Addis Ababa University

College of Technology and Built Environment

School of Mechanical and Industrial Engineering

Ergonomic Workplace Design for Sustainable Competitive Advantages of Manufacturing Firms: *A Case Study of Selected Metal Manufacturing Firms in Ethiopia*

BY

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Author’s Declaration

I hereby declare that this declaration, titled Ergonomic Workplace Design for Sustainable Competitive Advantages of Manufacturing Firms: A Case Study of Selected Metal Manufacturing Firms in Ethiopia, is the result of my own original research, which I conducted with the help of Dr. Kassu Jilcha and Professor Daniel Kitaw of the College of Technology and Built Environment (CTBE). Based on this research, no other university or organization has granted a degree or diploma. I certify that the study provided in this dissertation is the outcome of our initial

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Shemelis Nesibu Date

We hereby certify that this dissertation, entitled Ergonomic Workplace Design for Sustainable Competitive Advantages of Manufacturing Firms: A Case Study of Selected Metal Manufacturing Firms in Ethiopia, was conducted under our supervision.

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Abstract

The current landscape of metal manufacturing has led most firms to focus primarily on functional and technological advancements, often neglecting the needs and preferences of their employees. As a result, employees' roles tend to become static. Social value among workers is one key driver of competitiveness in modern manufacturing firms. There is a need to maintain the employees' physical and cognitive well-being in order to guarantee greater competitiveness for the manufacturing firms. A shift from "task-oriented" to "employee-oriented" workplace design results in revolutionary advantages for metal manufacturing firms in achieving sustainable competitive advantages. The inclusion of ergonomic principles in employee-oriented workplace design improves the interaction between employees and non-employee elements and is critical in fuelling organizational competitiveness.

This dissertation employs a critical realist constructivist approach, positing that reality is socially constructed and encompasses multiple perspectives, rather than being solely an observed phenomenon. This informs the aim of this study to explain, interpret, and construct knowledge from various accounts.

The general objectives of this dissertation are to examine holistic ergonomic workplace design models that guarantee the well-being and innovation capability of employees and, as a consequence, foster the development of sustainable competitive advantages for metal manufacturing firms. The research also aims to empirically investigate the impacts of ergonomic risk factors on employees' well-being and capability for innovation and the role of ergonomic workplace design in the pathways to sustainable competitive advantage. In addition, proactive tools and design strategies for ergonomic workplace design in this study are to be developed. The study employs both empirical and theoretical approaches with interplay between metal manufacturing companies' ergonomic theory and practice.

The outcomes of the systematic literature review are that the causal determinants of work-related disorders in metal manufacturing companies are non-employee and employee attribute mismatches in the workplace, suggesting the critical gap created by failure to consider all factors in the design stages.

Empirical research, conducted in sample metal manufacturing industries, utilized structural equation modelling (SEM) techniques. Information was collected through self-administered closed-ended questionnaires from 219 experienced workers, managers, experts, and team leaders. Analysis methods included SPSS version 26 and Covariance-based Structural Equation Modelling (SEM), and SEM-PLS version 3. Field observation and interviews were also employed to collect information related to ergonomic workplace design in selected metal manufacturing firms.

The empirical analysis has confirmed that reducing physical ergonomic risk factors is associated with a decrease in the risk of musculoskeletal disorders (MSD) (β=0.264, P=0.00) and an improvement in the innovation capability of employees (β=0.387, P=0.00). It was also observed that the prevalence of cognitive ergonomic risk factors reduces the innovation capability of employees (β=-0.202, P=0.00). Addressing the underutilization of information and communication technology infrastructures also lowers the risk of musculoskeletal disorders (β=0.357, P=0.00) and is associated with employees' capacity for innovation (β=0.387, P=0.00). These findings demonstrate the substantial impact of these variables on the incidence of musculoskeletal conditions and workers' capacity for innovation in manufacturing companies. Reducing the risks of musculoskeletal disorders also has an impact (β=0.336, P=0.00) on increasing the innovation capability of employees in manufacturing firms.

Besides, ergonomic workplace design significantly impacts cognitive well-being (β = 0.47, t = 6.1, P = 0.00), physical well-being (β = 0.36, t = 4.09, P = 0.00), and innovation capability (β = 0.30, t = 5.43, P = 0.00), and indirectly impacts the development of sustainable competitive advantages (β = 0.20, P = 0.00, (95% [0.13, 0.29]). The innovation capability of employees also significantly impacts the development of sustainable competitive advantages (β = 0.66, t = 12.1, P = 0.00).

