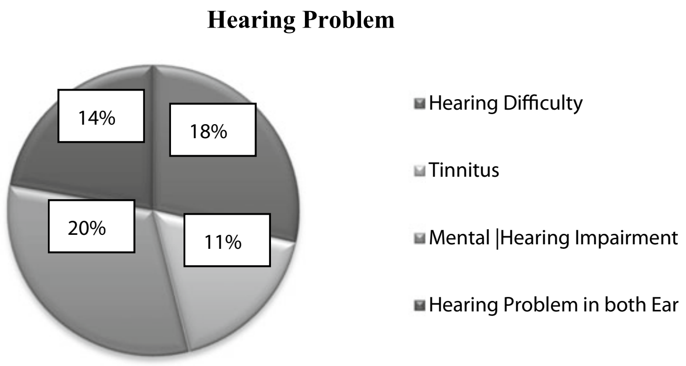

Fig. 6.2 Hearing problems of workers working in a noisy environment

numerous studies because its effects are similar to those of other stressors. Irritation and noise considerably increase when vibration or low-frequency components are present. Noise pollution can evoke many negative emotions, including anger, displeasure, dissatisfaction, helplessness, worry, distraction, agitation, and tiredness.

6.1.3.5 Mental Health Problems

Noise pollution is believed to expedite and aggravate hidden mental problems, although it is not recognized as a primary cause of psychological disease. Noise pollution causes tension, nervousness, headaches, emotional instability, anger, hormonal disorders, poor concentration, increased social conflicts, neurosis, and psychosis, to name a few adverse effects. News media often covers aggressive behavior owing to disagreements over noise, and in several cases, these disagreements result in harm or death.

6.1.3.6 Verbal Communication Interruption

In addition to making it difficult to understand spoken language, noise pollution can cause psychological problems, physical impairments, and behavioral changes. These include difficulty concentrating, doubt, annoyance, misunderstanding, reduced working capacity, harmed interpersonal interactions, and stressful reactions. These consequences could result in more accidents, a breakdown in classroom communication, and poor academic achievement. Children, the elderly, and those who do not speak the language fluently are among the most disadvantaged groups.

6.1.3.7 Working Performance

Laboratory and field research has demonstrated that occupational noise exposure negatively affects workers' ability to complete mental tasks. The results of field research on the impact of noise on safety and performance revealed that noise might cause task impairment and increase the frequency of errors, depending on the activity being performed and the type of noise.

6.1.3.8 Effects on Other Animals or Living Things

Animals, including birds, rats, fish, and domestic pets, are sensitive to various impacts from exposure to high noise levels and can experience the effects of factories, railways, crackers, explosions, and bustles in cities and aircraft. During migration, birds avoided areas with noise levels greater than 100 dB. Fish miscarriages and birds ceasing to lay eggs due to noise emissions from supersonic aircraft, trains, and other sources have been documented. In conclusion, it may be said that animals and other living creatures are directly responsible for the ecological balance and experience more distress than humans do.

6.1.3.9 Effect on Non-living Objects

Nonliving creatures are also affected by loud noise levels. Deafening noise levels and booms induce fissures in hills and national and archaeological sites. High-intensity explosions can cause building vibrations and broken glass. Research is being conducted in India and internationally to determine its impact on non-living creatures so that preventative measures can be adopted (Mushtaq 2009).

6.1.4 Objective

Moreover, sound generates headaches, impatience, anxiousness, and a sense of exhaustion, which could lead to more severe and persistent health problems combined with the other variables described above. Therefore, our study assessed the impact of noise pollution on workers' health in the S.I.T.E. area of Bhubaneswar, Odisha. Furthermore, a few recommendations are made based on the results of this study to investigate the adverse effects on workers in the industrial area working for 5–10 years, such that acoustic materials can be suggested, which can reduce pollution and its adverse effects on human health.

6.2 Literature Review

Any audible sound in an environment that causes concern is considered noise. It comprises background music, driving cars, and domestic and industrial noise (Dalton and Behm 2007).

Noise pollution was defined as a sound pressure level (dB) above 65. Noise is dangerous when it exceeds 75 dB, and it is advised to maintain noise levels in the environment below 65 dB during the day and below 30 dB at night to promote healthy sleep.

Developing a manufacturing work system that reduces safety risks while maximizing worker productivity and improving worker happiness is vital. Using ergonomic principles can help employers provide employees with a pleasant, secure, and comfortable work environment. The suggested work focused on the important components of industrial noise and analyzed its causes and consequences, particularly on productivity and human performance. 2012. established a computer-assisted ergonomics system to improve the application of ergonomics principles in industrial industries.

According to author noise is constant daily and can cause various auditory and nonauditory health problems. Social noise exposure is primarily influenced by loud noises that harm hearing in industrial environments. To reduce the detrimental consequences of noise pollution, this study discusses the need for businesses to use PPE, soundproof buildings, and vibration-resistant foundations (Panhwar et al. 2018).

The author (Oguntunde et al. 2019) developed a probability model for predicting noise pollution. Based on the survey findings by another author (Melamed et al. 2001), the physiological, auditory, and sleep-related noise impacts are statistically significant at a significance level of $\alpha = 0.05$.

Following Hashim et al. (2012), this study compared the evaluation of postural analysis using physical assessment methods and a self-report questionnaire for students between 13 and 15 years of age in a school workshop. Using both physical assessment techniques and questionnaire analysis, it was determined that the 13-year-old children were exposed to greater danger.

The study is to determine how electromagnetic fields and noise at a power plant in Shiraz affect people's psychological well-being. Humans are exposed to various physical and chemical components owing to substantial industrial and scientific breakthroughs. Some of these substances, such as electromagnetism, are called constant elements of the environment (Zamanian et al. 2010).

According to the author (Subramaniam et al. 2019), today's need is to minimize and eradicate noise at its source by utilizing various effective solutions. This study aims to understand how noise is produced and how to stop and control it.

The risk of noise exposure and its consequences on technical operators of tobacco processing machines in Nigerian cigarette firms are evaluated in this research by Hsu et al. The noise generated by various pieces of equipment used in the primary, secondary, and utility production departments was evaluated and examined in three different tobacco factories in Nigeria. This study found that high decibel noise levels harmed the health and productivity of technicians who spent an average of 12 h/day working on the manufacturing floor.

As a result, the term "noise" describes a sound that lacks an excellent musical quality or is unwanted or undesirable. Noise is just as dangerous a chemical as many pollutants. Noise is becoming a more pervasive and major source of discomfort and risk owing to increased mechanization, the use of more complex and extensive machinery and equipment, and a ramping up in the pace of production.

This study assessed the amount of noise exposure and the potential adverse effects on wheat processing workers. It is suggested that workers in the processing sections wear WHO Class-5 hearing protectors. According to Khaiwal et al. (2016), room acoustics are altered to lessen some sounds transmitted to offices in light of these findings.

This study aimed to determine how electromagnetic fields and noise at a power plant in Shiraz impact people's psychological health. As a result of substantial industrial and scientific advancements, humans are being exposed to various physical and chemical components. Some of these substances, such as electromagnetism, are known as constant components of the environment (Zamanian et al. 2010).

This study assessed workers from several industrial enterprises in Hyderabad for occupational exposure. It was found that Hyderabad's manufacturing industry employees were exposed to significant noise ($p > 0.05$) (Panwar et al. 2018).

This result suggests that the tractor driver's ear equivalent sound pressure level (Leq) was measured during the tillage operations. Six different tractor models with five different tillage implements (moldboard plow, disc plow, rotator, disc harrow, and duck foot cultivator) were evaluated at three different forward speeds. According to Lalremruata et al. (2019), noise control standards should be closely adhered to and supported by the required personal protection equipment, training, and procedures.

According to Mithanga et al., this study aimed to determine the maximum working hours allowed by excessive industrial exposure to noise hazards. Noise exposure was initially measured using a dosimeter, and the results demonstrated that noise-induced hearing loss (NIHL) was significantly more likely to occur in workers exposed to noise. The critical areas were the CAM and CNC departments, which must adhere to the NIOSH and OSHA rules at less than 0.125 and 1.33 h, respectively.

Farooqi et al. state that one of Pakistan's largest industrial cities, Faisalabad, may experience noise pollution due to the developing robust industrial and transportation infrastructures. This study aimed to map the noise pollution levels in different parts of Faisalabad, compare the levels of noise pollution for each source in the morning, afternoon, and late afternoon, and determine how noise negatively affects human hearing.

6.3 Research Procedures

6.3.1 Research Design and Sampling

This study was conducted in the Bhubaneswar region and outside of the city. Bhubaneswar is the capital of Odisha, India. The population of this city was 8.37 lakhs (according to the 2011 census), with an area of 422 km^2 Many small, medium, and micro companies and automobile workshops operate in this city, including the textile industry, automobile workshops, pipe manufacturing companies, and utensil manufacturing companies. Ergo-Fellow (Considering Background Noise Zero) has discovered that the length of sound hits inside and outside the room may be used to quantify the sound effect when a single machine measures noise inside a 3600-square-foot region. This implies that both the inside and outside residents are affected by noise. According to Panhwar et al. (2018) noise pollution causes annoyance and health issues and has become a severe environmental hazard. This essay aims to investigate and assess the degree of noise pollution in Ota's significant neighborhoods.

One hundred twenty workers from various workshops of automakers and small businesses in Odisha participated in the study. Seventy men (58% of the total workers) and 50 women (42%) were assessed for hearing problems in a noisy environment in Odisha, India. Workers' ages ranged from 18 to 60 years (Fig. 6.3). Figure 6.4 shows the workers' age distribution from 18 to 60 years, selected for evaluation. The maximum age of the workers was selected to be more than 30.

Figure 6.4 shows the number of workers of various ages who participated in the survey.

In Fig. 6.5, workers are unaware of the impact of the noise produced in industry and automobile workshops after continuous exposure to high noise during work hours, which affects health.

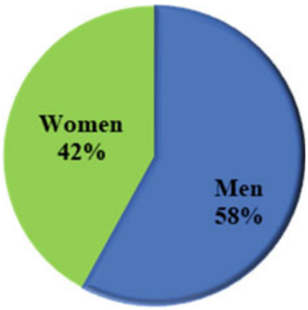

Fig. 6.3 Number of workers for the study

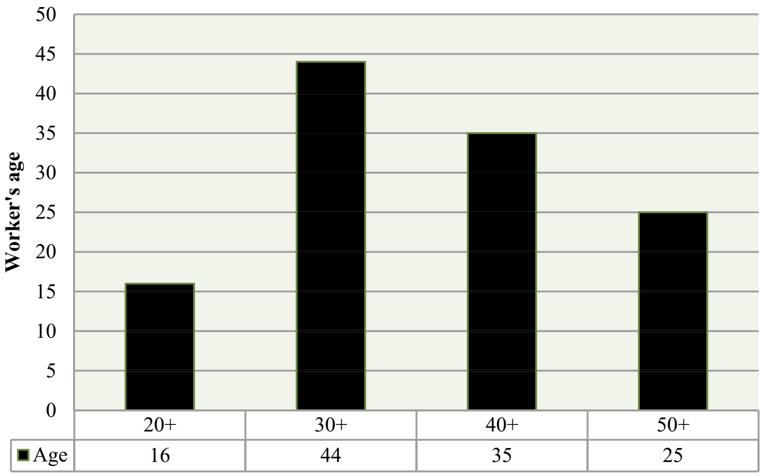

Fig. 6.4 Different age groups of workers participated in that study

Fig. 6.5 **a** Worker doing machine maintenance in a utensil manufacturing company, **b** Worker working in the automobile company workshop near Bhubaneswar

6.3.2 Health Impact Assessment Methodology

A questionnaire was designed to receive responses from industrial and medical doctors. Doctors were exclusively interviewed to examine illnesses in affected areas linked to noise pollution. Following data collection, the questionnaires were combined using information gathered from respondents during the consultation process. The questionnaire is available as a supplementary file. It was ensured that the respondents had no head injury or hearing loss. The flowchart of the study approach is presented in Fig. 6.6.

A survey was conducted to assess the impact of noise on workers in the noisy areas. A brief question was posed to the company's workers, residents, and staff in the company's working area, and they were asked to respond in the open field.

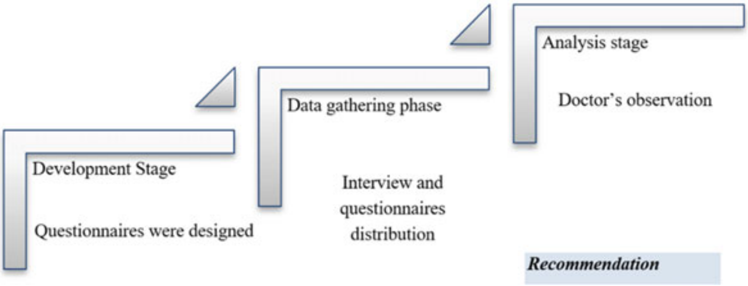

Fig. 6.6 Survey method for evaluation of the hearing impact

The questionnaire survey list was developed and filled out by posing various questions to residents in that region. Table 6.2 contains data from brief surveys on the characteristics of noise pollution, as per the questionnaire.

6.4 Results and Discussion

This is the doctor's survey report, which includes information on the effects of noise pollution on the auditory and nonauditory collected from KIMS Bhubaneswar from June 2022 to January 2023 (within six months). Data were collected for workers working for more than five years in the industry within the age range (18–50). Then statistical software Minitab 16 was used to determine the percentage of workers with hearing problems.

As per Table 6.3, the data were collected from the doctor team through a survey and categorized under nine factors (i.e., deafness, auditory fatigue, disturbance in sleeping, blood pressure rise, disease related to stress, heart rate rise, irritation, rise in breath, and nausea) for 120 patients (workers).

The main contributing factors include long-term noise exposure and continuous work for months or years. The effects of production rates that are not audible include a 14% increase in blood pressure and a 19% disturbance in sleep. The other nonauditory problems listed in Table 6.3 have lower values and fall within manageable ranges; therefore, their effects on blood pressure and sleep quality would not be as detrimental. Aneurysms, heart failure, memory loss, and cognitive challenges primarily result in nonauditory illnesses.

Table 6.4 details the awareness, practices, issues, infections, and awareness of the consequences of noise pollution for workers. As per Panhwar et al. (2018), the same 120 workers were questioned regarding their knowledge of noise pollution. Factor analysis was conducted using Minitab 16 on the data collected by 120 workers on questions (yes = 1 and no = 0) under the six dimensions of awareness, practices, issues, disease, consciousness, and custom effect).

Table 6.2 Questionnaire for research on noise pollution

Sl. no.		Questions
A		*Do you realize the impact noise has on you and others around you?*
	1	You know it harms your ears, brain, and overall health
	2	No, we're not looking for sounds
	3	It certainly irritates us
	4	We are used to noise
B		*Have you ever had a visitor inquire about noise pollution?*
	1	No, we never witness someone posing such queries
	2	Yes, a few times, people came to inquire about it, but nothing further transpired
	3	A brief survey was conducted in a few places in the region, but the outcomes were not particularly promising
	4	Due to ignorance, we disregard the advice provided by some particular industries
C		Do you have a favorite time of day when there is much noise?
	1	Yes, due to excessive noise, the first eight to ten hours of the morning are the most bothersome
	2	The evenings are Batter in the late hours
D		*Are you aware of the harm that noise may do to your health?*
	1	In no way
	2	I definitely, understand, like Deafness, irritability, and interrupted sleep
	3	Increasing blood pressure, hypertension, etc.
E		*Do loud sounds affect you when you're at work?*
	1	Undoubtedly, we are irritated
	2	Sometimes, yes
	3	My thinking has changed
	4	Undoubtedly, excessive noise irritates us and harms our health, causing us to visit an ENT specialist frequently
F		*Are there any other diseases that frequently run in families among your people?*
	1	No, our family is not affected by a particular disease or problem
	2	Yes, because of their noisy workplaces, some members of our family experience stress

According to the results of the structured questionnaires, most workers became familiar with noise pollution and ignored the safety instructions provided by relevant departments. Because almost all organizations operate continuously throughout the day without regard for noise pollution regulations, a higher proportion of employees (94%) complained about noise pollution during the first 18 working hours. As many industries lacked a safety department and insufficient safety equipment, a sizable portion of the workforce (91%) was unaware of noise pollution safety guidelines, leading to bad habits (83%). This study aimed to determine whether excessive noise pollution experienced by workers has adverse health effects on spouses, and 92% of family members reported no health issues.

Table 6.3 Disease number

Disease name	Percentage (%)
Deafness	30
Auditory fatigue	20
Disturbance in sleeping	19
Blood pressure rise	14
Disease-related to stress	8
Heart rate rise	7
Irritation	7
Rise in breath	4
Nausea	2

The findings of the clinical survey conducted in this study are presented in Table 6.5. Most of the labor force (approximately 90%) comprised men (80%) and adult workers (78%). Most of them (75%) had recently contacted clinics when the situation became problematic (78%), since it was previously acknowledged that there were insufficient labor safety precautions or awareness campaigns. Because the workforce is seen as the foundation of the country's economy, the health consequences of noise pollution on that population are concerning and could directly affect these industries.

Table 6.6 reports the ergonomic effects of noise exposure (OSHA). NIOSH (The National Institute for Occupational Safety and Health) states that sound levels up to 60 dB can be managed. Consequently, they become hazardous. Therefore, managers need protective equipment such as earmuffs or earplugs. Acoustic walls are critical steps that may be used to lower sound levels.

Duration T is computed by $T = \frac{8}{2^{L-90/5}}$, where L denotes the sound level.

6.5 Conclusions

According to our research, there is a connection between a higher health risk, a problem with noise pollution, and not following the rules and regulations that are already in place. Nonetheless, the companies and residents chosen for this study recognized that the amount of noise enterprises generated in the environment was above the permitted levels, which might lead to several health problems. The studies we evaluated showed a direct correlation between increased health risk and noise pollution. Because most industries are unconcerned about this issue and do not adhere to the norms and current regulatory requirements, noise pollution has numerous adverse effects on health, including auditory fatigue, hearing loss, and discomfort.

Explaining the severe effects of noise pollution and the considerable health effects discussed in this work is critical, as they include hearing impairment (26%), acoustic fatigue (18%), and sleep problems (16%). These side effects can lead to hearing loss,

Table 6.4 Questionnaire survey results on the impact of noise on the human

Characters	Serial no.	Questions	Percentage of workers (%)
Awareness	A	Do you realize the impact noise has on you and others around you?	
	1	You know it harms your ears, brain, and overall health	05
	2	No, we're not looking for sounds	20
	3	It certainly irritates us	30
	4	We are used to noise	40
Practices	B	Have you ever had a visitor inquire about noise pollution?	
	1	No, we never witness someone posing such queries	04
	2	Yes, a few times, people came to inquire about it, but nothing further transpired	04
	3	Yes, a brief survey was conducted in a few places in the region, but the outcomes were not particularly promising	18
	4	Due to ignorance, we disregard the advice provided by some particular industries	66
Issues	C	Do you have a favorite time of day when there is a lot of noise?	
	1	Yes, due to excessive noise, the first eight to ten hours of the morning are the most bothersome	94
	2	The evenings are Batter in the late hours	06
Disease	D	Are you aware of the harm that noise may do to your health?	
	1	In no way	91
	2	Definitely, understand, like Deafness, irritability, interrupted sleep	04
	3	Increasing blood pressure, hypertension, etc	5
Consciousness	E	Do loud sounds affect you when you're at work?	
	1	Undoubtedly, we are irritated	10
	2	Sometimes, yes	3
	3	My thinking has changed	83

(continued)

Table 6.4 (continued)

Characters	Serial no.	Questions	Percentage of workers (%)
	4	Undoubtedly, excessive noise irritates us and harms our health, causing us to visit an ENT specialist frequently	4
Custom effects	F	Are there any other diseases that frequently run in families among your people?	
	1	No, our family is not affected by a particular disease or problem	92
	2	Yes, because of their noisy workplaces, some members of our family experience stress	8

Table 6.5 Collects the health checkup data from hospitals and clinics

Sl no.		Questionnaire	Age (%)
A		How often do you go to the doctor?	
	1	Annually	3
	2	Six month	75
	3	3 month	10
	4	30 days	7
	5	15 days	5
B		Which age group suffers the most?	
	1	Children	2
	2	Young	80
	3	Aged	18
C		What was the patient's condition when they arrived at the hospital?	
	1	Patient reports are troublesome at this point	78
	2	When symptoms are vague, patients describe	11
	3	Preliminary patient reports	9
	4	Early on, patients arrived, but they disregarded medical advice	12
D		What kind of work does the patient do?	
	1	Office worker	10
	2	Labor	90
E		The most impacted gender is?	
	1	Male	80
	2	Female	20

Table 6.6 Ergonomic analysis of noise effects on workers in a specific machine based on noise exposure (OSHA)

Machines	Decibel (inside room)	Sound effects in hrs (h)	Outside the room	Sound effects in hrs (h)
Lathe machine	101	1.7	95	4
Grinding machine	134	0.031	120	0.125
Milling/ Drilling machine	104	1.1	99	2.3
Metal cutting saws	115	0.25	107	0.76
Automobile machinery	108	0.66	103	1.3
Weaving mills	94–99 (max)	2.3	90	8
Sawmills	95–105 (max)	1	89	9.2
Air Compressor	95–104 (max)	1.1	89	9.2
Oxy acetylene cutting	96	3.5	92	6.1
Steam turbine (12,500 KW)	91	7	89	9.2
Pulveriser	92	6.1 h	83	21.1 h
Riveting	95	4 h	86	13.9 h
Computer rooms	55–60	38 h	37	43.3 h
Ticking clock	30	47 h	23	49.1 h

annoyance, loss of efficiency, and performance. The current study suggests that new safety rules must be developed, and existing rules must be strengthened to ensure workers' fitness and safety.

6.5.1 Recommendations

Based on the results, the following recommendations were made:

- The present National Environmental (Noise Control) Regulation, implemented in 1996, should be reevaluated and amended according to current control, mitigation, and management needs to preserve the quality of our environment below the standard level.
- In addition to the Environmental Impact Assessment (EIA) given to companies to determine the risk to both human health and the environment, the Central

Environmental Authority (CEA) is requested to perform a Health Impact Risk Assessment (HIRA) with the support of the health authority.

- Every industry must have a system to measure its average noise level electronically. These records must be available for review by internal audits or appropriate law enforcement agencies.
- Industries should construct soundproofing, silent buildings, and storage facilities to reduce noise pollution.
- When installing heavy machinery, vibration dampers should be installed to minimize noise.
- Governmental and non-governmental NGOs should take proper action to control noise pollution in these locations.

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Chapter 7
Assessment of Industrial Workers' Discomfort Level by Simulation Annealing

Hullash Chauhan and Suchismita Satapathy

Abstract Musculoskeletal disorders and pains are generally found in human work activities, and workers in the industry are exposed to the risk of injuries and wounds. Industrial risk factors are the leading cause of health problems. Industrial workers can adversely affect their bodies, reducing productivity, product and work quality, and increasing musculoskeletal disorder problems, which cause serious health problems that affect workers' mental well-being and reduce their work efficiency. This chapter aimed to assess industrial workers' discomfort levels, which leads to mental stress. The discomfort questionnaire and the Ovako Working Posture Analysis System (OWAS) were applied. Simulated annealing (SA) algorithms were used to get the best fitness value. Based on the results, suitable ergonomic solutions can be adopted for design and growth.

Keywords Workers · Industry · Mental stress · Discomfort questionnaire (Ergonomics) · OWAS · SA · India

7.1 Introduction

Mental stress has been regarded as an essential aspect that can affect individuals' performances when they try for varying levels of complex tasks. Indeed, the exposure of human beings to higher levels of mental stresses that seem intolerable may affect the successful completion of tasks. Work stresses are the most harmful physical and emotional responses, which may happen due to different situational aspects.

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Higher job demands and a lower ability to control situations can lead to work-related stress. Mental stress seems unbearable and can interfere with the satisfactory performance of tasks that must be completed. Mental stress is the most destructive physical and emotional response that can occur due to all aspects of the situation.

7.1.1 Effect of Mental Stress on Human Health and Social Life

Usually, a person faces many kinds of stress daily, possibly due to the workplace, personal life, or social relations. Budgeting, family life, keeping up with local trends, and future planning are all challenges that arise daily. Social isolation and working long hours can generate stress. Stress is an emotional or physical reaction that changes a person's mood and behavior. It can be generated from any action or thinking that hurts people's sentiments and puts them in an uncomfortable situation. It raises the anger of a person and makes him tense and upset. It is the response to a requirement or any provocation.

Stress also has many negative impacts, like mental instability, inability to take pressure in the workplace, inability to focus, and increased physical sickness. The results of mental stress in the workplace are a reduction in job satisfaction, performance, and work interest. Stress can appear as a requirement, chance, restriction, pressure, or challenge. Stress is harmful at the individual level and the group level. It may be the initiator of any fight or any bad habits. Stress is not an illness. However, when enduring a specific force, it might likewise prompt a procedure of mental or physical illness, for example, cardiovascular infections, diabetes, a fit of anxiety, gloom, musculoskeletal complaints, brought down invulnerability, and burnout. Persons may feel powerless and sad and choose self-destructive plans. Commonly people experience stress related to the environment, psychological states, and social issues.

Stressed individuals are always under constant threat. It may cause medical complications like an imbalance in pulse rate, obesity, diabetes, and blood pressure (BP), which varies the metabolism. Stress is the leading cause of many diseases and is more dangerous in the long turn; it is common and can be reduced with proper counseling and workouts.

Moreover, stress can affect people in different labor sectors, such as farmers, manufacturing employees (industrial workers), and students. In the case of the farmers, as per Gerberich et al. (1998), stress, long hours, and fatigue contribute to injury risk among farmers. No health plan, insurance, solitary work life, prolonged outdoor work activity, unpredictable weather, natural disasters, volatile market, personal (family) problems, and financial pressure, among others, are the measurement parameters for a farmer's stressed life. Altogether, the above stressors in work life and personal life create chemical changes in hormones in the body, disturbing the blood pressure, pulse rate, and digestive system (Fink 2010; Donham and Thelin 2016; Simon and Zieve 2013). Ultimately, reactions like anxiety, mood swing, temper, and sweating may be found. The farmer becomes unsocial, loses trust, gets sick, and loses problem-solving ability (Donham and Thelin 2016). These symptoms are the symbol of mental stress, which makes him away from work life and more stressed. Some farmers suffer from heart disease, hypertension, stroke, and diabetes. In the end, premature death, depression, addiction, and suicidal attempt are also seen in many cases (Donham and Thelin 2016).

Physical stress involves injury, infection, surgery, overworking, a polluted environment, sickness, and musculoskeletal disorders. Psychological stress is called emotional stress, which occurs by fear, emotional factors, or cognitive factor. Mental stress is the mind's reaction because of physical and psychological stress. Some farmers are stressed due to family and financial issues. So, this becomes psychosocial stress that affects the farmer community on a large scale. A few farmers commit suicide because they cannot confront the issues expected to cause psychological stress.

Bjelland et al. (2002) performed a literature review on the validity of the Hospital Anxiety and Depression Scale (a scale used to rate anxiety and depression). They found this scale performed well in symptom burden assessments and the occurrence (i.e., possible cases) of anxiety and depression disorder in physical and mental stress. Similarly, Thomas (2011) has developed a psychosocial health stress scale to reduce the mental stress of farmers.

7.1.2 Musculoskeletal Disorders

Discomfort posture often leads to injury and accidents among laborers, which not only reduces productivity but also enlarges production costs. Hence, analyzing ergonomic postures becomes necessary to recognize, moderate, and prevent uncomfortable postures of laborers when the workplace design is changed (Chu et al. 2019). Mahendra et al. (2016) mention that musculoskeletal disorders and pains are generally found in human work activities, and workers in the industry are more at risk of injury. Industrial risk factors are the leading cause of health problems. Industrial workers can adversely affect their bodies, increasing musculoskeletal disorder problems and reducing productivity and product quality. According to Kolgiri et al. (2017), various methods are developed to record work-related body part discomfort regarding postures and movement. The choice of methods will depend upon the nature of the investigation and the purpose(s) for which the data will be used; these will determine the required level of accuracy and precision.

Similarly, Saha et al. (2017) quantified male construction laborers' cardiac strain and body posture strain related to manual material handling (MMH) tasks. Their results revealed that the mean peak heart rate of the workers was significantly different (higher) compared with that of the upper extremity intensive workers. Also, their study showed that most of the working postures were hazardous. Most workers suffered from head, neck, shoulder, lower back, and arm region pain. The well-being of farmers is a significant concern as they are exposed to more physical work and repetitive work with different body postures.

Uncomfortable postures often lead to injuries and accidents for the workers, which decreases productivity and increases production costs. An ergonomic posture analysis is therefore essential to identify, alleviate and prevent uncomfortable postures of workers when the workplace design is changed (Chu et al. 2019). Musculoskeletal discomforts and disorders cause severe health-related problems affecting farmers' mental well-being, reducing work efficiency. The discomfort levels of farmers in Indian agriculture lead to mental stress. With the help of a discomfort questionnaire and the "Depression, Anxiety, and Stress Scale (DASS-21)", the farmers' discomfort and mental stress levels were evaluated (Kniffin et al. 2021).

Giorgi et al. (2020) performed a literature review to deepen the psychological aspects linked to workplace factors following the epidemic rise of COVID-19 in order to address upcoming psychological critical issues in the workplace. They found that mental issues related to the health emergency, such as anxiety, depression, post-traumatic stress disorder, and sleep disorders, are more likely to affect healthcare workers, especially those on the frontline, migrant workers, and workers in contact with the public. In other research, Ornek and Esin (2020) examined the effects of the work-related stress model-based Workplace Mental Health Promotion Programme on job stress, social support, reactions, salivary immunoglobulin A and Cortisol levels, work absenteeism, job performance, and coping profiles of women workers. Their results showed no differences in sociodemographic characteristics, general health, or working conditions between the Intervention and control groups.

7.1.3 Problem Statement and Objectives

Based on the backgrounds mentioned above, this chapter aims to study the safety and issues of workers in the utensil manufacturing industry. The ergonomic analysis is conducted by the Ovako Working Posture Analysis System (OWAS) and discomfort questionnaire. Then, the mental pressure is predicted concerning the change of internal parameters, like blood pressure, temperature, and pulse rate, due to changes in physical stress parameters.

7.2 Literature Review

7.2.1 Stress and Its Effects

Schäfer et al. (2020) reported that the COVID-19 pandemic negatively impacted mental health. Then, future studies are lacking. Furthermore, it is significant to identify which factor transforms the stress response to the pandemic. Before, a sense of coherence (SOC) emerged as a main resistance factor. In their study, Dawel et al. (2020) studied pandemic deficiencies in work and social functions were sturdily linked with increased symptoms of depression and nervousness and reduced psychological well-being. These authors mention that minimizing disruptions to work and social function and improving access to community mental health services are fundamental policy goals to minimize the pandemic's impact on mental health and welfare.

Similarly, Bhui et al. (2016) identified two causes of workplace stress and different organizational and private interventions by workers to cope with stress in public, private, and non-governmental organizations (NGOs). Stress has been defined in several ways. It was initially conceived as an environmental pressure from the surroundings, then as internal tension within the people, and finally as a relationship between the situation and the individual. When an individual's resources are insufficient to cope with the demands, the stress caused by the environment and psychological and physical conditions is developed (Michie 2002). Stress is more likely to occur in some situations than others and in some people than others. Stress can interfere with the success of goals, both for persons and organizations (Michie 2002).

As the stress level increases, it highly impacts farmers' physical health. Due to this, production in agriculture is highly affected, which can significantly impact an individual's performance and the productivity of the entire agricultural sector. Farmers' performance, illness rates, absenteeism in the workplace, farm-related injuries, and accidents are all heavily influenced by mental stress. The farming community typically experiences stress when faced with demands that require them to change in some way; this increases psychological stress. Stress can affect an individual's ability to concentrate, feelings of tension, apprehension, and panic, as well as physiological reactions such as sweat, an increased heart rate, tensed muscles, and shallow breathing. Individuals who perceive the stressors as more dangerous are more likely to experience higher-stress responses than those who can respond constructively to those stressors. The problems and stress have become so widespread that the farmers cannot deal with them. Changes in climate, rainfall, crop disasters, strategies, government plans, and, more importantly, if farmers are emotionally worried, may result in a decrease in output rates and productivity.

Another context in which people suffer too much stress is education. Compared to the general population, college students are becoming recognized as vulnerable, suffering from higher anxiety, depression, substance misuse, and eating disorders (Browning et al. 2021). Son et al. (2020) performed a study with 195 students at a public university in the United States to find the effect of the pandemic on the mental health and well-being of university students. It was found from the data analysis that the effect of the pandemic has increased the aggressiveness and suicidal nature of students. In another study, Bhargava and Trivedi (2018) identified that stress mainly comes from educational tests, interpersonal relations, association issues, life-changing events, and job searching, which may cause young people mental, physical, psychological, and behavioral problems. Because of the various internal and external potentials placed on it, stress has become a part of students' academic lives. When change occurs at the individual and social levels, young people are mainly helpless to problems associated with educational stress. Therefore, it becomes essential to understand the source and impact of educational stress to deduce sufficient and effective intervention strategies (Reddy et al. 2018).

Frömel et al. (2020) have studied work-related mental health and addressed it at the school level between the academic stress (AS) of adolescent boys and girls and their physical activity (PA) during breaks and after school. These authors suggest measures to encourage healthy work habits throughout life. Similarly, Burzynska et al. (2020) identified physical stress, which consists of physical demands and working conditions, and they found that it was related to lower hippocampal levels and reduced memory performances. These relations were independent of age, gender, brain size, and socio-economic factors such as education, income, position, length of employment and employment status, sporting leisure activities, and general stress.

On the other hand, Von et al. identified the impacts of social and physical stress on the behavior of healthy young men. These authors found significant influences on various subjective increases in stress due to physical and social stress, but they did not find an interchange effect. Also, they found that physical stress significantly elevated cortisol, and physical and social stress and their combination modulated heart rate. The subjective stress response is modulated by social anxiety but not the cortisol or heart rate responses. Regarding behavior, their results show that social and physical stresses interact to modulate trust, reliability and sharing.

In another research, Assadi (2017) studied the effect of psychological and physical stress on lipid profiles. Mueller and Maluf (2002) have proposed the physical stress theory (PST). The basic principle of PST is that changes in the virtual levels of physical stress cause changes in an expected adaptive response in all biological tissues. specific threshold names each characteristic tissue response's upper and lower stress level. Despite the vital facts connecting psychological stress to illness risk, health researchers frequently fail to include psychological stress in models of health (Crosswell and Lockwood 2020). In 2009, the American Psychological Association linked stress to a severe health problem; though, a quantitative and accurate method of assessing and estimating the stress status of individuals remains a significant challenge. Here, an animal model with farm animals allowed showing that the discovery of biomarkers can quantify psychological stress and predict disease susceptibility (Sood et al. 2013). Several studies have shown that social support is essential for maintaining physical and mental health. In mental illness, the damaging effects of low social support and the preventive effects of excellent social support are well understood.

Through its effect on the hypothalamic–pituitary–adrenal (HPA) mechanism, noradrenergic system, and central oxytocin pathways, social support can reduce genetic and environmental vulnerabilities and impart stress tolerance (Ozbay et al. 2007). Psychological stress is a popular term for processes believed to contribute to various mental and physical states. Although there is a common interest in the rise and its health and well-being implications, there needs to be more consent on the definition of psychological stress (Smelser and Baltes 2001). Stress and hounding put a pressure on occupational health. Although the link between quality administration and health is becoming well established, the organization with stress and hounding in the workplace has yet to be studied. The document plans to examine the links between quality management values, occupational health, and stress at work (Lagrosen and Lagrosen 2020). Work-related stress and its adverse effects on human health have rapidly increased, and it causes many different responses to stress-associated illnesses and unhealthy behaviors in workers, particularly women. Thus, Ornek and Esin (2020) have investigated the effect of the "Workplace Mental Health Promotion Program" based on the "Work Stress Model" on work stress, social support, responses, immunoglobulin A and salivary, absence, job performer and coping profile of female workers.

Similarly, Sasaki et al. (2020) have studied the connections between workplace process implementation in reaction to COVID-19 and mental health and workers' work performance in Japan. Other authors, such as Park et al. (2020), have identified that long working periods were related to pressure, depression, stress, and suicidal get to see in young workers; aged 20–35. Also, long working times are known to harm human health. Omair et al. (2019) have identified the cost of employees' stress by creating a relationship between the firm's financial profit and the employees' societal promotion. These authors also conducted a study to compute the impact of typical stress between employees on the manufacturing process. Moreover, they concluded that specialized and successful manufacturing could only be possible by considering the working conditions of humanity in the industry.

Weber et al. (2019) investigated the connection between employee health, employee-related stress, and work-related disease organization to develop welfare. They found that mobile health interventions (i.e., "apps") convey mental health and are a more widespread process obtainable to individuals and organizations to improve workplace stress. On the other hand, Jacobs (2019) explored the meaning or nature of ineffective work-related stress caused by the manager inside and outside the workplace. This meaning was from the perception and experience of the employees. On his part, Ajayi (2018) investigated the impact of work-related stress on worker performance and job satisfaction. A sample of 150 Nigerian banking sector employees in Nigeria was used for this survey. He found that job stress significantly reduces the performance of an individual.

The "World Health Organization" defines stress in the workplace as the response that people may have when they present themselves to work demands and pressures which do not match their knowledge and skills and which call into question. Questioning about their ability to cope can be caused "by poor organization of work due to poor job design, the need for control over the work process, poor management, inadequate working conditions and need of support from equals and superior" (Maulik 2017). Workplace stress is an important issue that must be addressed to make progress, and day-to-day, the challenges facing people are increasing in many different areas as if progress creates new problems.

Slowly, the nature of the job has changed and is still ongoing. As a result of these changes, the number of illnesses has increased, moral and human aspects have faded, and new problems arise every day, so we are faced with stress at work which we call the “disease of the century” (Panigrahi 2016). Ismail et al. (2015) studied the relationship between stress at work and job performance. They used a survey to collect self-administered questionnaires from a senior and non-executive employee of a leading private investment bank in Peninsula Malaysia. They discovered that physiological and psychological stress were positively and significantly correlated with job performance. In Occupational Medicine, researchers show the current position and recommend further research to clarify the link between work and mental health (Fingret 2000).

Stress varies in the environment and requires the human body to react and adjust in response. The body produces physical, mental, social, and emotional responses to these changes. Mental stress is an inevitable part of life. Many events that happen to people and about themself as well as many things they do, put physical strain on their bodies. Bomble and Lhungdim (2020) have examined the mental stress of farmers in Maharashtra, India. According to National Crime Records Bureau (NCRB), 1,31,666 people committed suicide in India in 2014, with 12,360 being farmers. Indian farmers, especially marginalized and fragmented farm owners, walk and stagger under constant stress and hard work. Stress factors are falling, insecure incomes, insurmountable debt traps, and unpredictable weather. The sociology of Indian agriculture leads the way to chaos and entropy; farmer suicide is the shocking gauge of immeasurable distress (Ghoshal et al. 2020). Crimes and Enticott (2019) have analyzed the social and psychological impacts of the farmer’s subjective well-being and presenters’ tendency to work when suffering mental health problems.

Bratman et al. (2019) have recognized a growing body of empirical evidence that reveals the value of experience nature for mental health. With hasty urbanization and the decline of human contact with nature globally, crucial decisions must be made on protecting and improving the opportunities to experience nature. There is a potent link between mental stress and physical health. However, slight is known about the pathway from one to the other, analyzed the straight and circuitous effect of past mental health on current physical health and past physical health on current mental health use daily life choice and social capital in an intervention framework (Ohrnberger et al. 2017).

Yaribeygi et al. (2017) have studied the primary effect of stress on the physiological systems of humans. Stress can also be a trigger or aggravating factor for many diseases and pathological conditions. Any intrinsic or extrinsic stimulus that elicits a biological response is called stress. Schönfeld et al. have studied the primary transnational indication for various stress-buffer effects for the two dimensions of mental health. Compared to traumatic events, every stressor is gradually recognized as a significant risk factor for mental health. Stress has a major impact on mood, well-being, behavior, health, and social life. The response to acute stress in young, healthy people can be adaptive and generally does not pose a health burden. Especially in the elderly or sick, the long-term effects of stressors can harm health. The environment influences the connection between psychosocial stressors and illness, the number and persistence of stressors, and biological factors (Schneiderman et al. 2005).

7.2.2 The OWAS Method

Karhu et al. have developed the OWAS method in Finland to analyze work positions in the steel industry. It is one of the ergonomic tools used to analyze postures, i.e., work postures for the back (4 postures), arms (3 postures) and legs (7 postures), and the weight of the load handled (3 categories). The OWAS method is used to identify unsafe work postures that cause musculoskeletal injuries, and it mainly helps to analyze and evaluate work postures used during work. This method is used to analyze workers' back pain in the workplace. The OWAS score is calculated by adding all the scores of arms, legs, and back after calculating the individual score of the matrix by comparative analysis method of each OWAS question. The OWAS claim to be appropriate for the inexperienced upon request, but insufficient evidence supports this assumption.

An extensive literature review shows the application of the OWAS method for evaluating the level of risk caused by postural loads. For example, Ulutas (2017) qualified and evaluated working postures in a device-mechanized facility. In his research, twenty-five assembly line laborers were asked to assess the environmental conditions and complete a Cornell complaint survey based on their present tasks. Then, video records were analyzed to identify working postures using the OWAS method. In another study, Grimby-Ekman and Hagberg (2012) calculated the simple neck pain issues usually included in major epidemiological survey studies concerning aspects of health.

Moreover, Dabholkar et al. analyzed the pains and discomfort surgeons felt during surgery, and they found that these pains were most commonly attributed to awkward and persistent postures during surgery. Also, Dewangan and Singh (2015) performed an ergonomic study. They designed the pulpit in a wire rod mill at an integrated steel plant that faced declining worker productivity due to a lack of body postures and proper working conditions. Bergsten et al. (2015) investigated the relationship between psychosocial exposure and discomfort position of the back and shoulder in Swedish baggage handlers. Rahman et al. found that musculoskeletal disorders (MSDs) are the most common and broad category of work-related illness seen in both developed and developing countries.

Mercado (2015) analyzed the process and workplace layout in selected structural and fabrication shops in Batangas, Philippines. These workshops involve preparation, cutting, welding, grinding, and assembly with multifunction machines and various aspects of human labor. This author identified the risks of musculoskeletal disorders (MSDs) due to uncomfortable postures, strain, and fatigue; the position of workers was dangerous for themselves due to inadequate measurement of structures that needed to be changed. In another research, Ayub and Shah (2018) focused on measuring the risk for MSDs among laborers in manufacturing industries using ergonomic tools like QEC (quick exposure check) and Nordic questionnaires. Huda and Matondang (2018) assessed the worker's posture using the Work Posture Assessment (WPA) and Biomechanics method.

In contrast, Saeedi et al. (2018) investigated the effects of education in ergonomic principles on temporary musculoskeletal disorders of hospital staff. Similarly, Otto et al. (2017) developed a body-posture analysis system to preserve good ergonomic and human comfort conditions and to minimize health risks. This system evaluates human positions during the performance of activities and classifies them as good, fair, or foul to avoid health problems.

Brandl et al. (2017) have used to carry out a comprehensive ergonomic analysis of working postures using the OWAS method and 41 working posture analysis systems with an individual sample strategy. Suman et al. (2020) have studied to carry out different MSDs symptoms and estimate work posture and postural stress during welding. For their part, Galán et al. (2017) have found the applications of the OWAS method in different sectors or fields of knowledge and countries. The use of the OWAS technique has been classified by knowledge categories, by country, and by country per year.

Suman et al. (2018) quantified data on the musculoskeletal disorders of the laborers of the welding units. These data was collected, evaluated, and validated using Rapid Upper Limbs Assessment (RULA), OWAS, discomfort questionnaires, and suggested design solutions.

7.2.3 Discomfort Questionnaire

Musculoskeletal discomfort and disorder cause severe health-related problems that affect workers' mental well-being and decrease their work efficiency. This study uses the discomfort questionnaire to evaluate the discomfort levels of workers during work. The discomfort Questionnaire is one of the Ergonomic tools available in ErgoFellow 3.0. The discomfort questionnaire consists of details of all body parts frequency (like 1 to 2 times, more than 4 times, and more than 8 times, to mention few) in the scale (low, mid, moderate, and severe working) with no hours engaged (i.e., 1st hour, 4th hour or 8th hour of a day). After studying posture and recording the movement/frequency of body parts during a particular job, the percentage is calculated by comparing each body part with each other as a result of the discomfort questionnaire. Then, all body parts, the percentage of working and body parts in discomfort can be easily detected. Even the eye, nose, ear, legs, and all body parts can be analyzed with this questionnaire.

Several studies have been done about ergonomic tools and their applications in evaluating workplace discomfort levels. For instance, Dewangan and Singh (2015) have proposed an improved pulpit based on the ergonomic study in a wire rod mill at an integrated steel plant to reduce musculoskeletal disorders and thus increase the plants' productivity. Mercado (2015) has analyzed the workplace layout and process in structural and fabrication shops, generally focused on preparation, welding, cutting, grinding, and assembly jobs by using multi-function machinery and many aspects of human work in Batangas (Philippines) by using different ergonomic assessment checklists, direct observations, as well as tools like REBA, RULA and OWAS.

Further, the proposed designs' alternative effectiveness was measured using "Trade-off Analysis technique", such as "Standard Weighted Sum Method", "MAXIMIN decision", and "Analytic Hierarchy Process". Ayub and Shah (2018) have focused on measuring the risks for work-related musculoskeletal disorders among workers in a manufacturing company, using ergonomic tools like a quick exposure checklist (QEC), rapid upper limb assessment scores, and Nordic questionnaires. It was found that experienced workers reported more pain in upper body parts because of the poor design of workstations.

7.2.4 SA Algorithm

Simulation Annealing is an optimization technique for solving unconstrained and bound-constrained optimization problems. It is used for global optimization problems for a fixed amount of time. SA solves multi-objective optimization problems. MATLAB® is used to run the algorithm (SA code). It is used to get better solutions or optimal solutions.

Yao (1992) simulated annealing has proven to be a powerful stochastic method for solving complex combinatorial optimization problems. However, it requires much computing time to arrive at reasonable estimated solutions. Spinellis and Papadopoulos (2000) have described a simulated annealing advance to solve the buffer allocations problem in consistent manufacturing lines. Henderson et al. (2003) identified simulated annealing as an accepted confined search metaheuristics used to solve discrete and, to a lesser extent, constant optimization problems. Finally, Zhang et al. (2021) have used a simulated annealing algorithm to optimize the low effectiveness of the picking processes. Liu et al. (2021) studied the multi-objective optimization problem of irregular objects in aquatic product processing. They used the information guidance strategy to develop a simulated annealing algorithm to solve the problem according to the characteristics of the object itself. As a result, the simulated degradation algorithm was designed effectively improve the quality of the target solution.

7.3 Methodology

7.3.1 Materials

To measure workers' physical discomfort, a stopwatch, camera and video recorder are required to observe the job at different hours. The camera and stopwatch are required to record and measure the motion/frequency of workers' body parts while performing a particular job.

7.3.2 Method

To measure workers' physical discomfort and mental stress, the method applied in this research is divided into four stages, as shown in Fig. 7.1. In stage 1, workers are selected based on their work. Then, in stage 2, the discomfort level and working posture are analyzed by the OWAS ergonomic tool. Next, in stage 3, Minitab® 2017 is used to design equations from the data collected for workers. Finally, in stage 4, mental stress is analyzed using the SA method.

The following is a detailed explanation of how each stage was carried out.

- *Stage 1: Selection of Workers.* The workers were selected by observing the type of work performed and working hours. The workers engaged in similar work for 8–10 h in uncomfortable postures. These postures were selected, and images were taken. To address the ergonomic-related issues in the workplace, 75 workers were selected considering the type of job they performed. Then their physical discomfort in the workplace and its impact on their mental stress were analyzed. A total of 25 workers were selected from Odisha, and 50 were taken from Chhattisgarh states.
- *Stage 2:* To study discomfort level, the stopwatch and camera are used to record the individual postures of the workers during the plucking of vegetables. Then, the most discomforted workers concerning the frequency of operation and time were recorded. Then, for most discomfort workers, evaluation of discomfort level and analysis of working posture by OWAS and Discomfort Questionnaire. Then, the discomfort questionnaire and the OWAS method used the "ErgoFellow" software to determine workers' discomfort levels. The purpose of this research is to find the most discomforting working posture and the discomfort in the workplace due to this physical effort.
- *Stage 3: Data collection and equation generation.* After the OWAS method and the discomfort questionnaire analysis, awkward postures were found, and the blood pressure, temperature, and pulse rate were noted. Minitab® 2017 generated an equation utilizing a regression analysis model, considering output as mental stress and input as internal parameters, like blood pressure, temperature, and pulse rate. The correlation coefficients of different associated parameters with mental

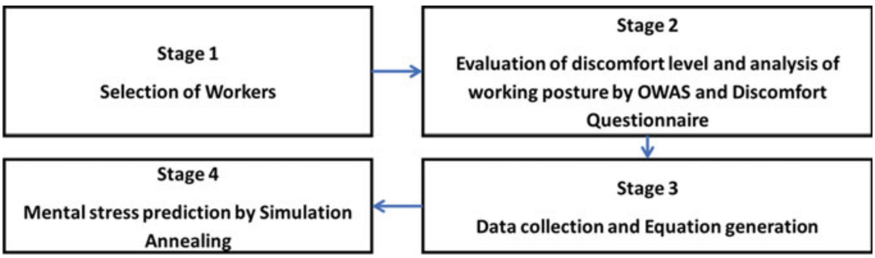

Fig. 7.1 Methodology

stress for workers and the corresponding *p*-vales were obtained using "Pearson product-moment correlation". The "Minitab® 2017" software was used to check the correlation between mental stress and other parameters such as Kcal burnt, pulse rate, BP (Low, High), and temperature.

- *Stage 4: Mental Stress Prediction by SA Algorithm.* A Simulation Annealing (SA) model is generated to measure mental stress by considering parameters like Kcal burnt, High BP, and Low BP, measured during heavy physical working conditions. Hence the Kcal burnt, BP, and pulse rate were recorded for 75 workers, and SA predicts mental stress. Further, the SA algorithm was used for the second case concerned with the internal parameters, such as Kcal burnt, pulse rate, High BP, Low BP, and Temperature, as independent variables among the workers to estimate mental stress. All the input-parameter for the algorithms was set in the range of 0–3. While the fitness or objective function was set as the mental stress of workers.

7.4 Results and Discussion

7.4.1 Discomforts Questionnaire

This study found that casting was done by a male worker in a bending posture continuously for 7–8 h daily (as shown in Fig. 7.2a). Also, it was found that a female worker did loading and unloading tasks repeatedly. These tasks strained her shoulder and neck muscles, which in turn caused musculoskeletal disorders and physical stress. Figure 7.2b shows the woman performing these tasks. Hence, the ergonomic analysis uses the discomfort questionnaire to study the most affected body parts during work.

For instance, by randomly selecting the worker for the discomfort level evaluation, for worker number 17, the discomfort evolution and discomfort side was depicted in Fig. 7.3. For worker number 17 (male worker), more discomfort was reported in the shoulder during 8 h among discomfort on left and right sides of eyes, neck, shoulder, trapeze, knee, elbow, wrist, and thigh, respectively. Figure 7.4a, b show the discomfort evolution and discomfort side for worker 17.

Similarly, for worker number 66, the discomfort evolution and discomfort side are depicted in Fig. 7.5. As can be seen, this worker (female worker) reported more discomfort in the foot and thigh during the 4th hour. Moreover, she reported discomfort in the shoulder, forearm and wrist during the 8th hour, with discomfort on the left and right sides of the eyes, shoulder, elbow, forearm, hand finger, thorax, thigh, and knees, respectively. Figure 7.6 shows that the worker had more discomfort on the right side of the wrist. Further, more discomfort frequency was observed in the neck for worker number 17, followed by the shoulder, lower leg, thorax, elbow and thigh. Similarly, the discomfort frequency was more in the head and neck, followed by the shoulder for worker number 66 (Fig. 7.7).

(a) (b)

Fig. 7.2 Workers doing solid tasks: **a** Casting, **b** Loading and unloading

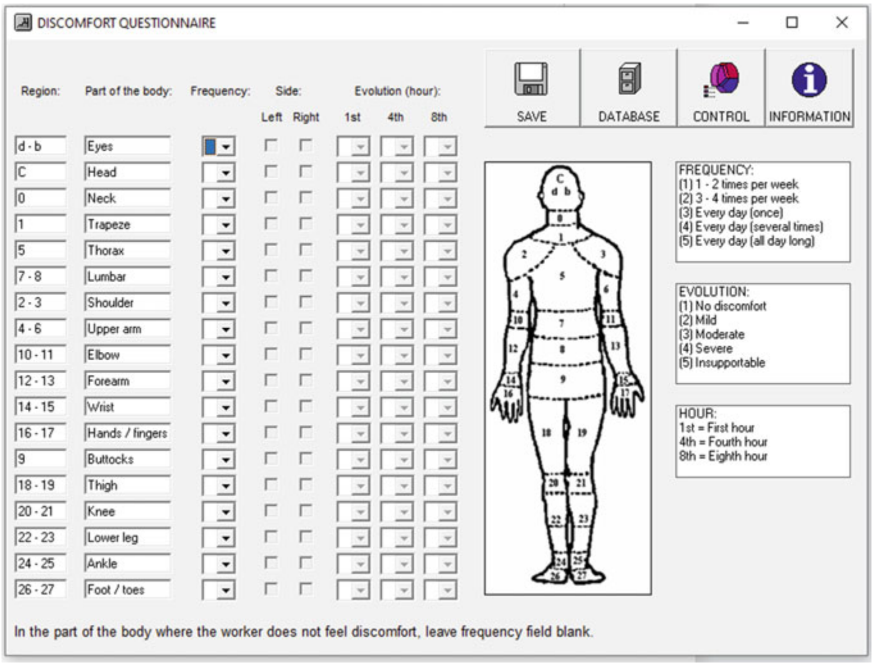

Fig. 7.3 Results of discomfort questionnaire for worker 17

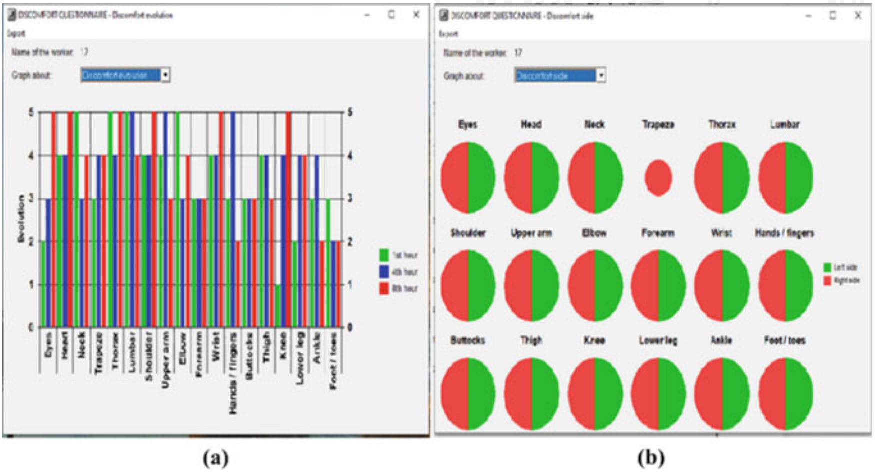

Fig. 7.4 For worker number 17: **a** Discomfort evolution, **b** Discomfort side

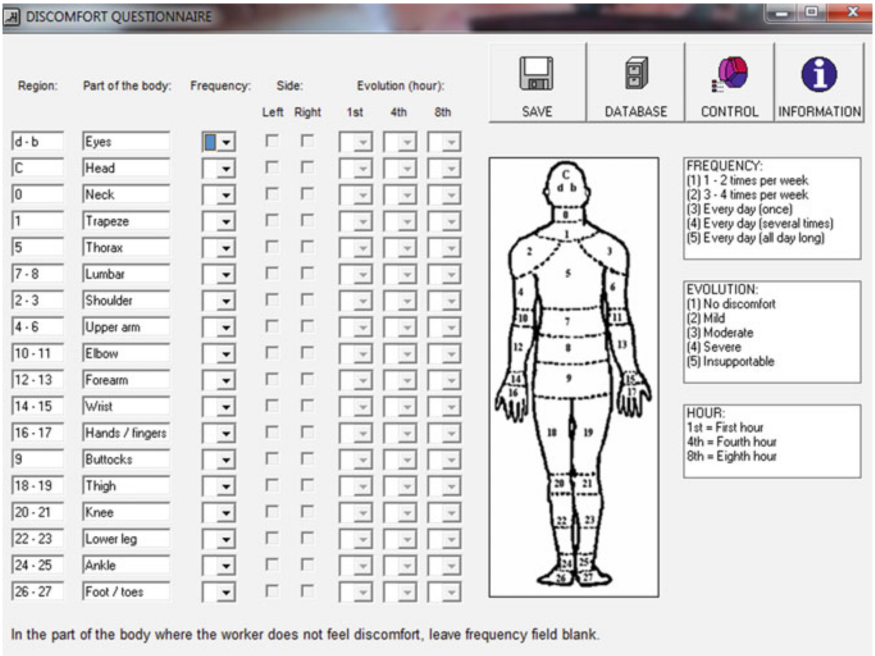

Fig. 7.5 Results of discomfort questionnaire for worker number 66

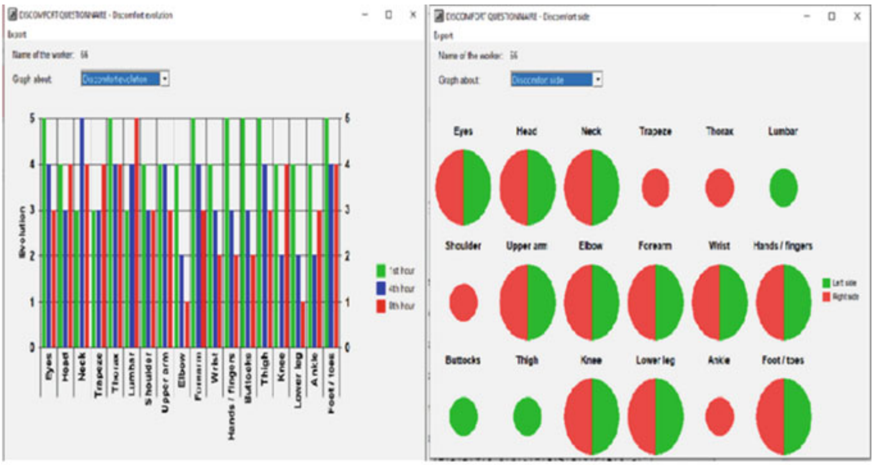

Fig. 7.6 For worker number 66: **a** Discomfort evolution, **b** Discomfort side

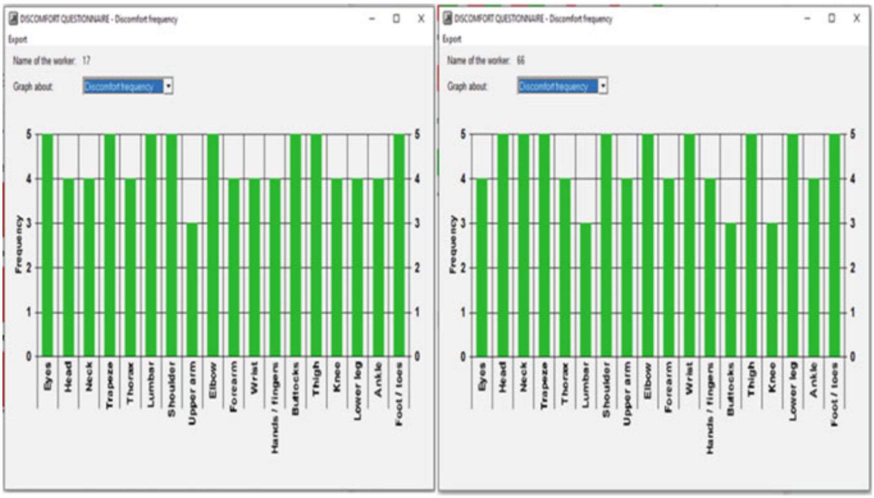

Fig. 7.7 Discomfort frequency of **a** Worker number 17, **b** Worker number 66

7.4.2 Ovako Working Posture Analysis System (OWAS)

The Ovako Working Posture Analysis System (OWAS) analysis was conducted on worker number 17 casting with molten metals as per Fig. 7.8.

Figure 7.9 shows the OWAS sheet in the software ErgoFellow. This sheet provides the individual postural score for the back, arms, and legs of male workers 17 and the

Fig. 7.8 Male worker pouring hot molten metal

total postural load with a value of 4. Then, corrective actions for improvement are immediately required in the molten metal pouring task. Similarly, Figs. 7.10 and 7.11 show the suggestion for immediate corrective action necessary for worker number 17 to avoid physical stress.

Figure 7.12 shows that women worker number 66 was doing loading and unloading work in a squatting posture with a heavy load on her head.

Figure 7.13 shows the individual postural score for the back, arms, and legs of female worker 66 and the total postural load with a value of 4. Then, corrective actions for improvement are required immediately to minimize physical stress and MSDs shown in Figs. 7.14 and 7.15.

As the above, ergonomic tools suggest immediate action. Hence to study physical workload on mental stress, Simulation annealing is conducted to measure mental stress against the change in body parameters like BP, temperature, pulse rate and Kcal burnt for both workers. Worker number 17 and 66 performed the same operation

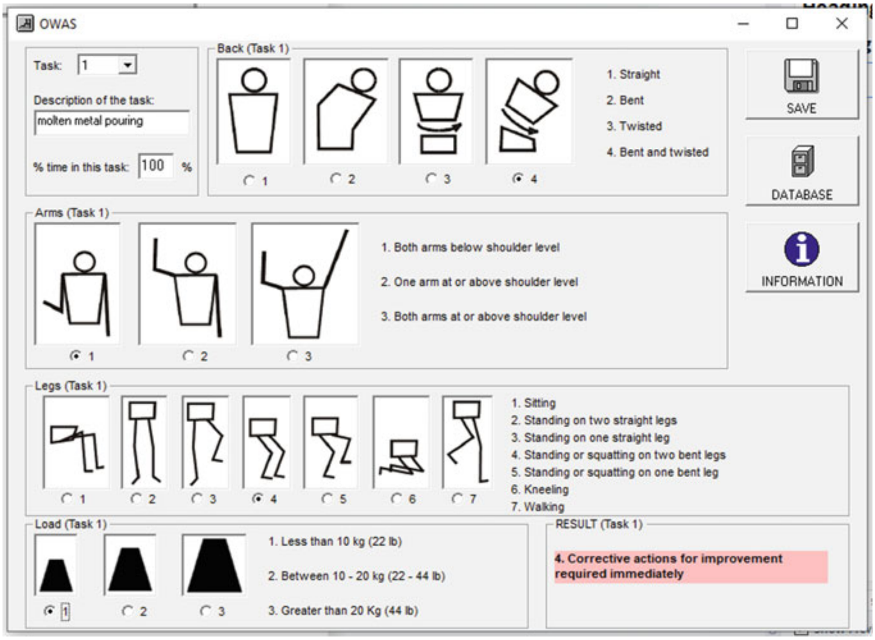

Fig. 7.9 Male worker pouring hot molten metal (Input)

for 7–8 h a day. Hence the physical stress impacted their mental stress, and SA was implied.

7.4.3 Output SA for the Evaluation of Mental Stress on Industrial Workers

After analysis in Minitab®, it was found that the mental stress of industrial workers was considerable at $p = 0.05$ with "High BP" (Table 7.1). High BP shows a good correlation with mental stress, which means that mental stress also increases due to heavy work with increasing blood pressure. Other parameters show less correlation as per the Pearson correlation coefficient.

Then, linear regression analysis was conducted by Minitab® software. The result was Eq. (7.1), where output = mental stress, a dependent variable and input variables/ independent variables = Kcal burnt, pulse rate, High BP, Low BP, and temperature.

$$\text{Mental Stress} = -3.77 - 0.00035C_1 - 0.0267C_2 + 0.0387C_3 + 0.0125C_4 + 0.0187C_5 \tag{7.1}$$

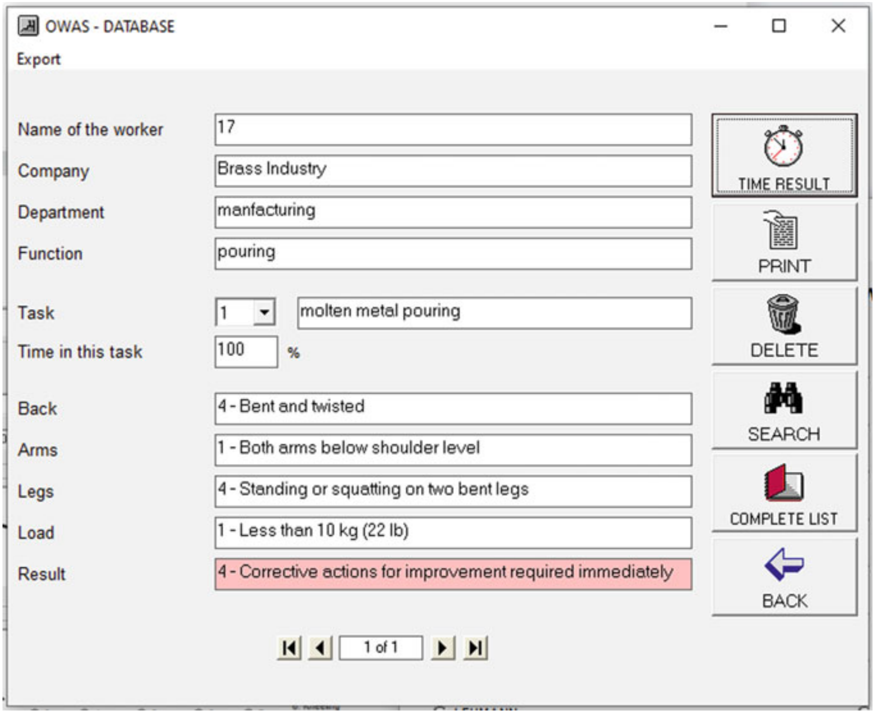

Fig. 7.10 Male worker pouring hot molten metal (Database)

Here, C_1 = kcal burnt, C_2 = Pulse rate, C_3 = High BP, C_4 = Low BP, and C_5 = Temperature.

Then simulated annealing (SA) model was created from the advancement of crystals after liquids. The thought depends on the strategy where fluids end or metals re-crystallize in the technique for tempering. As a rule, in physical science, the minor vitality state mainly implies a much-arranged state, for example, a crystal lattice. However, it is also well-known that base temperature is not a sufficient circumstance to find the ground condition of the material. Initial SA occurs from an initial solution at a high temperature, followed by subsequent changes based on annealing schedules. For any two-iterations, two objective values are considered to indicate as (new) f_i and (old) f_{i-1}, and their different value is calculated as: "$\Delta f = f_i - f_{i-1}$". Acceptance of new solution takes place for "$\Delta f \leq 0$", with the probability of "$P(T) = 1$". Otherwise, the acceptance with more negligible probability takes place, including "$P(T) = \exp(-\Delta f/kT)$," where 'k' represents the constant (i.e., Boltzmann) process parameter with 'T' to be the instantaneous temperature. Later to enough iteration numbers, the optimum solutions-value is obtained (Pandey and Parhi 2016). However, in the process of SA, the objective moves from the higher-energy regions to lower-energy regions in the search space.

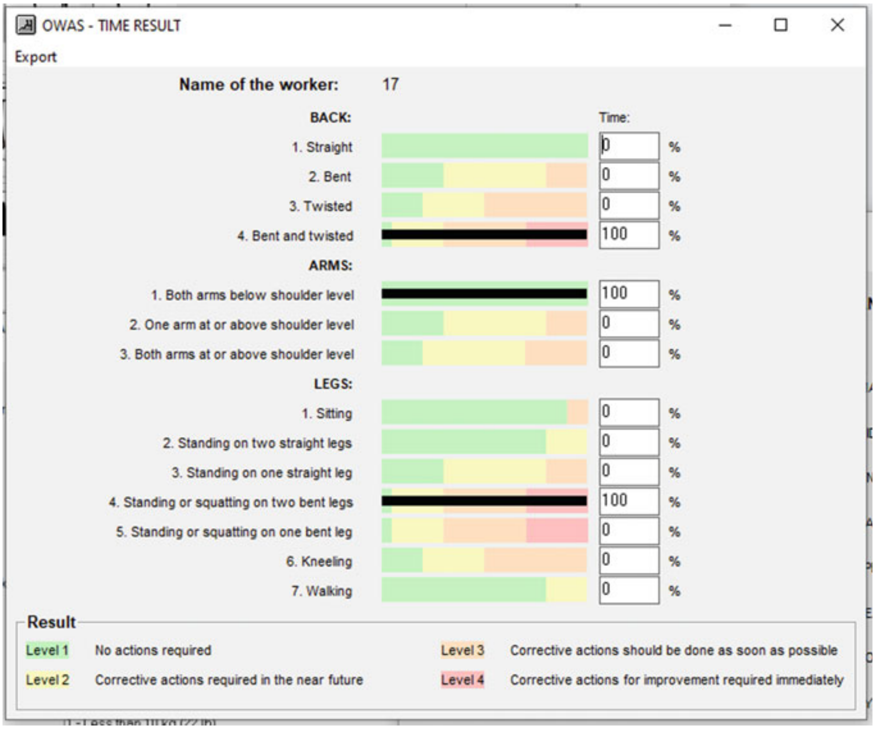

Fig. 7.11 Male worker pouring hot molten metal (Time result) OUTPUT corrective actions for improvement required immediately

Figure 7.16 shows the function, i.e., Eq. (7.1), as input to SA. There were 5820 iterations, after which the best function value was 0.48989, which lies between the range 0 to 1. It shows the fitness and accuracy of the Equation. It means that mental stress is highly affected by internal parameters, and the change of internal parameters in workers' bodies was found by physical stress. Hence, a comfortable workplace and advanced technology may change/reduce the workers' physical and mental stress.

7.5 Conclusions

In this chapter, a worker who works in a utensil manufacturing industry is more at risk of injury. Industrial risk factors are the leading cause of health problems. Industrial workers can adversely affect their bodies, reducing productivity and product work quality and increasing musculoskeletal disorder problems, which cause serious health problems that affect workers' mental well-being and reduce their work efficiency. The ergonomic evaluation of work postures was the first point in treating work-related body problems. Sometimes their working positions are unsuitable for an extended

Fig. 7.12 Female worker lifting brass metal

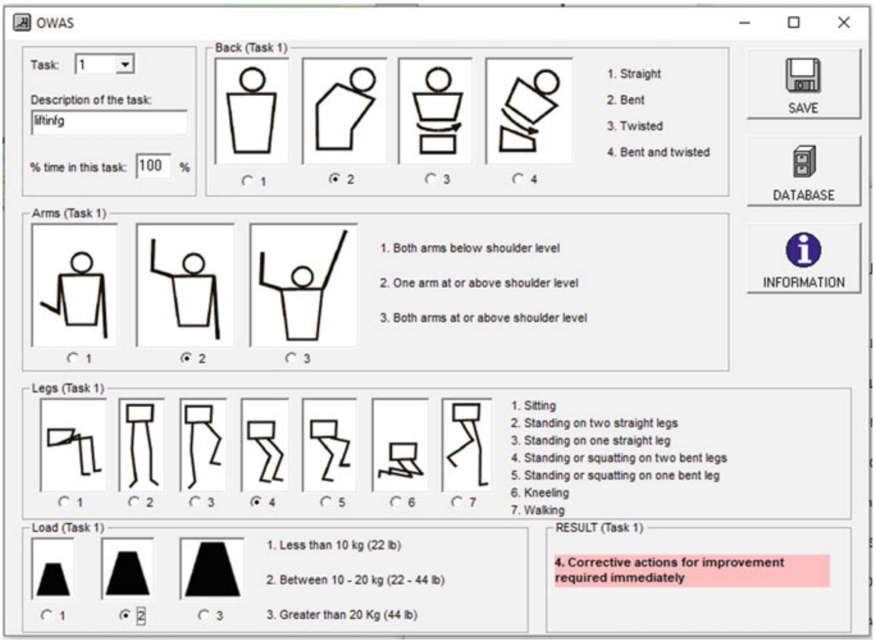

Fig. 7.13 Female worker lifting brass metal (Input)

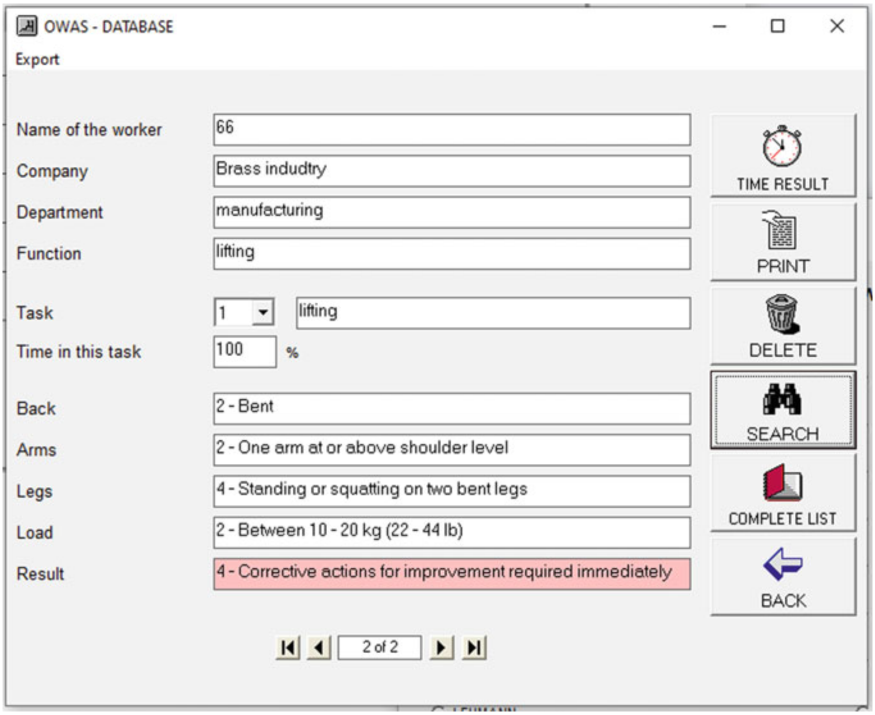

Fig. 7.14 Female worker lifting brass metal (Database)

period, which tends to lead to musculoskeletal disorders and problems and to lead to mental stresses. Based on the discomfort questionnaires for workers, discomfort frequency was observed in the neck for worker number 17, followed by the shoulder, lower leg, thorax, elbow and thigh.

Similarly, the discomfort frequency was higher in the head and neck, followed by the shoulder, for worker 66. OWAS was used to analyze the posture of industrial worker capture while working in industries. After the evaluation, it was obtained that corrective actions are required for the required improvement immediately. In SA, after 5820 iterations, the number of function evaluations was 6067, got the best function value obtained was 0.48989. The result shows that mental pressure highly impacts Kcal burnt, pulse rate, and high BP of workers in the utensil industry. Hence, to reduce mental stress, the ergonomic design of protective equipment is essential to reduce physical workload and comfort in the workplace.

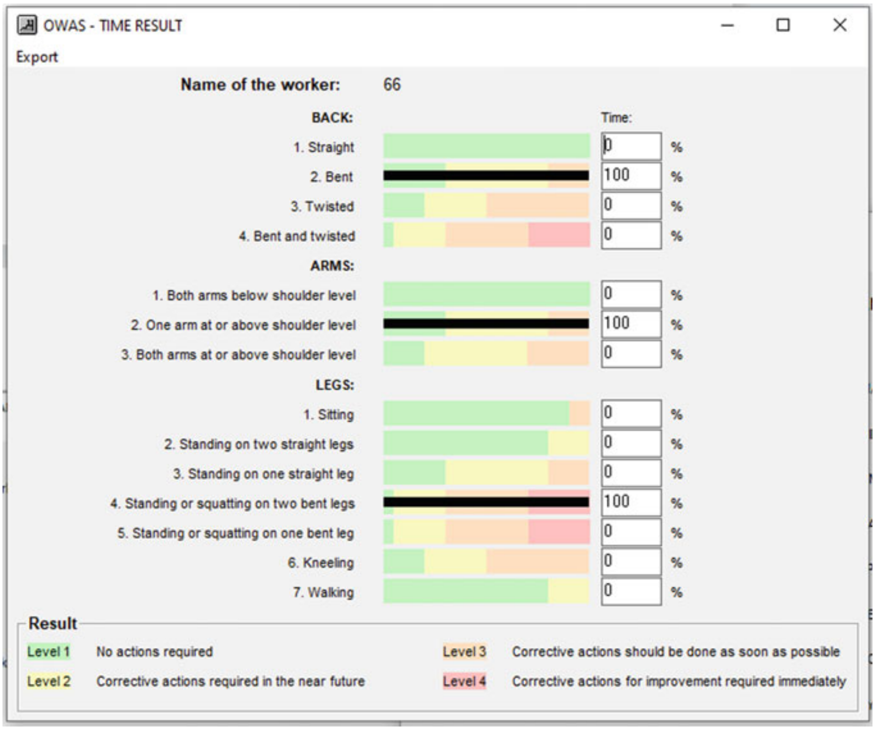

Fig. 7.15 Female worker lifting brass metal (Time result) OUTPUT corrective actions for improvement required immediately

Table 7.1 Correlation of mental stress and the associated parameters for farmers

Parameters	Correlation of mental stress
Kcal burnt	−0.043
Pulse rate	−0.175
High BP	0.379[a]
Low BP	0.157
Temperature	0.077

[a]Correlation is significant at $p < 0.05$ (2-tailed)

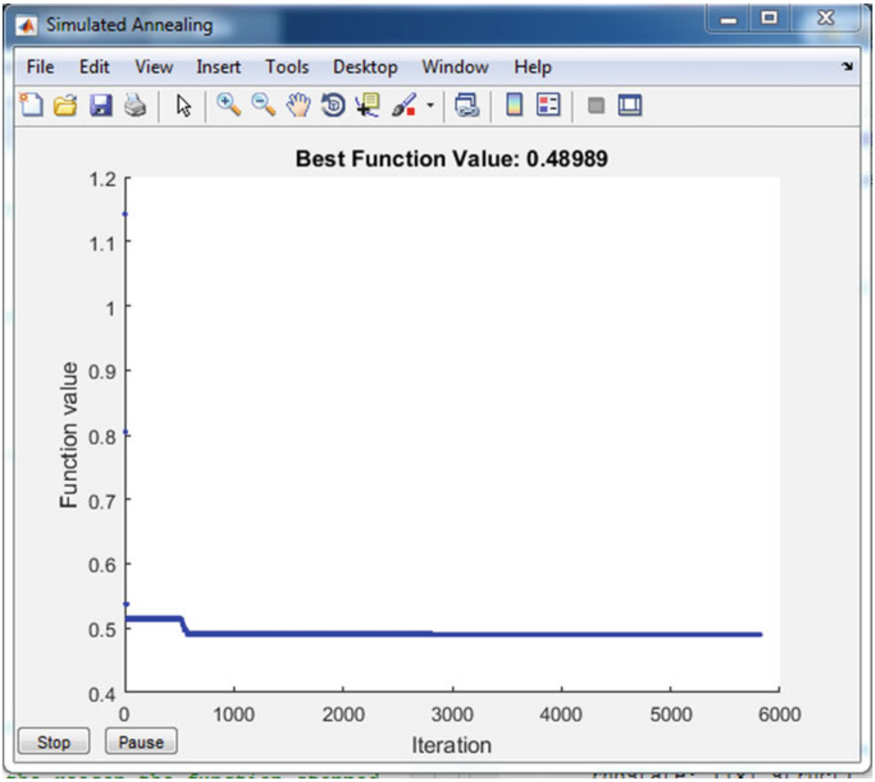

Fig. 7.16 Result of Simulated Annealing (SA) for Eq. (7.1)

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Chapter 8
Using the WASPAS and SA Techniques to Analyze Risks in a Noisy Environment Qualitatively—A Case Study of Different Manufacturing Industries Near Bhubaneswar

Tushar Kanta Mahapatra and Suchismita Satapathy

Abstract Noise is a critical environmental element that affects people's health because it affects their effectiveness, efficiency, and vulnerability to physical and psychological risks. Risks not considered during the planning stage could have significant consequences later in the project life cycle. Therefore, assessing health risks in the industry is a crucial part of workers' health and company growth. Therefore, the goal of this case study is to determine how loud noise influences how work is performed in the industry. For this goal, Simulation annealing (SA) was used. Moreover, the weighted aggregated sum product assessment (WASPAS) approach was applied to determine the risk created when working in a noisy environment. After analyzing the risk using the WASPAS method, sleeping was one of the biggest health concerns among all these threats. Many internal problems may develop if someone does not sleep enough at night. Another significant difficulty is high blood pressure, the second worst danger. In addition, the health issues of laborers during machining have been investigated using a proposed model to predict the connection limits through simulated annealing via MATLAB. These limits include vibrations, sound pressure, and temperature. When the risks to human health were compared, it was discovered that the inside room's human health impact was more significant than that of the outside room. Hearing conservation measures should be organized in a noisy environment. This study suggests that the WASPAS approach is more accurate than the multicriteria decision-making (MCDM) methodology for evaluating hazards in real-world settings and the SA method for evaluating the effects of noise on human health.

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8.1 Introduction

Noise pollution is a long-standing issue for humans because it temporarily interrupts natural equilibrium, which can lead to adverse health repercussions. There is no distinction between noise and sound from a physical perspective, and noise refers to how we perceive sound instead of sound, a sensory impression (Jariwala et al. 2017). Noise pollution is an unintended consequence of urbanization, industrialization, economic growth, and motorized transportation. It still poses a risk to environmental protection and human health and well-being, although it might not seem as hazardous as other types of pollution (Subramaniam et al. 2019; Khajenasiri et al. 2016).

The consequences of noise pollution are gradual and subtle: they may be uncomfortable immediately, but after extended exposure to damaging sounds, they become harmful (Melamed et al. 2001). Unlike air and water pollution, noise pollutants interfere with naturally occurring waves of a comparable sort in the same environment (Ghezavati et al. 2013). Although studies have shown that exposure to continuous or excessive noise levels can result in severe health impacts, noise-induced hearing loss (NIHL) is noise's most common health effect (Codur et al. 2017).

Excessive noise has been linked to aggressive behavior, ongoing tension, and tiredness, which can harm psychological health (Mithanga et al. 2013). Loud noise disturbs sleep cycles, leading to fatigue, poor performance, and sleep disorders. Later in adulthood, they may develop into more severe and enduring health issues (Hashim et al. 2012). Excessive noise levels are associated with cardiovascular problems. Studies have defined noise pollution as louder than 65 decibels (dB). Noise starts to feel uncomfortable at 120 dB and becomes dangerous at 75 dB. While ambient noise levels exceeding 30 dB at night cannot be tolerated, it is advised that sound levels should be kept under 65 dB during the day (Shapiro and Berland 1972).

Noise is perhaps the most prevalent workplace hazard as well as an environmental hazard (Sharaf and Abdelwahab 2015). All human activities produce noise levels, which can be further separated into two categories based on how they affect people's health: occupational noise and environmental noise. Environmental noise includes noise from traffic, music, and other sources (Dai and Li 2016).

The fact that noise is a physical phenomenon easily sensed in the workplace is one factor in many industries concerned about noise (Clark and Bohn 1999; Vasudevan et al. 2019). One of the most significant physical factors in most production facilities is unwanted sound, which presents various problems for industrial workers (Lalremruata et al. 2019). Several studies have found that 30 million workers in the United States (US) are often exposed to excessive noise (Chileshe and Adwoa Boadua 2012).

Noise is one of the most significant environmental risks in industrial areas, although the impacts vary according to the job and workplace (Basner et al. 2014). Several studies have confirmed the impact of noise on the auditory system (Kahya 2007). Many studies have shown that loudness also affects the cardiovascular system of workers, causing hypertension, headaches, sleepiness, tension, and irritability, resulting from disturbances in thoughts, feelings, and everyday activities (Berger and Ehrsson 2013). In addition, because of the increased noise levels in workshops, there are more human errors, which increase the risk of workplace accidents and ultimately lower productivity.

Industrial epidemiology studies have generally shown and supported the impact of noise on efficiency and mental health (Ising and Michalak 2004). Several studies have shown that noise pollution negatively affects workers' productivity and effectiveness. Generally, some incidents can be viewed as signs of how noise affects performance. Many studies have found that loud noise can increase errors and, as a result, the likelihood of accidents. This is especially significant when engaging in mental tasks that call for working memory, such as attention to multiple phenomena in complicated systems (Wu et al. 2016).

Based on previous discussions, noise is an environmental element that significantly impacts people's performance, and its impact may be measured in those exposed to noise at work (Firdaus and Ahmad 2010). In addition, one of the most delicate factors related to the impact of noise is performance, which harms people physically and psychologically and reduces their productivity (Singh and Davar 2004; Odeyinka et al. 2012).

Therefore, this study aimed to assess and investigate the impact of noise on those who work in noisy environments. Several multicriteria decision-making (MCDM) strategies have been developed to assess employee health risks in noisy situations. Multicriteria decision-making (MCDM) methods are becoming increasingly popular as prospective instruments for assessing and resolving complicated real-time problems. This is because of their inherent ability to analyze multiple alternatives against various factors to select the optimal choice (Turkis et al. 2015). Therefore, the primary goal of this study was to discover and evaluate the effects of industrial noise pollution on people's health using the WASPAS method. Moreover, this study evaluates how much noise affects the workers while working in a noisy environment, such as an automobile workshop or the textile industry near Bhubaneswar, using the simulated annealing (SA) method, which will help avoid unhappiness and the issues listed above in previous paragraphs.

8.2 Literature Review

Noise pollution is a sound that exceeds an acceptable level and becomes undesirable and unpleasant, hurting human health. The frequency content of sound waves is the most crucial aspect of hearing any sound to the human ear, and the average man's hearing ranges are between 20 and 20,000 Hz (www.global.widex.com accede on 07.12.2020). Noise is continuous in daily life and can cause a wide range of auditory and nonauditory health concerns (Kitahara et al. 1984). Loud noise impairs hearing in industrial areas and influences social noise exposure. This study emphasizes the importance of firms using personal protective equipment, soundproof buildings, and vibration-resistant foundations to mitigate the adverse effects of noise pollution.

Noise pollution has never been a new issue for people, especially in most industrial towns and large cities. Recent research has illustrated different noise pollution sources, noise measurements, noise impacts, and harmful effects on health (Mangalekar et al. 2012). The current requirement is to control and prevent this by applying various efficient methods at the source. This research aims to understand noise production methods and how to prevent and manage them (Wokekoro 2020).

Author's (Grailey et al. 2021; Babisch 2005), state that workplace culture can significantly impact a representative's mental health. In their study, 30 individuals representing a multidisciplinary group and all status levels were selected using an intentional inspection process. Furthermore, reduced work-related stress and higher worker wealth can lead to more significant organizational commitment, improved usefulness, and career life (Hashim et al. 2012). Research has shown a clear connection between noise pollution and an increased risk of cardiovascular disease. In addition to the critical link between noise pollution and high blood pressure, a risk factor for cardiovascular disease, studies have connected noise pollution to the incidence of myocardial infarction and stroke (Aluko and Nna 2015).

According to Lalremruata et al. (2019), hearing loss varies from person to person based on the intensity, frequency, and length of noise exposure. Their research found that sustained exposure to noise levels above 85 dB could cause this.

According to Mithanga et al. (2013), noise sources that may harm the health of exposed people or communities are called noise. In the Thika District of Kenya, this study evaluated the noise exposure level in the workplace in several manufacturing sectors. The study (Khajenasiri et al. 2016), was performed with university students to determine the effect of exposure to high noise levels on the performance and rate of error in manual activities. The primary goal of their study was to determine how exposure to noise at sound pressure levels between 70 and 110 dB affected healthy students. They found that a sound level of 110 dB was significantly associated with decreased performance. However, there was no connection between the error and performance duration at sound levels between 70 and 90 dB (Khajenasiri et al. 2016).