Taking into account the theory and empirical findings, proactive frameworks and design strategies for ergonomic workplace design have been developed to resolve the root causes of the existing gaps in ergonomics management literature and empirical manufacturing findings. These include *Workfit-Lever*, *Ergonomic Function Deployment (EFD) frameworks*, the Development of Sustainable Competitive Advantages formula, and other *algorithms* for designing an ergonomic workplace in manufacturing firms.

In summary, this study highlights the critical role that ergonomic workspace design plays in launching a more innovative and healthy working environment by integrating ergonomic risk factors, workers' well-being, and innovation capability. The proactive measures and design principles described provide a guide for putting ergonomic best practices into practice and preventing work-related disorders. Subsequent research is encouraged to continue elaborating on the intricate interconnections and potentialities of constructing sustainable competitive advantages in metal manufacturing firms.

Keywords: Competitive advantage, ergonomic risk factors, ergonomic function deployment, employee well-being, employee-centric workplace, proactive ergonomics, innovation capability, manufacturing industry, musculoskeletal disorders, workfit-lever

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Acronomy

EFD…..Ergonomic Function Deployment

WMD...Work-related musculoskeletal disorders

CD ....Cognitive Disorders

SCA...Sustainable Competitive Advantages

EWD..Ergonomic Workplace Design

PPE……………………………………………………........... Personal protective equipment

PhyErg………………………………………………...…................. Physical Ergonomics

CogErg..….....................Cognitive Ergonomics

ILO .... International labour Organization

OH&S ………………………………………………..................Occupational Health and Safety

WD ……………………………………………………….......................Work related disorders

MOLSA...Ethiopian Ministry of Labour and Social Affairs

NHE..non-human elements

Chapter One

Research Overview

1.1 Introduction

Globalization, technological advancement, and a competitive workforce are critical issues that have dramatically reshaped all organizations' work arrangements around (Nderitu et al., 2019). The integration of new technologies in the workplace is reshaping work patterns, especially the work performance between employer and employee and the organization of work itself (Frank, 2017). Due to this rapid growth of technological innovation, the gap between industrially advanced countries' haves and industrially developing countries' have-nots is increasing (Scott & Charteris, 2004; Thatcher & Todd, 2019). The occurrence of major shifts in the markets is forcing industries to rethink their ways of functioning and requiring a comprehensive working system to provide for relatively local resources, production processes, and environmental conditions (Garetti & Taisch, 2012; Manas, 1990).

Moreover, the manufacturing industries have become more technology-focused, and they often neglect social sustainability (Xu et al., 2021). Because of the existing technological deficiencies that characterize these industrial production systems, manufacturing enterprises need to devise and adopt holistic principles that would implicate social dimensions in their operations (Manas, 1990).

In light of these shifts and gaps observed within manufacturing firms, achieving sustainable competitive advantages now requires a holistic approach that goes beyond traditional metrics such as cost reduction and productivity improvement (Choe et al., 2015). Therefore, ergonomic workplace design will ultimately turn out to be one of the essential competitors in the market by joining the social aspects with the technical aspects, thus becoming a major bridge (Durugbo, 2020; Gregori et al., 2017; Neumann et al., 2021). Since the social value of the workforce is a critical driver of competitiveness for modern organisations. Ensuring the physical and cognitive health and overall well-being of employees is vital for improving the competitiveness of the manufacturing firms (Nderitu et al., 2019).
These enable the industries to develop a system that ensures the physical and cognitive well-being of employees via creating new working modalities and skills for workers that can eliminate factors that affect the well-being and innovation capability of employees within the metal manufacturing firms (Gregori et al., 2017; International Ergonomics Association (IEA), 2021). To ensure that manufacturing firms remain competitive in this digital era, it is essential to give equal

consideration to social factors alongside costs and product quality. Since it is neither possible nor convenient to eliminate human contribution to the process in the manufacturing industry (Choe et al., 2015). The recent shift to well-being, sustainability, and resilience under Industry 5.0 also indicated that manufacturing should be human-centric instead of system-centric, only driven by efficiency, quality improvement, and cost reduction (Lu et al., 2022). Hence, the sustainable innovation of the workplace for any production system has to include the requirements of workers and human-related issues.

In recent times, metal manufacturing firms have placed increased emphasis on workplace analysis, hazard prevention, control, and employee training to enhance safety standards (May et al., 2015). Large and medium-sized metal manufacturing firms have notably expressed dedication to employee safety and stakeholder welfare through various communication channels such as websites, notice boards, and annual reports. Globally, numerous directives have been enacted to improve workplace safety and health, with the introduction of the Occupational Health and Safety (OH&S) management system standard ISO45001 by the International Organisation for Standardisation (ISO).

Therefore, the envisioned workplace of the future is characterized as employee-centric rather than task-centric, aiming to elevate the role of workers and optimize production performance within the metal manufacturing firms. Through efficient system integration that matches tasks and environments' demands with employees' capabilities, this change emphasizes how crucial it is to integrate employees' performance and well-being (Dul et al., 2012). The metal manufacturing sector must adapt to the sustainability trends by addressing ergonomic risk factors that affect employee well-being and innovation capability, and the development of sustainable competitive advantages in manufacturing firms.

The overarching goal of this dissertation is to investigate the impacts of ergonomic workplace design on worker well-being, innovation capability, and the development of sustainable competitive advantages. Moreover, this study further aims to develop a holistic and proactive workplace design framework for workplace design that ensures employee well-being while fostering sustainable competitive advantages in selected metal manufacturing firms, particularly in developing countries. To achieve these objectives, a case study of metal manufacturing firms in Ethiopia was conducted, utilising data collected and analysed using SPSS, Amos Software, and Structural Equation Modelling (SEM). This dissertation is presented as a monograph, in which each chapter serves as an integral component of a cohesive study, rather than a collection of separate publications.

The original contributions of this research include the development of a comprehensive proactive framework, such as the ergonomic function deployment (EFD) framework, workfit-lever, and workplace design strategy for workplace design tailored to the unique contexts of manufacturing firms. The various aspects of ergonomic workplace design and their implications for worker well-being, innovation, and the development of sustainable competitive advantages in metal manufacturing firms are examined in each chapter, which directly relates to the main research questions. This integrated approach ensures that the findings collectively address the dissertation's main goals.

1.2. Background and justification

The manufacturing sector must play a major role in developing a sustainable future where people may live with a respectable standard of living. This involves developing sustainable production methods and providing goods that satisfy sustainability standards (Siemieniuch et al., 2015). Economic, social, and environmental factors should all be considered when evaluating sustainability (Calker et al., 2005; Hermundsdottir & Aspelund, 2022). Organisations that just prioritise economic sustainability may find it difficult to meet long-term sustainability goals (Gladwin et al., 1995). For overall organisational growth, the two pillars of environmental and social sustainability are equally important. According to the International Labour Organisation (ILO, 2010), upholding workers' rights is crucial for promoting organisational sustainability. Therefore, creating competitive manufacturing firms requires addressing human resource needs throughout the production process.

Recent trends that emphasise resilience, sustainability, and well-being call for manufacturing companies to adopt an ergonomic workplace design approach that puts employees' well-being and capacity for innovation first, through social sustainability, rather than just efficiency and cost reduction (Yuqian et al., 2022). Zink (2008) asserts that social sustainability includes ideas like work-life balance, empowerment, employee learning, human-centred workplace design, preventive occupational health and safety, and employee participation. When a manufacturing company fosters a positive work atmosphere and raises everyone's standard of living at work, it is considered socially sustainable (de Fine Licht & Folland, 2025). These elements aim to preserve or enhance human capital, representing a conscious human resources management approach. However, the global implementation of sustainability principles across various organizations has been inconsistent, hindering the achievement of sustainability goals.

Although technical innovation is a top priority for many organisations globally, there is often an imbalance that favours economic sustainability above social sustainability (UNIDO, 2020). To address issues including falling labour productivity, developed nations like the U.S. and Germany have encouraged manufacturing innovation through Industry 4.0 (Sungbum, 2016). But according to Xu et al. (2021), Industry 4.0 frequently places a greater emphasis on technology than on social sustainability. On the other hand, Industry 5.0 highlights resilience, sustainability, and employee-centricity as interrelated key characteristics (Lihui, 2022). Thus, in addition to technical elements, a constant evaluation of technological innovation should take into account the social concerns of employees (well-being and innovative capability) (Manas, 1990; Tamene et al., 2022). Additionally, the results of the study by Kouskoura et al. (2024) emphasise that environmental factors, knowledge, and creativity are the main ways to become competitive rather than depending only on accumulated wealth.