The author (Subramaniam et al. 2019) performed a study to estimate the maximum working hours due to employees' overexposure to the noise hazard in the industry. Initially, a dosimeter was employed to assess noise exposure. Suggestions for standard occupation noise openness were developed based on noise working safety circumstances assessments by NIOSH and OSHA. The authors (Subramaniam et al. 2019) showed that rapid development has increased noise pollution and public awareness of this issue in recent decades. This manufacturing business employs people and generates significant noise from machines.

The study showed the impact of electromagnetic fields and noise at a power plant in Shiraz on people's psychological well-being. Due to significant industrial and scientific advances, humans have been exposed to various physical and chemical components. Several of these elements are known as constant constituents of the environment, such as electromagnetism (Zamanian et al. 2010).

In this study, the authors (Badalpur and Nurbakhsh 2021) identified and evaluated the risks of a road construction project in Iran. The findings revealed that the most significant risks identified were the inaccessibility of barrow pits, loss of crucial workforce during the project life cycle, and hiring inexperienced subcontractors. This study also proposed the WASPAS approach as a more accurate method among MCDM techniques for evaluating risks in a real-world context.

8.2.1 Types of Risk

8.2.1.1 Sleeping Disturbance

Uninterrupted sleep is necessary for healthy individuals to function both physiologically and mentally. Environmental noise is a critical factor that causes sleep disturbance. Continuous sleep disruption results in mood swings, decreased performance, and long-term detrimental effects on health and wellness. Trouble getting to sleep, frequent awakenings, rising too early, and variations in the depth and stage of sleep are the primary causes of sleep disruption. Moreover, exposure to noise during sleep increases the heart rate, blood pressure, pulse amplitude, vasoconstriction, breathing changes, cardiac arrhythmias, and body movement (Berglund and Lindvall 1995).

8.2.1.2 Disorders of Mental Health

Noise pollution is not considered a cause of mental illness but is thought to accelerate and exacerbate the development of latent mental disorders. In addition, the following negative impacts may result from or be aggravated by noise pollution: argumentativeness, stress, nausea, headaches, emotional instability, impotence during sexual activity, hysteria, a surge in social disputes, nervousness, neurosis, and psychosis (Berglund and Lindvall 1995).

8.2.1.3 Displeasing Social Behavior and Annoyance

Annoyance is “a sense of dislike connected with any agent or condition, which an individual or group knows or believes will negatively affect them.” The broad spectrum of unpleasant feelings brought on by noise pollution—anger, displeasure, discontent, withdrawal, helplessness, despair, worry, distraction, agitation, or exhaustion—is not adequately described by the word “annoyance” (Basner et al. 2014).

8.2.1.4 Hearing Issue

Any undesirable sound our ears are not designed to filter can harm our bodies. Our ears receive a specific volume of noise without causing harm. Artificial noises such as jackhammers, horns, machines, aero-planes, and vehicles can exceed our hearing range. Repeated exposure to loud noises can quickly damage our eardrums, leading to hearing loss. In addition, it reduces our sensitivity to noise that our ears naturally detect and use to regulate our heart rate (Hartwig 2013).

8.2.1.5 Disturbance in Communication

High-decibel noise can cause issues and make it difficult for two individuals to speak freely. This might lead to misconceptions, and individuals may find it difficult to understand the other person. People may experience severe headaches and emotional instability if there is constant sharp noise. However, children are also in danger. Evidence shows that children who grow up in loud environments have higher stress hormones and blood pressure levels (Hsu et al. 2012).

8.2.1.6 Cardiovascular Problem

Cardiovascular disease, high blood pressure, and heart issues caused by stress are all increasing. According to previous studies, loud noise interrupts regular blood flow, increasing blood pressure and heart rate (Basner et al. 2014). Children are also in danger, and there is evidence that children living in noisy environments have increased blood pressure and elevated levels of stress chemicals.

8.2.2 WASPAS Method

One of the most recent and effective MCDM techniques for increasing alternative ranking accuracy, the WASPAS method, combines the Weighted Product Model (WPM) and Weighted Sum Model (WSM) (Coşgun et al. 2014). After lengthy investigations and discussions, they concluded that the WASPAS was more effective than the WSM and WPM (Trapp et al. 2007; Trapp and Hodgdon 2008). They also emphasized the precision of the WASPAS method compared to other methods. The current research has demonstrated the usefulness of the WASPAS method in various fields. Furthermore, among the MCDM techniques, the WASPAS method is recommended to be more accurate and acceptable for risk assessment in real-world settings (De et al. 2017).

Author presented a real-world case study of Belgrade to fully demonstrate the potential and applications of the picture-fuzzy WASPAS approach. Postomates the food delivery service is the most effective mode for Last-mile delivery (LMD) in Belgrade, according to the findings, followed by cargo bicycles, drones, conventional delivery, autonomous cars, and tube transportation (Perčić et al. 2021).

Weighted aggregate sum product assessment is a novel method that combines the weighted sum model (WSM) with the weighted product model (WPM) (WASPAS). Owing to its numerical simplicity and capacity to provide more accurate results compared to the WSM and WPM techniques, the WASPAS method is now frequently recognized as a helpful decision-making tool. The following subsections explain how the steps of the WASPAS method were applied in this study (Chakraborty et al. 2015).

Step-1 Constitution of Decision Matrix: In the first step, a decision matrix (X) is built to show how options perform according to the criteria. This matrix corresponds to Eq. (8.1), and the choice matrix column X_{ij} denotes how well an alternative is performed according to the j criterion.

$$X = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \dots & \dots & \dots & \dots \\ X_{m1} & X_{m2} & \dots & X_{mn} \end{bmatrix} \tag{8.1}$$

Step-2 Normalization of Decision Matrix: The two formulae below normalize each matrix component for normalization so that the performance metrics are equivalent and dimensionless.

$$\overline{X}_{ij} = \frac{X_{ij}}{Max_i X_{ij}} \tag{8.2}$$

$$\overline{X}_{ij} = \frac{Min_i X_{ij}}{X_{ij}} \tag{8.3}$$

Here, $\overline{X}_{ij}$ is the normalized value of X_{ij}; Eq. (8.2) is for beneficial criteria, and Eq. (8.3) is for non-beneficial criteria.

Step 3: Calculation of Relative Performances of Alternatives According to the WSM Method

The WASPAS technique seeks a joint optimality criterion based on the two optimality criteria. The WSM approach is comparable to the first optimality criterion, the mean-weighted success criterion. It is a well-known and recognized MCDM method for evaluating numerous alternatives per decision criterion. The WSM technique was used to determine the overall relative value of the ith alternative by applying Eq. (8.4):

$$Q_i^{(1)} = \sum\nolimits_{j=1}^{n} \overline{X}_{ij} W_j \tag{8.4}$$

where W_j denotes the weight (relative importance) of *the jth* criterion.

Step 4: Calculation of Relative Performances of Alternatives According to the WPM Method

The WPM approach uses Eq. (8.5) to evaluate the total relative value for each choice. Each criterion's alternative value was multiplied by the power of the identical indexed criterion weight to achieve this.

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{X}_{ij}\right)^{W_j} \tag{8.5}$$

The suggested combination generalized criterion is a weighted aggregation criterion of both the additive and multiplicative approaches.

Step 5: Calculation of Final Performance of Alternatives

The relative performances generated by Eqs. (8.4) and (8.5) are summed to determine the ultimate performance of alternatives Q_i, which depicts their positions in a general ranking. This was performed by applying Eq. (8.6).

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} \tag{8.6}$$

Equation 8.7 can be utilized to improve the ranking effectiveness and judgment accuracy. Q_i is a parameter that accepts values between 0 and 1.

$$Q_i = \alpha Q_i^{(1)} + (1 - \alpha)Q_i^{(2)} \tag{8.7}$$

Here, $\alpha = 0, 0.1, \ldots, 1$. The WASPAS approach becomes the WSM method when α is equal to 1 and the WPM method when α is equal to 0. This value is entirely under user control.

Step 6: Ranking of Alternatives

Q_i values were ranked from highest to lowest to determine the final rankings of the alternatives. The best option on this list is the first, whereas the worst is the last.

8.2.3 Simulated Annealing

A technique for finding the answer to the unconstrained and bound-obliged enhancing problem is called simulation annealing (SA). It helps locate global optimization in the presence of numerous close-by boundary conditions. This thermodynamic behavior and pursuit of global minima in a separate optimization issue are connected via simulated annealing (Aarts and Korst 1989). Additionally, it offers a logical way to take advantage of this link. Compared with other methods, SA algorithms provide practical solutions (from theoretical to practical engineering difficulties) with significantly reduced computational effort (Cunha and Marques 2020).

When a discrete optimization problem is handled using a simulated annealing technique, the objective function provides values for two solutions (the current and freshly chosen solution), which are compared at each iteration (Marques et al. 2018). To escape the local optimum in pursuit of the global optimum, a portion of the non-improving (inferior) answers is accepted instead of all improving alternatives.

According to Sengupta and Saha (2018), the reference-point-based simulated annealing algorithm (RSA) is a ground-breaking unconstrained many-objective optimization technique used to evaluate academic optimization problems. The authors propose an "archive-to-archive" approach, which significantly improves the results, in contrast to the older "point-to-point" archived multiobjective simulated annealing (MOSA) algorithms. Based on comparisons with the results of other methods, the authors showed that the RSA performs well for various problem types (Shi et al. 2014).

The study (Marques et al. 2018) proposed a multiobjective optimization model for the flexible design of water distribution networks (WDNs). This model has the following four objectives: the reduction of the pressure deficit and undelivered demand are objectives related to the hydraulic capacity of the WDNs. The third objective is the usual cost-cutting objective, whereas the fourth is lowering carbon emissions. The obtained results allow for a thorough examination of trade-offs between goals, show the value of considering the minimization of each goal, and highlight the advantages of using a flexible method to create WDNs to inform decision-makers better.

The study that provided a thorough analysis of optimization strategies based on simulated annealing (SA). A desired global minimum or maximum is buried amid many local minima or maxima in single- and multiobjective optimization problems, which are tackled using SA-based methods.

8.3 Methodology

8.3.1 Study Area

This research was conducted in the Bhubaneswar region in Odisha, India. This city has an area of 422 km^2 and a population of 8.37 lakhs (according to the 2011 census). To determine the impact of noise on the hearing capacity of workers, four industries were surveyed: the textile industry, automobile workshops, pipe manufacturing companies, and utensil manufacturing companies. In this study, 160 laborers were surveyed, of which 90 were male and 70 were female, aged between 30 and 55 years old. A total of 22 machines were chosen from an automobile company workshop, a college workshop, and a small factory to investigate the vibration of various machines during static, loading, and ideal conditions using a vibrometer and the sound produced during the activity was also noted. In doing so, the climate was monitored. Therefore, the machining region temperature measures the capacity of the machine operator, which works for 8–10 h. Furthermore, workers' noise and hearing impacts outside the wall were also measured.

8.3.2 Risk Identification

A thorough literature review determined that the noise generated by these industrial facilities might impact neighboring residents and people working in factories and plants. Depending on the frequency, amplitude, and range of industrial noise, it might annoy people and close or obstruct their speech and hearing, causing permanent hearing loss. This study identified the risk from four distinct regions: the education hub, plastic bucket manufacturing industry, automotive manufacturing company, and textile company in and around Bhubaneswar. Table 8.1 shows the different types of risks in the sectors (automobile workshops and small factories) near Bhubaneswar. All risks are mentioned (e.g., RN_1, RN_2, up to RN_{10}) in Table 8.1 (RN-It represents the risk number that affects a worker's working performance in noisy environments.)

In the expert decision-making matrix, integer scores from 0 to 5 represent the impact of noise on workers. The rate scale scores, ranging from 0 to 5, were as follows:0 for not impacting, 1 for very low impact, 2 for low impact, 3 for moderate impact, 4 for high impact, and 5 for very high impact.

This chapter presents the beneficial and unbeneficial criteria based on how much noise is generated during working hours and how much noise influences people. This study considers college workshops and the plastic recycling industry beneficial because they produce low noise while working. In contrast, automobile workstations and the textile industry are considered unbeneficial criteria, as they produce more noise while working.

This study analyzed 160 workers (40 from each sector, including several college workshops, the plastic recycling sector, automotive workstations, and the textile industry). A descriptive and analytical study assessed the effects of noise on several college workshops, the plastic recycling sector, automotive workstations, and the textile industry near Bhubaneswar, Odisha. Responses from experts such as academicians and doctors and a literature review were used to find the risk factors of noise (Table 8.1). Then, the weighted aggregated sum product assessment (WASPAS)

Table 8.1 Identifying risks for human beings while working in a noisy environment

Identification of risk	Risk number
Sleeping issue	RN_1
Listening trouble	RN_2
Stress	RN_3
Increased blood pressure	RN_4
Headaches	RN_5
Workplace focus	RN_6
Fatigue	RN_7
Sadness	RN_8
Anxiety	RN_9
Aggressive attitude	RN_{10}

multicriteria decision-making tool is used to prioritize the risk factors of noise. First, the entropy method was used to determine the weights of the noise risk factors, and then the WASPAS method was used to rank them. Later Simulation Annealing method was used to predict the hearing capability of 160 workers engaged in the textile industry, plastic manufacturing industry, automobile workshops, and experimenting machines in educational institutions.

8.4 Result Analysis for the Risk Factor of Noise Analysis

8.4.1 Entropy Method for Calculating the Critical Index Weights

Finally, the index weights were computed using Shannon's entropy. First, each criterion's entropy level (Ej) is calculated using Eq. (8.8). The index weights were computed using Shannon's entropy.

$$E_j = -k \sum_{i=1}^{m} \left[\overline{X}_{ij} Ln \overline{X}_{ij} \right] \tag{8.8}$$

$$k = \frac{1}{Ln(m)} \tag{8.9}$$

The *jth* criterion variability level *d(distance)* was calculated using Eq. (8.10):

$$d_j = 1 - E_j \tag{8.10}$$

The weights of each criterion were derived using Eq. (8.11) if there was no estimate of the weights of the quantities.

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{8.11}$$

8.4.2 Calculating the Critical Weightage

The weights of the risk factors, initial weights for the criterion, and a normalized decision-making matrix were constructed using the following equations: Table 8.2 shows the normalized value of the risk factors selected.

Table 8.3 shows the entropy level of risk factors of 4 industries selected for the study.

Table 8.2 Normalized criteria

Risk	Alternatives			
	Alternative-1	Alternative-2	Alternative-3	Alternative-4
	Education Hub	Plastic manufacturing company	Automobile industry	Textile industry
RN_1	0.22222	0.13095	0.19853	0.18088
RN_2	0.11111	0.15753	0.21560	0.17035
RN_3	0.07778	0.06873	0.08804	0.06462
RN_4	0.07831	0.06642	0.05446	0.03947
RN_5	0.05229	0.05534	0.03927	0.08048
RN_6	0.06897	0.07950	0.05450	0.10428
RN_7	0.07407	0.09091	0.06340	0.06237
RN_8	0.03200	0.06500	0.04308	0.03104
RN_9	0.07438	0.05348	0.04823	0.05034
RN_{10}	0.03571	0.05085	0.08108	0.06747

Table 8.3 Entropy level

E_1	E_2	E_3	E_4
0.77686	0.79950	0.79285	0.79163

Based on Eq. (8.3), the variability level was estimated. Table 8.4 shows the respective variability (distance) of different industries' risk factor.

The criteria weights are determined based on Eq. (8.4). Table 8.5 shows the weights for the risk factor of 4 industries.

The adjusted standards (Eq. (8.3)) were used to calculate the values and weights of each criterion to estimate the overall relative relevance of the *ith* choice. The results are presented in Table 8.4. It should be mentioned that risk is ranked according to the Q_i values. After all the calculations, we could enter the risk response phase because Table 8.5 shows the critical risks. The overall relative importance of the *ith* alternative was determined using Eq. (8.4). From Table 8.1 Identifying risks for human beings while working in a noisy environment by collecting data for risk factors from 160 workers, a weighted sum of Table 8.6 was generated.

Table 8.4 Variability level

d_1	d_2	d_3	d_4
0.22314	0.20050	0.20715	0.20837

Table 8.5 Weights of different criteria that be considered

W_1	W_2	W_3	W_4
0.26591	0.32547	0.16510	0.19891

Table 8.6 Values of weighted sum model (WSM)

Risk	Alternative-1 education hub	Alternative-2 manufacturing company	Alternative-3 automobile industry	Alternative-4 textile industry
RN_1	0.04	0.13	0.16	0.20
RN_2	0.09	0.12	0.14	0.16
RN_3	0.08	0.14	0.12	0.12
RN_4	0.08	0.16	0.07	0.07
RN_5	0.13	0.20	0.05	0.14
RN_6	0.11	0.15	0.06	0.16
RN_7	0.11	0.14	0.07	0.09
RN_8	0.27	0.22	0.04	0.04
RN_9	0.12	0.28	0.05	0.06
RN_{10}	0.27	0.32	0.07	0.08

Table 8.7 was generated from Table 8.1 risk factors of noise by calculating Weighted product.

The following is a generalized combined criterion for the weighted aggregation of the additive and multiplicative methods. Table 8.8 shows the value of the weighted aggregated sum product assessment (WSPM) value by combining all the WPM and WSM data. Subsequently, the overall noise risk ranking was assessed. This ranking allows us to determine the types of risks that have a lower impact on humans and a more significant impact. According to Table 8.8, all dangers are directly related to the people. Sleeping is one of the biggest health concerns among these threats,

Table 8.7 Values of the weighted product model (WPM)

Risk	Alternatives			
	Alternative-1 education hub	Alternative-2 manufacturing company	Alternative-3 automobile industry	Alternative-4 textile industry
RN_1	0.62	0.75	1.00	1.00
RN_2	0.75	0.74	0.98	0.95
RN_3	0.72	0.78	0.95	0.90
RN_4	0.73	0.80	0.86	0.80
RN_5	0.83	0.87	0.81	0.92
RN_6	0.78	0.79	0.85	0.96
RN_7	0.78	0.78	0.86	0.84
RN_8	1.00	0.89	0.80	0.72
RN_9	0.81	0.97	0.81	0.79
RN_{10}	1.00	1.00	0.88	0.83

Table 8.8 Ranking table

Risk	Preference of WSM	Preference of WPM	Preference of WSPM	Rank
RN_1	0.54	0.47	0.33	10
RN_2	0.51	0.51	0.42	7
RN_3	0.46	0.48	0.40	9
RN_4	0.38	0.41	0.41	8
RN_5	0.52	0.54	0.48	3
RN_6	0.48	0.50	0.44	5
RN_7	0.40	0.44	0.44	5
RN_8	0.57	0.51	0.63	1
RN_9	0.51	0.50	0.46	4
RN_{10}	0.74	0.73	0.63	1

and many internal problems may develop if someone does not sleep sufficiently at night. Another significant difficulty is high blood pressure, the second worst danger. Moreover, high noise levels can affect people's health and mental wellness. Finally, the main concerns of people working in noisy environments include stress and hearing issues.

8.4.3 Simulation Annealing (SA)

Simulation annealing was used to predict the hearing level of 112 workers among 160 workers of textile, plastic manufacturing, automobile and educational institution lab operators, those having medical issues of hearing-related problems. Among them, 65 men and 47 women workers. Those 65 men of the age group 30–55 and women of the age group 30–50. A maximum of them (33 men) were working in the textile industry, 25 in the automobile industry, 5 in the plastic industry, and 2 in educational institutes. Among women workers18, workers were from the textile industry, 17 were from the automobile, 11 of the plastic industry and one was from the educational institution. This optimization was performed to the hearing capability of 112 workers (inside persons) engaged in machining operations. Similarly, 48-person data collected from those working or standing 500 m outside the machine room has hearing issues (outside persons). Both cases were analyzed to determine the impact of noise pollution on hearing capability.

8.4.3.1 Research Methodology for SA

A total of 22 machines were chosen from an automobile company workshop, a college workshop, and a small factory to investigate the vibration of various machines

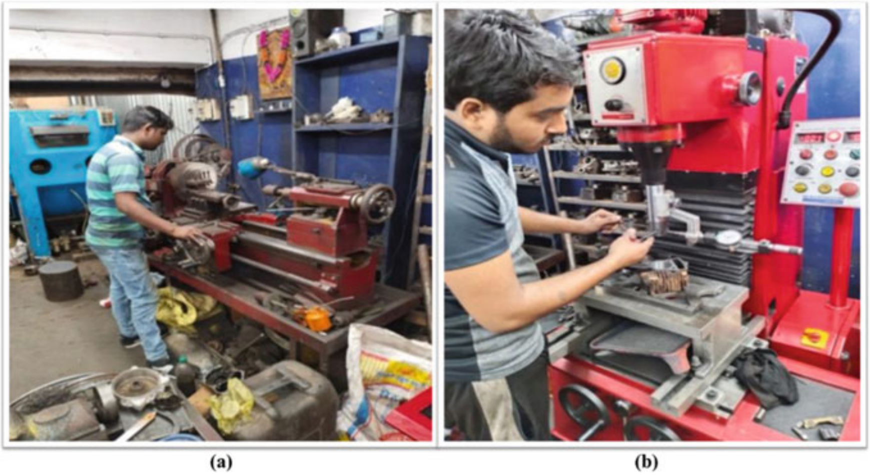

Fig. 8.1 Laborers working in the operation area

under static, loading, and ideal conditions using a vibrometer. Similarly, the sound produced during the activity was measured. In doing so, the climate was monitored. Therefore, the machining region's temperature measures the consultation capacity of the machine administrator, which operates for 8–10 h. Furthermore, the meeting capacity of the external individual, those working in a chamber or outside the machine segment region, is measured.

Figure 8.1a, b show laborers working on the lathe machine in an automobile workshop near Bhubaneswar

8.4.3.2 Vibration Measurement

A minimal device explicitly designed for predictable vibration evaluation and checking down to 1 Hz is the MVM555. This unit reinforces the most recent development strength, enabling easy transportation and relocation. The updated circuit plan and high-quality parts preserve the accuracy throughout scope. A unique component of this device is a piezoelectric accelerometer. This component is used to measure the vibrations produced by the action. A Maico 53 audiometer was used to test the consultation levels of individuals working inside the workspace and outside the active region.

8.4.3.3 Sound Measurement

Instruments such as the TENMA RS-232 Sound Level Meter (SLM) were used to compute the sound level of the noisy environment, with a measurement range of

35–130 dB. The accuracy (1 kHz) was ±2 dB, and the frequency measuring range was 30 Hz–12 kHz. The temperature range of the operation was 0–400 °C.

8.5 Results and Discussion for SA

In Table 8.9, the entire analysis is presented as a percentage. This method was used to analyze information on the previously discussed impact of noise on workers' health in Odisha, India, acquired from multiple sources.

In the past ten years, SA has become a well-known tool for improvement. Many discrete optimization issues and issues involving constant variables have been addressed. A few articles reviewing applications and computations have been published in SA. After collecting the data from the machines, such as the machine's vibration, noise during the operation, and outside temperature (for 22 machines), then entering these values into the "Minitab® 2016" software, the Equation describing the impact of noise on a human concerning their hearing issue was collected. The simulated annealing optimizations were performed by "MATLAB® 2016." Figure 8.2 shows the residual plots for 112 inside persons engaged with machines.

After the formation of the Equation using Minitab®, the regression equation is as shown in Eq. (8.13):

$$IP = 49 + 1.62X_1 - 1.26X_2 - 0.04X_3 + 0.304Y_1 - 0.024Y_2 - 0.063Y_3 \quad (8.13)$$

where *IP* = *Inside Person*. Moreover, for vibration, X_1 = Startup, X_2 = Idle, X_3 = Load, and for the sound level, Y_1 = Startup, Y_2 = Idle, Y_3 = Load.

Table 8.9 Percentage of workers/employers affected by different types of risk

Risk	Alternatives			
	Alternative-1	Alternative-2	Alternative-3	Alternative-4
	College workshops	Plastic recycling sector	Automotive workstations	Textile industry
RN_1	0.24	0.22	0.54	0.7
RN_2	0.12	0.23	0.47	0.54
RN_3	0.14	0.2	0.39	0.42
RN_4	0.13	0.18	0.22	0.24
RN_5	0.08	0.14	0.15	0.47
RN_6	0.1	0.19	0.2	0.56
RN_7	0.1	0.2	0.22	0.3
RN_8	0.04	0.13	0.14	0.14
RN_9	0.09	0.1	0.15	0.22
RN_{10}	0.04	0.09	0.24	0.28

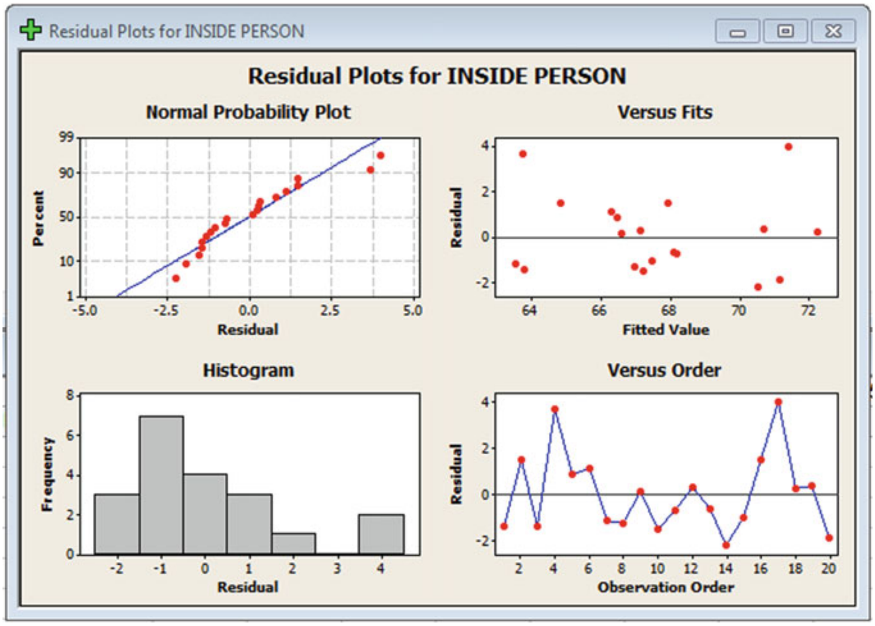

Fig. 8.2 Residual plots for inside person

After putting all the data in Eq. 8.5 for Simulated Annealing, the best value was 2.5297, the iteration value was 9339, and the function evaluation value was 9736, as shown in Fig. 8.3. From Fig. 8.3, it is clear that the noise and vibration have a negative effect, as after 9736 runs, it also shows that the value is not zero, which indicates that all the workers are highly affected.

The analysis was conducted for workers outside the noisy machining location, and their impact on hearing was also studied. Figure 8.4 shows the residual plot for workers at 500 m outside the room.

After inputting all the data in the above Equation for simulated annealing, the best value was 2.45774, the iteration value was 7198, and the function evaluation value was 7505, as shown in Fig. 8.5. After comparing the SA graph of the inside and outside hearing impact, it is clear that the high noise produced during the operation affects the hearing, hearing loss, sleeping problems, and other psychological issues of employees working 8–10 h in this environment. Actions should be taken to minimize and control these hearing problems, as all workers suffer from hearing problems. Some acoustic walls may be structured, absorbing sound to comfort workers engaged within 500 ms.

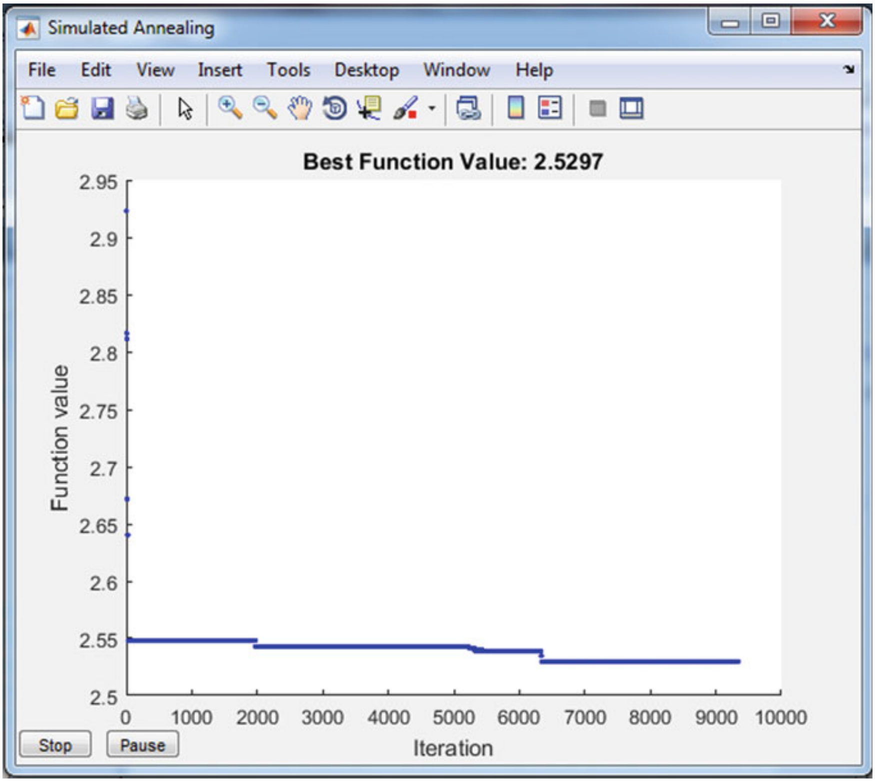

Fig. 8.3 Simulated Annealing value inside the person

8.6 Conclusions and Recommendations

8.6.1 Conclusions

Organizations should remember that managing risks and uncertainties is essential for success in a noisy environment while identifying and evaluating hazards. This study focused on identifying risk factors in several industries, including the college workshop, plastic recycling business, automotive industry, and textile company in Odisha, India, and qualitatively analyzed the risk factors using WASPAS and SA approaches. After identifying the risk factors by qualified professionals during a brainstorming session, hazards were ranked using the WASPAS approach. These findings indicated that stress, sleep apnea, excessive blood pressure, and hearing impairment were the main problems. The WASPAS technique evaluated and ranked risks in a real-world context, and the outcomes were entirely correct. Each study has limitations that, if adequately acknowledged and addressed, will improve the results of follow-up research. First, only high-level threats that could be classified as risks

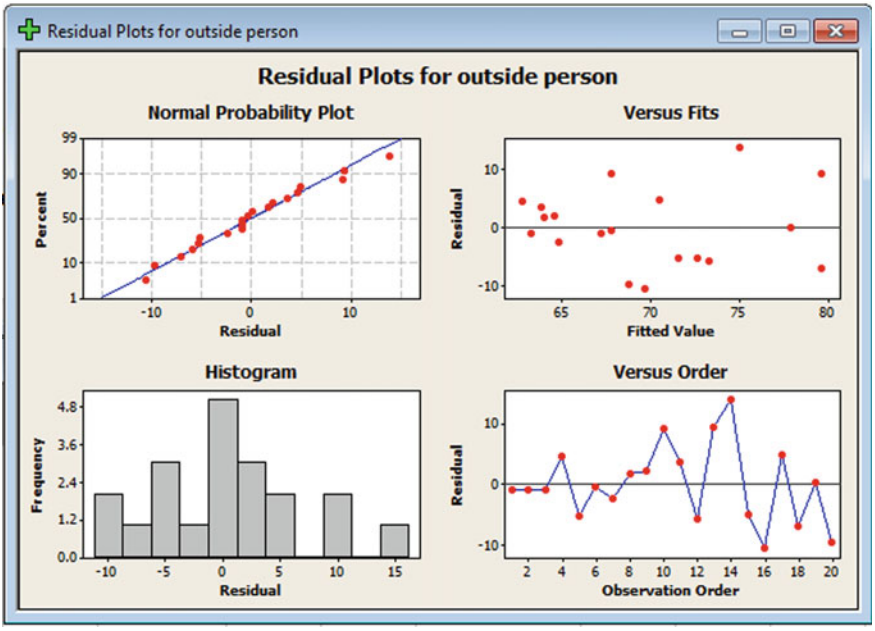

Fig. 8.4 Residual plots for workers who are working outside of the noisy environment room

across all project domains and were found to be riskier during brainstorming sessions were identified.

Also, the health issues of laborers during machining have been investigated using a proposed model to predict, through SA via MATLAB®, the connection limits, such as "Vibration, Sound Pressure, and Temperature." When the risks to human health were compared, it was discovered that the inside room's human health impact was more significant than that of the outside room. Hearing conservation measures should be organized in a noisy environment.

The noise produced by the various machine operations of factories and workshops introduced in this review causes discomfort for laborers who have gripped a few times, requesting an improvement in the noise climate. Therefore, a noise study began with estimations to record the sound level inside the working environment. It is demonstrated that the consequence of error is insignificant after prediction by SA and that the expansion of noise in the working environment influences human behavior and hearing capacity. The results of this study are also prone to change because they were conducted in a specific place.

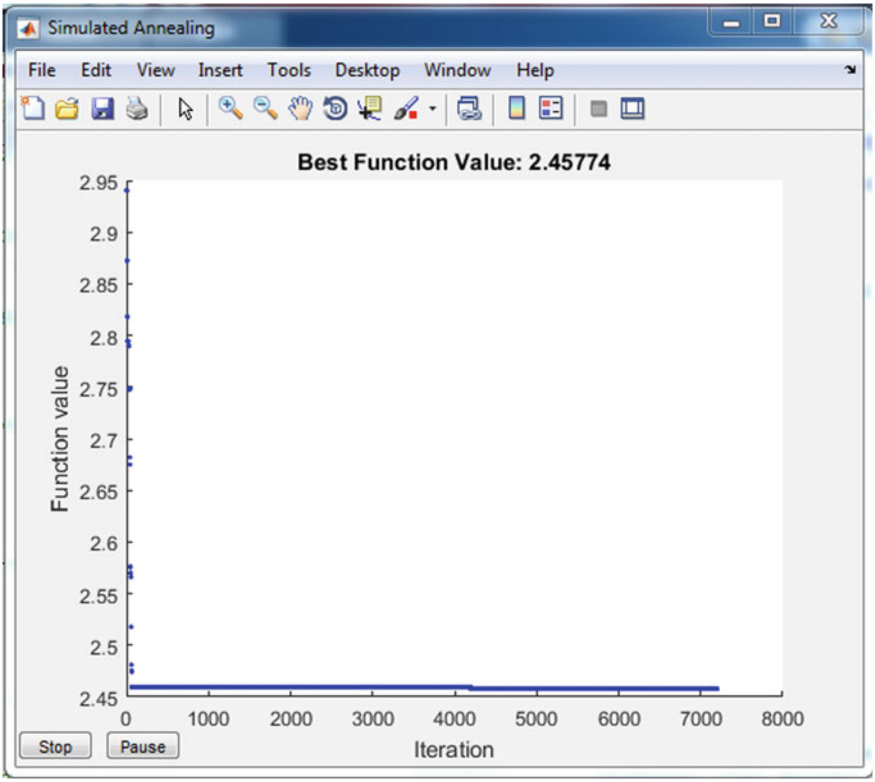

Fig. 8.5 Simulated annealing value outside person

8.6.2 Recommendations

Once the methodology was applied and the results analyzed, the following recommendations were made:

- The present National Environmental (Noise Control) Regulation, implemented in 1996, should be re-evaluated and amended according to the current control, mitigation, and management needs to preserve environmental quality below the standard level.
- Occupational safety and health employees can provide guidance and knowledge to minimize workplace noise.
- Noise levels should be regularly assessed, and work practices should be continuously improved to safeguard workers' hearing.
- The Central Environmental Authority (CEA) is asked to conduct a Health Impact Risk Assessment (HIRA) with the assistance of the health authority in addition to the Environmental Impact Assessment (EIA) submitted to corporations to determine the risk to both human health and the environment.

- This study recommends reducing noise at its source or when choosing machinery and adhering to its proper maintenance procedure (periodic lubrication and maintenance). Investors should be strengthened to consider weighted sound power when buying machinery.
- Suppose the building is designed with appropriate noise-absorption materials, where applicable. In this case, it is desirable to approve new industries because noise is an environmental pollutant that impacts the community's daily life.
- According to the area's geography (physical environments, schools, playgrounds, residences, and hospitals), it is advisable to establish noise management methods using preventative and mitigation techniques.

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Chapter 9
Need of Ergonomics for Autonomous Vehicles

Debesh Mishra

Abstract Although "autonomous vehicles (AVs)" are becoming increasingly common, it is unclear whether ergonomics will be included in this new technology. For driverless vehicles or AVs, ergonomics is still required. This chapter attempts to provide a solution using crucial data on two topics. The primary components of human-driven vehicle ergonomics, such as "vehicle ergonomics", "warehouse-ergonomics", "training and education", and "research and profession", were first explained. The second discussion focuses on the features of AVs used in both "on and off-highway" situations, such as in the agriculture and mining sectors. Considering these two factors will help decide how much ergonomics are still required for AVs and whether they are essential.

Keywords Autonomous vehicles · AVs · Ergonomics · Human-driver mode · Driving systems

9.1 Introduction

Transportation ergonomics is crucial in human-driven vehicles. The development of autonomous (driverless) and connected vehicles (AVs) in this study calls the need for transportation ergonomics into question. Before the AVs industry becomes a reality, transportation experts and researchers must address several issues. Several governmental and commercial organizations have started conducting field experiments and demonstrations. In addition to reducing human error, AV technology is anticipated to impact sustainability, mobility, and safety (Elliott et al. 2019; Narla and Stowell 2019; NCHRP 2017; Shladover 2017; Stanton 2019). The use of this technology in both passenger and cargo trucks is increasing globally. Around the world, AVs have already begun to emerge on the highways.

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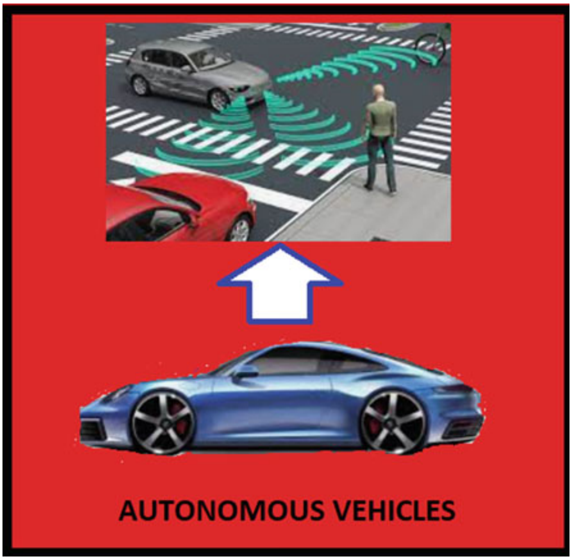

Fig. 9.1 Latest technology-based AVs on highways

The scientific field of ergonomics focuses on understanding how people interact with other system components and employs theory, principles, and data to improve system performance, safety, and human well-being. This is simply a science of creating systems suited to individual users. Various psychological, biological, engineering, and human factor concepts are included in ergonomics. Using these concepts, ergonomics produces an environment with minimal risk of harm. By focusing on ergonomics, transportation designers can ensure that every component of their work is user-friendly. Figure 9.1 illustrates the latest technology-based AVs on highways.

There are now centers for AVs education, products, standards, testing, and validation. The development of enabling technologies has attracted significant investment from scientists, engineers, and researchers. Following a detailed analysis of the application of transportation ergonomics to human-driven vehicles and the features of AVs, this chapter attempts to provide a solution to this topic. This review provides an in-depth understanding of transportation ergonomics and automation, which is required to address this issue.

9.2 Overview

Researchers and practitioners in the multidisciplinary subject of ergonomics come from various disciplines, including engineering, psychology, biology, industrial hygienists, safety experts, and healthcare professionals (Fig. 9.2). There are many

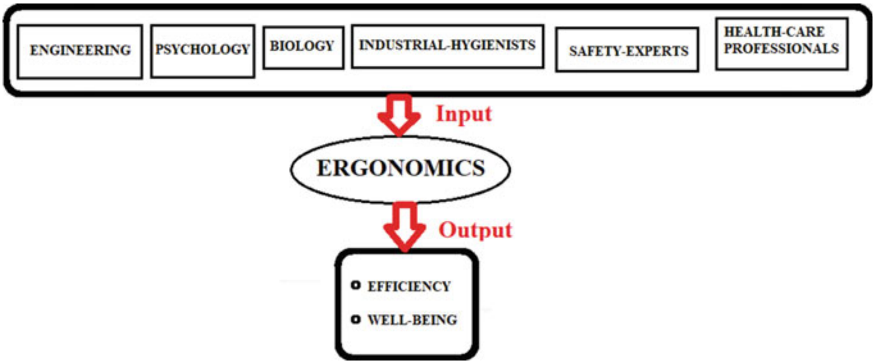

Fig. 9.2 Ergonomics' input and output

different forms of ergonomics; however, the ones that are most relevant to transportation (Salvendy 2012) include the following: the "physical-ergonomics", also known as "industrial-ergonomics", which covers the human body's reaction to the growth of "physical and physiological" demands. Strain injuries caused by vibrations, forces, repetitions, and postures are some examples included in this category.

The next category is "cognitive-ergonomics", also known as "human-factors ergonomics", which primarily studies mental processes such as perceptions, reminiscence, reasoning, and the linkage between persons and other system aspects. Workload-related, mental strain, decision-making, and human mistakes are examples of this category. "Organizational ergonomics" is another category aiming to improve organizational "policies, structures, and procedures" in the workplace. Examples of this category include shift work, incentives, scheduling, communication systems, and collaborative teamwork.

Similarly, preventive ergonomics' as one more category, tries to raise workers' knowledge about workplace safety, the "value of physical and mental health", and the importance of working in pleasant environments that decrease muscle fatigue. The last category includes "environmental ergonomics," which studies human interactions with physical space and considers factors such as pressure, temperature, climate, and sound/noises. This determines the best spatial layout for the growth of the correct environment.

9.2.1 Practices in "Ergonomics and Automation"

Several studies have addressed providing technical ways to prevent operators from acting incorrectly (Grosse et al. 2015; Mishra and Satapathy 2019a, b, c, 2021a, b). For example, Silleli et al. (2007, 2008) designed an autonomously deployed anchor system to prevent continuous rolling during a sideways roll-over, thereby safeguarding the operator from injury in the event of an overturn.

The necessity for ergonomic workplace design has been acknowledged in commercial and academic studies, and attention has recently grown. In this context, ergonomics is defined as a discipline that connects humans and automated labor, aiming to optimize working circumstances while considering the human talent and performance constraints (Vink et al. 2006). Work requiring repeated motions, frequent raising and lowering actions, and employment managing heavy loads benefits from ergonomic workplace design (Otto et al. 2017). According to Conti et al. (2006), the overarching goal of ergonomic workplace design is to organize the workpieces and instruments used in production and logistics while aligning the work process with the human body and mind. Using a human-centered workplace rather than a technology-centered design provides the advantage of optimally leveraging people's talent. As a result, blue-collar employees benefit more from the usability, maintainability, and operational safety of ergonomic-focused workplace designs (Hendrick 2003).

A strong association between economic productivity and occupational health and safety has previously been demonstrated through investments in ergonomic design and automation technologies (Das et al. 2008; Neumann et al. 2006). Valero et al. (2016) indicate that the subjectivity and lack of accuracy of visual assessments require replacing such observations with more accurate and precise posture-measuring instruments and methodologies in research aimed at examining "Musculoskeletal Disorders (MSDs)" in the construction sector. A few recent studies employed accelerometers in smartphones to determine human workstation activity (Akhavian and Behzadan 2016; Ahn et al. 2019; Bangaru et al. 2020; Bayat et al. 2014; Nath et al. 2017; Sherafat et al. 2020; Yang et al. 2019).

9.2.2 Transportation-Ergonomics Elements

The previous ergonomics forms are used for two domains in transportation ergonomics: "automobiles and warehouses". Examples of such vehicles include passenger cars, lorries (trucks), and buses. Warehouses typically include loading docks to load and unload items from trucks. The loading and unloading of cargo at seaports, railroads, and airports are sometimes the purpose of these devices. Forklifts and cranes are frequently used to move commodities kept as raw materials, packaging materials, spare parts, components, or completed goods related to manufacturing, production, and agriculture (Wikipedia 2022).

As shown in Fig. 9.3, transportation ergonomics consists of four essential components: ergonomics of vehicles, ergonomics in the warehouse, education and training, and associations for research and professionalism. Two primary categories have been developed to increase vehicle ergonomics based on the vehicle type: "design standards and operational guidelines."

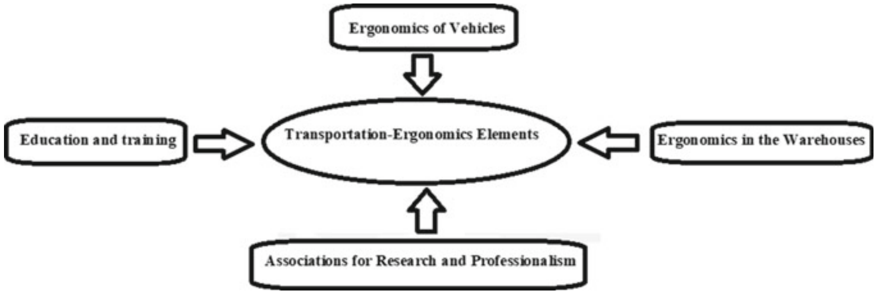

Fig. 9.3 Elements of human-driven vehicle's transportation-ergonomics

9.2.2.1 Ergonomics of Vehicles

Ergonomics of vehicle standards have been created both nationally and worldwide (ANSI 2020). These guidelines include test methodologies for analyzing aspects that affect a driver's performance and comfort. The "International Organization for Standardization (ISO)" addresses all elements of road vehicles, including "safety, performances, ergonomics, test techniques, the environment", and the "introduction of new technology" (ISO 2020). These requirements benefit manufacturers, health authorities, supply chain regulators, vehicle owners, drivers, and other road users. In addition to these standards, many organizations have produced operational ergonomic recommendations.

The following are examples of ergonomic and operating guidelines:

Tactile, auditory, and visual communication between the driver and vehicle are part of the ergonomic guidelines of the vehicle. Some standards linked to these aspects are as follows.

(A) Road Vehicles: Transportation and control-system ergonomics

- Management-concepts and compliance-methods
- In-vehicle visual-presentation specifications and testing methods
- Occlusion approach for assessing visual demand due to in-vehicle system uses.

(B) Road Vehicles: Camera Monitoring System Ergonomics and Performance

- Requirements and test processes
- Auditory-presentation specifications for in-vehicles.

(C) Road Vehicles: Ergonomic criteria for line-service bus driver workplaces

- General-description and basic-requirements
- Accessibility
- Information and control devices
- Cabin-environment.

(D) Ergonomics of the thermal environment: Thermal environment evaluations in vehicles

- Thermal-stress assessment "principles and methodologies"
- Equivalent-temperature determination
- Valuation of thermal comfort using human-subjects.

Moreover, for using a vehicle for commercial or personal purposes, operating guidelines have been established for promoting ergonomic principles, such as (a) leaving and safely entering vehicles, (b) proper vehicle setup, (c) manual material handling after driving, (d) using the vehicle as a mobile office, (e) management of exhaustion, and (f) work-relief exercises. However, the literature contains specific operating guidelines (Antich 2017).

9.2.2.2 Ergonomics in the Warehouses

In warehouses where commodities are handled, workers perform various jobs that put them at risk of injury, notably musculoskeletal illnesses. Pushing and dragging carts, lifting and carrying large items, regular physical material-handling activities, bending and reaching, and twisting the body are all parts of the job. To reduce occupational injuries, warehouses must apply ergonomic approaches and best practices.

According to studies by Tarrant (2019) and Ware and Fernandez (2014), a list of optimal practices for three ergonomics activities is presented: moving and lifting, posture-related, and pulling and pushing activities in Sect. 2.1.2. These best practices can be applied to all warehouse tasks. Moving and lifting a product in a warehouse is critical because these best practices enable workers to perform it safely. The safest postural correction techniques are used to reduce the risk to the muscles and other soft tissues. The best pulling or pushing practices strive to minimize the pressure of pulling or pushing manual stuff. Workstations should be constructed to integrate ergonomic concepts, such as "anti-fatigue floor mats" and "well-designed tables, desks, and chairs", in addition to these three jobs. Concerned managers should also ensure proper training of employees and operators.

9.2.2.3 Optimal Practices to Perform Different Tasks

The optimal practices for performing different tasks include the following.

(A) **Moving and Lifting**:

- Lifting aids are used to reduce awkward postures such as bending and twisting.
- Mechanical devices are used for lifting materials to lessen the "forces on the body" (use of pickers).
- Using transportation devices for materials transport (use of conveyors and carts).

- Lifting within the “safe zone” (between knuckles and elbows).
- Use of proper lifting techniques (bent knees and hips).
- Reducing the lifting frequency, particularly for heavy loads.

(B) **Posture-related**:

- Working closer to the neutral posture.
- Using work surfaces with the right height for bending or reaching elimination.
- Extension poles and adjustable height platforms were used to achieve elimination.
- Creating kneepads and stools for squatting reduction.
- Use sitting/standing stools for prolonged standing fatigue reduction.

(C) **Pulling and Pushing**:

- Selection of pushing activities rather than pulling, owing to strong leg and back muscle requirements.
- Reducing traveling distances.
- Ensuring the cartwheels are correctly maintained and working efficiently.
- Performing regular maintenance of labor-intensive materials’ handling “carts and casters”.

9.2.2.4 Education and Training

The training of drivers and workers is an essential aspect of transportation ergonomics. Driver training programs concentrate on ergonomic difficulties for people who drive regularly or over long distances. The training often teaches drivers how to operate their bodies and avoid injury when “lifting, driving, and using a laptop in the vehicles”. It stretches inside and outside the vehicle to avoid pain (Anderson Ergonomics Consulting 2020). Training programs for workers inform them about the risk factors that exist in the workplace and how to manage such risks. Typically, training is customized for a unique work situation.

Several institutions offer daytime undergraduate courses and ergonomic certifications in their continuing education programs. There are also graduate degrees in ergonomics; for example, the “University of California, Berkeley” has an online “Ergonomics Training Program,” which has trained graduates and postdocs who have become professors and governmental/industrial leaders. Design, engineering, anthropometry, physiology, biomechanics, public health, environmental health sciences, risk assessments, statistics, and root-cause analysis are covered in the course provided (Center for Occupational and Environmental Health 2020), which requires the participants to pay a charge for these ergonomics courses. However, the “Indian Institute of Technology” offers free online certificate programs such as ergonomics in vehicle design (Indian Institute of Technology 2020). Moreover, many ergonomic-based books have been published (Gkikas 2017; Salvendy 2012) to gain an in-depth knowledge of ergonomics.

9.2.2.5 Associations for Research and Professionalism

The development of ergonomics as a discipline and field of study depends critically on research. Various publications are accessible to disseminate ergonomic research, covering topics such as occupational health, musculoskeletal problems, driver safety, anthropometry, biomechanics, industrial design, physiology, psychology, and kinesiology. There are also ergonomic research institutions, such as "The Transportation Study Institute" at the "The University of Michigan" that undertake vehicle ergonomics research on the physical interaction between vehicle passengers and their interiors (Transportation Research Institute 2020). The various effects of interior design features on driver and passenger postures, positions, and comfort are among the studied topics intended to create and improve industry methods and models for vehicle design and define criteria for establishing passenger accommodation levels. A novel seating accommodation model that forecasts the distribution of backward/forward driver positions based on stature and important vehicle characteristics is an intriguing breakthrough. Improved methods for arranging crash dummies of various sizes have been developed using this model. The study was conducted on automobiles and trucks driven on roads and in many locations.

There are now national and international ergonomics associations, such as The Association of Canadian Ergonomists, the Human Factors and Ergonomics Society of the United States, the Ergonomics Society of Australia, the Chinese Ergonomics Association, and the International Ergonomics Association. These organizations foster and enhance research by sharing information about human qualities that may be used to build systems, tools, products, and settings. For example, the United States "Human Factors and Ergonomics Society" has established "National Ergonomics Month" (October-2020) to encourage workplace "wellness and productivity". These organizations also host regular conferences to facilitate "networking and information" sharing. The "Applied Human Factors and Ergonomics Conference" (July-2020) and the "Applied Ergonomics Conference" (August-2020) are some examples.

9.3 AVs Characteristics

To what extent do AVs require ergonomic intervention? Before answering this query, it is necessary to study the information concerning autonomous cars operating on and off highways. The following facts provide the justification and foundation for the response to this question:

9.3.1 On-Highway AVs

In addition to the driver-only level, the "Society of Automotive Engineers (SAE) International" has identified five stages of driverless vehicles (SAE International 2014, 2016). While "Levels 0–2" are automated systems that humans operate, "Levels 3–5" are automated driving systems that provide the human driver with varying degrees of control. The following are the six levels.

9.3.1.1 Human Drivers

Level-0 (driver-only): All driving activities are performed by the human driver, including steering, braking, throttling, and power applications.

Level-1 (Assistive automation): A driver assistance system handles either "steering or acceleration," with the human driver being required to handle the other components of dynamic driving.

Level-2 (Partial-automation): Either "steering and acceleration" are handled by one or more driver assistance systems, while the human operator is expected to handle the remaining duties involved in dynamic driving.

9.3.1.2 Automated Driving-Systems

Level-3 (conditional automation): While an automated driving system completes all parts of the dynamic driving duty (in the conditions for which it was built), the human driver must react correctly when asked to take over. The driver is not obliged to observe the situation as closely as possible at earlier levels.

Level-4 (high automation): An automated driving system handles every part of the dynamic driving duty and monitors the state of the roads. This level of automation is restricted and does not address all driving scenarios.

Level-5 (complete automation): An automated driving system conducts all elements of dynamic driving under all road and environmental conditions. Because of its smart design, the vehicle can independently execute all safety–critical tasks while monitoring the state of the road.

It should be noted that Level-3 allows partial self-driving automation in particular "traffic or environmental circumstances". Here, the driver relinquishes complete control of all safety–critical operations and relies on the vehicle to monitor any changes in conditions that necessitate a return to driver control. After a suitable transition period, the driver must retake the vehicle control. Level-5 allows complete automation, in which the vehicle is intelligently built to monitor road conditions and conduct all safety–critical driving operations for an entire trip.

It is essential to distinguish between "self-driving and AVs". Self-driving AVs are what Level-3 and -4 of automation refer to because they are required to have a driver (the presence of the driver is a must). Level-5 AVs, however, do not require drivers.

Most autonomous bus systems deployed in Singapore, China, and elsewhere utilize passenger safety drivers who only take control of the vehicle in extreme circumstances (Easa 2020). Parking automation technology has been developed and applied. Regardless of whether the driver is in the car, this technology facilitates parking and driving. The car begins to park once the driver exits the vehicle and clicks a button on the smart key. This mode allows for "parallel and vertical parking" (Diachuk et al. 2020).

9.3.2 *Off-Highway AVs*

Automation is gaining appeal in various off-highway applications, including mining, agriculture, and construction sectors. Changes in off-highway equipment/vehicle design are required as these sectors progress toward intelligent control to ensure that the equipment/vehicle is better utilized, safer, and more effective. Straka (2020) outlined various applications of sophisticated technology to solve operators' ergonomic challenges and suggested improving cab ergonomics by increasing the number of screens in the cab interior to allow operators to monitor the equipment's state better.

Because multiple operators operate in the cabs, the 'displays/screens' must be configured to accommodate variances in operator heights.

- It is advisable to use position-control technology to adapt displays to the operator's preferences to reduce strain, compensate for glare, and increase the operator's accessibility. Mounts for tablets and smartphones that may be used in taxis can also be made using the same technology.
- It is advisable to address the diversity of off-highway equipment access locations outside the cab, such as tool cabinets and engine hoods, which should be well-locked and easily reachable.
- It is recommended that the 'heating, ventilation, and air-conditioning systems be improved to enhance the operator's cab air quality (cabs' sealing for improved control of cool air leakages and keeping the dust out).
- Installing a tiny camera 'on the door' or 'the side of the mirror' to give the operator a broader view of the surroundings is advised to increase the operator's safety and accessibility.

These recommendations would be beneficial in the direction of completely autonomous driving.

9.4 Do AVs Require Ergonomic Intervention?

The ergonomic application will still be necessary for AVs in general, as shown by the AVs features and the analysis of ergonomic components for human-driven vehicles. First, Level-3 autonomous passenger cars feature both automatic and human-driver modes. As a result, the ergonomic necessities of drivers prevail. Even with Level-4 complete automation, drivers must remain present in vehicles, and most ergonomic rules must be followed. Second, most design criteria and operating principles are relevant to AVs. Third, while safe drivers drive most "autonomous buses," most ergonomic regulations remain unchanged. To ensure the safety of operators in off-highway AVs, ergonomic concepts must be applied.

However, certain unique varieties of autonomous highway cars that do not need a driver to operate them do not require ergonomic implementation. For example, in "Houston, Texas," the "CVS Pharmacy" has deployed AVs to distribute medications across three zip codes (Muir 2020). Customers in the "CVS website" pilot section can place prescription and non-prescription orders. If the automatic delivery option is selected, one of "Nuro's Toyota Priuses" will bring the order to the curbside at the customer's address within "three hours". Customers must identify and unlock the packages when an autonomous vehicle arrives.

Investigators address the human aspects and ergonomic challenges linked with AVs. For example, researchers at the "The University of Michigan" have created many experimental procedures to address automation-related difficulties and practical educational approaches to improve driver engagement with AVs. Additional significant problems include vulnerable road users' safety and assessing the design and functionality of vehicle controls, screens, and other AV information systems (Molnar et al. 2017; Stachowski et al. 2019; Stanciu et al. 2018).

It is worth noting that many human factor specialists believe that additional ergonomic research is required for AVs. Kyriakidis et al. (2020) interviewed 12 experts on the human aspects of autonomous driving to find distinct viewpoints on critical difficulties in AV innovations. According to experts, (a) the autonomous system should improve safety while shifting from automatic to human-driver mode, and it should also notify the driver of its operational status and capabilities; (b) more research is needed to address the high-frequency related interactions between AVs and vulnerable road users; and (c) driver-training programs should be modified to ensure human capabilities in using AVs.

The transition from automatic to human-driver mode is a critical human factor challenge in Levels-3 and -4 self-driving AVs. When the vehicle-user interface alerts the driver to shift, the driver must have sufficient time to control the physical vehicle. This time is determined by the driver's situational awareness and the intricacy of the scenario. Furthermore, increased levels of automation promote carelessness, allowing the driver to indulge in other "non-driving activities". Such drivers would require a significantly extended period to restore situational awareness and resume driving control modes. Consequently, an automated system must be built to handle a vast number of drivers (99 percentile), as in the case of "perception reaction time" in highway geometrics (AASHTO 2018). Drivers' response modeling should be based on "uncertainty analysis" (Easa and Cheng 2013; Easa and Diachuk 2020; Greto and Easa 2019), with a very high-reliability level employed in this scenario (Grugle 2019).

"Is greater ergonomics required for warehouses?" is a further query that arises, and yes is the response. Some warehouses are becoming entirely automated owing to the increasing trend of driverless vehicles, in which pallets and items move mechanically on conveyor systems, cranes, and automatic storage. Because automatic storage systems can efficiently utilize vertical storage, they are widely used in chilled warehouses and when land becomes expensive. A warehouse should be correctly slotted to improve inventory rotation requirements, labor costs, and effectiveness. Automation of warehouses undoubtedly presents new issues for implementing ergonomics to protect the safety and well-being of operators, similar to off-highway AVs.

9.5 Barriers to the Application of Ergonomics in the AV Sector

The transport sector and how mobility is viewed are significantly affected by AVs. In recent years, a dearth of competent drivers needs to be addressed (Scherr et al. 2019). The available vehicles have some aided driving features, but a human driver is still required because the vehicle cannot watch its environment (Fisher 2020). There will be a transitional period before the technology is fully automated, which will advance incrementally (Fritschy and Spinler 2019). This transition will continue until 2050 when completely autonomous vehicles will become the standard (Fisher 2020).

Studies and tests are necessary to ensure that automated AVs have independent acceleration and control, can monitor their surroundings, and react quickly to complex driving situations without human involvement (Bracy et al. 2019). Safety and infrastructure are also mentioned by Bagloee et al. (2016) as obstacles to adopting automated driving, which could have catastrophic consequences (Amini et al. 2019). Roadside sensors should be added to AV sensors to ensure the car can function under all circumstances (Yang et al. 2020). However, a significant obstacle to the broad acceptance of this technology is the high cost of the sensors and techniques (Kong 2020). Even though there is still a need for drivers, fully automated semi-AVs will improve their comfort and safety (Van Meldert and De Boeck 2016); they will also enhance the safety of other road users (Li et al. 2020).

9.6 Benefits in the AVs Applications for the Users and Service Providers

More specifically, vehicle ergonomics entails "fitting" the parts to intended customers or building the interior so that users can fit in the area and operate the technology supplied without inconvenience or functioning mistakes (Bhise 2011). The proportion of people who can squeeze in a car with sufficient body clearance is determined by occupant packaging and ergonomics, which is an essential factor. The term "inside-out" refers to the contemporary user-centered car design strategy, which mainly emphasizes the requirements and concerns of the occupants, which help form the internal volume and the external characteristics (Happian-Smith 2001).

These strategies are used by ergonomists who participate in the official design process to alert other fields to ergonomic concerns. AVs have level-5 automation, meaning they have automated driving characteristics that do not require a human to contribute as a pilot. Such vehicles have cutting-edge devices, including controllers, sensors, computers, effectors, programs, and sophisticated software, enabling them to perform all driving duties autonomously (Pisarov and Mester 2021). As they provide "the opportunity for secure, effective, accessible, and cheap transportation," AVs can alter the chance for secure, practical, accessible, and cheap transportation. According to numerous sources, the advantages of using self-driving cars commercially include reducing CO_2 emissions, improving fuel efficiency, decreasing congestion in the roadways, and intensifying pedestrian safety by removing human factors like intoxication, sleepiness, anger, and distraction. However, other factors can lead to accidents, enabling the disabled and the elderly to remain independent (Lewandowski 2018).

Evaluating the convenience and safety features of designed goods using virtual ergonomic instruments is helpful. Digital people were first used to evaluate the ergonomics of car models, primarily concerning the drivers' workspace, and they included human models that reflected the most fundamental 3-dimensional body measurements (Reed and Huang 2008). These models were subsequently used to designate reach zones for positional settings based on experimental data intended to simulate real bodily postures (Reed and Huang 2008).

Human building modules and simulated environment systems are now crucial in evaluating human car factors and ergonomics, helping to identify passenger limits, reach zones, visual domains, and appropriate body postures (Aromaa and Väänänen 2016). Vulnerable road users, such as the elderly and people with impairments, encounter significant difficulties when using private and public transportation. Some of these difficulties include transportation choices that are unavailable and urban environmental constraints. The discontent of people with available transportation options is supported by numerous international studies (Allu et al. 2017; Claypool et al. 2017). The most vulnerable road users worldwide are expected to benefit the most from self-driving vehicles (Goggin 2019).

There is general agreement among researchers that the extensive use of autonomous cars for personal and commercial transit will result in a substantial drop in traffic accidents owing to the technology and by eliminating the possibility of human error (DHL 2014). Autonomous trucks' ability to reduce transportation firms' expenses is another benefit (Hjalmarsson-Jordanius et al. 2018). Because fewer drivers are needed (Fagnant and Kockelman 2015), labor expenses will be cheaper (Li et al. 2020). Second, since there are fewer car crashes, there will be less harm and less need for repairs (Autonomous Trucks for Logistics Centers 2018).

Fuel prices and usage have also decreased (Alam et al. 2015; Sen et al. 2020). Assuming that AVs are battery-powered, there are some possibilities for ecology and sustainability due to reduced fuel expenses (Berger 2016). There will be less time spent traveling, which means fewer vehicles will be used, and there will be less traffic, a significant source of air pollution in cities (McKinsey Global Institute 2013). Because of the ability of drivers to engage in non-driving tasks while traveling to their location (Noruzoliaee et al. 2018), autonomous driving also presents the possibility of improved road and driver utilization (Bagloee et al. 2016). Because these activities might be beneficial, there is a chance that the journey time will not be wasted and that administrative assignments can be completed during this period (Pudāne et al. 2018).

Because AVs can use the road more efficiently than human-driven vehicles, the capacity of the road is expanded, thereby reducing congestion and traffic (Noruzoliaee et al. 2018). Additionally, as vehicle operation times lengthen, traffic spreads out throughout the day rather than during work time, necessitating fewer vehicles. This leads to fewer accidents, less damage to property, and less traffic, all of which improve mobility for everyone (Csiszár and Földes 2018; Lewis et al. 2020; Berger 2016).

There are additional benefits from introducing automated driving that does not fall under the prior categories. According to König and Neumayr (2017), technology presents an opportunity to implement new automated driving solutions while being open to the public. This would increase the likelihood of successful implementation (Wintersberger et al. 2019). According to Liu and Xu (2020), experiential learning offers a chance to support the technology, foster favorable attitudes, facilitate its diffusion, and result in a poor understanding of it Kohl et al. (2018).

The introduction of AVs also presents an opportunity to alter the perception of movement (Amini et al. 2019). While there are numerous factors to consider, such as technological and social (Nastjuk et al. 2020), there are numerous opportunities, particularly in sharing vehicles' ideas and using them as required (Ryan 2019). In addition, it has completely altered the concept of owning a vehicle in favor of a more uniform and shared road environment (Saghir and Sands 2020). Similarly, Li et al. (2020), AVs will be operational twenty-four hours a day, seven days a week, and will not be affected by the weather to the same extent as human vehicles (Fritschy and Spinler 2019). This results in fewer delivery delays and greater flexibility for transportation businesses (Li et al. 2020). Because delivery dates and times will better satisfy customers' needs and planned dispatches will come on time, increasing their happiness, it will also foster improved consumer relationships (Neuweiler and Riedel 2017).

When activated in fully autonomous mode (Li et al. 2020; Pudāne et al. 2018), automation may be partially used initially for a specific period or under specific circumstances (Maurer et al. 2016). It allows drivers to complete other tasks concurrently while driving, increasing their productivity and saving time rather than using it while driving (Pudāne et al. 2018). According to research, drivers will complete paperwork and managerial duties (Trösterer et al. 2017). Drivers might need more advanced skills to watch vehicles or perform other traveling duties (Van Meldert and De Boeck 2016). This will allow drivers to communicate more with transit schedulers or perform more manufacturing, maintenance, and repair tasks than they could previously. Technology cannot replace these duties (Sen et al. 2020). Thus, it can be inferred that the organization, as well as the responsibilities of schedulers, clients, and vehicle drivers, will undergo significant changes (Trösterer et al. 2017), with drivers' responsibilities shifting from a practical to a more strategic or supervisory role (Fritschy and Spinler 2019; Maurer et al. 2016).

Vehicle control is another element that influences reluctance to change. According to König and Neumayr (2017), individuals who use self-driving cars feel secure and more at ease with technology if they can quickly regain control if necessary. Users who cannot operate the car must also understand its functions and why they take specific actions (Koo et al. 2014). While using autonomous cars, drivers may receive two different kinds of information: a "how" message outlining the actions taken and a "why" message outlining the rationale behind those activities (Koo et al. 2014). Drivers are perplexed and may not drive safely without the "how" information because they cannot determine whether they are at fault or the car (Koo et al. 2014). However, providing drivers with "why" information improved their perception and led to excellent results, which has been acknowledged as the ideal level of data (Koo et al. 2014).

The best way to ensure that humans and machines could coexist peacefully was to give drivers both signals, but this was not well received by users who were already distrustful of automation (Koo et al. 2014). Drivers' willingness to use autonomous cars and their desire to do so are adversely affected by their fear of releasing control while not fully comprehending the technology (Nastjuk et al. 2020). AVs are expected to encourage conventional automakers to adopt new business strategies. The fact that ride-hailing services are building their own versions of the technology, as well as comments made by the CEOs of "Tesla and Ford" AVs indicating the companies' intentions to launch their mobility services, are arguments in favor of this hypothesis (Lambert 2017; Sherman 2018). Consequently, individuals may not be able to purchase or own vehicles in the future. Instead, businesses offer transportation services based on AV teams (Matousek 2018).

9.7 Conclusions

To answer this question, "Would ergonomics still be required for automated cars?" This article elaborates on the features of ergonomic applications of human-driven vehicles and the characteristics of forthcoming AVs. The review found that most self-driving AVs need the same ergonomic standards currently employed in conventional vehicles and that their automated features also call for further ergonomic-based research. New AV training programs, attentive driving, and the switch from automated to human-driver modes are among these new research topics.

Short-term discomfort is linked to long-term injuries and disabilities later in life. Therefore, early intervention through ergonomic implementation is critical. This emphasizes the critical significance of developing dedicated research institutes and academic programs focusing on the influence of automation on "human factors and ergonomics". Warehouse and off-highway vehicle automation are also on the rise. To protect the safety and well-being of the operators, these new automated systems require developing novel ergonomic applications. The burgeoning of automated systems for automobiles and warehouses presents numerous difficulties and possibilities for creating cutting-edge ergonomic applications. This study did not discuss bus-stop ergonomics, which is somewhat weak. However, they will become more significant as smart technologies are adopted at bus stops and terminals. Organizations are enthusiastic about the role of ergonomics in automated systems as prospects for AVs on and off the highways increase.

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Chapter 10
Design and Simulation of a Mechanical Device to Reduce the Ergonomic Postural Risk Levels of Workers During the Installation of Panelled Walls

Román Eduardo Méndez and Berthana M. Salas-Domínguez

Abstract The installation of paneled walls can result in the injury of the involved workers regardless of whether the installation occurs in residential construction or during exhibition booth assembly. This chapter discusses a study conducted to assess the postural risk to the workers and, based on these findings, presents a novel design which can help reduce the levels of ergonomic risk. This proposed mechanical device was developed based on the results of postural assessments of six workers who had installed paneled walls. These assessments were performed with the following instruments: RULA method, audio-visual material, Cinema 4D©, and Jack™ software. Initial results show that the final score on the RULA scale for the Holding Stage was consistently a 7 across all postural assessments. When using the newly created design, the results of the postural assessments ranged from 2 to 3 on the RULA scale. When the results of the average final global score are compared across the first and second postural assessments a decrease of 61.4% in the postural risk levels can be observed. The findings of this study suggest that this proposed novel design may improve postural load levels by minimizing the need for the worker to perform the Holding Stage when installing paneled walls.

Keywords Ergonomics · Postural assessment · Paneled walls · Design proposal · Design simulation

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10.1 Introduction

Paneled walls installation is a worldwide activity used mainly in architecture and exhibition fields, the process involves workers that are not always trained, and neither have the appropriate personal protective equipment for the related tasks, the design and application of new tools such as a positioning wall device can be an advantage to reduce ergonomic risks. Ergonomics as a multidisciplinary science conjugates the study of the user related to the environment and the object to be used; with the combination of design and ergonomics, workers' quality of life can be improved. This chapter is organized as follows: Sect. 10.1 gives an introduction to paneled walls, their installation stages and processes, the ergonomic implications, and the objective of the study. Section 10.2 summarises the methods used to conduct the study, the participants, the instruments and the procedure. Section 10.3 reports the findings of the postural assessment, the design proposal and its simulation. Finally, Sect. 10.4 shows the discussion of the results with the theoretical approaches reviewed, and future research is recommended.

10.1.1 Panelled Walls, Description and Installation Process

The term 'Panelled Walls' (PWs) refers to and has its origins in prefabricated components used in residential construction. The elaboration of PWs consists of modulating panel dimensions (1.22 $\times$ 2.44 m) to match the overall dimensions of the walls forming the final structure to be built (2.50, 3.0, 4.0, 5.0 m, etc.) (Shewchuk et al. 2009). PWs were developed to reduce work-related injuries and illnesses and to increase efficiency and productivity in the residential construction industry (Baradaran-Noveiri et al., 2022; Kim et al., 2010). In practice, the installation process of PWs involves various tasks related to panel sizes and weights (Jia et al., 2011). Common PW sizes can range from 1.20 m to 2.40 m, with increments of 0.60 m (Kim et al. 2008) to 6.0 m, with a mass of up to 250 kg (Nussbaum et al. 2009). For this reason, teams of several workers carry out manual wall installation and handling tasks (e.g., lifting, carrying, dragging, etc.) (Kim et al. 2012). In the context of the study conducted and presented in this chapter, wooden paneled walls are used in the exhibition booth assembly process, weighing between 17 and 25 kg. They are manually handled and installed by six workers.

PWs design is based on various structural criteria, considering maximum material lengths, transportation, and stacking (Kim et al. 2008). A panel designer, working from architectural drawings, specifies panel sizes and various aspects of pre-assembly for wall fabrication (Nussbaum et al. 2009). These fabrication aspects indicate that panel design decisions also influence worker tasks and do not consider the workers who will handle them (Kim et al. 2006b); as a result, workers may be exposed to ergonomic risks due to the dimensions and weights of the walls as well as changes in the work process (Kim et al. 2010). PWs are produced off-site in a factory or workshop under controlled environments (Baradaran-Noveiri et al. 2022; Jia et al. 2011) and transported to pallet construction sites.

Workers must handle these large and heavy walls, increasing the risk of work-related injuries (Kim et al. 2008). Off-site production offers opportunities to reduce hazards, construction time and costs, and the need for skilled and experienced workers at the installation site, among other factors (Baradaran-Noveiri et al. 2022; Kim et al. 2010). The walls are transferred from the pallets to the installation site almost fully assembled (Kim et al. 2006b, 2012; Nussbaum et al. 2009), then a team of installers transport and install the walls at the required locations, and they are set up in a sequence of designated positions at the installation site (Kim et al. 2008; Nussbaum et al. 2009).

In a previous study (Méndez 2021), it was observed that workers manually handle the panels, either individually or with the help of another worker, often without safety/work gloves, and they use some mobile support such as self-made trolleys, depending on the weight of the panels and the distance to the installation site.

10.1.2 Stages in the Task of Installing Panelled Walls

From the point of view of ergonomic analysis in construction work, the task is defined as: 'the largest group of activities that a single worker normally performs together to achieve a common goal' (Buchholz et al. 1996, p. 178). For a task to be performed successfully, it is necessary to define its basic aspects, objectives, requirements and the means necessary to carry it out (De Keyser 1998).

The stages or categories (Kim et al. 2006a) that constitute the PW installation task, recorded, described and defined by the authors consulted, are as follows (Table 10.1): Lifting, carrying, moving or transferring, hoisting/erecting, holding, fixing and lowering of the PW (Jia et al. 2011; Kim et al. 2006a, 2010, 2012; Nussbaum et al. 2009).

10.1.3 Ergonomics, Ergonomic Risk Factors and Working Posture

Ergonomics studies the existing relationships between work and the physical and cognitive capabilities of people, with implications in the design or redesign of work with its tools and tasks, as well as the environment where it is developed so that they harmonize with the capabilities and limitations of the human body (Inyang and Al-Hussein 2011; Inyang et al. 2012). This is because ergonomics considers biological, psychological and sociological aspects, contributing to and aiming at the

Table 10.1 Stages involved in the installation of panelled walls

Stage	Authors who mention it	Remarks/Features
Lifting	Jia et al. (2011), Kim et al. (2006a, 2010, 2012), Nussbaum et al. (2009)	The wall is obtained from a wall stack or at floor level a. Lift a wall horizontally from floor level or the height of the worker's knuckles, and lift a wall inclined from 0 to 45° b. Lift a wall when it is oriented horizontally c. Lift a wall while oriented vertically so that the wall remains vertical when completed
Carrying	Jia et al. (2011), Kim et al. (2010, 2012), Nussbaum et al. (2009)	After lifting, a worker moves the wall to the designated location a. Carry a wall oriented horizontally or inclined at approximately 45° to the floor b. Carry the wall in a horizontal position c. Carry the wall in a vertical position d. Carry the wall oriented vertically while holding it, leaning over the shoulder
Moving/ transferring	Jia et al. (2011), Kim et al. 2010, 2012), Nussbaum et al. (2009)	a. Push forward a wall placed vertically on its longest side b. Pushing or pulling the vertically oriented wall while resting on the floor c. Push or pull the wall by holding one side of the wall up while the other side rests on the floor d. Pushing or pulling the wall without lifting it
Hoisting/ erecting	Jia et al. (2011), Kim et al. (2006a, 2010, 2012), Nussbaum et al. (2009)	After carrying, a worker shifts the horizontally oriented wall to a vertical position and places the wall in the desired location a. Erect a wall until it stands vertically by raising it from ground level or the height of the worker's knuckles b. Lower one side of the wall to touch the floor and push up the wall until it is vertical c. Rotate the wall to a vertical orientation without touching the floor
Holding	Kim et al. (2006a)	A worker holds the wall vertically after the hoisting stage is completed
Fixing	Kim et al. (2006a)	While one worker is holding the wall, another worker is nailing that wall to another, which will join
Lowering	Nussbaum et al. (2009)	Lower the wall to floor level. No matter the order or sequence

safety, comfort, and efficiency of the work done by a person, group or organization through objects and environments (Gómez-Conesa and Martínez-González 2002; Prado-León 2015a).

Ergonomics is defined in a basic way as the scientific study of human work (Pheasant 1991, as cited in Prado-León 2015a; Prado-León and Ávila-Chaurand

2014). The purpose of ergonomics is 'to adapt work to humans by studying the risks posed by the physical work environment' (Gómez-Carrillo et al. 2016, p. 29). The object of study of ergonomics is the person concerning his or her daily work and the rest of the activities he or she performs (Gómez-Conesa and Martínez-González 2002).

Work can involve purpose and effort in a particular workplace (Prado-León and Ávila-Chaurand 2014). The workplace is defined as a 'subset of an environment where people are exposed daily to the environment while interacting and carrying out their livelihood activities' (Perry et al. 2010, p. 708), which can be risky during their performance due to various factors. These ergonomic risk factors, according to Inyang et al. (2012), include (a) awkward postures, (b) repetitiveness, (c) static force and load, (d) contact stress, (e) hand-arm vibration, and (f) work environment.

The Occupational Safety and Health Administration (OSHA) lists the following risk factors and their definitions: 1. Force: the amount of physical effort to perform a task, 2. Repetitiveness: performing the same movement or a series of continuous and/or frequent movements over an extended time, 3. Awkward and static postures: imposing stress on the body, for example, prolonged and repetitive work above shoulder height, kneeling, bending, stooping, working with bent wrists or twisting the torso while lifting loads, and 4. Contact stress: pressing the body or parts of the body against hard or sharp edges (OSHA 2004).

Gómez-Carrillo et al. (2016) define a risk factor as 'the element or component of a job that increases the chance of injury or illness of a worker' (p. 42) and ergonomic risk as the 'set of attributes of the task or job, more or less clearly defined, that increases the probability that a person, exposed to them, develops an injury at work' (Genis 2010, as cited in Gómez-Carrillo et al. 2016, p. 43). The authors consulted mention that ergonomic risk(s) by themselves do not cause harm; the danger lies in their combination and relationship between them, for example, the worker's posture and exposure time, since to maintain specific postures at certain times, the muscles may require excessive efforts generating muscle fatigue (Gómez-Carrillo et al. 2016).

Defined as the body positions adopted by a person when performing an activity (Gómez-Carrillo et al. 2016; Prado-León and Prado-León 2015b), work postures have a purpose outside themselves because they are related to external working conditions for this reason when performing a postural assessment, the task itself and the work environment are taken into account considering the variability of work methods and body postures among people doing the same work and activities (De Keyser 2004; Hammarskjold et al. 1989; Keyserling et al. 1993, as cited in Gómez-Carrillo et al. 2016).

A consequence of forced long-duration working postures is static loading. When this happens, the efficiency of muscular work is low because blood circulation and muscle metabolism decrease. If the static postural load is continuous or repeated, it generates local muscle contraction and fatigue; when this is the case, it can cause discomfort and pain in muscles, joints, tendons, and other tissues of the musculoskeletal system and work-related disorders or pathologies (Gómez-Carrillo et al. 2016). For Gómez-Carrillo et al. (2016), the postural load is 'the degree of effort and discomfort caused by the adoption of postures (forced or inadequate during work)' (p. 50) while performing a task.

López-Torres et al. (2014) argue that postural strain appears when a worker does not adopt a neutral body posture for a certain period, which favors 'the presence of pain symptoms, inflammation, dysesthesia, paraesthesia and limitation of the worker to perform his work' (p. 111–112). Some consequences of postural strain are impediments in daily activities, temporary work incapacity, absenteeism, decreased productivity, economic losses, and significant damage to health (López-Torres et al. 2014).

10.1.4 A Couple of Examples of Simulation and Monitoring Technologies Used in Postural Ergonomic Assessments

The use of computer simulation is a valuable technological resource in ergonomic evaluations. Therefore, simulation was considered in this study. According to Gill (1998), using simulation in ergonomic design is valid because a 'virtual human is an accurate biomechanical model of a human' (1998, p. 223). The author adds that virtual simulations are well known in the automotive and aerospace industries for evaluating volumetric factors such as reach, clearance and manual material handling problems (Gill 1998).

Inyang et al. (2012) identify and quantify work-related ergonomic injuries in structural carpentry activities of panel construction, using a virtual reality model of the construction process to perform an ergonomic assessment in a production line. The virtual reality model is created and simulated using 3D Max Studio software to represent the process as accurately as possible, considering activity duration and postures adopted by the workers during the task. To determine postural risks, an ergonomic assessment is done by observing the simulation in action, based on the methodology proposed in previous work (Inyang and Al-Hussein 2011).

The study conducted by Inyang et al. (2012) focuses on two structural carpenters constantly exposed to the risks of poor postures: back and neck bending and squatting. The postures are assessed from the following ranges of bending angles for the back: 0–20º, 20–60º, >60º; for the neck: vertical, 0–20º, 20–60º, >60º; and for leg postures: squatting and kneeling. Worker 1 is exposed to squatting and kneeling postures for about two hours (106.91 min of daily exposure), back bending over 60º (111.71 min), and neck bending 0–20º (163.71 min). Their postures are classified as medium risk for the back and legs, and the worker 2 postures are classified as low risk. The authors propose two recommendations to reduce the risks: (1) redesign of the carpenters' worktable and (2) introduction of a new workstation. These recommendations are intended to reduce poor posture and even downtime between tasks. Using a simulation model can eliminate the need for site visits and assessments, reducing time and cost and providing an alternative for work design and planning.

Ray and Teizer (2012) conducted a study focused on developing a proposal to estimate and classify postures during construction work using audio-visual technology (3D Kinect™ monitoring camera). The recorded postures were classified as ergonomic or non-ergonomic based on 'computer algorithms using OpenNI postural registration software' (pp. 451–454), and the data obtained were used to contribute to the education and training of workers in the healthy development of their activities in the workplace.

The study by Ray and Teizer (2012) is limited to the analysis of overhead work, lifting loads at floor level and working in kneeling and crawling postures. They classified the postures as 1. Standing, 2. Squatting or sitting, 3. Bending or stooping, and 4. Crawling. With the use of the 3D camera, the postures performed by the participant are captured in images and classified within the above activities to determine if there is an ergonomic risk, such as (a) overhead work, the worker must reach or climb something and raise one or both arms; (b) lifting loads at floor level, squatting or sitting posture for lifting loads, including manual handling of materials; (c) lifting loads while bending or stooping; (d) crawling or crawling posture when working close to the ground.

With the posture classification, the authors develop a series of computer algorithms based on ergonomic principles to systematize the images obtained by the 3D camera, which monitors the work in motion and thus shows on the screen when a risky posture is being performed in a red or green signal if it is being performed correctly; for example, if the image shows a working posture above the head, it is marked in red if the angle of the arm is greater than 60º.

Furthermore, on the other hand, for squatting or bending lifting activities, the feedback (outputs = posture risk/no risk) shown by the algorithms when analyzing a range of postures involved varies as follows: standing-no risk, squatting-back-at-risk, squatting-back-at-risk, standing-no risk. When working close to the floor, the feedback from the software is standing-safe, bending-knees-at-risk, bending-knees-at-risk, and standing-safe. According to the authors, this analysis tool makes it possible to develop real-time training and monitoring of construction workers and to train them to look after their health and safety at work.

10.1.5 Study Approach

This study builds on the results of a previous study by Méndez (2021), in which six stages were found, classified and defined within the PWs installation task during the exhibition booths assembly process: carrying (C), lifting (L), holding (H), fixing (F), work organization (O) and complementary activities (X). The stage identified as presenting the highest postural risk to workers was the holding stage (HS), with a 38% degree of influence (22 min, on average, of exposure to postural risk) in the PWs installation task, according to the analysis carried out. Therefore, the objective of this study is to assess the postural risk of workers when performing the HS during

Table 10.2 Participants description

Subject	1	2	3	4	5	6	Mean
Age (years)	42	35	36	18	30	30	31.8
Height (cm)	160	170	179	165	172	160	167.6
Weight (kg)	72	94	94	60	95	60	79.1

Table 10.3 Performance levels of the RULA method according to the final score obtained (Hedge 2001; McAtamney and Corlett 1993)

Action level	Score	Description
1	1–2	Acceptable posture
2	3–4	Investigate further; it may be necessary to change
3	5–6	Investigate further and change soon
4	7	Investigate and change immediately

the installation of PWs and, based on this, to develop a design proposal that might reduce the level of ergonomic risk found.

10.2 Materials and Methods

10.2.1 Participants

Six male subjects participated in the study with an age range of 18–42 years, whose mean age, height, and weight were 31.8 years, 167.6 cm, and 79.1 kg, respectively (Table 10.2).

With the signed authorization and consent to participate in each participant's study, postural analysis was performed on these six workers, employees of a company dedicated to the installation of PWs located in the west of Mexico City in 2016.

10.2.2 Instruments

Photographic material (photographs and frames) and 3 videos of the work area and participants, with a minimum duration of 50 min, were obtained with a Sony® FDR-AX100 digital video camera (Méndez-González 2018).

The assessment of the upper limb postural load was performed by applying the Rapid Upper Limb Assessment (RULA) method (McAtamney and Corlett 1993), using the employee evaluation form (Hedge 2001) to capture data on the postures adopted by the workers during the performance of the tasks assessed. Table 10.3 below shows the values of the RULA method:

Cinema 4D©, release 15 (Maxon 2013). 3D modeling software was used to elaborate the design proposal (educational license. University of Guadalajara, Mexico).

Jack™ (Siemens 2015). Human simulation program to evaluate the design proposal using a 3D model (educational license. University of Guadalajara, Mexico).

10.2.3 Procedure

Postural assessment. The RULA tool was used to determine each worker's postural risk level and develop an intervention proposal based on the assessment obtained.

Preparation of the proposal. Based on the results, a design proposal was made using Cinema 4D. The anthropometric data of industrial workers from Ávila-Chaurand et al. (2007) were used as a reference for sizing the design. The model was tested in a virtual simulation.

Simulation, initial postural assessment, and comparison of postural assessments of the design proposal. The Jack™ software was used to simulate the HS within the installation task of PWs because computer simulations allow analyzing different scenarios and visualizing future results without the need to repeat on-site observations (Inyang et al. 2012), obtaining more accurate and objective results. Two male users with anthropometric values of the 5 and 95th percentile, respectively, were simulated with anthropometric data from Ávila-Chaurand et al. (2007) to manipulate the 3D model of the design proposal. The 3D model of the design proposal was exported from the Cinema 4D© program to a standard format to be imported into the Jack™ program (see the procedure recommended by Sundin et al. 2004). RULA values of the simulated postures were also calculated using the Jack™ program.

Use of Jack™ software. The simulation and assessment process was based on the following:

1. Complete the 3D model design proposal.
2. Import the 3D model into the virtual scenario.
3. Have the anthropometric data of the 5 and 95th percentiles ready.
4. Generate scalable virtual human figures (biomechanical and anthropometric) and insert required anthropometric data for the 5th percentile when the software requests.
5. Place the human figure in the virtual scenario.
6. Manipulate human figure posture according to the designed sequence of use.
7. Insert strength and load values (2–10 kg) when the software requests.
8. Select the RULA assessment tool from the menu.
9. Simulate each posture to be assessed.
10. Record and collect the data from the assessment for each posture of the human figure of the 5th percentile.