Manufacturing industries in developing countries often remain reliant on outdated technologies and practices from developed nations, frequently functioning at the levels of the 2nd or even the 1st Industrial Revolution (UNIDO, 2020). These industries frequently find it difficult to take advantage of the potential provided by the fourth industrial revolution and to use new production methods. This problem is made worse by a lack of expertise in third-industrial-revolution technologies, such as ICTs and basic automation. In order to create their own systems, infrastructures, and products that suit the demands and preferences of their workforce, these industries have not yet looked inward to harness the creativity and well-being of their resources, including their employees.

Research indicates that organisations can develop innovations that give them long-term competitive advantages (Johannessen & Olsen, 2009). Since both ergonomics and sustainable practices are human-centred and essential for enhancing organisational competitiveness, ergonomics is essential to the shift towards sustainable development (Larisa et al., 2021). By optimising interactions with machinery and work equipment, ergonomics provides solutions to workplace issues brought on by mismatches between employee needs and systemic aspects (Budnick, 2012). Managers and employees in metal production companies generally lack awareness of the critical role ergonomic office design plays. Research indicates that the potential of ergonomics is often underutilized, with a focus on safety issues rather than broader employee needs like health, self-actualization, esteem, and belonging (Esabel, 2015). Integrating employees' needs into the manufacturing process is highlighted as a strategy to enhance competitiveness in the manufacturing firms (Lu et al., 2022). As a result, there is a clear need to treat the underlying causes of work-related illnesses in manufacturing companies by moving away from a reactive to a proactive strategy. The understudied field of cognitive ergonomics and its use in workplace design can improve employee well-being and creativity in addition to physical well-being (Koirala &

Maharjan, 2022). Utilising this technology allows metal production companies to make the most of their human resources.

It is impossible to overestimate the importance of human resources as a key factor in manufacturing companies' performance. However, the state of the workforce has a significant impact on how well production systems perform (Berlin & Adams, 2017). According to Boatca et al. (2018), workplace safety and employee well-being are crucial components of human resource efficiency. Achieving targeted results without wasting inputs or endangering the workforce is crucial to ensuring competitive product output. Inadequate ergonomic solutions put businesses at risk of developing work-related musculoskeletal disorders (WMSDs), even though human resources can increase a company's flexibility, creativity, and problem-solving abilities. Research indicates that it is neither feasible nor practical to eliminate human involvement in processes, even with a high degree of automation in the manufacturing industry (Article et al., 2018). Consequently, manufacturing industries in developing countries must steer the current industrial evolution towards sustainable competitive advantages. These intricate, high-tech systems necessitate continuous ergonomic input throughout the production process, from design to failure assessment (De Looze et al., 2010).

Worker performance and overall productivity in manufacturing industries can be greatly impacted by the development of various work-related disorders, injuries, and accidents that can result from inadequate ergonomic principles implemented in the workplace across industries (Bridger, 2009; Inyang et al., 2012). According to estimates from the International Labour Organisation (ILO), occupational accidents and work-related disorders cost the world's economy about $2.8 trillion a year, or about 4% of GDP (ILO, 2013). According to the organization's assessment, systematic inconsistencies between the needs of employees and the features of non-employees' workplaces were responsible for 2.34 million deaths in 2013 alone and 2.79 million deaths in 2019.

Significant issues with occupational health and safety procedures and management have been brought to light by studies carried out in Ethiopia, Africa, and India. According to Muthukumar et al. (2019), there is a greater chance of injury in metal production companies in India than in other contemporary work settings; 47.3% of occurrences include heavy machinery and restricted areas. The ILO reports that in 2010, there were 63,900 work-related deaths and 1.54 million debilitating injuries in 54 African nations as a result of the continent's disregard for occupational health and safety regulations. For example, Akter et al.(2015) emphasised the risk factors that are linked to the incidence of musculoskeletal problems among metal workers in Bangladesh. Govaerts et al. (2021) conducted a systematic review that provided insights into work-related musculoskeletal disorders across various secondary industries in Europe. Similarly, Altundaş Hatman et al. (2024)

examined risk factors for work-related musculoskeletal disorders among unionized metal industry workers.