11. Repeat the procedure for the 95th percentile.

10.3 Results

10.3.1 Postural Assessment

To carry out the study and the design proposal, the HS was selected within the installation process of PWs because it was the riskiest for workers, according to Méndez (2021) and Méndez-González (2018). A postural assessment was performed using the RULA method on each worker to know the level of ergonomic risk to which they are exposed when executing their task. The same body segments and characteristics used in the evaluation stage were considered to evaluate the design proposal. The partial score was obtained for each subject's body segments: arm, forearm, wrist (body group A), neck, and trunk (body group B), and the final score for each assessed posture. The assessment results made to subjects 1–6 with right and left extremities are shown below (Tables 10.4, 10.5, 10.6, 10.7, 10.8 and 10.9), and then a compilation of the results was made.

The results of the final scores showed that the postures adopted by all the subjects were static and had a score of 7 on the RULA method scale, indicating research and immediate changes in the evaluated stage. Variations occurred in the different body segments. After obtaining the scores for each subject, the results were compiled in a single table (Table 10.10), and the results are shown with a numerical value to facilitate their reading.

The table above shows that the subjects with the highest levels per body group were: subject 2 (body group A, I = 10; body group B, I = 12), subject 4 (body group B, D = 11, I = 11), subject 6 (body group A, D = 10, I = 10). The body segments with the highest levels in the different postures assessed were the neck: subject 2 (D = 6, I = 6), subject 3 (D = 6, I = 6), subject 4 (D = 5, I = 5), subject 5 (D = 5, I = 5) and the arm: subject 2 (I = 5), subject 3 (I = 5), subject 6 (D = 5, I = 5), subject 1 (D = 4, I = 4). Lower scores were obtained for the wrist: subject 4 (D = 4), subject 5 (I = 4), subject 6 (D = 4, I = 4), and the trunk: subject 2 (D = 4, I = 4), subject 4 (D = 4, I = 4), subject 5 (D = 4, I = 4). All final scores resulted in 7, indicating the highest risk level.

10.3.2 Design Proposal

The proposal (Fig. 10.1) was made to reduce the postural risks identified in the HS. A device was designed considering the following parameters analyzed during the evaluations (Table 10.11): (a) Percentage of exposure to postural risk (Méndez 2021), (b) Static postural load (Table 10.10), (c) Dimensions of PWs and saturated workspace (Méndez 2021; Shewchuk et al. 2009), (d) Use of the device (Table 10.12),

Table 10.4 Postural assessment in the holding stage. Subject 1

Frame	RULA score		
	Body part group A	R	L
	Upper arm	4	4
	Lower arm	3	3
	Wrist	3	3
	Wrist twist	1	1
	Total A	7	7
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	4	3
	Trunk	2	2
	Total B	7	5
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

R = Right limb; L = Left limb

and (e) Anthropometric dimensions of Latin-American industrial workers (Ávila-Chaurand et al. 2007).

The illustration in Fig. 10.1 is the conceptual design proposal 3D mode.

The overall dimensions of the proposal are 110 cm × 25 cm × 60 cm. The design has three main parts: 1. Press, with an opening range of 0 to 30 cm, where one end of the PW is clamped, preventing it from swinging, 2. Handle with grip so that the worker can move the device, 3. Swivel wheels for freedom of movement on site. For the handles and press trigger, a neutral hand posture and power grip were considered for handling the device (Fig. 10.2).

Figure 10.3 shows a general scheme of how the device clamps the PW at one end at a time, allowing the workers to move freely to continue assembling or working on the same or other walls.

Table 10.5 Postural assessment in the holding stage. Subject 2

Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	5
	Lower arm	3	3
	Wrist	3	2
	Wrist twist	1	1
	Total A	6	10
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	6	6
	Trunk	4	4
	Total B	10	12
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

R = Right limb; L = Left limb

10.3.3 Simulation of the Design Proposal

A simulation of the use of the proposal was carried out. Five stages of use and two virtual subjects (5 and 95th percentile) were simulated. Subsequently, the postures performed were assessed, and their postural risk level was determined.

10.3.4 Characteristics of the Stages of Use for Simulation

The stages have been set according to the basic sequence in which the worker would use the device to hold the wall, preventing it from swinging and making it easier for other workers to carry out the various stages of PW installation. Five stages were defined: 1. Positioning the device, 2. Opening the press, 3. Clamping the wall, 4. Releasing the wall, and 5. Removing the device (Table 10.12).

Table 10.6 Postural assessment in the holding stage. Subject 3

Frame	RULA score		
	Body part group A	R	L
	Upper arm	3	5
	Lower arm	2	2
	Wrist	3	3
	Wrist twist	1	1
	Total A	6	8
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm:	Without support	Without support
	Body part group B		
	Neck	6	6
	Trunk	1	1
	Total B	10	10
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

R = Right limb; L = Left limb

10.3.5 Anatomical Characteristics of the Subjects for the Simulation

The following anthropometric dimensions of male industrial workers aged 18–65 years in a standing position were used to form the simulation of two 5 and 95th percentile subjects to simulate the use of the device (Table 10.13).

Jack software automatically generated the missing body dimensions of the subjects. Below are the assessment results with a 5 and 95th percentile subject using the designed device (Tables 10.14, 10.15, 10.16, 10.17, 10.18, 10.19, 10.20, 10.21, 10.22 and 10.23).

After obtaining the scores for each subject 5 and 95th percentile using the device, the results were compiled in a single table (Table 10.24), and only the results with numerical value are shown for easy reading.

The final majority score was 3, indicating that further investigation and a change may be needed. Three stages had a final score of 2, with acceptable posture, for the 95th percentile subject in the press opening, wall clamping, and wall release stages.

Table 10.7 Postural assessment in the holding stage. Subject 4

Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	3	3
	Wrist	4	3
	Wrist twist	1	2
	Total A	8	7
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	5	5
	Trunk	4	4
	Total B	11	11
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

R = Right limb; L = Left limb

The highest scoring subject by body group was: subject P95 in stage 1 (body group A, R = 4, L = 4; body group B, = 3, = 3) and in stage 5 (body group A, R = 4, L = 4; body group B, R = 3, L = 3). The body segments with the highest levels when evaluating the different simulated postures were the lower arm: subject P95 in stage 1 (R = 3, L = 3) and stage 5 (R = 3, L = 3) and the trunk: subject P95 in stage 1 (R = 3, = 3) and stage 5 (R = 3, L = 3).

In order to know if the design proposal implementation facilitates the performance of the HS and reduces the postural ergonomic risk factors of the workers, the percentage reduction of the risk level was calculated by comparing the average of the first postural assessment with the second one in each body segment for each limb, left and right, shown in Table 10.10 (first postural assessment) and Table 10.24 (second postural assessment). The results are shown in Table 10.25 below.

In the results shown, it can be observed that the level of risk of all the body segments decreased, except for the wrist twist of the right limb, which remained the same. The segments that had a decrease higher than 55% were: the upper arm, left side (55.2%), wrist, right side (57.5%), and neck, both sides (79.1, 78.2%). The final

Table 10.8 Postural assessment in the holding stage. Subject 5

Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	3
	Wrist	3	4
	Wrist twist	1	2
	Total A	5	7
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	5	5
	Trunk	4	4
	Total B	10	10
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

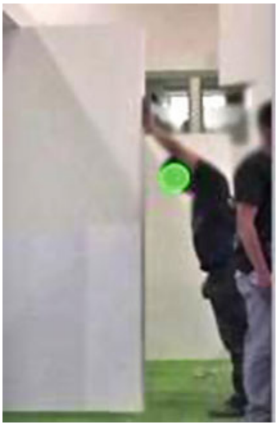
R = Right limb; L = Left limb

total score average of the second posture assessment decreased by 61.4% compared to the first, showing an overall improvement for the workers.

10.4 Discussion

The existing ergonomic postural risk factors in the execution of the HS were assessed using the RULA method. This method was used for the following reasons 1. It does not require special equipment and uses a coding system that is easy to learn, 2. It helps to identify ergonomic risks efficiently and facilitates the decision to intervene, 3. Its use can give an order of priority to the jobs and tasks analyzed through the final scores, 5. The magnitude of the individual postural scores, muscle use and force exerted indicate which aspects of postural conflicts are likely to be expected (González-Muñoz 2017; McAtamney and Corlett 1993). This method has economic advantages because it does not require prior expertise and can be used in different work environments without interrupting the activities of the observed workers (García-García

Table 10.9 Postural assessment in the holding stage. Subject 6

Frame	RULA score		
	Body part group A	R	L
	Upper arm	5	5
	Lower arm	3	3
	Wrist	4	4
	Wrist twist	1	1
	Total A	10	10
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	3	3
	Trunk	3	3
	Total B	7	7
	Muscle use	Mainly static posture	Mainly static posture
	Strength/load	<10 kg, intermittent load	<10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	7	7

R = Right limb; L = Left limb

et al. 2013); however, one of the limitations of its use is that it does not provide accurate engineering controls or precise changes in activity (Torres-Gómez 2015).

The 100% of the final scores of the postures adopted by the subjects showed that they were static and had a score of 7 on the RULA scale, the highest level rated by the method, which indicates investigating and implementing immediate changes in the assessed stage (McAtamney and Corlett 1993). Variations occurred in the partial scores by body group, A or B: subject 2 (body group A, L = 10; body group B, L = 12), subject 4 (body group B, R = 11, L = 11), subject 6 (body group A, R = 10, L = 10), and in the different body segments, with the highest scores for the neck: subject 2 (R = 6, L = 6), subject 3 (R = 6, L = 6), subject 4 (R = 5, L = 5), subject 5 (R = 5, L = 5), the arm: subject 2 (L = 5), subject 3 (L = 5), subject 6 (R = 5, L = 5), subject 1 (R = 4, L = 4), the wrist: subject 4 (R = 4), subject 5 (L = 4), subject 6 (R = 4, L = 4) and the trunk: subject 2 (R = 4, L = 4), subject 4 (R = 4, L = 4), subject 5 (R = 4, L = 4). In their study, Nussbaum et al. (2009) found that the lower back (50%), upper back (22%), and arms (22%) were the most affected areas during the installation of PW. Nimbarte et al. (2010) reported the neck as the most affected area, and Inyang et al. (2012) reported the back (111.71 min) and neck

Table 10.10 Postural assessment of the six subjects

H												
	Subject											
	1		2		3		4		5		6	
RULA score	R	L	R	L	R	L	R	L	R	L	R	L
Body part group A												
Upper arm	4	4	2	**5**	3	**5**	2	2	2	2	**5**	**5**
Lower arm	3	3	3	3	2	2	3	3	2	3	3	3
Wrist	3	3	3	2	3	3	4	3	3	4	4	4
Wrist twist	1	1	1	1	1	1	1	2	1	2	1	1
Total A	7	7	6	**10**	6	8	8	7	5	7	**10**	**10**
Body part group B												
Neck	4	3	**6**	**6**	**6**	**6**	**5**	**5**	**5**	**5**	3	3
Trunk	2	2	4	4	1	1	4	4	4	4	3	3
Total B	7	5	10	**12**	10	10	**11**	**11**	10	10	7	7
Final score	7	7	7	7	7	7	7	7	7	7	7	7

H = Holding Stage; R = Right limb; L = Left limb

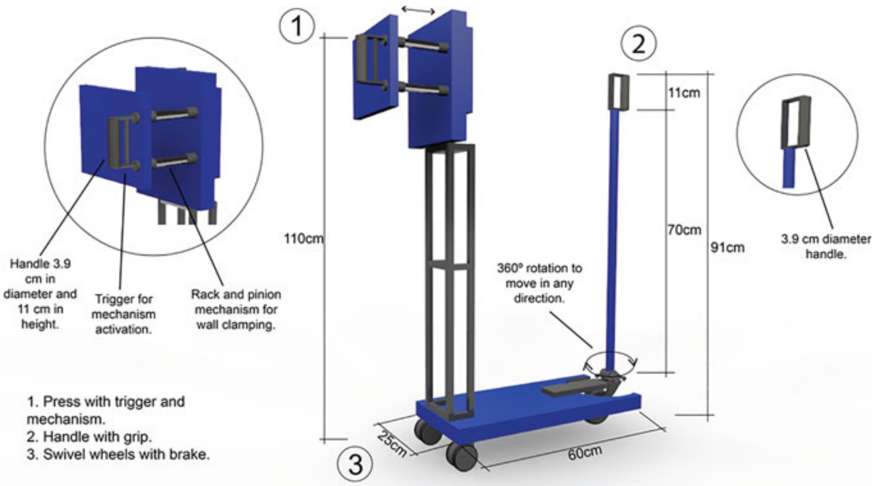


Fig. 10.1 Conceptual design proposal

(163.71 min) as the most exposed body segments. These results were considered so that the proposed design would have the least possible impact on these areas of the body.

Table 10.11 Parameters for the design proposal

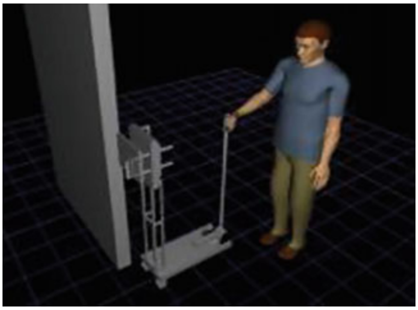
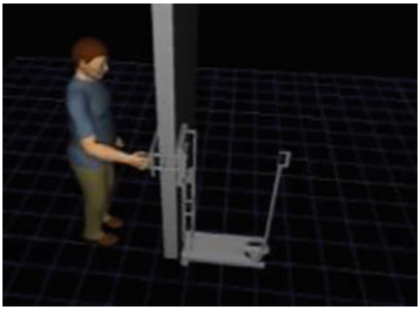
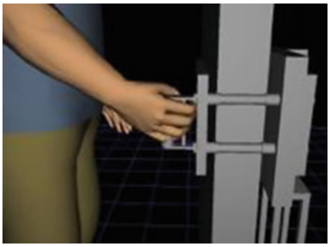
	Description
Exposure to postural risks	Holding stage (HS). First place in the order of influence with 38% frequency
Posture	Arms muscle use: mainly static posture in the RULA score
Paneled walls (PWs)	Characteristics: (a) 1.22 m × 2.44 m × 0.05 m, 25 kg and (b) 1.22 m × 1.60 m × 0.05 m, 17 kg
Saturated workspace	Workers need freedom of movement at the lateral ends of the wall while installing it
Designed device	Function in five stages: 1. Positioning the device, 2. Opening the press, 3. Clamping the wall, 4. Releasing the wall, 5. Removing the device
Anthropometry	Anthropometric dimensions of Latin-American male industrial workers aged 18–65 years, male sex in standing position: flexed elbow height (5th percentile = 906 mm), hand width (95th percentile = 103 mm), handgrip diameter (5th percentile = 39 mm)

In order to reduce the postural risk factors for workers during the execution of the HS, a design proposal has been developed with six ergonomic parameters (Table 10.11):

1. Exposure to postural risks. The HS represents 38% of the PWs installation task and affects other stages performed by the workers to achieve their objective of completing the structure.
2. Posture. The workers adopt a mainly 22 min static posture during the execution of the stage, affecting the neck, arms, wrist and trunk; the final results of the evaluation using the RULA method indicate that this situation must be changed immediately.
3. Panelled walls. It is necessary to have a device with characteristics that can adapt to the different wall dimensions. However, most have the standard dimensions of 1.22 m × 2.44 m, and other walls are modulated from this size to reach the heights of each type of construction.
4. Saturated workspace. The wall is mainly assembled by its lateral ends. Then it must be held by the device in such a way that the workers have freedom of movement to fix this wall to the other walls and any other stage within the task of PWs installation.
5. Use of the device in five stages: (a) Positioning the device, (b) Opening the press, (c) Clamping the wall, (d) Releasing the wall, and (e) Removing the device.

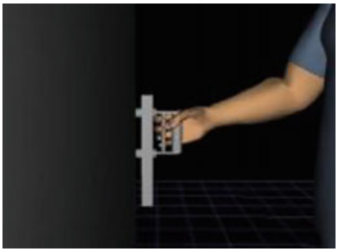
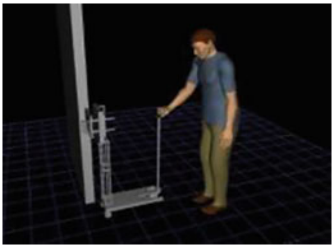
The stages described above were considered in the simulation of the design proposal and established according to the basic sequence in which the worker would use the device to hold the wall and make it easier for other workers to continue with the various stages of the PWs installation. The proposal is intended to be simple to use, and its implementation on-site does not affect the workers' delivery times, as recommended by Sporrong et al. (1999) in this type of proposal for construction workers.

Table 10.12 Stages of use considered for simulation

	Description	Image
1. Positioning the device	The worker transports the device near one end of the panelled wall	
2. Opening the press	The worker opens the press of the device to place the mouth of the press around the end of the panelled wall	
3. Clamping the wall	The worker closes the press to hold the wall	

(continued)

Table 10.12 (continued)

	Description	Image
4. Releasing the wall	The worker opens the press again to release the wall	
5. Removing the device	The worker removes the device	

Images were obtained using Jack™ software

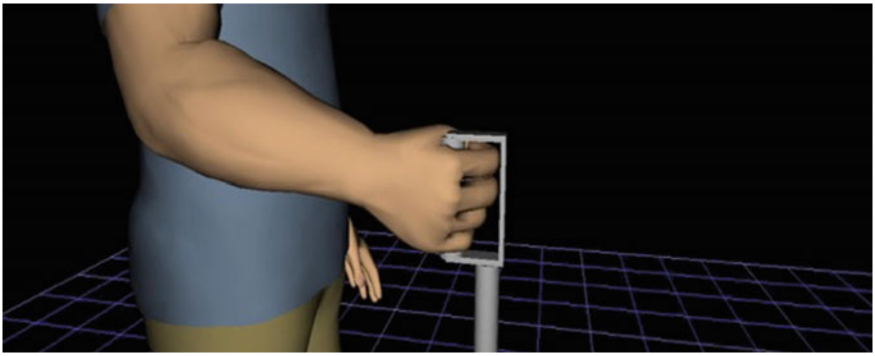


Fig. 10.2 Power grip to manipulate the device

The designed device has three main parts: (a) Press, where one end of the paneled wall is clamped to prevent it from swinging; (b) Handle with grip so that the worker can move the device; (c) Swivel wheels for freedom of movement on site. Moreover, the sixth parameter is the anthropometric dimensions of industrial workers aged 18 to 65 years from the Latin American male population, who are in a standing position (Ávila-Chaurand et al. 2007).

The decision to propose a mechanical device to reduce the postural risks found in the execution of the HS is based on the postulates of Mirka et al. (2003) and

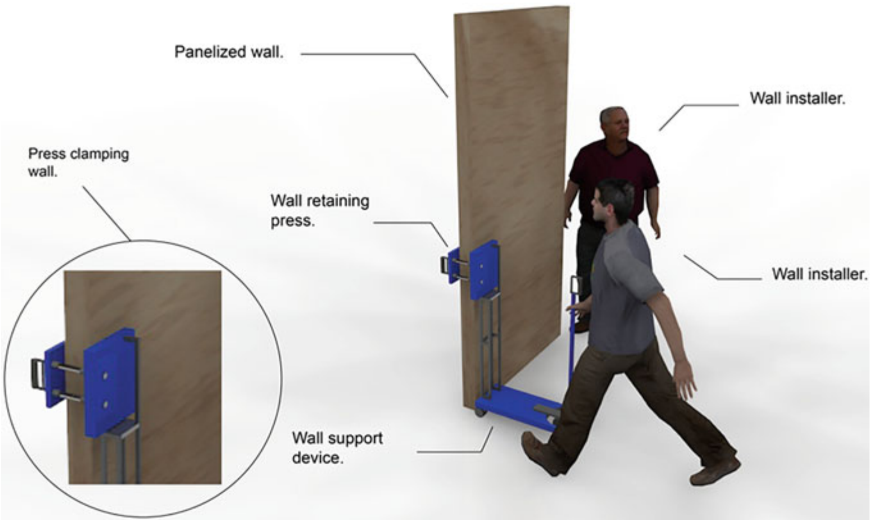


Fig. 10.3 Use of design proposal

Table 10.13 Anthropometric dimensions for simulation

Dimensions (mm)	Percentiles	
	5	95
Weight (kg)	55.31	97.30
Height	1576	1780
Flexed elbow height	906	1046
Hand width	83	103
Hand grip diameter	39	50

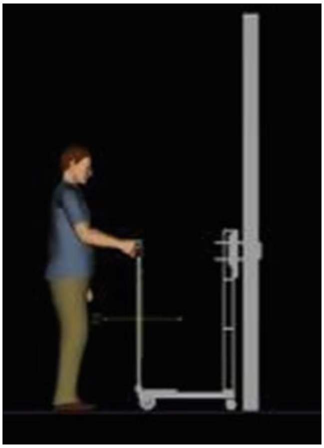
Source Ávila-Chaurand et al. (2007)

Albers et al. (2005), who argue that engineering controls are the most effective methods to reduce, control or eliminate exposure to risk factors that cause work-related musculoskeletal disorders.

A computer simulation was used to assess the level of postural risk when using the proposed design. Two subjects, representing the 5 and 95th percentiles, were simulated to assess the posture when performing the five device stages. The simulation was carried out using Jack™, which allows accurate biomechanical models of subjects of varying sizes to be positioned in a virtual environment, carrying out assigned tasks and then analyzing as they perform the activity (Jayaram et al. 2006; Shaikh et al. 2004).

Jack™ has incorporated the RULA method for postural assessment. The average final score was 2.7, and 70% of the final scores were 3, indicating further investigation and a possible need for change. 30% of the final scores were 2, indicating acceptable posture. This score corresponds to the performance of the 95th percentile subject in

Table 10.14 First stage postural assessment. Subject percentile 5

Stage of use			
1. Positioning the device			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

the ‘Opening the press’, ‘Clamping the wall’ and ‘Releasing the wall’ stages, which in turn had the highest score per body group in the ‘Positioning the device’ stage (body group A, R = 4, L = 4; body group B, R = 3, L = 3) and in the ‘Removing the device’ stage (body group A, = 4, L = 4; body group B, R = 3, L = 3).

The body segments with the highest scores were the lower arm: subject P95 at ‘Positioning the device’ (R = 3, L = 3) and ‘Removing the device’ (R = 3, L = 3) and the trunk: subject P95 at ‘Positioning the device’ (R = 3, L = 3) and task 5 (R = 3, L = 3). Overall, the sub-scores and final scores remained low. The final scores remained within the first two action levels of the RULA method. It is observed that the first and last stages of device use have the highest scores.

The results of the new design proposal were compared with the results of the postural assessment of the study participants. On the one hand, it is important to note that the results of the study participants’ assessments were obtained by performing

Table 10.15 Second stage postural assessment. Subject percentile 5

Stage of use			
2. Opening the press			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

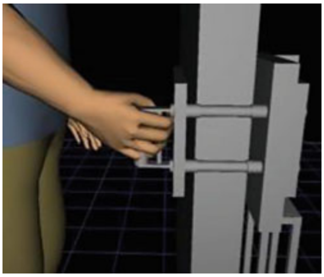
R = Right limb; L = Left limb

only one stage of the PWs' installation task, the HS, as this was identified as the one that posed the greatest risk to workers due to its level of exposure. The final score on the RULA scale for all assessments was 7, which requires a complete change in the task to be performed.

On the other hand, the evaluation results for the design proposal were obtained by virtually simulating five stages of device use, with scores between 2 and 3 on the RULA scale. The design of the device is intended not only to improve the postural load levels of the study participants but also to reduce as much as possible the need for the worker to perform the HS during the installation of PWs.

The results obtained by comparing the average of the final global score of the second postural assessment with the first, finding a percentage decrease in the levels of postural risk of 61.4%, show that, under the main objective, the implementation

Table 10.16 Third stage postural assessment. Subject percentile 5

Stage of use			
3. Clamping the wall			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

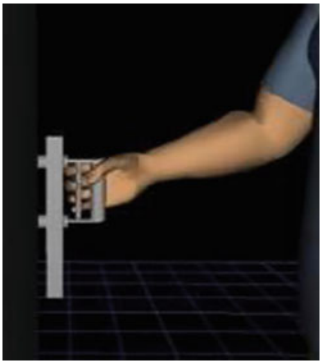
R = Right limb; L = Left limb

of a design proposal to help carry out the task of installing PWs, might reduce the levels of postural ergonomic risk factors in workers.

10.4.1 Conclusions and Recommendations

The postural assessment made it possible to know which body segments of the workers' upper limbs are affected and in what way when performing the task of installing PWs and, based on this assessment and the Hierarchical Task Analysis (HTA) (Méndez 2021), a design proposal was drawn up and a simulation and evaluation of the same, were carried out.

Table 10.17 Fourth stage postural assessment. Subject percentile 5

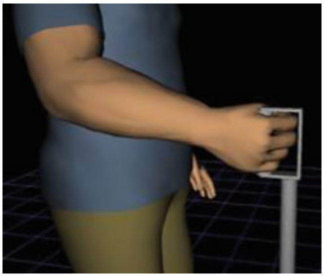
Stage of use			
4. Releasing the wall			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

It is suggested to continue with the research process so that the users for whom it is intended can test the design proposal once it is manufactured and continue looking for ergonomic risks. It is also recommended that workers know the importance of postural hygiene and the proper execution of their tasks to avoid injuries through ergonomic and occupational safety training courses.

It is also advisable to approach the subject from the perspective of other ergonomics research fields in order to generate other intervention proposals, such as studies on workers' energy expenditure; environmental ergonomics research to carry out studies on the working environment, lighting, temperature, ventilation, visual load, noise, vibrations; and cognitive ergonomics to find out what kind of mental load workers are exposed to. To conduct complete research, it is necessary to study in-depth the internal dynamics of the workers using social sciences such as anthropology and sociology.

Table 10.18 Fifth stage postural assessment. Subject percentile 5

Stage of use			
5. Removing the device			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

One of the limitations of the research was the number of participants and the fact that they were all male. Being a small group of six subjects, it cannot represent the paneled wall installers and exhibition booth assemblers in Mexico; however, the study could be replicated with a representative sample of this population. As a future research project, this proposal can be evaluated in a real scenario if the device is physically built.

As an important observation or note, it is necessary to clarify that the HS cannot be eliminated because it is part of performing the PW installation task; however, as the postural load is reduced with the implementation of the design proposal, the level of effort required decreases, and consequently the level of risk exposure decreases as well.

Table 10.19 First stage postural assessment. Subject percentile 95

Stage of use			
1. Positioning the device			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

Table 10.20 Second stage postural assessment. Subject percentile 95

Stage of use			
2. Opening the press			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

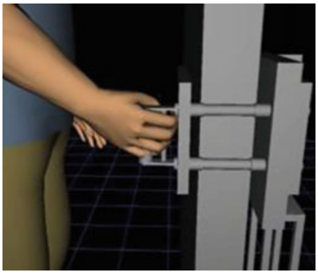
R = Right limb; L = Left limb

Table 10.21 Third stage postural assessment. Subject percentile 95

Stage of use			
3. Clamping the wall			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

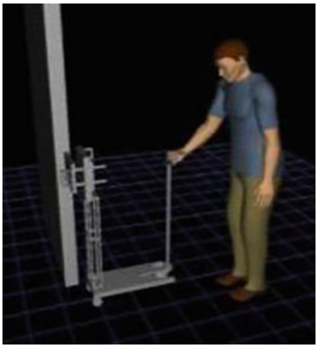
R = Right limb; L = Left limb

Table 10.22 Fourth stage postural assessment. Subject percentile 95

Stage of use			
4. Releasing the wall			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

Table 10.23 Fifth stage postural assessment. Subject percentile 95

Stage of use			
5. Removing the device			
Frame	RULA score		
	Body part group A	R	L
	Upper arm	2	2
	Lower arm	2	2
	Wrist	1	1
	Wrist twist	1	1
	Total A	3	3
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Arm	Without support	Without support
	Body part group B		
	Neck	1	1
	Trunk	1	1
	Total B	1	1
	Muscle use	Normal, no extreme use	Normal, no extreme use
	Strength/Load	2–10 kg, intermittent load	2–10 kg, intermittent load
	Feet and legs	Well supported	Well supported
	Final score	3	3

R = Right limb; L = Left limb

Table 10.24 Postural assessment of simulated stages of device use

Stage	1				2				3				4				5			
Simulated subject	P_5		P_{95}		P_5		P_{95}		P_5		P_{95}		P_5		P_{95}		P_5		P_{95}	
RULA score	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Body part group A																				
Upper arm	2	2	2	2	2	2	1	1	2	2	1	1	2	2	1	1	2	2	2	2
Lower arm	2	2	**3**	**3**	2	2	2	2	2	2	1	1	2	2	2	2	2	2	**3**	**3**
Wrist	1	1	2	2	1	1	2	2	1	1	1	1	1	1	2	2	1	1	2	2
Wrist twist	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total A	3	3	**4**	**4**	3	3	2	2	3	3	2	2	3	3	2	2	3	3	**4**	**4**
Body part group B																				
Neck	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Trunk	1	1	**3**	**3**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**3**	**3**
Total B	1	1	**3**	**3**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**3**	**3**
Final score	3	3	3	3	3	3	2	2	3	3	2	2	3	3	2	2	3	3	3	3

1 = Device placement; 2 = Press opening; 3 = Wall clamping; 4 = Wall release; 5 = Removal of device; P5 = 5 Percentile; P95 = 95 Percentile; R = Right limb; L = Left limb

Table 10.25 Average results in postural assessments and percentage decrease in risk level

Body segment	Limb	1º RULA assessment-average	2º RULA assessment-average	Difference	%
Upper arm	R	3	1.7	1.3	43.3
	L	3.8	1.7	2.1	**55.2**
Lower arm	R	2.6	2.1	0.5	19.2
	L	2.8	2.1	0.7	25.0
Wrist	R	3.3	1.4	1.9	**57.5**
	L	3.1	1.4	1.7	54.8
Wrist twist	R	1	1	0	0.0
	L	1.3	1	0.3	23.0
Neck	R	4.8	1	3.8	**79.1**
	L	4.6	1	3.6	**78.2**
Trunk	R	3	1.4	1.6	53.3
	L	3	1.4	1.6	53.3
Final overall score		7	2.7	4.3	**61.4**

R = Right limb; L = Left limb; % = Percentage of decrease in postural risk

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Chapter 11
Identification and Classification of Design Attributes for a Product to Verify Ergonomic Factors in Office Chairs

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Abstract Prolonged seated posture in office work directly affects the safety and performance of the worker. Human sustainability refers to the care of people in their health and quality of life, and ergonomic design is one of the means to preserve human resources in workspaces. This chapter uses Kano Model and Factor Analysis to determine and classify the design attributes for an ergonomic factor tester product for office chairs. Two stages were considered in the development process; the first referred to the application of the Kano Model, applied to a sample of 29 office workers, and the second one, to the realization of the factorial analysis, applied to 87 users related to the use of office chairs. For both studies, the attributes were divided into two groups, one referring to the ergonomic chair's characteristics and the other to the testing product. As a result, a total of 9 ergonomic attributes for the chairs and eight design attributes for the product were obtained, which were classified mainly as attractive attributes for the user; in turn, they were grouped into 3 and 2 groups, respectively; therefore, the analyzed variables can be encompassed.

Keywords Kano model · Factorial analysis · Office char

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11.1 Introduction

The worker is part of the backbone of any company in its formation and development of human capital. The sustainable management of human resources has among its objectives the care and effect of employees (Davidescu et al. 2020). Their health, quality of life, and well-being in general influence their performance and directly affect productivity in the organization, so efforts should be focused on preventing symptoms and providing adequate conditions for a working environment that complies with comfort and does not affect the individual with the presence of pathologies in the future (Salazar Peñaloza and Restrepo Sánchez 2021).

Nowadays, most occupations require a sitting posture for work performance, whether in offices or industries. In this regard, the sitting posture has become the most common work posture in today's workplace, and more than 75% of employees in industrialized countries do their work while sitting (Li et al. 2020). Specifically, office work may present fewer risk factors than other work settings. Still, they should be considered and included (Mondelo et al. 2001), as prolonged maintenance of the sitting posture leads to drawbacks that result in musculoskeletal problems (Janwantanakul et al. 2018).

The ergonomic design of the workplace attempts to obtain an adequate fit between the worker's aptitudes or skills and the requirements or demands of the job. The ultimate goal is to optimize the productivity of the worker and the production system while ensuring workers' satisfaction, safety, and health (Castro Carrasco 2016). Applying ergonomics in offices is an indispensable element not only to take care of the quality of life of the employees but also to guarantee their full performance during their stay in the workplace, based on conditions that make the task comfortable and that do not diminish the motivation necessary to carry it out (Dainoff 2019; Mondelo 2014). In this sense, ergonomic design is a means to preserve human resources in workspaces (Kumar 2017).

The chair, as an essential element of the seated posture, has evolved along with the culture of the time and place, resulting in many different designs, from very sober and functional to designs where comfort or utility was not considered but the design as an artistic representation (Alberruche Lucas 2015). That is why, as raised by Daza-Beltrán et al. (2014), the characteristics creation of the chair and its adjustability, both to the subject and the work surface, are determinants in the sedentary posture and can have effects on lumbar curvature, intradiscal pressure, muscle activity, blood circulation, tissue pressure, and body heat (Kee et al. 2019; O'Sullivan and McEvoy 2021). Therefore, given the great variety of office chair designs currently available on the market, when selecting a chair, not only the characteristics of the workstation should be considered and the person who will perform the job (Peñahora et al. 2018). Based on this, this chapter aims to identify attributes for the design of a device capable of verifying the suitability of office chairs to the characteristics of the workers who will use them; in other words, a device for verifying ergonomic factors in office chairs.

Currently, there are several methods used to define those attributes that should be considered as a starting point for a product's design to ensure the best user satisfaction with a specific product, and for the proper development of the proposed project, it was necessary to use some of these methods to define and classify the design requirements. The Kano Model, for example, has provided a powerful tool focused on determining the product qualities most likely to generate users' satisfaction (Sehrawat and Rai 2020). This method was developed to categorize a product's or service's attributes based on how well they can satisfy customer needs (Fuentes 2018). In addition, when many variables are collected simultaneously, there may be an interest in finding out whether the questions in an applied questionnaire, for example, are grouped in some distinctive way. On the other hand, factor analysis is a data reduction technique to find homogeneous groups from a large set of variables (IBM 2015). In this way, by applying this tool, it is possible to find groups of variables with ordinary meaning and thus reduce the number of dimensions needed to explain the subjects' responses.

Therefore, this chapter offers an analysis using the Kano Model to determine and classify the attributes that should be present in the design of a product that verifies ergonomic factors in office chairs according to the needs detected by users related to this type of chair, as well as grouping the variables obtained using the factor Analysis.

11.2 Objectives

This work aims to identify and classify the design requirements of an ergonomic factors tester device for office chairs. The following are the specific objectives of this research:

1. Obtain the attributes detected by the client about an office chair's ergonomic characteristics and the verifying device's basic properties.
2. Apply Kano Model to classify the attributes obtained according to the quality dimensions established by Kano.
3. Develop a factor analysis to group the classified attributes.

11.3 Methodology

This section describes the materials, samples, and methods used in this research. Two stages were considered in the development of the project. The first stage was directed at applying the Kano Model, and the second stage consisted of conducting a factor analysis. An online survey was sent to experts to identify the attributes used in the Kano Model. The Kano Model was applied once to a group directly related to using office chairs. For the application of the factor analysis, an online questionnaire was conducted on a group of office chair users, with the variables detected in the Kano model. The results are reported, as well as their analysis and interpretation. It is, in this sense, a cross-sectional and descriptive study.

11.3.1 Materials

For applying the expert survey, the Kano Questionnaire, and the Likert scale questionnaire, the online forms platform known as Google Forms© was used. For the compilation of the results of the three questionnaires, as well as for the analysis and interpretation of the Kano Model, an Excel template was used with the necessary tables, graphs, and equations. The statistical software SPSS version 26 was used to analyze the factor analysis data.

11.3.2 Sample

For the expert survey, purposive or optional sampling of 6 Ergonomics specialists was carried out to define the attributes. To apply the Kano Questionnaire, a random or casual selection was conducted among 29 people of both sexes, aged between 18 and 50 years, all belonging to the labor sector, mainly in offices, or at least using office chairs to carry out their work. In the case of the factorial analysis, an accidental sampling was carried out among 87 users related to the use of office chairs, also aged between 18 and 50 years.

11.3.3 Kano Methodology

Regardless of the type of product to be analyzed, the steps to follow to apply the Kano model are as follows:

Step 1—Identification of customer needs: A group of experts used an online questionnaire consisting of three parts. The first one indicates the reasons for the questionnaire, and the other two refer, respectively, to office chairs to know the experts' opinion on the characteristics, comfort, and usability of existing office chairs; and to the product to be designed, seeking to understand how useful it could be, as well as its characteristics and functionality. The eight questions were open-ended but limited in the number of items to be included in the response. The questionnaire and a link for their answers were sent to the experts by e-mail. Figure 11.1 shows the questions included in the online questionnaire. To consult the questionnaire in its entirety, consult the following link: https://forms.office.com/Pages/ResponsePage.aspx?id=lWO64WR6kkuq86fAIMPRj_m_BsdfNhFKgDm1E8HwxsBURVBPRVNBSFFHQ1Q5Uk5OUFNKTlZJTlkxUi4u.

Step 2—Construction of the Kano Questionnaire: Once the attributes provided by the experts had been obtained, a filtering process was carried out on all the responses received to use the common and unrepeated ones for constructing the Kano questionnaire. The questionnaire was based on two questions for each attribute: the functional question and the dysfunctional question. While the former asks how

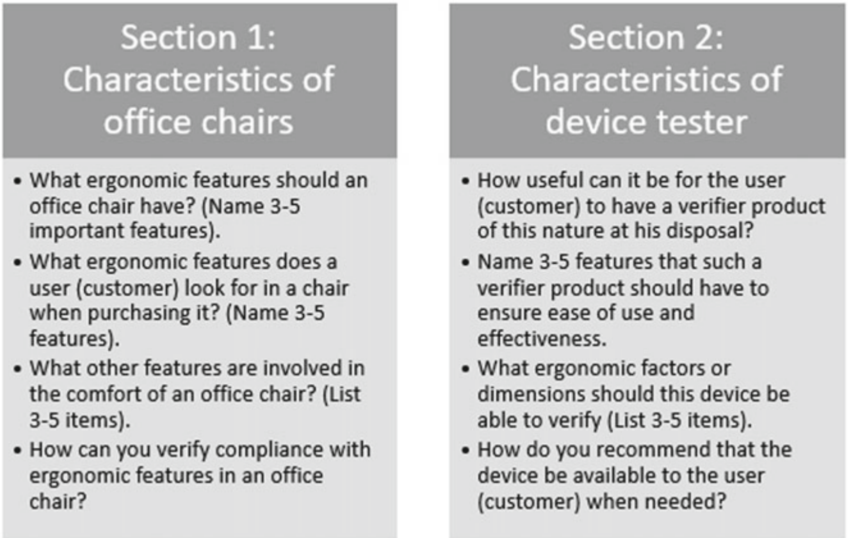


Fig. 11.1 Online questionnaire questions for experts

the customer feels when the attribute is present in the product, the latter asks how the customer feels, in the opposite case, when the attribute is not present in the product. The questions were single-choice, and the respondent selected, for both the dysfunctional and functional questions, one of the following options:

1. I would like to
2. Must be present
3. I do not care
4. I do not like it, but I tolerate it
5. I would not like it.

The combination of functional and dysfunctional responses to the same attribute resulted in the initial classification of user needs. Figure 11.2 shows the evaluation table of the Kano model by which this first classification was obtained.

As stated by Hern and Hern (2001), these classifications are as follows:

1. A (Attractive): it is one that, when present, makes the user happy but, when absent, does not make the user unhappy.
2. U (Unidimensional): it refers to an attribute that has a positive, linear relationship to customer satisfaction; that is, the more thoroughly the attribute is met, the more satisfied the user is.
3. (Obligatory): it is one that, when present, does not help to boost user pleasure but, when lacking, results in consumer discontent.
4. I (Indifferent): it does not make the user happy or unhappy, whether it is present or missing.

ATTRIBUTES			Dysfunctional Questions (Negative responses)				
			I would like to	Must be present	I don't care	I don't like it, but I tolerate it	I would not like it
			1	2	3	4	5
Functional Questions (Positive responses)	I would like to	1	C	A	A	A	U
	Must be present	2	R	I	I	I	O
	I don't care	3	R	I	I	I	O
	I don't like it, but I tolerate it	4	R	I	I	I	O
	I would not like it	5	R	R	R	R	C

Fig. 11.2 Kano evaluation table

5. R (Reversible): while present, it detracts from customer happiness; when absent, it increases it.

Step 3—Evaluation and interpretation: Applying the Kano table to the answers of the 29 users and using the Kano Evaluation Table, the attributes already classified as defined by the method were obtained, as well as the processing of the way in percentages for both study sections. With the information obtained from the frequency analysis, it was decided to continue the development of the Kano Model only for the "Verification Device" section since it is the object of study of the research. For this purpose, the Satisfaction Coefficient (CS) and the Dissatisfaction Coefficient (DS) were calculated to know the average impact of a product attribute on the satisfaction of all customers. These coefficients provide insights into the importance and influence of different attributes on overall customer satisfaction (Hsieh and Lin 2019; Yousuf et al. 2019). Finally, to evaluate the statistical significance of the Kano model ranking, the absolute difference of the two highest frequencies of the alternatives (attractive, unidimensional, obligatory, indifferent, and reversible) was calculated and compared with the Q statistic, which was calculated using predefined formulas in Excel. These actions were performed in Microsoft Excel spreadsheets, and Figs. 11.3 and 11.4 shows some of the original pages in Spanish of the Excel template used for data analysis.

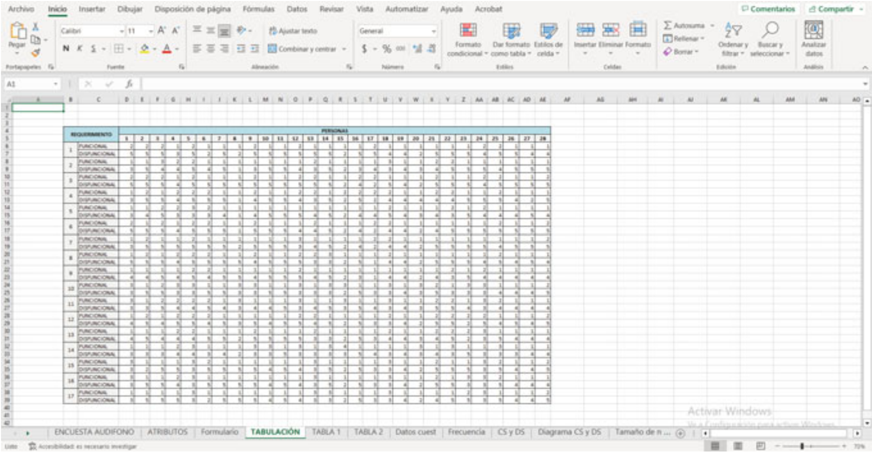
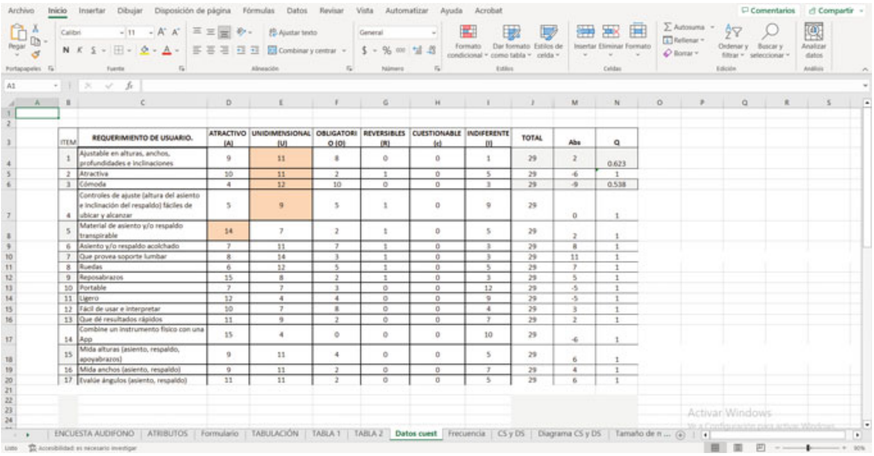


Fig. 11.3 Screenshot of excel template for the tabulation of questionnaire answers



ITEM	REQUERIMIENTO DE USUARIO.	ATRACTIVO (A)	UNIDIMENSIONAL (U)	OBLIGATORIO (O)	REVERSIBLES (R)	CUESTIONABLE (c)	INDIFERENTE (I)	TOTAL	Abs	Q
1	Ajustable en alturas, anchos, profundidades e inclinaciones	9	11	8	0	0	1	29	2	0.623
2	Atractiva	10	11	2	1	0	5	29	-6	1
3	Cómoda	4	12	10	0	0	3	29	-9	0.538
4	Controles de ajuste (altura del asiento e inclinación del respaldo) fáciles de ubicar y alcanzar	5	9	5	1	0	9	29	0	1
5	Material de asiento y/o respaldo transpirable	14	7	2	1	0	5	29	2	1
6	Asiento y/o respaldo acolchado	7	11	7	1	0	3	29	8	1
7	Que provea soporte lumbar	8	14	3	1	0	3	29	11	1
8	Ruedas	6	12	5	1	0	5	29	7	1
9	Reposabrazos	15	8	2	1	0	3	29	5	1
10	Portable	7	7	3	0	0	12	29	-5	1
11	Ligero	12	4	4	0	0	9	29	-5	1
12	Fácil de usar e interpretar	10	7	8	0	0	4	29	3	1
13	Que dé resultados rápidos	11	9	2	0	0	7	29	2	1
14	Combine un instrumento físico con una App	15	4	0	0	0	10	29	-6	1
15	Mida alturas (asiento, respaldo, apoyabrazos)	9	11	4	0	0	5	29	6	1
16	Mida anchos (asiento, respaldo)	9	11	2	0	0	7	29	4	1
17	Evalúe ángulos (asiento, respaldo)	11	11	2	0	0	5	29	6	1

Fig. 11.4 Screenshot of excel template for Abs and Q calculations

11.3.4 Factorial Analysis

The online questionnaire platform Google Forms was used to evaluate the attributes to be analyzed (Smith 2020). For the assessment of these attributes, a digital visual scale of 5 response points (Likert scale) was used, which included the terms "unimportant" on the left, with a value of (1) and "extremely important" on the right, with a value of (5) (Jones et al. 2018). The rated attributes resulted from the first developed stage of the Kano Model (Lee et al. 2017).

The results obtained from the questionnaire were entered into the SPSS version 26 statistical software to conduct further analysis. In each group, Cronbach's alpha and factor analysis of the variables were applied separately. Cronbach's alpha was used to assess the internal consistency and reliability of the measured variables within each group (Field 2013). The analysis included the Keiser Meyer Olkin (KMO) Test, which measures the sampling adequacy; the Total Variance Explained, which indicates the proportion of variance accounted for by the extracted factors; and the Rotated Component Matrix, which displays the factor loadings for each variable (Hair et al. 2019).

11.3.5 Data Analysis

An Excel template was used to analyze all the data referring to the Kano Model with the necessary tables, graphs, and equations. The factorial analysis involved several steps. First, the internal consistency of the data was assessed using Cronbach's alpha index to ensure the reliability of the measured variables within the dataset (Field 2013). Next, the adequacy of the sample was evaluated using the Kaiser–Meyer–Olkin (KMO) index, which measures the sampling adequacy for factor analysis (Hair et al. 2019). Factor extraction was performed using the principal component method, and varimax rotation was applied to simplify and interpret the extracted factors (Tabachnick and Fidell 2019).

11.4 Results

Based on the methodology developed, with the application of questionnaires and the analysis of the data obtained from them, this section presents the results for the two stages: Kano Model and Factor analysis.

11.4.1 Kano Model

11.4.1.1 Step 1: Identification of Customers' Needs

As a result, nine ergonomic requirements for the chairs and eight design requirements for the product were obtained. Table 11.1 summarizes the 17 attributes obtained.

Definitions of attributes that may confuse what they refer to are added below.

For office chair:

- Attributes referring to adjustability refer to the parts of the chair being variable in terms of their positions and/or dimensions (Attributes 1 and 4).

Table 11.1 Attributes obtained from the questionnaire to experts

Office chair	Device tester
Attribute 1: Adjustable in heights, widths, depths, and inclinations	Attribute 1: Portability
Attribute 2: Attractive	Attribute 2: Lightweight
Attribute 3: Comfortable	Attribute 3: Easy to use and interpret
Attribute 4: Adjustment controls (seat height and backrest tilt) are easy to locate and reach	Attribute 4: Fast results
Attribute 5: Breathable seat and/or backrest material	Attribute 5: Combine a physical instrument with an App
Attribute 6: Padded seat and/or backrest	Attribute 6: Measure heights (seat, backrest, armrest)
Attribute 7: Providing lumbar support	Attribute 7: Measure widths (seat, backrest)
Attribute 8: Wheels	Attribute 8: Evaluate backrest and seat angles
Attribute 9: Armrests	

- Attributes 8 (Wheels) and 9 (Armrests) refer to these elements on the office chair.
- For verifying the device:
- Attribute 1 (Portability) refers to the device being easily transported by weight, materials, dimensions, and shape.
- Attribute 2 (Lightweight) responds to the fact that the materials and dimensions to be used guarantee the minimum weight of the device.

11.4.1.2 Step 2: Kano Questionnaire Design

Two questionnaires were designed, one for the office chairs and the other for the verification device. Both were composed of the attributes to be evaluated, the functional and dysfunctional questions for each attribute, and the five response options. Tables 11.2 and 11.3 show how the questions were formed.

11.4.1.3 Step 3: Evaluation and Results of the Kano Model

This section presents the results for classifying the attributes, calculating CS and DS, the Statistical Test "Q" and the "K" index.

1. **Attributes Classification**

By applying the Kano table to the answers of the 29 users and using the Kano Evaluation Table, Tables 11.4 and 11.5 were obtained, which show the attributes obtained already classified as defined by the method; and the processing of the method in percentages. The Kano table with the answers of the 29 users can be

Table 11.2 Questionnaire design. Office chair

Attribute	Positive question	Negative question
1	If the chair is adjustable in height, width, depth, and inclination, how would you feel?	If the chair is NOT adjustable in height, width, depth, and inclination, how would you feel?
2	If the chair looks attractive, how would you feel?	If the chair NOT looks attractive, how would you feel?
3	If the chair is comfortable, how would you feel?	If the chair is NOT comfortable, how would you feel?
4	If the adjustment controls (seat and back heights and tilts) are easy to locate and reach, how would you feel?	If the adjustment controls (seat and back heights and tilts) are NOT easy to locate and reach, how would you feel?
5	If the seat and/or backrest were made of a breathable material, how would you feel?	If the seat and/or backrest are NOT made of a breathable material, how would you feel?
6	If the seat and/or back of the chair are padded, how would you feel?	If the seat and/or back of the chair are NOT padded, how would you feel?
7	If the chair provides lumbar support, how would you feel?	If the chair NOT offers lumbar support, how would you feel?
8	If the chair has wheels, how would you feel?	If the chair NOT has wheels, how would you feel?
9	If the chair has armrests, how would you feel?	If the chair NOT has armrests, how would you feel?

Table 11.3 Questionnaire design. Device to verify ergonomic factors in office chairs

Attribute	Positive question	Negative question
1	If the device is portable, how would you feel?	If the device is NOT portable, how would you feel?
2	If the device is lightweight, how would you feel?	If the device is NOT lightweight, how would you feel?
3	If the device is easy to use and interpret, how would you feel?	If the device is NOT easy to use and interpret, how would you feel?
4	If the device provides immediate results, how would you feel?	If the device does NOT give immediate results, how would you feel?
5	If the device combined a physical instrument with a digital application for its operation, how would you feel?	If the device did NOT combine a physical instrument with a digital application for its operation, how would you feel?
6	If the device measures the heights of chair elements such as the seat, backrest, and armrests, how would you feel?	If the device does NOT measure the heights of chair elements such as the seat, backrest, and armrests, how would you feel?
7	If the device measures the width of chair elements such as the seat and backrest, how would you feel?	If the device does NOT measure the width of chair elements, such as the seat and backrest, how would you feel?
8	If the device can evaluate seat and backrest angles, how would you feel?	If the device can NOT evaluate seat and backrest angles, how would you feel?

consulted in the following link: https://docs.google.com/spreadsheets/d/1FbVOEWvtwbixIfbIKfsZkVWrtgsdsNpy/edit?usp=sharing&ouid=114466855837179788380&rtpof=true&sd=true.

The classification obtained for this section reveals that most attributes were categorized as Unidimensional (U in table) based on the sampling conducted (Jones et al. 2018). This fact indicates that these attributes have a proportional relationship with customer satisfaction. Therefore, the designed device must assess the presence of these attributes in the chairs to be analyzed, as they play a significant role in determining customer satisfaction levels (Lee et al. 2017).

In the second section, the classification made it possible to define more clearly the order of priority of the attributes to be resolved in the design of the same. Contrary to what was initially believed, the questionnaire showed that respondents were Indifferent primarily to the presence of attribute 1 (portability of the device), even though it is dispersed between Attractive and Unidimensional so that this attribute should be further evaluated to determine whether an error or misunderstanding may influence this response in the formulation of the question.

Likewise, it became evident at this point that both attribute 4 (Adjustment controls easy to locate and reach) of the Office Chair and attribute 8 (Evaluate backrest

Table 11.4 Classification of the attributes for the "Office chair" section, obtained with the Kano questionnaire

Attributes	A	U	O	C	R	I	T	Clasf.
1. Adjustable in heights, widths, depths, and inclinations	9	11	8	0	0	1	29	U
	31%	38%	28%	0%	0%	3%	100%	
2. Attractive	10	11	2	1	0	5	29	U
	34%	38%	7%	3%	0%	17%	100%	
3. Comfortable	4	12	10	0	0	3	29	U
	14%	41%	34%	0%	0%	10%	100%	
4. Adjustment controls are easy to locate and reach	5	9	5	1	0	9	29	I/U
	17%	31%	17%	3%	0%	31%	100%	
5. Breathable seat and/or backrest material	14	7	2	1	0	5	29	A
	48%	24%	7%	3%	0%	17%	100%	
6. Padded seat and/or backrest	7	11	7	1	0	3	29	U
	24%	38%	24%	3%	0%	10%	100%	
7. Providing lumbar support	8	14	3	1	0	3	29	U
	28%	48%	10%	3%	0%	10%	100%	
8. Wheels	6	12	5	1	0	5	29	U
	21%	41%	17%	3%	0%	17%	100%	
9. Armrest	15	8	2	1	0	3	29	A
	52%	28%	7%	3%	0%	10%	100%	

Meaning of column headings: A, Attractive; U, Unidimensional; O, Obligatory; C, Questionable; R, Reversible; I, Indifferent; T, Total; Clasf, Classification of the attributes for the sample of 29 users

Table 11.5 Classification of the attributes for the "Device to check ergonomic factors in office chairs" section, obtained with the Kano questionnaire

Attributes	A	U	O	C	R	I	T	Clasf.
1. Portability	7	7	3	0	0	12	29	I
	24%	24%	10%	0%	0%	41%	100%	
2. Lightweight	12	4	4	0	0	9	29	A
	41%	14%	14%	0%	0%	31%	100%	
3. Easy to use and interpret	10	7	8	0	0	4	29	A
	34%	24%	28%	0%	0%	14%	100%	
4. Fast results	11	9	2	0	0	7	29	A
	38%	31%	7%	0%	0%	24%	100%	
5. Combine a physical instrument with an App	15	4	0	0	0	10	29	A
	52%	14%	0%	0%	0%	34%	100%	
6. Measure heights	9	11	4	0	0	5	29	U
	31%	38%	14%	0%	0%	17%	100%	
7. Measure widths	9	11	2	0	0	7	29	U
	31%	38%	7%	0%	0%	24%	100%	
8. Evaluate backrest and seat angles	11	11	2	0	0	5	29	A/U
	38%	38%	7%	0%	0%	17%	100%	

Meaning of column headings: A, Attractive; U, Unidimensional; O, Obligatory; C, Questionable; R, Reversible; I, Indifferent; T, Total; Clasf, Classification of the attributes for the sample of 29 users

and seat angles) of the Device to be designed could not yet be classified in any of the groups because the responses obtained were equally dispersed in two different classifications, leading to two possibilities: the question was not well understood, or the public was varied in their levels of satisfaction.

The results in Tables 11.4 and 11.5 were grouped as follows. For Office Chairs, the following attributes were defined:

(a) **Attractive attributes**

1. The chair seat and/or back material are breathable.
2. The chair has armrests.

(b) **Unidimensional Attributes**

1. The chair is adjustable in height, width, depth, and inclinations.
2. The chair has an attractive appearance.
3. The chair is comfortable.
4. The chair has a padded seat and/or backrest.
5. The chair provides lumbar support.
6. The chair has casters.

None were defined regarding Mandatory, Questionable, Reversible, and Indifferent Attributes.

In the case of the Ergonomic Factors Verification Device, the following attributes were defined:

(a) **Attractive attributes**

1. The device is lightweight.
2. The device is easy to use and interpret.
3. The device gives fast results.
4. For its operation, the device combines a physical instrument with an App.

(b) **Unidimensional attributes**

1. The device can measure the heights of different seat elements, such as the seat, backrest, and armrests.
2. The device can measure the width of different chair elements, such as the seat and backrest.

(c) **Indifferent Attributes**

1. The device is portable.

Regarding Mandatory, Questionable, and Reversible Attributes, none were defined for Ergonomic Factors Verification Device.

Concerning the percentages obtained, it became evident that, in the "Device" section, attributes 2 and 5 are classified as Attractive but with a particular predilection for Indifference. In the case of requirements 3 and 4, although Attractive, the percentages obtained show their dispersion in the responses; for attributes 6 and 7, it is evident that they are primarily Unidimensional, although with a certain tendency to be Attractive. In this sense, and based on the highest frequencies obtained so far, it was concluded that priority should be given to attributes 6 and 7 (U), 5(A), 2(A), 4(A), and 3(A), in this order.

About the data obtained from the "Office Chair" section, it was decided to conclude the analysis of the Kano Model at this point and focus on the attributes of the device itself since, as mentioned above, the Unidimensional attributes will be the ones that will be most corroborated in the device to be designed.

2. **CS and DS calculation**

Although it can be said that a classification of the attributes has already been obtained, the Kano method allows an even deeper analysis for their classification since it is possible to have the same number of responses in two categories, as in attribute 8 of the Device. The coefficients of Satisfaction (CS) and Dissatisfaction (DS) were calculated for a better interpretation. Equations (11.1) and (11.2) are employed to calculate the coefficients, which are used to determine the average influence of an attribute on user satisfaction (Nakamura and Kano 2002).

$$\text{Coefficient of Satifaction (CS)} = \frac{\text{Attractive} + \text{Unidimensional}}{\text{Attractive} + \text{Unidimensional} + \text{Obligatory} + \text{Indifferent}} \quad (11.1)$$

$$\text{Coefficient of Insatifaction (DS)} = \frac{\text{Obligatory} + \text{Unidimensional}(-1)}{\text{Attractive} + \text{Unidimensional} + \text{Obligatory} + \text{Indifferent}} \quad (11.2)$$

According to Hern and Hern (2001), the maximum value considered for these equations' interpretation is 1 for the CS and −1 for the SD, so:

- If the examined attribute has a CS value close to 1, it is understood that including it will result in high user satisfaction.
- If the value of the analyzed characteristic is near one, it is assumed that the absence of the attribute will result in significant user unhappiness.
- If any of the coefficients have a value near zero, it is assumed that the attribute will not make people unhappy if it is not present.

As presented in the methodology, this stage was limited to the analysis of the study section referring to the ergonomic factor verifier device to be designed. Based on this, the results obtained from calculating the CS and DS indices for the analyzed attributes are presented. Table 11.6 summarizes the values of these indices, which were calculated using specific formulas in Excel. Figure 11.5 graphically represents these values. Figure 11.6 shows the attributes already classified according to Kano based on the CS and DS values.

No requirement exceeds the level of dissatisfaction above that or satisfaction.

Most of the deals are attractive to the user. The numbers represented respond to the same order of the requirements already presented in the previous tables. The relationship between the numbers in the graph and the attribute they represent is shown in Table 11.7.

Table 11.6 Calculation of CS and DS for ergonomic factor tester device for office chairs

Attributes	CS (+)	DS (−)
1. Portability	0.5	−0.3
2. Lightweight	0.6	−0.3
3. Easy to use and interpret	0.6	−0.5
4. Fast results	0.7	−0.4
5. Combine a physical instrument with an App	0.7	−0.1
6. Measure heights	0.7	−0.5
7. Measure widths	0.7	−0.4
8. Evaluate backrest and seat angles	0.8	−0.4

Meaning of column headings: CS, Satisfaction Coefficient; DS, Dissatisfaction Coefficient

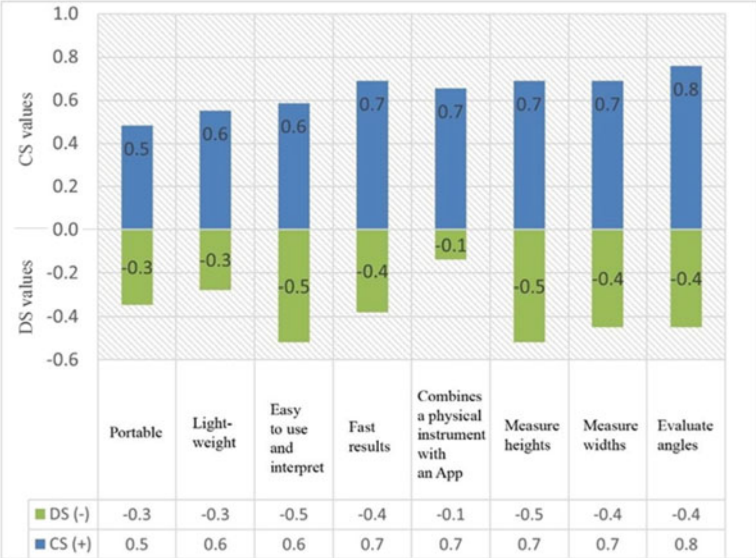


Fig. 11.5 CS and DS values graphic

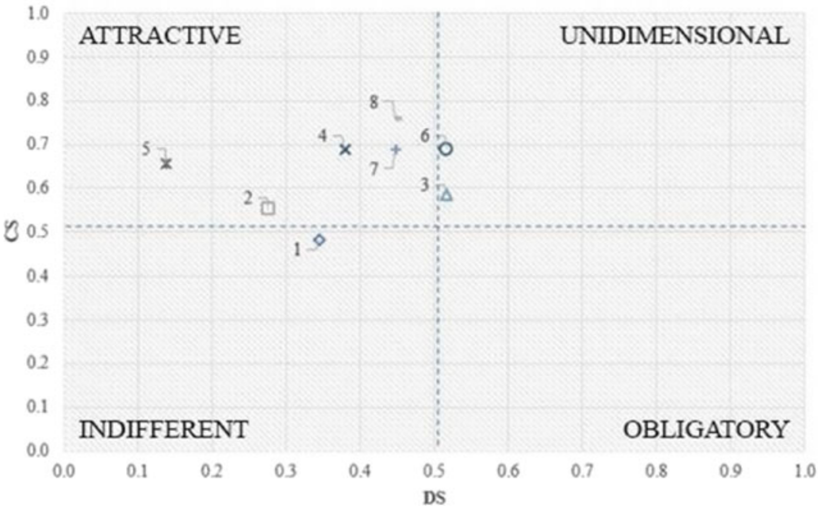


Fig. 11.6 Classification of attributes according to CS and DS values

Using the calculation of CS and DS, and their graphic representations, it was observed that most of the attributes were attractive to the user surveyed so that their presence in the product will increase customer satisfaction; in this sense, the order of priority, according to the values obtained, for their incorporation in the design,

Table 11.7 Relationship between the numbers in the graph and the attributes

Item	Attribute
1	Portable
2	Lightweight
3	Easy to use and interpret
4	Fast results
5	Combines a physical instrument with an App
6	Measure heights (seat, back, armrests)
7	Measure widths (seat back)
8	Evaluate angles (seat, backrest)

would be as follows: as unidimensional attributes are attributes 6 and 3 respectively, which, even being in this group, are pretty close to the group of the attractive ones; which, in turn. It would be formed by attribute 8, as the one with the highest CS, although the variation between them could be better, followed by 7 and 4 at the same level, followed by 5 and 2, in that order.

With this new analysis, attribute 8 was initially split between two classifications and placed first among the attractive elements. In addition, a variation in the order of the attributes was observed concerning the conclusion taken in comparing frequencies. It was also reaffirmed that attribute 1 was indifferent to the user surveyed, even though it was dispersed between attractive and unidimensional in the analysis of Fig. 11.4 above.

Based on this analysis, the attributes were regrouped again, and it was concluded that the design attributes of the product to be designed, according to the Kano Method, should be as follows in Tables 11.8 and 11.9.

Table 11.8 Expected product characteristics (Unidimensional attributes)

Item	Attribute
6	Measure heights (seat, back, armrest)
3	Easy to use and interpret

Table 11.9 Expected product characteristics (Unidimensional + Attractive attributes)

Item	Attribute
6	Measure heights (seat, back, armrest)
3	Easy to use and interpret
8	Evaluate angles (seat, back)
7	Measure widths (seat, back)
4	Give fast results
5	Combine a physical instrument with an App

11.4.1.4 Statical Test "Q"

To evaluate the statistical significance of the classification obtained by the Kano model, a comparison was made between the absolute difference (Abs) of the two highest frequencies of each of the variables analyzed and the statical test "Q" (Hern 2001). To find the absolute difference, Eq. (11.3) was used, and Eq. (11.4) shows the calculation of the "Q".

$$Abs = a - b \tag{11.3}$$

Meaning of letters in the formula:

Abs is the absolute difference between the two highest frequencies, *a* and *b* are the frequencies of the highest observations for each attribute.

$$Q = 1.6 \times \sqrt{\frac{(a + b) \times (2n - a - b)}{2n}} \tag{11.4}$$

Meaning of letters in the formula:

Q	is the statical test "Q".
a and b	are the frequencies of the highest observations.
n	is the total number of responses.

For each response, the value of the Q statistic is compared to the absolute difference between a and b, or Abs (a–b). The ranking of the attribute is not statistically significant if the value of Abs (a–b) is less than Q. Conversely, the order is statistically significant if the value of Abs (a–b) exceeds the Q statistic. Table 11.9 shows the calculated value of Abs and Q and its significance.

The significance of Kano's classification was evaluated through the corresponding formula for calculating the "Q" test. In this sense, Table 11.10 shows that 7 of the 8 assessed attributes present a statistically significant classification, so there are no identifiable market segments or problems in formulating the question. On the other hand, with attribute No. 8 (Evaluate angles), the value of Abs (a-b) is lower than the value of Q, so this item could be studied further to identify if there are different market segments or if the question presented some error during its application. Note that even though this is the case, in the previous analysis, this was the attractive attribute with the highest level of satisfaction (CS), so the result could be based on market differences, but it will still be studied further.

11.4.1.5 Concentration Index of "K"

Kano also offers the possibility of analyzing the responses through the evaluation of K (index of concentration of responses) (González-Rodríguez et al. 2019), the values of this variable should be found from 0 to 1, and the level of dispersion (divergence)

Table 11.10 Statistical test "Q"

Item	Requirement	Abs	Comp. Abs and Q	Q	Test Q
1	Portable	5	>	0.774	Acceptable
2	Lightweight	3	>	0.793	Acceptable
3	Easy to use and interpret	2	>	0.763	Acceptable
4	Delivers fast results	2	>	0.784	Acceptable
5	Combine a physical instrument with an App	5	>	0.817	Acceptable
6	Measure heights (seat, back, armrests)	2	>	0.784	Acceptable
7	Measure widths (seat, back)	2	>	0.784	Acceptable
8	Evaluate angles (seat, back)	0	<	0.801	Research

Meaning of columns: Abs (a–b), the absolute difference between the two highest observed frequencies; Comp- Abs and Q, Comparison between Abs and Q value

can be found if its values are close to 0, the concentration is the opposite. The K index offers valuable insights into customer agreement or disagreement regarding their preferences and satisfaction with different attributes (Santos et al. 2021). The values determined in this study are presented in Tables 11.11 and 11.12.

Finally, using the "K" index, the behavior of the attributes, according to their concentration, could be appreciated. First, the difference between the extremes was insignificant, ranging from a minimum of 0.552 (Attribute 1) to a maximum of 0.683 (Attribute 4). The attributes with the highest concentration of responses were those of attributes 4, 2, and 3, which indicates more extraordinary coincidence in

Table 11.11 Values obtained for K

Item	Attribute	K
1	Portable	0.5529069
2	Lightweight	0.6784696
3	Easy to use and interpret	0.6630099
4	Delivers fast results	0.6834317
5	Combine a physical instrument with an App	0.6011273
6	Measure heights (seat, back, armrests)	0.5963319
7	Measure widths (seat, back)	0.6117749
8	Evaluate angles (seat, back)	0.6130297

Table 11.12 Other values obtained for K

Magnitude	Value	Attribute
Median	0.6124023	–
Minimum	0.5529069	1
Maximum	0.6834317	4

the valuations of these by the users surveyed. Question 1 had the most significant variability, with a value of $K = 0.553$, the attribute with the highest dispersion. Still, in general, the K values obtained indicated clarity in the formulation of the questions.

11.4.2 Factorial Analysis

As a result of the factor analysis carried out, the following results were obtained: Cronbach's alpha indexes are above 0.87 in the general study of all the variables, as well as in the analysis of those related to the verifying device, whose value exceeds 0.91, while in the office chair group, they exceed 0.61. DeVellis (2017) states that a Cronbach's alpha coefficient of 0.70 or higher typically indicates acceptable internal consistency. Streiner and Norman (2015) highlight the importance of Cronbach's alpha in assessing the reliability of a scale. They indicate that the scale's items are sufficiently correlated with one another and measure the same attribute. In contrast, a low level of internal consistency may be indicated by Cronbach's alpha coefficient below 0.70. This might result from the scale's items' low correlation with one another or their inconsistent measurement of a shared trait. Therefore, Cronbach's value obtained for all variables and the verifying device indicates a high internal consistency among the scale items. This implies that the items are adequately correlated with each other and consistently measure a common characteristic. At the same time, for analyzing the variables corresponding to the office chair, the value obtained indicates some internal consistency in the scale items. Still, it is relatively low, so it is advisable to perform a more detailed analysis and consider possible improvements in the scale to obtain greater internal consistency. Tables 11.13, 11.14 and 11.18 present these results.

Likewise, the values obtained for significance, corresponding to the KMO test, were below 0.05, which means that the sample size used for the analysis was sufficient to obtain reliable values. Tables 11.15 and 11.19 present these results. The results are presented independently for each section defined in the attributes to be evaluated; in this sense, nine elements were analyzed for the first group (Office chairs) and eight elements for the second group (Verifying device). Tables 11.16, 11.17 and 11.22 present the analyses for the office chair variables, while Tables 11.20, 11.21 and 11.23 present those for the verifying device.

Table 11.13 Cronbach's alpha for all variables

Cronbach's alpha	No. of elements
0.872	17

Table 11.14 Cronbach's alpha for variables referring to Office Chair

Cronbach's alpha	No. of elements
0.610	9

Table 11.15 KMO Test Results for Office Chairs

Test	Value
Kaiser–Meyer–Olkin measure of sampling adequacy	0.669
Bartlett's test for sphericity	Aprox. Chi-square: 125.513
	gl: 36
	Sig.: 0.000

Table 11.16 Total variance explained for office chairs

Item	Initial eigenvalues			Sums of loads squared of extraction			Sums of loads squared of rotation		
	T	% V	% A	T	% V	% A	T	% V	% A
1	2.66	29.58	29.58	2.66	29.58	29.58	2.05	22.76	22.76
2	1.36	15.14	44.72	1.36	15.14	44.72	1.57	17.48	40.23
3	1.13	12.53	57.24	1.13	12.53	57.24	1.53	17.01	57.24
4	0.895	9.943	67.186						
5	0.850	9.443	76.629						
6	0.691	7.681	84.310						
7	0.542	6.026	90.336						
8	0.489	5.434	95.770						
9	0.381	4.230	100.000						

Extraction method: an analysis of principal components
T = Total; %V = Percentage variance; %A = Accumulate percentage

Table 11.17 Rotated component matrix for office chairs

Variable	Component for factorial loading coefficient		
	1	2	3
Adjustable chair in heights, widths, depths, and inclinations			0.782
Attractive appearance			
Comfortable chair	0.534		
Easy to locate and reach adjustment controls			0.681
Breathable seat and/or backrest material?	0.739		
Padded seat and/or backrest	0.656		
Chair with lumbar support	0.786		
An office chair that has wheels		0.713	
An office chair that has armrests		0.765	

Table 11.18 Cronbach's alpha for the variables corresponding to verifying device

Cronbach's alpha	No. of elements
0.913	8

Table 11.19 KMO test results for verifying device

Test	Value
Kaiser–Meyer–Olkin measure of sampling adequacy	0.850
Bartlett's test for sphericity	Aprox. Chi-square: 560.098
	gl: 28
	Sig.: 0.000

Table 11.20 Total variance explained for verifying device

Item	Initial eigenvalues			Sums of loads squared of extraction			Sums of loads squared of rotation		
	T	% V	% A	T	% V	% A	T	% V	% A
1	5.02	62.71	62.71	5.02	62.71	62.71	3.78	47.21	47.21
2	1.05	13.07	75.78	1.05	13.07	75.78	2.29	28.57	75.78
3	0.691	8.636	84.419						
4	0.437	5.461	89.880						
5	0.333	4.158	94.038						
6	0.276	3.450	97.488						
7	0.149	1.863	99.350						
8	0.052	0.650	100.000						

Extraction method: an analysis of principal components
T = Total; %V = Percentage variance; %A = Accumulated percentage

Table 11.21 Rotated component matrix for verifying device

Variable	Component for factorial loading coefficient	
	1	2
Portable device	0.653	
Lightweight device	0.504	0.649
Easy to use and interpret		0.810
A device that gives fast results		0.825
Combine physical instrument with an App	0.740	
Measure heights of chair elements (seat, backrest, and armrests)	0.910	
Measure the width of chair elements (seat and backrest)	0.919	
Able to evaluate seat and backrest angles	0.887	

Extraction method: an analysis of principal components. Rotation method: Varimax with Kaiser [a]normalization
a. The rotation has converged in 3 iterations

Table 11.22 Identification of the groups of variables obtained by factor analysis to office chair

Group	Variable
G1: Comfort	Comfortable chair
	Breathable seat and/or backrest material
	Padded seat and/or backrest
	Chair with lumbar support
G2: Accessories	Office chair with wheels
	Office chair with armrests
G3: Adjustability	Adjustable chair heights, widths, depths, and inclinations
	Easy-to-locate and easy-to-reach adjustment controls

Table 11.23 Identification of the groups of variables obtained by factor analysis to verifying device

Group	Variable
G1: Functionality	Portable device
	Combine physical instruments with digital application
	Measure heights of chair elements such as seat, back, and armrests
	Measure the widths of chair elements, such as the seat and backrest
	Capable of assessing seat and backrest angles
	Lightweight device
G2: Usability	Easy to use and interpret
	Gives fast results

11.4.2.1 Cronbach's Alpha for All Variables

The results obtained using SPSS statistical software are presented in Table 11.13.

11.4.2.2 Results for the Variables Referring to Office Chair

This section presents the values obtained corresponding to the calculation of Cronbach's alpha and the KMO test, the total variance explained, and the rotated component matrix, tools that the statistical software allowed us to calculate when entering the data into it. Tables 11.14, 11.15, 11.16 and 11.17, produced by the software, summarize the above.

The variables in the table are listed in the first column, and the corresponding factorial loading coefficients for each component are provided in the subsequent columns. The loading coefficients represent the strength and direction of the relationship between each variable and the identified components (Field 2013). A higher absolute value indicates a stronger relationship.

In this case, Component 1 is associated with attributes such as adjustable chair features, comfortable chair, easy adjustment controls, breathable seat/backrest material, padded seat/backrest, and chair with lumbar support. Component 2 appears to be related to wheels in the office chair, while Component 3 is associated with the company of armrests. The extraction method used was an analysis of principal components, and the rotation method employed was Varimax with Kaiser normalization. The rotation process converged after six iterations.

11.4.2.3 Results for the Variables Related to the Ergonomic Factors Verification Device for Office Chairs

As in the previous section, this one presents the values obtained corresponding to the calculation of Cronbach's Alpha and KMO test, the total variance explained, and the rotated component matrix for the variables of the verifying device. Tables 11.18, 11.19, 11.20 and 11.21, produced by the software SPSS version 26, summarize the above.

The factorial loading coefficients indicate the strength and direction of the relationship between each variable and the identified components. A higher absolute value indicates a stronger relationship. This table shows that the variables "Portable device", "Lightweight device", "Combine physical instrument with an App" and "Measure heights of chair elements" have relatively high loading coefficients on Component 1. On the other hand, variables like "Lightweight device", "Easy to use and interpret", "A device that gives fast results", "Measure the width of chair elements" and "Able to evaluate seat and backrest angles" have relatively high loading coefficients on Component 2.

The variable "Lightweight device" has values in both components in the factorial loading coefficient table. This means that this variable has a moderate relationship with both identified components. The loading coefficient of 0.504 in Component 1 indicates a positive but relatively weaker relationship, while the loading coefficient of 0.649 in Component 2 indicates a more robust and positive relationship. This situation suggests that the variable "Lightweight device" may somewhat contribute to Component 1 and Component 2. This variable may have characteristics or attributes related to both the portability and lightweight nature of the device (Component 1) and the ease of use and speed of obtaining results (Component 2).

11.4.2.4 Identification of the Groups of Design Attributes Generated by Factor Analysis

The main result obtained from the factorial analysis was the grouping of the variables analyzed; in this sense, three groups were generated for the office chair, and two groups were obtained for the verification device. It should be noted that each group was named according to the characteristics of the variables that formed them. These results are presented in Tables 11.22 and 11.23.

11.5 Conclusions and Recommendations

As stated at the beginning of the research, the design of safe workstations influences the well-being, health, satisfaction, quality, and efficiency of the activity performed (Mondelo et al. 2001; Hendrick and Kleiner 2002; Hignett 2003). Therefore, the design of tools for testing ergonomic parameters in office chairs can contribute to the safety of such workstations. Based on this, the execution of methods that help identify the design parameters of interest for users is fundamental for designing such artifacts (Vink and Kuijt-Evers 2018). In summary, the methodology used in this study includes an instrument for identifying and classifying attributes according to the needs detected by the surveyed users, resulting in a reliable tool for inquiring about these attributes. Likewise, statistical software allows the deepening to higher levels of previous results, constituting a more complete and accurate analysis for developing products verifying parameters (Field 2013; Hair et al. 2019).

Finally, the conclusions developed from this research are presented in the following paragraphs.

The application of questionnaires to experts contributes to an accurate elaboration of the methods used in this study. Accordingly, the people qualified as experts should be appropriately selected, and the questions should be as straightforward as possible to ensure the results of the successive stages are consistent.

Identifying the attributes defined by the experts and their correct grouping constituted the basis of the research. Although it did not include other elements of analysis, it is not limited to having new ones, so this research could continue to be enriched in subsequent stages.

Applying the Kano model is a powerful tool to classify those attributes or design requirements during the creative process of a product. So, the results obtained showed the level of importance of each one according to the sample surveyed, which becomes a starting point for the definition of the final attributes in the design project to be developed. The use of factor analysis defines groups of variables that allow them to understand those main characteristics to be considered for developing a device for ergonomic factors in office chairs, as well as knowing the properties of interest to the user when using a chair.

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Part III
Computational Techniques

Chapter 12
Food Safety and Tractability with IoT

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Abstract The cultivating divisions in India contribute around 17% of the country's Gross domestic product (GDP) and offer work to approximately two third of the general population. However, because of the ongoing work in the food areas, its latent capacity has not been tapped in India. India has an exceptionally enormous population. India is home to more than 120 million people. Because of this explanation, interest in vegetables is likewise very high. However, there is a ton of wastage due to the absence of a legitimate production network. Since vegetables occupy a place among transitory merchandise, they spoil rapidly. These things require appropriate capacity, bulking, processing and transportation to diminish the wastage. The fundamental objective of this research is to discover the issues and difficulties in the vegetable production network and the answer to the issue in a production network. The data has been gathered from different distribution sources like newspapers, papers, articles and magazines, and they try to clarify the obstacles in the vegetable inventory network. The analysis found that inaccessibility of cold chain, poor offices infrastructure, significant expenses, and attrition of new products are the limits influencing the vegetable area. The issue of the production network is resolved by enhancing the cold chain framework, legitimate availability, utilization of current innovation, appropriate grouping, awareness, and the level of information of the farmers. In an agrarian economy like India, vegetables play a pivotal role. Therefore, the network of vegetable stores plays an important role in promoting the food sector.

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12.1 Introduction

The Indian economy has always been based on agriculture. Yet roughly 30–35% of all food produced in India is lost due to a lack of effective infrastructure and a food processing sector. Post-harvest losses of food grains in India account for 7–10% of the overall production from farm to market and 4–5% at the market and distribution levels, according to a World Bank assessment conducted in 1999. According to the research, the losses would be sufficient to feed between 70 and 100 million people. Consequently, the post-harvest losses have significantly impacted the economy's local and macro levels. Food safety plays an integral part in solving post-harvesting loss and smooth supply chain tractability.

A supply chain inventory network fundamentally demonstrates the progression of materials, data and money between each piece of an association to guarantee that the right item arrives at the correct place, time, and in the proper condition. Inventory network management assumes a significant part in showcasing merchandise and services. Supply chain management manages the administration of creation, change, appropriation and advertising exercises to guarantee that a purchaser is provided with a wanted item. Consequently, the executive's store network is characterized as the plan and physique activity, board data and monetary frameworks expected to move work and products from creation to the point of utilization smoothly and proficiently.

Agriculture has always been the foundation of the Indian economy. In any case, due to the absence of a competent framework and food handling industry, about 30–35% of all food sources created in India are wasted. According to a 1999 World Bank report, food grain losses in India are 7–10% of total production from ranch to storefront and 4–5% in the market and distribution. The report said that the misfortunes would be sufficient to care for around 70–100 million individuals. Subsequently, the post-collect misfortunes have had a significant effect at both the miniature and large-scale levels of the economy.

In this venture, we assess the economic store network and the board models for agro-food varieties like natural products and vegetables. Through this task, we target to answer the post-reap food circulation issue that has tormented the Indian farming area for a long time. Food safety is a growing global problem. As per Alexandratos and Bruinsma (2012), food supplies must be enhanced by 60% (estimated at 2005 food production levels) to meet the food demand for 2050.

A reliable food traceability system that can track and monitor food is required if individuals are to address food safety concerns technically. The entire process of producing food, including the steps of cultivation/breeding, processing, and transportation of food raw materials storing goods, and selling them. Lin et al. (2018) have proposed a self-organized, open, trustworthy, and ecological food traceability system based on blockchain and Internet of Things (IoT) technology. This system includes all stakeholders in a smart agriculture ecosystem, even if they do not necessarily trust one another. As its name suggests, the Internet of Things is a network between things.

The growth of the IoT is predicated on the Internet. The focus of the Internet is the individual; however, the specific has been included in the IoT: a car, a bed, a comfortable environment in a person's life, a house, or even a microwave oven (Atzori et al. 2010). This network can cover anything, allowing us to accomplish the objects exchanging information with one another, between individuals and objects to attain the intelligent detection, locating, observing, and control of the thing.

According to Cisco (2019), the IoT has transformed how data is collected and has further expanded the view of the Internet, from computers connected via the Internet to any object that receives or can transmit digital data. Therefore, IoT can become a huge source of information. A clear indicator of the growth of IoT is the phenomenal growth of machine-to-machine (M2M) connections, from just under a billion connections in 2017 to 3.9 billion in 2022. The people, processes, data, and things make networking more relevant and valuable.

Ferahtia (2021) mentions that the IoT is expanding rapidly and can potentially be a huge data source. IoT has created opportunities in numerous fields, but some obstacles must be resolved. The potential application of IoT in food safety has received little attention. Meng et al. (2015) focused on using consumer-taken mobile phone photos and IoT technology to track products when in-question and relevant trials have been conducted.

As per Queiroz et al. (2019), the food crisis all over the world was ranked as the seventh-highest risk in the year 2018 by the World Economic Forum. Kayikci et al. (2020) have explored traceability systems requirements and applications in different fields like harvest, transportation, transfer of ownership and involvement in product supply chain processes of agrifood products. Tian (2017) has explored a new direction for food safety based on hazard analysis and critical control points (HACCP). Later on, Lin et al. (2018) examined the combination of blockchain and IoT with existing ERP systems to create a smart agriculture ecosystem on food safety issues.

In the supply chain, the leaders, on an elementary level, show the movement of materials, data and records among every one of the bits of a relationship to ensure that the right thing shows up at the helpful spot at the correct time and in the proper condition. Deftly chain management expects a huge capacity in exhibiting of products and services. Supply chain management deals with the organization of creation, change, scattering and elevating activities to ensure a buyer is given the needed thing.

Thus, the leaders' maintenance store network is portrayed as the physical layout and action, board information, and structures related to the money expected to move the product and adventures from the reason for creation to the motivation behind the use in a smooth and helpful way. For a better comprehend current trends in this interdisciplinary field that combine operational management as well as related research possibilities and problems in sustainable supply chains, Linton et al. (2007) made several recommendations.

van der Vorst et al. (2009) have proposed a new unified method for analyzing logistics, sustainability, and food quality and apply for the advance by introducing a new simulation environment. Trienekens and Zuurbier (2008) discussed consumer concerns related to food scandals and mentioned that the globalization of food production has led to a global and interconnected system for food production and distribution. As a result of these developments, many public and private food safety and quality standards have been developed over the past decade.

The National Food Safety Bill 2013, passed by decree in Parliament, is no small feat by the Indian government. This law promises nearly 68% of India's 1.2 billion people subsidized food crops at a cost of nearly $4 billion. The bill aims to provide quality, nutritionally safe grains at affordable prices to disadvantaged children, women, and the poorest sections of society. Ahumada and Villalobos (2011) presented an operating model that produces short-term planning decisions for fresh food manufacturing. In particular, the developed application helps growers maximize profits by making production and distribution decisions during harvest.

van der Vorst et al. (2007) suggested ways to enhance the architecture of food supply chain networks by utilizing time-dependent product quality information. Good flows can be proactively controlled, and improved chain designs can be built if the product quality at each stage of the supply chain can be predicted in advance. The authors present a case study to demonstrate the value of this novel idea of quality-controlled logistics. Mula et al. (2010) identified the goal of providing a starting point for mathematical modeling problems in supply chain production and transportation planning for production control researchers. On the other hand, Bilgen and Ozkarahan (2007) tackled a blending and shipping issue that a corporation that oversees the supply chain for wheat is experiencing. The delivery of bulk goods from loading ports to destination ports, which various vessel types can supply, represents a problem.

Dabbene et al. (2008) focused on the design of the supply chain, especially the distribution stage of perishables. Perishable products, such as fruits and meats, cannot be achieved without considering the perishability and variability of the products entering the retail chain. Blackburn and Scudder (2009) proposed the supply chain design technique for melons and sweet corn. They examined two examples of a particular sort of perishable and fresh produce. Melons and other products forms attain their highest worth at the moment of harvest; after that, their value declines exponentially until the commodity chills.

van der Vorst et al. (2011) analyzed how to use real-time product quality information to improve the design and management of the Agrifood supply chain network and to evaluate the "critical quality" and "logistics control points" of the supply chain network, introducing a preliminary diagnostic tool. The business decision-making environment is increasingly complex due to the emergence of competing economic, environmental, and social objectives, a concept characterized by the current pressures of global economic uncertainty and climate change goals (Oglethorpe 2010).

Fritz and Schiefer (2008) studied the context for future research needs and formulated priority challenges for management improvements to increase the food industry's sustainability. In another study, Chaabane et al. (2012) presented a mixed integer linear programming-based frame for a sustainable supply chain plan that incorporates life cycle analysis (LCA) principles in addition to traditional material balance introducing the work at each supply chain node.

Wognum et al. (2011) evaluated the current state of information systems to support sustainability in the food supply chain and communicate it to key stakeholders. Similarly, Carter and Rogers (2008) introduced the concept of sustainability (integration of environmental, social, and economic standards that enables organizations to achieve long-term economic viability) in the logistics literature and broadened the Sustainable Supply Chain Management (SSCM) standards. On the other hand, Akkerman et al. (2010) examined quantitative operations management approaches to managing food distribution and related these to industry concerns. Food quality, safety, and sustainability are the most important parts of the food supply chain.

Rong and Grunow (2010) developed a production and distribution preparation model for food supply chains to tackle food safety and tractability issues. In another research, Szymańska et al. (2014) presented the reasons for buying organic food and its definition to the customers. Similarly, Lambert and Enz (2017) studied how to introduce customers to the reasons for buying organic food and its definition. Moreover, Zhu et al. (2008) investigated the development and scale-up of the implementation of green supply chain management (GSCM) practices among manufacturers.

With data collected from 341 Chinese manufacturers, two models measuring GSCM performance were tested and compared by confirmatory factor analysis. Finally, Green et al. (2018) suggested that the use of Just in Time (JIT) and Total Quality Management (TQM) is directly and favorably related to the green supply chain management technique. The green supply chain method, JIT, and TQM are complementary in that when used together; they have a bigger influence on environmental performance than when used separately.

Deng et al. (2019) examined innovatively to improve the sustainable operation of fresh product supply chains from risk propagation. Agriculture has reliably been the establishment of the Indian economy. Given the nonattendance of compelling structure and food-getting-ready industry, around 30–35% of all sustenance made in India is wasted.

According to a World Bank outline in 1999, post-gather mishaps of food grains in India are 7–10% of the total creation from farm to promote level and 4–5% at market and course levels. The report said the setbacks would adequately deal with around 70–100 million people. This way, the post-gather incidents have had a critical impact at both the economy's trim- and full-scale levels. In this endeavor, we are to survey viable deftly chain the chiefs' models for agro-sustenance, for instance, natural items and vegetables. Through this endeavor, we target responding to the post-harvest food dispersal issue that has tortured the Indian cultivating region for quite a while.

12.2 Methodology

This section describes the methodology followed to validate the research. In this test, we will put our food sample, for example, a tomato in our device fitted with IOT-based sensors. These sensors will be connected to a laptop with standard data required for the test.

The sensors in the device will detect the temperature, humidity and chemical composition of the tomato, compare the obtained data with the data stored in the laptop, and give the results in the form of glowing LED lights fitted on the device.

If the food sample is in optimal condition, it will show green light; if it is between optimal and rotten, it will show yellow light. The rotten food sample will show red light, and the food sample will be automatically ejected out of the device via a sliding mechanism. The mechanism is depicted in Fig. 12.1.

The equipment used in this research is the following:

- Arduino Uno R3 Board
- DHT 11 (Temperature and Humidity sensor module)
- MG811 Module, Air Carbon Dioxide/CO_2 Sensor
- MQ-3 Alcohol Ethanol Gas Sensor Module
- Jumper wires
- LED Lights (red and green).

Arduino uno is connected to sensors like MQ-3, MG811 and DHT 11, which is connected with the LED light with symbols red and green, symbolizing vegetables in good quality (green symbol/light) and bad condition or bad quality (red light). Wires are used to connect the basket carrying vegetables. The large data is stored in the cloud for the freshly plucked vegetables (percentage of gas sensed, ethanol sensed, and temperature and humidity), and the readings of the stated sample are compared with the cloud-stored data to detect led light.

The gas sensors are usually used to detect the alcohol concentration in a person's breath. The sensors send out an analog resistance output based on the alcohol concentration. This sensor is connected to the Arduino to send out a reading based on the concentration of the gas being released. Figure 12.2 shows an MQ3 gas sensor.

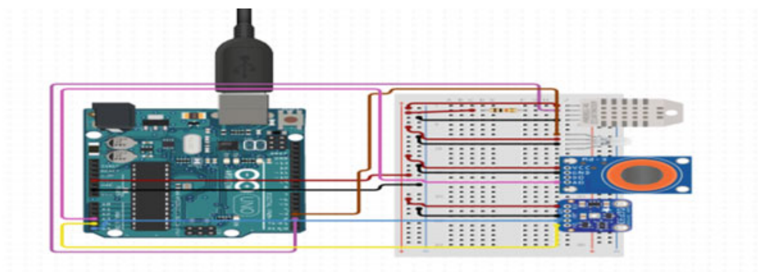

Fig. 12.1 Arduino board

Fig. 12.2 MQ3 gas sensor

CO_2 gas sensor SGP30, shown in Fig. 12.3, offers more detailed pure air quality indications since the Signal Ground Point (SGP) sensor incorporates numerous metal-oxide sensing components on a single chip. This gas sensor, designed to monitor indoor air quality, can identify volatile organic compounds (VOCs), including H_2 (hydrogen). This sensor is based on SGP30, an air quality sensor. It has long-lasting stability and consumes very low power, making it preferable for indoor air quality testing. The sensor SGP30 is a digital multi-pixel gas sensor. Compared to the other sensors, SGP30 provides more detailed information about the gas.

Arduino Uno is an open-source microcontroller board based on a Microchip ATmega328P microcontroller. The board has digital and analog input/output pins that can be easily interfaced with different expansion boards and other circuits. The Arduino board can be connected using a universal serial bus (USB) cable or by an external 9 V battery though it can take up to 20 V of power. Shivaji et al. (2022)

Fig. 12.3 SGP 30

Fig. 12.4 Arduino Uno R3 board

have explained that an open-source electronic operating system or board, as well as the software needed to program it, is referred to as Arduino. Figure 12.4 shows an Arduino Uno R3 Board.

Arduino is made to enable access to electronic devices to artists, designers, fans of entertainment, and anybody interested in making interactive environments or objects. Arduino boards can detect light, a finger, or a tweet. Read on a button, make it a release, and use it to start a motor, switch on a light, or publish anything online. Sending instructions to the onboard microcontroller will tell it what to do. A brief description of the mobile robot's whole system is provided in this article. The Arduino has more names for the sensors and is simple to use. Voltage is measured using a voltage separator. The microcontroller board is the base of the Arduino Uno. A 16 MHz ceramic resonator, needles (which may be used as six PWM outputs), analog inputs, a USB connection, a power jack, an icsp title, and a reset button are all included in this 14 digital input/output device. Uno, a controller for the ATMega328 family, is the following project (creative commons licensed under attribution-share a 2.5).

The series controller is the atmega328. An integrated growth environment for creating, compiling, and uploading new microcontrollers is available. Six of its 14 digital inputs and output pins, including six pulse-width modulation (PWM) pins, are used for communication. It also features sensors, switches, and electronic devices like motors. It has a USB connection jack, an external power supply jack, and 16 MHz ceramic resonators. It contains a reset button, gnt pins (for grounding), and 5 V pins in addition to 16 MHz ceramic resonators, a USB connection jack, an external power supply connector, and an icsp plug-in circuit serial programmer (5 V supply). Its input voltage ranges from 7 to 12 V, and its operating voltage is 5 van (up to 20 V). Its operational voltage is 5 V, and the input voltage ranges from 7 to 12 V if you consume more energy while working (up to 20 V). Using more energy at work and in daily activities can lower energy use. Work and increased energy use in daily activities can reduce workplace energy use. By using more energy at work and in daily life, you can lower the amount of energy your office uses. Its working voltage is 5 V, and the input voltage is 7–12 V (up to 20 V).

It includes an ATMEGA microcontroller, which processes data and efficiently supports the IoT system. The Arduino's versatility makes it feasible to create a variety of Internet of Things projects by simply altering a small amount of code.

When the vegetables come near the sensors' vicinity, it collects data and sends it to the computer with the help of an Arduino Uno R3 board. Then this data is sent to an Excel Sheet to plot different graphs, which will tell us the change in concentration of the vegetables with time. After 2–3 experiments, we will know how much time or in which circumstances the vegetables undergo decay. Using this data, it will be easy to measure the freshness of these vegetables. The LED will tell the user whether the vegetables are fresh by illuminating the RED or GREEN light for non-fresh and fresh vegetables.

12.3 Results and Discussion

When the vegetables draw close to the area of the sensors, the sensors gather information from the vegetables and send it to the Personal Computer (PC) with the assistance of an Arduino Uno R3 board. Then, this information is sent to an Excel sheet to plot various diagrams that will reveal the adjustment of vegetable centralization over time. After 2–3 examinations, it comes to realize how long or in which conditions the vegetables go through decay. Using this information, it will not be difficult to quantify the newness of this vegetable. The LED will tell the client if the vegetables are new by individually enlightening the RED or GREEN light for non-new and new vegetables.

The different vegetables are tested to measure their freshness (Table 12.1). Temperature is noted in degrees, humidity in $(\text{Kg/gram})^{-1}$ and decays percentage of vegetables are also found. The decay percentage range lies above 80%, and redlight blinks after 80%. It shows that vegetables are not in good condition and immediately need to be taken care. Within 60–80% in usable condition, below 60% are considered fresh vegetables.

It is seen in Table 12.1 that some vegetables, like leafy vegetables, peas, beans, spinach, and tomato, to mention a few, are showing a blinking red light as their decay level percentage is high (i.e., for peas 93%, for spinach 95% etc.). So immediate replenishment is required for the vegetable with high decay percentage. The rest, shown with a green symbol, are in good condition and can be usable. Table 12.2 shows the light signal blinking as per decay percentage (i.e., Red light (Above 80%) decay, Yellow light (60–80%) decay and Green light (below 60%) decay, respectively).

Even if domestic and international regulations may increase the supply chain's complexity, IoT technology makes it easier for manufacturers and customers to track

Table 12.1 Data found after testing

Vegetables tested	Temp in degree	Humidity (1/kg/gram)	Decay percentage
Tomato	67	110	82
Brinjal	49.5	56	45
Carrot	44	43	20
Beat root	45	41	11
Cabbage	53	78	67
Pumpkin	48	34	56
Bittle gourd	39	54	23
Spinach	44	105	95
Broccoli	38.7	57	69
Bean	43	45	86
Cauliflower	43	65	75
Leafy vegetables	31	56	93
Lettuce	36	86	34
Okra	46	87	26
Peas, green	46	102	93

Table 12.2 Light signal after test for vegetables

Vegetables tested	Red light (Above 80%) decay	Yellow light (60–80%) decay	Green light (below 60%) decay
Tomato	Red		
Brinjal			Green
Carrot			Green
Beat root			Green
Cabbage		Yellow	
Pumpkin			Green
Bittle gourd			Green
Spinach	Red		
Broccoli			Green
Bean	Red		
Cauliflower		Yellow	
Leafy vegetables	Red		
Lettuce			Green
Okra			Green
Peas, green	Red		

food goods. Transparency offers several other advantages, including efficient inventory management, reduced costs, and more. The possibilities for maximum productivity have increased thanks to IoT, which has also helped the sector remain environmentally benign. IoT solutions like cloud computing and sensors have simplified managing water and soil, distributing water, and obtaining weather data. Due to the development of customer knowledge of product origin and process stability, the agriculture business likewise requires more technology. Appropriate produce distribution and storage are other crucial aspects that have expanded the usage of IoT in agriculture.

IoT technologies can be utilized to cut down on food product waste during storage and delivery. Using instruments like real-time temperature tracking sensors also provides increased food safety. The sensors can also be utilized to control the storage facility's temperature. They can also track other aspects of food safety, like pH, odor, moisture, and humidity. Thanks to IoT devices, supply chain managers can track and monitor products from the point of manufacture to last-mile delivery. This facilitates the collection of precise and current data by the brands. This information can enhance systems and procedures, such as streamlining the manufacturing and delivery timetables. The Internet of Things (IoT) technologies ensure active cold chain management by allowing supply chain leaders to monitor food safety data points. IoT has assisted businesses in increasing profitability and enhancing customer happiness by managing the food supply chain. It has also helped supply chain managers conserve energy by using energy more effectively. Hence, new IoT-based technology and devices can reduce food waste and provide food safety, starting from agri fields to food plates.

12.4 Conclusions

In this test, vegetables, for instance, a tomato, were tested in our gadget fitted with IOT-based sensors. These sensors were associated with a PC with the standard information needed for the test. The sensors in the gadget identified temperature and mugginess, as well as the chemical composition of the tomato. This information was compared with the information stored in the computer, which allowed the sensors to provide the results based on the brightness of the LED lights installed in the device. If the food test was observed to be in ideal condition, then it was a green light. The blinking of yellow light occurred when it was found between ideal and spoiled.

The spoiled food (wasted food) test will be shown a red light, and automatically, the gadget will send it out using a sliding component. This device has helped to check the quality of all kinds of vegetables. The application of this device is vast. It will help to control food waste through effective supply chain management. During the supply chain, the bulk material is transported in lorries or containers, and the device with a large capacity to note, detect readings, and monitor will help to dispatch many vegetables as per the date of plucking. The limitation of the research was the use of large capacity sensors, which do not detect the utility time of vegetables. Thus, more research is required to detect the utility of vegetables. If all items are stored in a batch in a basket, the sensors may be unable to detect them.

Therefore, an image sensor with vegetable images is needed to detect the name of the vegetables according to the image. Then that image sensor can check the quality of the vegetables and detect the expiration date. In addition, an automatic dispatch system or car should be added to send the batch for dispatch. In the future, AI can be added to report a lot to the computers or mobile systems of the merchandisers. Therefore, further work is essential to complete the supply chain tracking system. The selection of a robotic system is good, but on a large scale, the price will be too high to hire many cobots. More research is needed on non-vegetarian foods, frozen foods, packaged foods, and dairy products.

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Chapter 13
System Dynamic: An Intelligent Decision-Support System for Manufacturing Safety Intervention Program Management

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Abstract System Dynamics (SD) has been recognized as one of the computational technique approaches used in studying the behavior of complex feedback systems over time in diverse fields of engineering, health, social, agricultural, and management systems. This chapter deals with SD and its applications in various disciplines; simple considerations in drawing causal loop diagrams; stock and flow diagrams; and safety management systems. Furthermore, its interaction with computer programming and the application of SD in manufacturing for safety strategy selection and cost-saving are discussed. Thus, it reveals its application as one of the modeling and

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computational techniques useful in manufacturing safety systems for intervention strategy allocations.

Keywords System dynamics · Safety management · Stock and flow diagram · Causal loop diagram · Safety intervention strategies

13.1 Introduction

The pace of technological advancement in the modern era is unprecedented, and increasingly, most tasks are completed digitally. Sarker et al. (2020) reported that the existence of the data age, where most things within us are associated with data sources, consequently tends to digital recording. Sarker (2021) acknowledged that numerous types and natures of data exist, like smart city data, social media data, Internet of Things (IoT) data, business data, cyber security data, and health data, to mention but a few. Data could be structured, unstructured, or semi-structured (Ramasamy et al. 2020; Sarker et al. 2021). The nature of the data determines the application type suitable for its analyses. Still, the quantum of data in this industrial revolution era is enormous (Shorten et al. 2021).

Thus, higher levels of analytical tools are required. Statistical methods have been helpful for this purpose but with limitations. Nowadays, better analysis, prediction, accuracy, and data management techniques and tools are essential for adequately sorting, processing, and analysing data appropriately and intelligently. One of the ways of improving safety in manufacturing industries is through the use of safety program interventions via intelligent decision-supporting systems that will help enhance and strengthen the safety systems in these organizations. These decision-supporting systems use one or more of the various available computational techniques.

13.1.1 Computational Techniques

In simple terms, the computational technique is the process by which the computer performs modeling and simulations of a specific process. Computational techniques are user-friendly, easier, reliable, and achieve targets with high speed. These techniques include artificial intelligence, image processing, simulation, optimization methods, machine learning and numerical methods, which are efficient for solving mathematical, geographical, and statistical problems through computer aids (Raharja et al. 2021).

Hence, solving problems using computational techniques is most time step-wise. The computational technique involves designing, implementing, and using models to analyze and solve scientific problems. Through the activities, analysis facilitates meaningful inferences. The computational technique has found various applications for solving dynamic problems emanating from managerial, complex social, ecological, economic, and physiological systems (Babanezhad et al. 2020).

Understanding the theory of computation is imperative because it provides the basis for highlighting efficient algorithms executed on personal computer devices. Aside from this, it enhances the research and development of programming languages and compiler design. Also, it makes the actualization of construction efficient. The essence of operation research is modeling a real-life scenario that assists the researcher in understudying the varied behavior of a particular problem corresponding to the description of the specified problem (Sada and Ikpeseni 2021). A model is an abstraction of an idealized representation of a real-life problem (Uzuner and Cekmecelioglu 2016). Some peculiar modeling techniques are mathematical and black-box modeling.

Numerous modeling tools and software have recently been adapted to simulate real-world situations. Black box models include the design expert, generic algorithm, fuzzy-logic, adaptive neuro-fuzzy inference system, artificial neural network, support vector machine, multi-gene genetic programming, grey wolf optimizer, particle swamp optimization, and system dynamics, among others (Adeyi et al. 2021; Saleh et al. 2020). Each has a different approach to use but the same theoretical background. By computation, the modeling tools are supplied with historical data, i.e., observed data of the typical real-life scenario (Hasan and Sobhan 2020). Then the various tools will be manipulated by simulations to ensure an optimized model.

Consequently, the model can be used for decision-making when facing complex dynamic systems. Finally, the model results can be used to communicate essential findings to assist the managers and employees in understanding the system's behavior, and improvements can be suggested accordingly. Therefore, computational dynamics provides methods and viable tools to model and analyze dynamic systems (Chinnam and Baruah 2004).

13.1.2 Computational Techniques and Manufacturing

The computational approach is used in manufacturing industries to make decisions and solve complex problems such as creating sample products and assessing quality. It is also used for managing inventory, designing challenges, process design, heat transfer, fluid mechanics, soil mechanics, and control of manufacturing equipment, robots, etc. When these are done, the managers' burden is relieved, profit maximization is at the top of the agenda while time expended on seeking solutions to peculiar problems is minimized. Manufacturing processes are sometimes characterized by herculean tasks, which, if not adequately addressed, may cost the company a setback in terms of time and profits. Therefore, manufacturing operations such as designing, planning, control, scheduling, distribution, processing, marketing, production, and resource allocation, amongst others, require an active and prompt approach to monitor these operations (Raharja et al. 2021).

Using the computational approach is paramount because it will maximize time for decision-making and other judgmental needs of the manufacturing line. The computational technique turns industrial workflows into instrumented, data-collecting digital processes integrating operator, machine, and sensor data to actualize business goals. Through computation, the efficiency of manufacturing processes is determined as emerging performance metrics related to virtually all aspects of specified production are provided, thus giving the knowledge window to learn more about how the production line operates after computation compared to its manual operation.

Computation can control the manufacturing equipment when an industrial computer gadget monitors the processes, acquiring and analyzing data mostly outdoors. Despite this, several complicated processes are effectively handled while speedy production is ensured. Furthermore, an improvement in the quality of the product throughout all stages of the manufacturing process, and not just the end product, is guaranteed. The improvement is achieved by enhancing the plant's efficiency in increasing output and decreasing mishandling and waste of raw materials. In a typical manufacturing system, computation, especially the one that has to do with neuro-fuzzy, uses the synergetic function of a neuron and fuzzy logic such that the neuron serves as the thinking faculty of the system while fuzzy logic, on the other hand, does the judgments.

It does not just mostly pass judgment in a usual way whereby a particular treatment will be given to a process; the question then arises, is the apportioned treatment commensurate? Instead, it melts judgment based on requirements to optimize resources. Therefore, computation facilitates human resources to deploy a specified task at the right time. Furthermore, computation makes raw material quantification possible to avoid wastage and substandard products. However, for safety sustainability in any industry, implementing safety program activities or strategies is highly vital. Thus, the dynamic system tool plays a major role in effectively allocating these activities or strategies to save costs due to its feedback system.

According to International Labour Organization (ILO), there are around 340 million occupational accidents and 160 million victims of work-related illnesses annually worldwide (ILO 2022). Information on these statistics makes it imperative to make more efforts to research this subject matter. However, this is dynamic and complicated; hence, the adoption of system dynamic is one of the computational techniques suitable for such attributes.

13.1.3 System Dynamics (SD)

System Dynamics (SD) comprises two words, system and dynamics. The word system is a set or collection of things or parts connected as a whole to give a particular function, and the word dynamic implies motion or changes. Thus, dynamic systems are systems that tend to change with time. Therefore, SD is a methodological and mathematical modeling technique for studying and managing complex feedback systems, such as those in business and other social systems (Williams and Harris

2005; Bala et al. 2017). It is a solution technique tool for understanding the nature and features of a complicated system involving delays, feedback and nonlinearity over time (Affeldt 1999).

However, System Dynamic Society (2022) defined system dynamics as a computer-aided method to design strategy and policy to make better decisions in complex, dynamic system situations. The approach provides methods and tools to model and analyze dynamic systems. Model results can be used to communicate essential findings to help everyone understand the system's behavior. Hence, SD modeling is a framework for seeing interrelationships rather than things and patterns of change rather than static systems (Yearworth 2014).

13.1.4 Historical Background of System Dynamics

SD is a systems-level modeling methodology and a computer simulation technique introduced initially by Jay W. Forrester at the Massachusetts Institute of Technology, Cambridge, in the 1950s as a tool for business managers to analyze complex issues involving the stocks and flows of goods and services (Maani and Cavana 2000; Tidwell et al. 2004; Gu et al. 2022). In 1956, Forrester's initial goal was to determine how his background in science and engineering could be brought to bear, in some useful way, on the core issues that determine the success or failure of corporations. Forrester's insights into the common foundations that underlie engineering and management led to the creation of SD. These were largely triggered by his interactions with General Electric (GE) executives in the mid-1950s (Yu and Hunt 2004), and from the late 1950s to the late 1960s, SD was applied almost exclusively to corporate/managerial problems. Subsequently, SD methodology has been widely used in numerous areas, such as in economics, finance, environmental studies, healthcare, information technology, management of large construction projects; management of software development; simulation of complex biological, biophysical, and safety management systems, enterprise management and social systems (Affeldt 1999; Yu and Hunt 2004; Tidwell et al. 2004; Ajayeoba 2021).

13.1.5 Application of System Dynamics Model

This safety system dynamics model applies in any manufacturing sector, such as chemicals, food and drink, construction industry, industrial manufacturing, automobiles, and consumer electronics, with organized safety systems. Where there are safety records where yearly budgets, and accident records are available. Thus, system dynamics has several uses in various industries, including reducing accidents and cost-saving measures in the manufacturing sector. Many areas of application of system dynamics include manufacturing, agriculture, management, and automobiles (Table 13.1).

Table 13.1 Some areas of applications of system dynamics

S/N	Purpose	Area of application	Country	Authors
1	For sustainable utilisation of water resources by improving environmental investment and reducing total sewage	Water utilisation	China	Sun et al. (2017)
2	The program was designed from mixed results of safety behaviour over 36 weeks for an effective accident prevention strategy in a construction company	Construction company	Singapore	Guo et al. (2018)
3	The study attempts to simulate the impacts of changes in government intervention policy using System dynamics	Agricultural industry	Malaysia	Ramli et al. (2012)
4	For complex and nonlinear interaction of important factors such as the energy policy, incentives of renewables, price of energy, and nuclear decommissioning in the electricity sector, providing guidelines for policymakers and managers to make better-informed decisions	Energy industry	Sweden and Norway	Tang and Rehme (2017)
5	Applying the system dynamic approach provides deep insights into sustainable development and presents efficient policies for agriculture sustainability	Agricultural industry	Iran	Bastan et al. (2017)
6	A system was built to identify areas required for sustainable improvement in an automotive component manufacturing organization	Automobile industry	India	Thirupathi et al. (2019)

(continued)

Table 13.1 (continued)

S/N	Purpose	Area of application	Country	Authors
7	Used to develop a model to effectively select the safety strategy to increase the safety level in Sawmill Safety System in Nigeria	Sawmill industry	Nigeria	Ajayeoba et al. (2019)
8	Used to develop a hybrid model of accident occurrence and preventions in relation to cost savings or loss	Manufacturing industry		Adebiyi et al. (2018)
9	Used to study the behavior of hydropower plants and develop a dynamic model for profitability	Electricity generation industry	Iran	Daneshga and Zahedi (2022)
10	Used to improve the understanding of the hotel energy system, focusing on the pros and cons of using renewable energy technology in the hotels	Tourism	Australia	Dhirasasna et. al. (2020)
11	Used to identify the relationship within the demand, supply, and competition concerning the sales of some pharmaceutical products during their life cycle	Pharmaceutical industry	Iran	Mousavi et al. (2022)

System dynamics is also used in a variety of manufacturing industry applications, such as:

i. *Risk Assessment and Mitigation*: System dynamics modeling can be used to locate and assess potential risks in manufacturing processes and create methods for reducing such risks.
ii. Supply Chain Management: System dynamics can also be utilized to simulate and improve the performance of supply chain operations, which can result in cost savings.
iii. Maintenance and Asset Management: System dynamics modeling can improve manufacturing facility maintenance and asset management procedures, resulting in cost savings and increased equipment reliability.
iv. Process Improvement: System dynamics can also be utilized to find areas where processes in manufacturing facilities can be improved.

In general, the use of system dynamics in the manufacturing industries to reduce accidents and save money is a promising area of research, and there are numerous possible uses for this method in various production operations.

13.1.6 Steps for System Dynamics Modelling

The steps for simulating a system dynamics model are summarised below (Bala et al. 2017):

i. Identify the problem, and formulate the mental model in a verbal description.
ii. Develop a dynamic hypothesis regarding causal loop diagrams and the stock and flow structure of the system.
iii. Create a basic structure of the causal diagram from the verbal model.
iv. Augment causal loop diagrams into system dynamics flow diagrams.
v. Translate the system dynamics flow diagrams into the available SD software or a set of simultaneous differential equations.
vi. Estimate the parameters.
vii. Validate the model, analyze the sensitivity and analyze the policy.
viii. Application of the model.

13.1.7 System Dynamics Software

Some common software used in SD are Vensim, Simulink, STELLA, Dynamo, Anylogic, Insight Maker, iMODELER, Powersim, Extend, and Model Maker. Users' interest is influenced by the program's simplicity and the time to learn basic model creation (Sapiri et al. 2017).

13.1.8 System Dynamics Modelling Assumptions

Every SD model has specific assumptions, and these assumptions, according to Yearworth (2014), can be summarized as:

i. A structural account of system dynamics expressed as feedback patterns is enough to explain complex system behavior for successful interventions to be designed.
ii. There is the capability to cause a structural account of dynamic complexity to be expressed as a system dynamics model through direct or indirect engagement with domain experts.
iii. Models can be parameterized for simulation, allowing them to reproduce current and historical behavior.
iv. Modeling provides insight into where it may be possible to intervene in the system, and the effects of such modeling interventions are checked.
v. The property of an endogenous account of behavioral dynamics. For System Dynamics to be a useful tool, its models account for all the dynamic complexity seen in a system.

13.1.9 Causal Loops

The Causal Loop Diagram (CLD) is the conceptual system of a dynamic model that shows the behavior of all the components (variables) of the system's causal relationships and feedback loops (Yearworth 2014). It is well used at the initial drafting stage to show the conceptual relationship between the system components, though it does not show the details as a stock and flow diagram. CLD offers a simple way of saying or expressing clearly the understanding of a particular system's dynamic, interrelated nature. Thus, it is an essential representative tool for the feedback configuration of systems.

13.1.10 Simple Considerations in Drawing Causal Loop Diagram

The following points must be considered in drawing causal loop diagrams:

i. In naming a variable in the loop, it is advisable to use a simple and more apparent noun (i.e., always avoid the use of verbs and phrases to name variables)
ii. Use measurable variables/quantities)
iii. The loop should be explicit enough to avoid raising unnecessary questions.
iv. Be simple enough by grouping the multiple consequences of a particular variable into one.

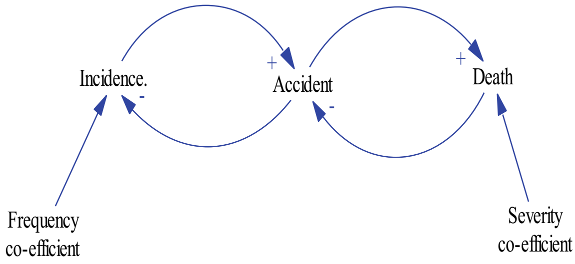


Fig. 13.1 Example of a causal loop diagram

v. Draw the loops with increasing length as they advance from short-term to long-term processes.
vi. Try as much as possible to avoid overlapping links for clarity.

Figure 13.1 shows an example of a causal loop diagram. Accidents increase with the number of incidents (represented by an arrow (+) sign). In contrast, the number of accidents, in turn, decreases the number of incidents (represented by an arrow (−) sign). The number of deaths increases with the number of accidents (represented by an arrow (+) sign), and the number of accidents decreases as the number of deaths increases (represented by an arrow (−) sign). The first positive relationship is represented by an arrow (+) sign in the two loops. The second relationship is negative, represented by an arrow with a (−) sign. However, frequency co-efficient and severity co-efficient are the two basic variables that affect the number of incidences and the number of deaths, respectively, which invariably affect the number of accidents.

13.1.11 Stock and Flow Diagram (SFD)

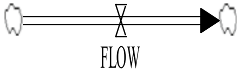
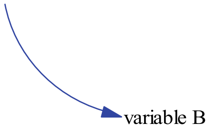
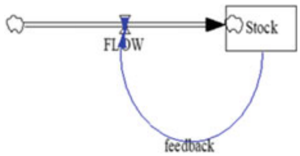
The stock and flow diagram (SFD) describes the system's structure regarding flows and accumulations. They are the basis of system dynamics modeling. SFDs consider more detailed system elements than the CLDs using the relevant symbols (Table 13.2). In addition, SFDs consider the unit of each variable and the relationships between the variables. Thus, it makes creating a computer model of the system easy.

13.1.12 Simple Considerations in Drawing Stock and Flow Diagram

Then, after well-formed CLDs, the next step is to draw their corresponding CFD by adapting the CLD considering the following steps:

i. Determination of all the units of all CLD variables

Table 13.2 Symbols for the relevant elements used in stock and flow diagram

Elements	Description	Symbol
Stock	It is the basis of any system that describes the system's condition under consideration. A flow can begin and ends in stock. The inflow and outflow of the quantities affect the state of the stock	
Flows	They are the quantities that flow into or out of stock over time and the only variables that affect stock changes	
Delays	It Shows feedback that is never instantaneous and may range from fractions of seconds to years	
Auxiliary/ Variable	To link from one variable to another variable. It is an intermediate variable that breaks the flow equation into smaller parts. They are added so that the model is more straightforward to understand	
Link polarity	Causal effects can either be negative or positive. If A causes B with +ve influence, then, all other things being equal, as A increases (decreases), B increases (decreases)	
Parameter	Variable with constant value over time	Capital Letter
Feedback	Feedback is data about a stock's state that can be used alone or in conjunction with other variables to modify a Flow	

ii. Identification and construction of the stocks
iii. Flow identification and construction
iv. Connection of all flows to their respective stocks and vice versa by confirming that inflows and outflows leave the stock.
v. Addition and connection of needed auxiliary variables
vi. Addition of all relevant equations into the stocks and flows and their check units
vii. Finally, give the initial value, provide the required equations for all the flows, and determine the time interval for the simulation.

The stock and flow diagram in Fig. 13.2 depicts the causal loop diagram in Fig. 13.1. It shows the accident as the stock, incidence and death as the flows, and the frequency co-efficient and severity co-efficient as variables. Thus, the causal loop diagram and stock/flow diagram are the basic elements of a dynamic system model (Fig. 13.3).

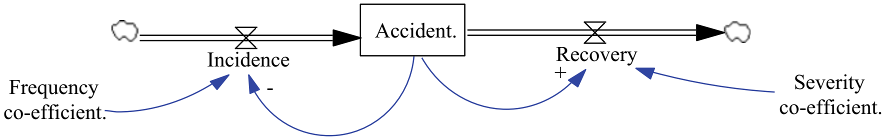


Fig. 13.2 Example of a stock and flow diagram

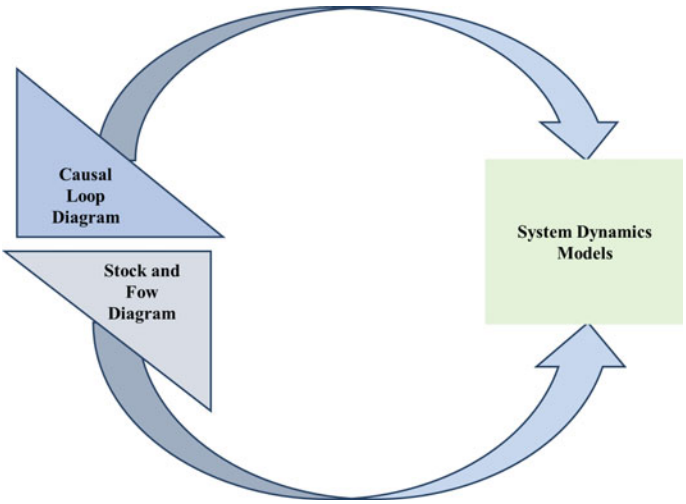


Fig. 13.3 Component of a system dynamic model

13.1.13 Safety Performance Evaluation (SPE) Approaches and Models

Safety Performance Evaluation (SPE) is an important fragment of safety management systems for offering required information on the organization's quality concerning its development, implementation, and results (Sgourou et al. 2010). Consequently, it influences the management's decision-making regarding occupational safety and health matters. Several attempts have been made to evaluate the performance of a safety program. For example, Adebiyi et al. (2007) classified the approaches into ten: a statistical approach, expectation function, risk assessment approach, statistical quality control, price deflation, questionnaire, engineering economic factor, system analysis approach, Artificial Intelligence (AI), and systems theory. Sgourou et al. (2010) classified SPE approaches into six: safety element method, universal assessment instrument, safety culture questionnaire, safety diagnosis criteria, occupational health and safety self-diagnostic tool, and the pyramid of major chemical accident prevention.

The approach is viable depending on the level of exposure to the required information, the industry to be evaluated, and the area to be evaluated.

Also, several SPE models commonly used have been classified as qualitative and quantitative.

i. The quantitative models are based on evaluating the frequency, severity and economic loss resulting from accidents.
ii. The qualitative models are based on evaluating the potential system of risks and the increasing severity of the hazard.

However, no generally agreed-on approach, method or model has been reported to be the best, but the influx of many computational techniques has made the evaluation easier.

13.1.14 Safety Management System

Safety management determines and implements safety policy (Liu et al. 2020), and it is one of the major factors on which the development of the Fourth Industrial Revolution depends. Many studies show that stress management's commitment to safety is essential to the firm's safety climate and a crucial factor in achieving good safety performance (Fernandez-Muniz et al. 2012). This commitment is reflected in managers' knowledge of the existing problems, their conviction that the firm can achieve high levels of safety, their ability to demonstrate a lasting positive attitude towards safety, and their ability to promote safety actively at all levels in the organization. Some of the elements of safety management include:

(i) Safety culture—This has been seen as an auspicious way of reducing accidents in every world sector (Ismail et al. 2021). Having the right mind to do the right thing will avert accidents. It represents employees' attitudes toward a company's approach to safety, risk perceptions, beliefs about responding to and controlling risk, and participation in activities that represent a safety culture (Arblaster 2018). Safety management emphasizes cultivating a positive safety culture within high-reliability industries (Adie et al. 2005).
(ii) Safety management emphasizes the importance of cultivating a positive safety culture within high-reliability industries (Adie et al. 2005).
(iii) Behavior-based Safety (BBS) is an approach to intervene and modify unsafe human behaviors. Many scientific studies have concluded that unsafe behavior is a major cause of accidents (Zhang and Fang 2013). Therefore, the BBS approach is drawing more and more attention to occupational safety and has been considered a useful tool for safety management (Ting et al. 2020).
(iv) Safety Inspection—Inspection is a common element of safety management systems, controlling hazards by early detection and correction. Inspection is a part of internal safety management and external or enforcement systems (Woodcock 2014).
(v) Safety Management By Walking Around (SMBWA) is an unstructured, hands-on approach in which managers directly participate in their subordinates' work-related activities. In contrast to rigid and remote management approaches,

MBWA managers spend significant time informally visiting work areas and interacting with employees. The practice is unscheduled, casual, and friendly. As managers walk around, they can chat with employees.

13.1.15 System Dynamics and Computer Programming

In computing, a "program" is a specific set of instructions for the computer to execute a particular task. System dynamics involves causal mapping and the development of computer simulations to understand system behavior (Currie et al. 2018). Computer programming characteristics include flexibility, user-friendliness, portability, reliability, and accuracy. Others are reusability, readability, efficiency, maintainability, and generalizability. Therefore, the computer program is suitable for dealing with the complexity, iteration volume per time, and dynamic nature of SD. Defining, developing, and documenting all the SD parameters and variables and their relationships with computer programs involves all the stakeholders in the manufacturing industry, i.e., the manufacturing engineers, safety engineers, factory workers, and management (Ajayeoba 2021). The computer program now seeks to integrate and capture the dynamic nature of the identified variables, showing their dynamic interactions between the inputs and the outputs, thus, producing the required safety program outputs in terms of graphs, tables, or any other needed format available on the safety program interface. Some common programming languages include C, C#, C++, Python, ALGOL, Pascal, and Matlab.

13.1.16 Safety Intervention Programme

A proactive approach to accident prevention is the key to reducing the incidence rate in many manufacturing industries. Thus, a proactive approach to accident prevention is a reliable and effective leading indicator that provides hazard information before an accident is required. Ajayeoba et al. (2018) mentioned that safety perception should be seen not only as a means of preventing accidents but also as a way of saving costs. Every well-established manufacturing industry has a budgeted allocation yearly for safety, which is expected to be spent on safety intervention programs or activities that will prevent any form, consequence, type, or cause of an accident in the industry. This safety intervention program is an active set of intervention activities used to prevent an accident or its possible occurrence. However, depending on the industry, this budget runs into millions or billions of dollars. This seriously concerns the management; some will try to look for shortcuts to avoid doing the right things. But priority implementation, rather than all or most intervention activities being conducted concurrently, will save costs and achieve its aim.

One of the safest ways of prioritizing implementation is to use intervention strategies. The safety intervention strategy is a combination of any of the following

Table 13.3 The safety intervention strategies

S/N	Safety strategy	Symbol
1	T, PPE, Im	S_1
2	T, PPE, Im, Mg	S_2
3	T, PPE, Im, Aw	S_3
4	T, PPE, Im, Ai	S_4
5	T, PPE, Im, Mg, Aw	S_5
6	T, PPE, Im, Mg, Ai	S_6
7	T, PPE, Im, Aw, Ai	S_7
8	T, PPE, Im, Mg Aw Ai	S_8

intervention activities: training (T), personal protective equipment (PPE), incentive/motivation (Im), machine guarding (Mg), awareness creation (Aw), and accident investigation (Ai) (Adebiyi and Charles-Owaba 2009). Considering the use of at least the combination of training, PPE, and motivation/incentives in the combinatorial analysis of the strategies (Ajayeoba et al. 2019), no single intervention activity makes a safety strategy, but at least three (Adebiyi and Onawumi 2014). For example, using a combinatorial analysis equation by Ajayeoba et al. (2019), the developed safety intervention strategies are shown in Table 13.3 (Ajayeoba et al. 2019).

13.2 Methodology

Considering a manufacturing industry with a well-organized safety system and functional safety intervention policy and using system dynamics rules for identifying the basic quantities and the associated symbols, Table 13.4 was developed. The stock and flow diagram was developed using the supplied elements in Table 13.4 (Fig. 13.4) and the developed causal loop diagram in Fig. 13.5 and the. The model equations required for the smooth running of the model are calculated based on the principle of dimensional consistency. For example, the prevented Accident and Accident caused are calculated by solving Eqs. (13.1) and (13.2)

$$\text{Pn} = \frac{d\text{Ap}}{dt} \tag{13.1}$$

where Pn is a function of Ti, Pap, Td and Ti

$$\text{Cn} = \frac{d\text{Ac}}{dt} \tag{13.2}$$

$$Bp = f(Ac, Fb) = Ac.Fb \tag{13.3}$$

Table 13.4 Quantities and Specifications

S/N	Element	Symbol	Description	Dimensions
1	Rate (FLOW)	Pn	Accident prevention	Q/T
		Cn	Accident causation	Q/T
2	State (STOCK)	Ap	Prevented accident	Q
		Ac	Accident caused	Q
3	Auxiliary	Bp	Planned budget	N
		Ba	Actual budget	N
		Cst	Cost of strategy	N
		Sap	Quantity of accident preventable by the targeted strategy	Q
		Td	Target decision	Q
		Vap	Value of accident prevented	N
		Cs	Cost saving	N
		Tq	Accident reduction target	Q
4	Input	Fb	Budgeting factor	N/Q
	Parameter	Pb	The proportion of the planned budget to be implemented	Dimensionless
		Pst	The proportion of actual budget per each strategy	Dimensionless
		Es	Strategy effectiveness index	N /Q
		Ti	Productive time lag	T
		Pap	Probability of prevented accident	Dimensionless
		Cu	Estimated cost per accident	N/Q
		Ta	Percentage accident reduction target	Dimensionless
		Fac	Accident causing factor	1/T
		Pac	The probability of accident caused	Dimensionless

Note N = Naira (Nigeria currency. This can be any currency), Q = Quantity (e.g., people), T = Time (e.g., second, minute, hour)

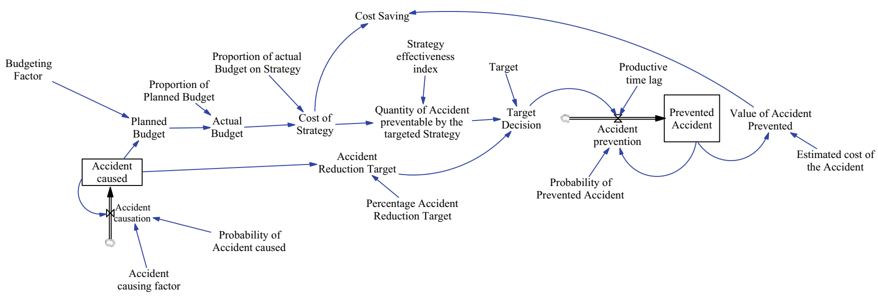


Fig. 13.4 Stock and flow diagram for manufacturing safety intervention programme. Adapted from Ajayeoba et al. (2019). Where Pn is a function of Fac and Pac.

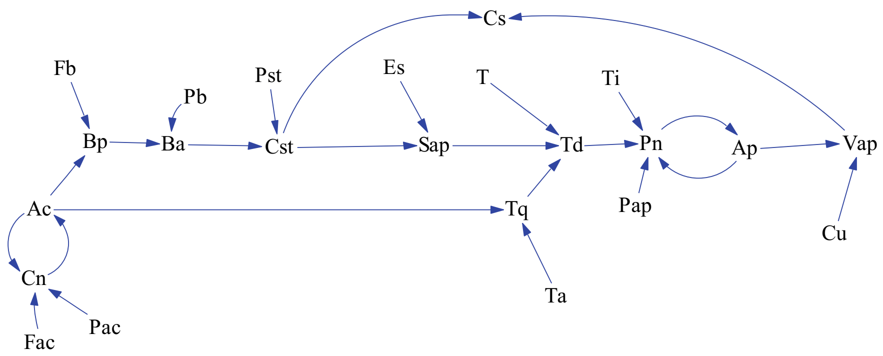


Fig. 13.5 Causal loop diagram for manufacturing safety intervention programme. Adapted from Ajayeoba et al. (2019)

The Auxiliaries will be determined at every simulation instance as the input parameters are calculated and supplied to the system. The functions determine the following:

(i) Planned Budget—The budget recommended for the year for the safety unit is a function of an accident caused and the considered Budgeting Factor, as expressed by Eq. (13.3).

(ii) Actual Budget—This is the actual approved money for the year and its function of Bp and Pb, as expressed by Eq. (13.4).

$$Ba = f(Bp, Pb) = Bp.Pb \tag{13.4}$$

(iii) Cost of strategy—This is the actual budget for each strategy (S1–S8 as shown in Table 13.3), and it is the function of the actual budget and proportion of the budget per each strategy. The highest *Cst*, which is less or equal to *Ba*, is calculated by applying Eq. (13.5), and it is selected.

$$Cst = f(Ba, Pst) = Pst \leq Ba \tag{13.5}$$

(iv) Quantity of accidents preventable by the targeted Strategy—This is the actual number of accidents that the selected strategy can prevent, and it is obtained by Eq. (13.6).

$$Sap = f(Cst, Es) = Cst.Es \tag{13.6}$$

(v) Target Decision—This is the selected strategy in which its intervention activities should be able to combat the targeted accident reduction. It is calculated using Eq. (13.7).

$$Td = f(Sap, T) = \text{Sap.T} \tag{13.7}$$

(vi) Accident Reduction Target—This is the number of accidents required to be prevented. This variable is obtained through Eq. (13.8).

$$T = f(Ac, Ta) = Ac.Ta \quad (13.8)$$

13.3 Expected Results

The expected results are the cost and value of accidents prevented.

i Value of Accident Prevented—It is the overall cost saved when direct and indirect costs of accidents are prevented. It is the cost of all the prevented accidents (fatal, serious, minor and trivial wounds), and it is a function of the prevented Accident and estimated cost per Accident. It is calculated by applying Eq. (13.9).

$$Vap = f(Ap, Cu) = Ap.Cu \quad (13.9)$$

According to Adebiyi et al. (2018), the cost of accidents fatal, serious, minor and trivial wounds were calculated as N29,617,953.03 (≈$65,000), N13,339,567.15 (≈$29,000), N853,503.28 (≈$2000) and N49,600.00 (≈$100), respectively. The fatal accident cost per person can be as high as $1,310,000 (National Safety Council, 2021). Multiplying these values with the respective numbers of prevented accidents simulated will give the value of accident prevented.

ii Cost Saving—This is the total amount saved by implementing safety strategies and preventing the payment of claims and litigation (the difference between the cost of the accident prevented and the cost of the strategy selected). It is calculated using Eq. (13.10)

$$Cs = f(Cst, Vap) = Cst - Vap \quad (13.10)$$

Application of SD in the safety strategy selection will not only prevent accident occurrence but save costs for the industry, increasing the total annual profit as it will save costs of lost workday injury and fatality, among other annual costs. For example, in the United States of America, work injury costs for the year 2020 were estimated at $163.9 billion, according to the National Safety Council (2021), and this cost increases with the increase in high-risk activities. Thus, investing in safety strategies is better than paying for the cost of accidents. Preventing accidents is essential for guaranteeing the safety and well-being of employees and offers enormous financial advantages to businesses and society. Industries can safeguard their employees and lessen the financial toll of accidents by implementing initiatives to prevent them.

13.4 Discussion

The planned budget is based on the budgeting factor (N/Q) and the number of accidents caused. Consequently, the actual budget is then calculated as the proportion of the planned budget to be implemented. The cost of each intervention activity and the proportion of the actual budget per each strategy required, the cost of each strategy is determined and the quantity of accidents preventable by each targeted strategy is calculated as the effectiveness index of each strategy is supplied. The target is determined by selecting the number of accidents preventable by the strategy, which is equal to or greater than the accident reduction target. This is, however, determined by the proportion of the budget that seeks to accomplish the given reduction target (T) so that the cost of the safety strategy that can meet the reduction target is achieved. Thus, the accident prevention rate determines the number of accidents prevented; hence, the value of accidents prevented is determined, and the difference between the actual budget and the value of accidents prevented calculates the cost savings.

Thus, for easy simulation, the computer programme can be written to create a visual user interface that accepts system input variables and parameters from the user through particular input tabs and dialogue boxes on the interface to perform the required calculations and produce acceptable output.

13.5 Conclusions and Future Applications

Application of System dynamics in the use of safety intervention activities/strategies will help in policymaking for effective manufacturing safety planning, evaluation, decision-making, and monitoring in manufacturing safety systems. This will save safety assessment time and costs, reduce accident rates and the cost of litigation, and increase productivity/profit. System dynamics promise to enhance security and lower accidents in manufacturing sectors. Future system dynamics study and application can focus on the following areas:

(i) Integration of big data analytics: Big data analytics can be included in system dynamics models to give more precise and up-to-date insights on potential safety issues and ways to mitigate them
(ii) Human factors: System dynamics can be used to examine how fatigue and stress affect safety performance in the manufacturing industries, e.g., a system dynamics model can be used to determine how workload and work schedules affect the chance of accidents and injuries.
(iii) Supply chain resilience: System dynamics can be used to model and optimize the supply chain's resilience, which can help lessen the effects of interruptions and the possibility of accidents.
(iv) Cyber security: System dynamics can simulate and optimize cyber security tactics in industrial plants, preventing cyber-attacks and safeguarding against potential safety hazards. Integration with Industry 4.0 technologies: System

dynamics can be combined with Industry 4.0 technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) to build smart production systems that can improve safety, lower accidents, and save costs.

(v) Predictive Maintenance: System dynamics can be used to create models for predictive maintenance that can assist manufacturers in identifying probable equipment failures before they happen, lowering the risk of accidents and downtime while saving money.

(vi) Simulation-based Safety Training: System dynamics can be utilized to create simulation-based safety training programs that can aid employees in enhancing their safety expertise and lowering the chance of accidents.

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Chapter 14
University-Industry Technology Transfer in Developing Countries for Smart Cities

Roberto Frías-Castillo, Julieta Flores-Amador, Roberto Romero-López, and Pilar Pérez-Hernández

Abstract This chapter presents a Technology Transfer Model proposed for the Autonomous University of Ciudad Juarez, Mexico's most important industrial city. The model includes the key managerial, linkage, technological, and research elements required for university–industry (U-I) technology transfer. The convenience of this model is that it takes advantage of the accumulated capabilities in Ciudad Juarez universities to improve the products and processes in manufacturing firms located in the city using technology and knowledge transfer, which could lead to the economic and technological development of the region.

Keywords Technology transfer · Innovation · University-industry linkage · R&D

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14.1 Introduction

Since the last decade, smart manufacturing has been an important issue in this rapidly changing and competitive world, in which innovation and technological-scientific knowledge have played a crucial role in generating innovations. Developing countries usually advance at a limited pace when creating new technologies despite their efforts to design and implement new policies to achieve competitive and innovative capabilities. In countries such as Mexico, Research and Development (R&D) activities are mainly conducted at universities and research centers; thus, it is widely accepted that academia is an important source of innovation that can influence both enterprises and the country's development.

The linkage between universities and industries (U-I) is a fundamental component of the innovation system. It is a network in which many agents interact in a certain industry or economic sector within a specific institutional structure to generate, use, and diffuse technology (Lundvall et al. 2002). Therefore, firms and universities in Mexico collaborate through different channels, such as human resource mobility, joint R&D, consulting, and patents, to obtain several benefits (e.g., product and process innovation, scientific publications, and funding) (De Fuentes and Dutrénit 2016).

Technology transfer (TT) is another U–I interaction channel in which a new knowledge or technology developed at universities is adopted by a firm to enhance a product or process, making the adopting firm more effective and competitive by achieving its production, quality, manufacturing, timing, cost reduction, or customer satisfaction goals. TT involves many elements and attributes from two entities with different cultures, knowledge, objectives, regulatory frameworks, dynamics, and contexts (Bozeman 2000).

This document focuses on Ciudad Juarez, a Mexican city located at the border with the United States. The city's main economic activity is the manufacturing industry, accounting for 2018 2651 units related to this industry (INEGI 2020). Ciudad Juarez has been accumulating economic and human capital for five decades, developing technological and organizational capabilities that potentially can be used to innovate. Additionally, most universities in the city have supported the manufacturing industry through graduate and undergraduate programs and provided solutions and new technological applications for local firms.

Some models of the TT process have been developed in less-developed countries. Some have focused on universities' technology management (IPN 2018; UNAM 2022), the process followed by researchers to generate research (Colciencias 2018; Vásquez Rizo 2010), and the technology transfer process (Jagoda et al. 2010; Junior et al. 2014). This study proposes a new model for technology transfer that includes the perspectives mentioned above, based on the university's technology management process, the researcher's knowledge production process, the process of transferring new knowledge or technology, and the capabilities required to perform TT successfully.

The remainder of this chapter is structured as follows. Section 14.2 describes the theoretical framework of the TT and Ciudad Juárez innovation systems. The proposed model for measuring the TT activity is presented in Sect. 14.3. In Sect. 14.4, the methodology is presented, the case study of the Autonomous University of Ciudad Juárez (UACJ). A brief discussion of the subject is given in Sect. 14.5, based on the partial results of this research. Finally, the conclusions and future work are presented in Sect. 14.6.

14.2 Theoretical Framework and Related Work

This section presents the relevant concepts and similar work related to the model proposed in this chapter.

14.2.1 Innovation Systems

Innovation systems are institutional structures that support national, regional or local innovation. It requires interaction between the productive sector (firms), the government (policies, public organisms, and development agencies), the scientific sector (universities and research centers), technological mediators (technological clusters, incubators, technology transfer offices), funding (investors), and the public sector (Cooke et al. 1997; Dudin 2013; Lyasnikov et al. 2014; Trippl and Tödtling 2007) (Fig. 14.1).

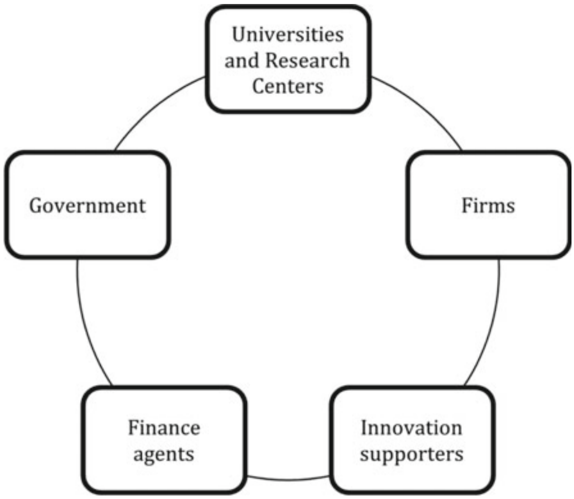

Fig. 14.1 Innovation system agents

In developing countries, national systems are characterized by a lack of absorptive and technological capabilities and the limited creation of new knowledge. Thus, it is important to analyze how innovation-related activities arise and how they adapt to economic and technological environments (Intarakumnerd et al. 2002). According to Llisterri and Pietrobelli (2011), technological change in developing countries is based on accumulative capital and, particularly in Latin American countries, comes from new equipment and machinery acquisition to improve the firm's processes—organizational and service innovations—rather than in product development—technological innovation. At the regional level, innovation systems fulfill the following functions: (a) supply of economic and human resources for innovation within companies; (b) knowledge generation carried out by institutions dedicated to science and technology; (c) interaction and collaboration between agents; (d) specialized knowledge of the companies in the region; and e) the demographics and socioeconomic indicators of the region (Crespi and D'Este 2011).

Aceytuno and Cáceres (2012) affirmed the study and analysis of regional innovation systems as follows: (a) Specialization patterns and innovation levels can vary significantly within different regions of a country or specific territory (De Fuentes and Dutrénit 2013) or transferred to the regions (Economía 2016). This is the case for Ciudad Juarez and the maquiladora industry, which will be presented in further sections.

14.2.2 University-Industry Collaboration

In recent decades, the creation and exchange of knowledge among innovative systems have evolved. First, knowledge is created due to the intrinsic academic aspirations in every discipline. Subsequently, knowledge is produced regarding the needs of industry, government, and society in general (Vega-Jurado et al. 2007).

Since their origins, universities have had two specific missions: (a) profession-oriented, which seeks to train students according to society's needs and opportunities offered by the labor market, and (b) science-oriented, which pursues the generation, application, and distribution of knowledge to improve society (Tocto-Cano et al. 2020; Abu-Naser et al. 2016; Renta Davids 2013).

On the other hand, globalization has changed a firm's perspective on conducting business, as it has been forced to continuously innovate to enhance its performance and quality by reducing its production times and costs (Audretsch et al. 2014). Some firms have not been able to acquire intellectual capital to develop innovation; therefore, they have generated links with research institutions to overcome this situation (Audretsch et al. 2014). Some authors affirm that university-industry collaboration is a subject of interest because it can represent a powerful source of knowledge and innovation (Ankrah et al. 2013; Santoro and Chakrabarti 2002).

Therefore, a third mission has arisen from universities: to become a source of economic and social development agents by supporting activities, such as patenting,

Table 14.1 Stages of U-I collaboration process

Stage	Description
Drivers	The main factors that attract researchers to collaborate with firms are gender and age, previous collaboration experiences, academic level, specialization subject, personal motivations and access to research funding. From the university perspective, relevant factors include the institutional affiliation, the university's mission and strategy, its experience doing TT and the resources (economic and human) that enable it to collaborate
Benefits	Researchers benefit from collaboration by obtaining funding to complete research, the acquisition of lab equipment and new ideas to develop more research that leads to new knowledge, which can result in academic publications, patenting, networking, graduating students, economic incentives and real-life problem solutions
Barriers	They are obstacles for TT to succeed. Technology transfer happens for a reason: the need to enhance the firm's performance through a product improvement or a more efficient process; economic, material and human resources are required to achieve this. Furthermore, barriers to U-I collaboration include different enterprise cultures, management styles, dynamics, goals, ineffective communication, leadership, entrepreneurship, mistrust among agents, the difference in the knowledge level of research groups, and the lack of policies, incentives, funding and appropriate infrastructure (technical and organizational) to perform R&D

licensing, firm incubations, and technology transfer, to take advantage of the knowledge created within non-academic environments (Berbegal-Mirabent et al. 2015; Cervantes 2017; Montecinos and Contreras 2021; Briones et al. 2018).

Universities and research centers are key agents in the innovative development of regions as creators of new knowledge and potential technological solutions to industrial problems; thus, governments have implemented various policies focused on supporting these relationships (Giuliani and Arza 2009). As a result, new university organizational structures have arisen to perform technological management activities, such as technology transfer offices; supporting activities, such as patenting, licensing, I + D contracts, audits, spin-offs creation, and business incubators; and assisting entrepreneurs' assessments, funding searches, and procedures to establish a business (De Fuentes and Dutrénit 2012; Tuunainen 2005).

Some authors have underlined three stages of the U–I collaboration process: drivers, channels, and benefits (Dutrénit et al. 2010). Because this study focused on technology transfer, other channels were not included in the description. Only the researcher/university perspective is described in Table 14.1 (Arza 2010; Bekkers and Freitas 2011; Bozeman et al. 2016; D'Este and Patel 2007; Giuliani and Arza 2009); this research does not include the analysis of the firms' processes and capabilities.

14.2.3 Technology Transfer

TT involves the assessment, adoption, and implementation of technology. TT is defined as the process of transferring technologies, knowledge, skills, and production processes among R&D, universities, and other institutions that benefit from it in the form of new products, processes, or services from which firms generate efficiencies, productive growth, and market benefits (Hernández 2013).

Universities and research centers engaged in R&D activities generate various outcomes; some want to be commercialized in the industry or social sector. This practice, in which the supply side seeks to match demand, is identified with the technology-push perspective of the technology transfer stage of the innovation life cycle. The literature review supports the notion that research results transferred to the productive arena have been considered the main issue since the early ‘60 s, in contrast to the limited disclosure of models developed/used by Universities and R&D institutions to identify ready-to-commercialize technologies in the context of a TT-structured process (Hernández 2013).

Technology transfer between U and I can be formal or informal. Informal channels include access to knowledge through experience and specialized equipment, training, recruiting, and research residencies. These channels are based on personal contact between researchers and employees at the firm. In contrast, the formal channels of TT include contracts for exploiting knowledge, expertise, and equipment (e.g., patenting, licensing, consulting, and R&D contracts) (Azagra-Caro et al. 2017).

Universities and R&D organizations working under the technology-push perspective face the challenge of selecting technologies at their mature stage to be transmitted to their final users through commercialization efforts. This complex procedure, involving an internal R&D environment, is considered a Technology Supply and an external business environment in which Technology Demand occurs (Hernández 2013).

In general, the technology transfer between U-I consists of the following stages: identification of technological opportunity, technological monitoring, planning of the technology, negotiation with the firm, implementation of technology, and assessment of the impact of this implementation (Junior et al. 2014). Despite this, a set of activities must be performed at each stage to succeed with the TT.

A general overview of the state of the art of this research is shown in Fig. 14.2, which includes the agents (universities, government, and firms) and all the interactions that influence the generation of technology transfer, as well as the benefits to both universities and firms located in Ciudad Juarez.

14.2.4 Smart Cities

Globalization transposes national borders and highlights the diversity of growth paths that economies can follow. Countries, regions, and cities differ in terms of the amount of available economic, human, and cultural resources and assets. However, growth rates and levels of well-being depend, above all, on the development of the forces driving growth and the effects of their interaction (Barquero 2005).

Knowledge and technology have become an inexhaustible source of change for society and territories, key elements for competing globally. This idea is not new;

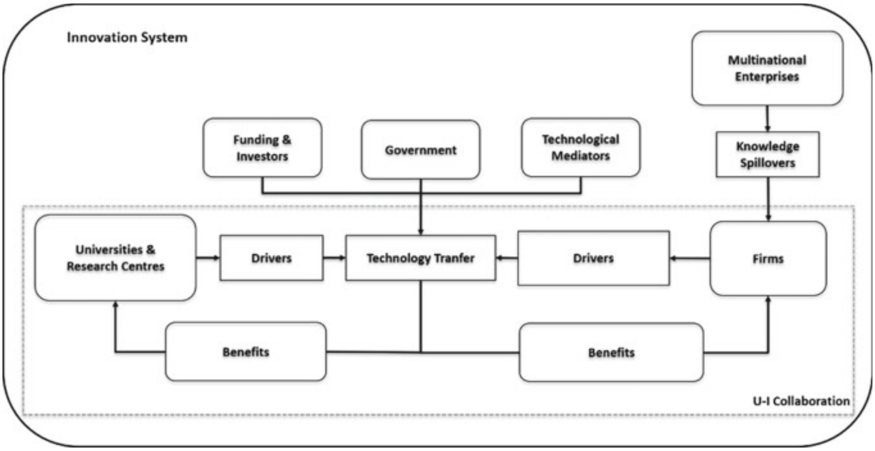

Fig. 14.2 Overview of the innovation system from the technology transfer perspective

what is novel is the intensive use of knowledge and technology to achieve competitive advantages among nations, organizations, and individuals (Pérez Hernández and Escobar 2014).

Cities represent spaces where new ideas are born, information is accumulated, and knowledge is generated, perhaps nowhere else. Cities generate wealth, products, services, and employment that are satisfactory to their inhabitants and elsewhere. They are also the engines of large commercial and business activities, so their economic impact is significant. The city is the central space for changes in economic and productive systems and reorganization of the institutional system. Thus, urban development is associated with income growth (investment and employment), structural changes, and innovation processes. Therefore, it can be said that cities play a strategic role in the evolution of societies and the economic development of all historical periods (Barquero 2005).

A logical consequence of the current stage of the global economy is the ease of coding (or marketing) knowledge and having access to it; however, knowledge has become crucial to sustain or increase the competitive position of firms and regions since it is increasingly determined by what (Markusen 2017) calls "the paradox of adherent territories within slippery spaces." This paradox is expressed in two characteristics: first, innovative activity is not evenly distributed in the geographical space, and, specifically, knowledge-intensive economic activities are geographically agglomerated; second, there is a tendency towards spatial concentration over time. Global competitiveness has forced most industrialized nations to specialize in exporting products with technological or absolute advantages (Storper 1992).

There is consensus in the literature that the structure of the cities of the future must be based on (1) the extensive structure of digital networks that allow the flow of information and knowledge intensively; (2) Information and Communication Technology (ICT) must be used to improve the quality of life of citizens; (3) ICTs should be the basis for the development of structures that allow mobility, sustainability, and proper management of government activity; and (4) spaces where innovative activity is held, which is known today as Industry 4.0 (Pérez Hernández and Escobar 2014).

The changes experienced in society are increasingly frequent and accelerated and impact all activities; the creation, production, distribution, and exchange of all types of tangible and intangible assets are changed by the impulse of ICTs, the knowledge generated and acquired, collaborative work in networks, global supply chains, and innovation spaces give that element sticky territories. In this context, a new generation of spaces emerges. Smart Cities (SC) arise where knowledge is intensive, innovative, and intelligent for all activities (Komninos 2013).

Global economic and production changes have implied changes in the need to coordinate the productive cycle, R&D, services, manufacturing, and consumption on a global scale, and the location of these activities has become a strategic element. Komninos (2013) suggests that with ICTs, the local innovation system acquires greater depth and scope while its functions become more transparent and effective.

Komninos (2008) proposed the concept of SC to refer to a territory of high capacity to learn and innovate, supported by digital spaces and virtual environments for knowledge management and innovation. The term refers to areas provided with supportive learning, technological development, and innovative procedures, with digital spaces, information, and knowledge processing, which are transferred between the actors.

14.2.5 Context: Ciudad Juarez Innovation System Agents

In 2011, Latin American innovation systems were characterized by reduced efforts to establish industrial and social infrastructure to enhance technology transfer, the proof of which is the reduced joint research projects between U–I, inefficient management of intellectual property, and low-level entrepreneurship, which happens out of need rather than an opportunity. In addition, the private sector only participates in 20% of the funding for research projects, while approximately 70% of the investment comes from public funds (Pineda Márquez et al. 2011). Many universities in countries such as Mexico, Brazil, and Colombia have carried out important changes to achieve an appropriate environment to facilitate TT and innovation, such as the establishment of offices to promote innovation, enterprise incubators, specialized information and technological services, and the implementation of intellectual property regulations (Pineda Márquez et al. 2011).

Ciudad Juarez's industry mainly focuses on automotive and transport (33.3%) and computation, communication and electronic accessories (24.1%) sectors. Transnational Corporations (TNC) such as Johnson Controls, TPI Composites, Bombardier Recreational Products, Continental Automotive, Robert Bosch, APTIV, Honeywell, Lear, and Delphi Technologies have subsidiaries in the city. Through foreign direct investments, these and other TNCs specialize in the local workforce and attract higher value-added manufacturing units in which more complex activities, such as automatization, design, research, and development, are performed (Carrillo and Lara 2005).

From the knowledge-creation side, Ciudad Juarez has research centers and universities such as the Advanced Materials Research Centre (CIMAV), Technological Institute of Ciudad Juárez (ITCJ), Technological University of Ciudad Juárez (UTCJ) and UACJ. These institutions offer programs in many engineering specialties according to the firm's needs and sectors. They have also implemented technological enterprise incubators, technology transfer offices, consulting services, and continuing education courses through linkages with industry programs, models for industry services, and internships of researchers and students at firms. In addition, some support organizations for the industry are present in the city; for example, there are 24 technical training centers focused on computational, electric, electronic, and metal-mechanical sectors, the most important being the High Technology Center (CENALTEC), which offers services and training to large firms and medium and small companies that deliver different services to TNC in the city.

The national, state, and local governments have implemented programs to pursue innovation in the region. The National Council of Science and Technology (CONACYT) is a national public organization created to promote the creation and diffusion of science and technology in the country through different mechanisms, such as policies, programs, and funding, in four directions: (a) scientific and technological infrastructure; (b) development, retention, and attraction of specialized human resources; (c) promotion of high-impact innovation and entrepreneurship; and (d) diffusion and promotion of R&D + i (CONACYT 2022).

As an innovation supporter in Ciudad Juárez, the Technology Hub aims to empower collaborative growth to construct a community of innovation leaders. This innovation ecosystem has a binational enterprise incubator, a risk capital fund, and a fab lab, which promotes innovation and smart manufacturing projects based on education and values such as collaboration, trust, equity, responsibility, ecology, and philanthropy (TechnologyHub 2022).

14.3 Proposed Model

This section presents a structural equation model of technology transfer (Fig. 14.3). To measure the TT between universities and industry, four dimensions were defined: technological management (TM), technological capabilities (TC), research capabilities (RC), and technology transfer process (TP). The technology transfer results (TR) and technology transfer benefits (TB) were also included in the model as observable variables. Overall, the model includes the institution and researcher's capabilities required to facilitate the TT process and the activities needed to transfer new technologies or knowledge to firms successfully. The following subsections describe the model dimensions.

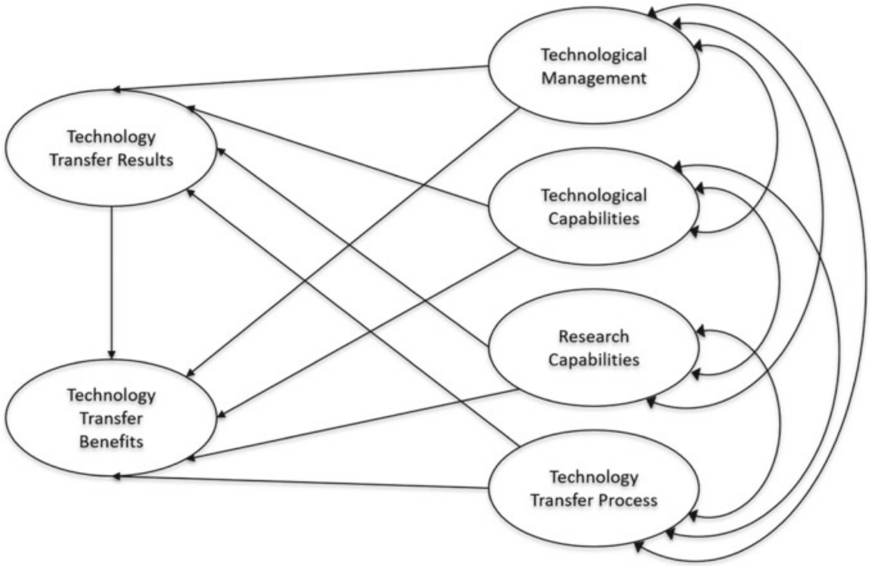

Fig. 14.3 A general overview of the technology transfer model

14.3.1 Technological Management

Technological management represents a series of actions, tools, and techniques that reunite science, engineering, business, organizational processes, and human resources to increase the competitiveness of institutions through the settlement and execution of strategic and operational goals that allow the creation, compilation, organization, diffusion, use, and exploitation of knowledge to enhance the performance of human resources (Lindblom and Tikkanen 2010; Agrawal and Mukti 2020; Nonaka and Takeuchi 1995).

Universities adopt mechanisms of technological management (MT) as part of their strategy to respond to their industrial and social environmental needs and requirements, such as monitoring the technological demand of local industry sectors, identification and linkage with technological partners, assessment to recognize technological inventions' value, training programs to generate a TT and innovation culture, design of intellectual property policies, identification of potential customers for technologies developed at the university, and evaluation of those technologies, which are usually performed by technology transfer offices (Siegel et al. 2007).

Other universities also carry out TM, and the activities of these offices involve support to researchers asking for federal funding for technological projects, generating collaborative contracts with firms and other organizations, and carrying out complete administrative management related to accounting, human resources, and information technology to facilitate TT. For this model, technological management (TM) is defined as Eq. (14.1):

$$\eta_1 = \gamma_2\eta_2 + \gamma_3\eta_3 + \gamma_4\eta_4 + \gamma_5\eta_5 + \gamma_6\eta_6 + \varepsilon_1 \quad (14.1)$$

where η_1 is TM, η_2 is TC, γ_2 is the regression weight, η_3 is RC, γ_3 is the regression weight, η_4 is TP, γ_4 is the regression weight, η_5 is TR, γ_5 is the regression weight, η_6 is TB, γ_6 is the regression weight, and ε_1 is the estimated TM error.

14.3.2 Technological Capabilities

Technological capabilities are activities that dominate new technologies, adapt them to the local environment, and improve, diffuse, and exploit them (Lall 1992). They can then develop and manufacture complex products and processes that are attractive to the market (Lall 1992; Morrison et al. 2008). These capabilities are dynamic and flexible as they adapt to ever-changing environmental conditions (Teece et al. 1997).

The accumulation of technological capabilities (TC) depends on investments made in human resources, infrastructure, R&D, and collaboration with agents in the environment; thus, a common categorization of TC is (a) investment (plant and equipment), (b) human resources (training and education), and (c) technological efforts of production, design, and R&D. TC can be seen as a firm's procedures, processes, equipment, plant, and technological knowledge, as well as how an enterprise develops and enhances technology and how manufacturing activities allow it to transform R&D into innovative products. Other essential elements to reinforce technological capabilities are the institution's individual and collective learning processes and its ability to integrate, reconfigure, and communicate knowledge (Kruss et al. 2015).

To develop these TC at universities, some activities must be undertaken. For example, developing investments in TC is necessary to generate strategies to retain quality researchers, attract new ones, and acquire new equipment, machinery, software, and supplies to perform research (Chaves 2017). Linkage TC includes researchers' activities and programs to collaborate with external researchers and firms, such as academic conferences and networking events, to identify opportunities. Researchers must also obtain certifications according to industry standards in quality, manufacturing, and logistics. For the model, technological capabilities (TC) are defined in Eq. (14.2):

$$\eta_2 = \gamma_1\eta_1 + \gamma_3\eta_3 + \gamma_4\eta_4 + \gamma_5\eta_5 + \gamma_6\eta_6 + \varepsilon_2 \quad (14.2)$$

where η_2 is TC, η_1 is TM, γ_1 is its regression weight, η_3 is RC, γ_3 is its regression weight, η_4 is TP, γ_4 is its regression weight, η_5 is TR, γ_5 is its regression weight, η_6 is TB, γ_6 is its regression weight, and ε_2 is the estimated TC error.

14.3.3 Research Capabilities

Research capabilities involve the process by which knowledge is created, obtained, stored, used, and diffused by members of an institution. It directly relates to human capital because people possess the know-how, education, knowledge, values, attitudes, and abilities; in this sense, researchers continuously learn to produce new knowledge, which is presented to the scientific community in many forms (Nelson 2009).

Research capabilities (RC) are required to convert tacit knowledge into explicit knowledge, facilitate the transmission and permanence of knowledge in time and space, and generate information flows worldwide. Indicators to analyze RC are related to academic production, such as academic publications and patents generated in a period.

RC models have been proposed to (a) obtain information about the capabilities, strengths, weaknesses, and potentialities of research groups; (b) update the information, activities, and results obtained by researchers and their collaborators; (c) consolidate a mechanism that allows knowledge of research group dynamics to generate statistics to prove its productivity; and (d) consolidate all this information as a tool to design better policies to support research group activities (Colciencias 2018). All these indicators can be used as an instrument of internal management at universities to evaluate the researcher's performance and provide incentives. These models include four main typologies (Colciencias 2018). Table 14.2 shows these typologies and their corresponding indicators.

In Mexico, CONACYT has implemented the National Researchers System (SNI) to encourage Mexican researchers to conduct high-quality research. Depending on its merits, SNI grants a level corresponding to an economic incentive, and researchers can continue doing their valuable work (CONACYT 2022). For the model, research capabilities (RC) are defined as Eq. (14.3):

$$\eta_3 = \gamma_1\eta_1 + \gamma_2\eta_2 + \gamma_4\eta_4 + \gamma_5\eta_5 + \gamma_6\eta_6 + \varepsilon_3 \tag{14.3}$$

Table 14.2 Indicators for research capabilities

Type	Indicators
New knowledge generation	Research articles, research books and patents
Technological development and innovation	Technological products, business products, participation in developing regulations and norms in innovation, consulting
Social appropriation of knowledge	Citizen participation in science, technology, and innovation (STI), pedagogic strategies on STI, social communication of knowledge, and diffusion of specialized knowledge
Human resources formation	Master's and doctoral dissertations, R&D projects, R&D + i projects, social responsibility projects

where η_3 is RC, η_1 is TM, γ_1 is its regression weight, η_2 is TC, γ_2 is its regression weight, η_4 is TP, γ_4 is its regression weight, η_5 is TR, γ_5 is its regression weight, η_6 is TB, γ_6 is the regression weight, and ε_3 is the estimated RC error.

14.3.4 Technology Transfer Process

As mentioned, the TT process involves transmitting a new technology from an institution that performs R&D activities to another organization that requires a technological solution to improve its performance. Junior et al. (2014) propose a useful model of TT based on the stage-gate model; they divide the process into six stages, which will be described below in Table 14.3.

For the model, the technology transfer process (TP) is defined as Eq. (14.4):

$$\eta_4 = \gamma_1\eta_1 + \gamma_2\eta_2 + \gamma_3\eta_3 + \gamma_5\eta_5 + \gamma_6\eta_6 + \varepsilon_4 \tag{14.4}$$

where η_4 is TP, η_1 is TM, γ_1 is its regression weight, η_2 is TC, γ_2 is its regression weight, η_3 is RC, γ_3 is its regression weight, η_5 is TR, γ_5 is its regression weight, η_6 is TB, γ_6 is the regression weight, and ε_4 is the estimated TP error.

14.3.5 Results and Benefits of Technology Transfer

The results of the technology transfer measure the firm's and research group's satisfaction and existing barriers in U–I collaboration that affect the results, such as communication, differences in the knowledge level of agents, trust, differences in the dynamics of the agents that affect the timing of the transfer, suitability of the TT, funding sufficiency, and other managerial difficulties.

For the model, the transfer results (TR) are defined by Eq. (14.5):

$$\eta_5 = \gamma_1\eta_1 + \gamma_2\eta_2 + \gamma_3\eta_3 + \gamma_4\eta_4 + \varepsilon_5 \tag{14.5}$$

where η_5 is TR, η_1 is TM, γ_1 is its regression weight, η_2 is TC, γ_2 is its regression weight, η_3 is RC, γ_3 is its regression weight, η_4 is TP, γ_4 is the regression weight, and ε_5 is the TR estimated error.

The benefits for the university and its researchers are academic products utilized to obtain institutional and federal incentives to conduct research, such as research articles, books and chapters, presentations at academic events, undergraduate and graduate theses, and patent registrations. It also includes intangible benefits such as accessing new research topics, knowledge exchange, and application of knowledge to real situations. For this model, the technology transfer benefits (TB) are defined in Eq. (14.6):

Table 14.3 Stages of the technology transfer process

Stage	Description
Opportunity identification	It is the analysis of market trends and the monitoring of competitors' technologies. It should include forming an assessing team, elaborating roadmaps for understanding the identified technologies, an initial market evaluation of these, a previous analysis of the required resources and investments, and the potential risks and barriers to adopting the new technology
Technological monitoring	Firstly, it is important to generate the specifications the new technology must fulfill, including the economic and technological value that each solution will represent to the adopting firm. In this step, all existing and needed capabilities must be established, such as the specific resources needed to implement the solution, and potential suppliers, technological intermediaries and government agencies that could be involved in the process
Negotiation	Involves detailed communication among the agents to establish the pricing, payment method and calendar for the technology transfer. The contract should include responsibilities and contributions for both the researchers and the firm's employees and the adequate mechanisms that will be used to implement the new technology, such as meetings, training, visits, communication channels, and testing
Planning for the implementation of the new technology	The research group must generate a detailed plan with all project activities, timing, scheduling, resourcing and responsibilities. Workflow and organizational changes must be identified to adopt the new technology
Implementation of the technology transfer	This stage depends on the cooperation and management of the agents, having good control by fulfilling the developed plan. Adjustments in products and processes in the firm may arise and need to be done. Other activities include selecting and contracting suitable people to provide training to employees in the company, analyzing purchase decisions related to new materials or equipment needed to carry out the TT, and comparing the planned and the real results of the implementation to identify any problems. Until then, the transfer process is done
Evaluation of the impact of the technology transfer	It should include financial, market, technological and organizational aspects, considering that some results may be intangible or will not be reflected from the beginning. The identified problems in the previous stage must be corrected to eliminate them. Finally, opportunities to enhance the technology (or to create new technologies) may be identified

$$\eta_6 = \gamma_1\eta_1 + \gamma_2\eta_2 + \gamma_3\eta_3 + \gamma_4\eta_4 + \gamma_5\eta_5 + \varepsilon_6 \tag{14.6}$$

where η_6 is TB, η_1 is TM, γ_1 is its regression weight, η_2 is TC, γ_2 is its regression weight, η_3 is RC, γ_3 is its regression weight, η_4 is TP, γ_4 is its regression weight, η_5 is TR, γ_5 is the regression weight, and ε_6 is the TB estimated error.

14.4 Autonomous University of Ciudad Juarez: A Technology Transfer Study

Funded in 1973, its current mission is to create, conserve, and diffuse knowledge to educate internationally competitive professionals through quality educational programs and pertinent scientific research in the regional environment, contributing to the diversification of economic activities by promoting the application of scientific and technological research results in local firms and improving the quality of life in the region.

The objectives of the UACJ are a) related to U–I collaboration, which aims to promote knowledge and technology transfer to the community through a growing set of educational programs, the provision of specialized services to the region, and the increase of agreements with social, governmental, and productive agents; and b) related to research, the UACJ seeks to increase the productivity of scientific research, technological development, and innovation by strengthening its articulation with regional needs (UACJ 2022a).

About its educational offering, currently, UACJ has 70 undergraduate, 40 master and 10 doctoral programs divided into seven different units; of these, 20 graduate, nine master and three doctoral programs are related to engineering. A total of 261 full-time professors work on the engineering campus, and currently, 76 of them hold membership in the SNI (30% of the total), 27 have the candidate level, 45 have the first level, and four have the second level (UACJ 2022a). This shows the quality of research on UACJ, which accounts for more than 50% of SNI researchers in the state.

For technology transfer activities, the UACJ created the Technology Transfer and Intellectual Property Office (OTT.PI), which aims to promote impulse innovation and technological development based on social and productive needs through U-I collaborations to create, develop, transfer, and implement technological products, processes, and systems with the final goal of converting the manufacturing industry in the city into a more technological and innovative region (UACJ 2022b).

OTT.PI offers the following services: detection of stages of technological maturation, technological monitoring with specialized software, processing of industrial property before the IMPI, consulting and support for the development of technological roadmaps, advice for obtaining private and public capital funds, technology training, and transfer intellectual property (UACJ 2022b).

A questionnaire was designed and validated to analyze the TT process of UACJ researchers and was then delivered to the researchers. This questionnaire has five sections: general information on the researcher, capabilities for technology transfer (technological management, technological, and research capabilities), TT process, TT results, and collaborations. This questionnaire uses a 5 Likert scale: Never, Rarely, Occasionally, Frequently and Permanently.

In the first random survey, 220 researchers answered the questionnaire, and 94 (43%) had performed technology or knowledge activities with firms in the social or productive sector, despite the lack of an integrated model for technology transfer. According to 46 (49% of the total) participants, they had an unsatisfactory to regularly satisfactory experience of technology transfer with firms, due to the management process at the university, the interaction with the firm, the implementation of the technology, or the results obtained.

14.5 Discussion

Universities and firms get involved in TT projects for one reason; thus, the results and benefits for both agents are important aspects to consider. Achieving customer (firm) and research group satisfaction is necessary to consider the success of TT. Accomplishing technical specifications, solving the firm's problem, and correctly implementing the new technology usually indicate a positive result, which impacts the university's reputation.

Barriers to U–I collaboration greatly influence the results of the TT. Different dynamics among the participants may affect the timing of accomplishment; a difference in the knowledge levels of the agents may provoke a misunderstanding of the technology's use or performance; having sufficient communication channels directly affects the process of TT; and errors in management, delays in paperwork, and insufficient funding could cancel the technology transfer.

The benefits obtained by the university and research groups also depend on the TT results. Accessing new research topics, exchanging information and knowledge among agents, applying advanced knowledge and technologies in universities to real-life situations, getting funding to complete ongoing research or getting new equipment and materials, and generating scientific networks to develop deeper, more frequent, and higher-quality collaboration projects.

Positive results increase institution and individual reputation, which may result in more technology transfer projects with the same or other firms. In addition, it impacts graduating students and the creation of scientific products; researchers usually publish journal articles, research books, patent generation, and licensing, among others, to get more incentives from the university and federal programs promoting research and innovation.

14.5.1 Why is a Technology Transfer Model Needed?

Even though many universities from developing countries already have an adequate and functional structure to promote and carry out technology transfer, others, such as UACJ, are not well articulated—mainly because different institutional instances do all activities—since it lacks an integrated technology transfer model that allows it to carry out, in a better way, this type of project has greater ease and fluidity.

In this sense, the collected information shows the need for greater institutional efforts to participate in events with firms from the social and productive sectors to promote collaboration (64%) and boost research financially to perform more research-oriented activities to solve regional problems (69%). Regarding the generation of strategies to retain and attract quality researchers, more than 60% of the respondents mentioned that the UACJ never or occasionally carried them out.

Another issue was related to acquiring advanced equipment, machinery, and materials to conduct research, where 83% answered that this was never done or occasionally by the university. Related to the interaction with the private sector, the UACJ never performs or occasionally performs activities to exchange information (70%), learn from firms (70%), and apply knowledge from other institutions (67%).

Regarding researchers' activities to increase collaboration, 42% never or occasionally look for potential partners in local industrial, commercial, or service firms; 32% responded that they never or occasionally collaborate with research from other institutions; and 48% never or occasionally receive training to be certified according to current industry standards.

Researchers work with students' theses that resolve specific problems in the industry; items related to this topic show that 36% of respondents never perform or occasionally do these activities with an undergraduate thesis, while 54% never or occasionally do it for a graduate thesis. Related to the above, 55% of researchers never develop or occasionally do research projects in collaboration with other national universities, while 66% never or occasionally do it with foreign universities.

Regarding direct collaboration on R&D activities, 82% of the respondents affirmed that they never or occasionally performed research internships in local firms. In comparison, 77% of them never or occasionally provided services such as R&D and training for the social and productive sector in Ciudad Juarez. Regarding innovative production, 69% of the participants had never or occasionally developed intellectual property figures, such as patents, utility models, industrial designs, and software.

Answers related to the TT process show that 58% of researchers never or occasionally conduct meetings to determine the firm's needs, 55% never or occasionally create specialized teams to resolve the problem, 52% never or occasionally state the resources and knowledge the firms have to accomplish the technology transfer, 56% never or occasionally carry out technological monitoring activities to decide the best option to develop, and 41% never or occasionally develop detailed plans for the TT.

Continuing with the TT process, 54% of researchers never or occasionally identified potential suppliers for the technology development; 52% of respondents mentioned they never to occasionally identify the required changes to the firm's products and processes to adopt the new technology; 58% never to occasionally evaluate the risks the firm will take in adopting new technology; 58% mentioned they never to measure the impact on productivity the new technology occasionally will have on the firm's performance, and 48% of the answers showed that researchers never to determine the technical and economic feasibility of the TT occasionally.

Based on the results, there is a big opportunity for improvement in the UACJ and the researcher's activities and methods for technology transfer, which can bring more and better benefits for them and the firms they collaborate with.

Local manufacturing and service firms represent big opportunities to carry out technological collaboration projects that generate greater innovations that could impact the region's development and the university. In this sense, this model is generated to take advantage of this opportunity by implementing the necessary policies and functions in the UACJ so that it is administratively prepared to conduct technology transfer projects when needed.

14.6 Conclusions and Future Work

Owing to the current level of rapid technological change and competitiveness, universities and research centers must introduce themselves in the production sector to develop advanced technologies; this is more relevant in developing countries because they are always economically and technologically speaking. In this sense, Mexican universities must design and adopt business-oriented policies and strategies to better understand firm dynamics and market trends. These policies and strategies must focus on results and have quality research control centered on applying the knowledge created by researchers.

The concept of a Smart City originates when technology permeates all human activities, modifying them to such a degree that it can also modify its environment so that the hypothesis proposed at the beginning is accepted. Ciudad Juarez has different challenges for the future and requires technology to solve water supply and electricity problems. In addition to seeking planning and design solutions through the use of new materials for construction, it also requires adopting sustainability criteria should be adopted in terms of solid waste management, wastewater treatment, emission control, implementing management systems, information control, and educational means to make a more efficient government.

An effort to document experiences and good practices in technology transfer is required, which will contribute to the professionalization and construction of a local theory of technology transfer management adapted to the conditions of the region and its institutions. This model is designed to define a robust process for technology transfer from the UACJ to firms in social and productive sectors, considering that Ciudad Juarez has a large manufacturing activity continually evolving technologically.

The next step is to develop recommended strategies, actions, and policies based on the collected information. These will be presented to UACJ to help them improve the institutional and researcher's performance on technology transfer, increasing the impact on local firms' technological development.

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