Due to insufficient safety management systems, research conducted specifically in Ethiopia has highlighted the high frequency of occupational injuries in the metal manufacturing industry. For example, Kifle et al. (2014) found that the steel and iron manufacturing sector had an annual injury prevalence rate of 33.3%, which was mostly caused by a lack of workplace safety and health management systems. According to research done in Addis Ababa by Berhan (2020), workers in medium- and large-sized metal manufacturing companies are more likely to be involved in accidents because of things like a high workload, a lack of personal protective equipment (PPE), and a weak safety culture. Similar studies conducted across various regions of Ethiopia confirm that the manufacturing industry faces a high rate of workplace accidents (Yessuf et al., 2014; Alamneh et al., 2020; Gebremichael, 2015; Tadesse & Kumie, 2016).

The transition to a proactive model, integrating ergonomic principles into the planning stages by designers, decision-makers, and production engineers, is essential to eliminate the root causes of work-related disorders and develop safer, more efficient workspaces. International standards such as ISO 45001 emphasise a proactive approach to occupational health and safety management, focusing on reducing injuries and promoting both physical and mental health. This standard replaced the previous BS OHSAS 18001:2007, which primarily managed OH&S hazards and internal issues. Adopting ISO 45001 encourages organisations to implement comprehensive safety and health management systems.

The study conducted by Shiferaw & Söderbom (2019) explores aspects such as competitiveness, export capability, and productivity, providing important information about how Ethiopian manufacturing companies perform in the international market. Although manufacturing companies are important to the economy, they only make up 5% of the GDP and employment sector, according to a 2019 report by Shiferaw & Söderbom, titled "The Ethiopian Manufacturing Sector Productivity, Export, and Competitiveness." Furthermore, according to the UNDP study from 2023, manufacturing businesses' share of GDP decreased from 5.9% in 2019 to 4.4% in 2022 *(UNDP, 2023)*. This study's focus on metal manufacturing companies has several justifications. Metal manufacturing firms play a crucial role in economic growth and are also known as one of the most challenging work environments, and it is highly risky (Umugwaneza et al., 2019). In Ethiopia, the metal and engineering industries are pivotal for industrial development and are expected to contribute significantly to GDP growth (14[1]). However, because ergonomic

[1] Federal Democratic Republic of Ethiopia. Growth

principles are not being properly implemented, workers in these environments are subject to a number of risks, including vibrations, loud noises, dangerous machinery, and poorly designed workstations. These risks can result in accidents, injuries, and a variety of disorders. Addressing these ergonomic concerns not only supports employees' health but also enhances their creativity and innovation capabilities (Frank et al., 2016).

Limited studies have focused on proactive approaches to preventing work-related disorders in metal manufacturing, often emphasizing personal protective equipment (PPE) or generic safety management models. Research indicates the urgent need for targeted ergonomic workplace design to address specific challenges faced by employees in the metal manufacturing firms. Transitioning to an employee-centric ergonomic workplace design offers transformative benefits, emphasizing social sustainability and human-centric principles. Integrating ergonomic principles in each stage of workplace design is essential for developing sustainable competitive advantages in metal manufacturing firms for evolving markets (Durugbo, 2020). Therefore, this study aims to highlight the importance of ergonomic workplace design in fostering a safer and more productive environment in the metal manufacturing sector.

1.3. Problem statement

The 2013 World Manufacturing Competitive Index report revealed country-level ratings on a 10-point scale for key drivers of manufacturing competitiveness, with Germany (9.47/10), the U.S. (8.94/10), Japan (8.14/10), China (5.89/10), and India (5.82/10) emphasizing talent-driven innovation. Notably, in China, the cost of labor and materials scored a perfect 10/10, the highest rating among Germany, the U.S., and Japan (Deloitte, 2013). The report only includes South Africa (4.92/10) and Egypt (3.42/10) from African countries, indicating that other countries, including Ethiopia, remain relatively uncompetitive and contribute minimally to the overall economy.

Access to talented workers serves as a crucial indicator of a country's competitiveness. Even though Ethiopia's economy is among the fastest-growing in Africa (Arkebe, 2018), its manufacturing sectors continue to lag behind in terms of promoting economic transformation and growth. While sustainability garners global attention, the role of ergonomics in designing ergonomic-centric manufacturing systems for sustainable competitiveness remains undervalued in the industry. The current system prioritizes efficiency, quality improvement, and cost reduction, neglecting the social dimensions crucial for sustainable operations (Yuqian et al., 2022; Meyer et

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and Transformation Plan II (GTP II) (2015/16-2019/20). Addis Ababa: National Planning Commission, 2016.

al., 2018). The existing manufacturing setup lacks a focus on employee well-being, with social sustainability being identified as the weakest sustainability pillar that demands immediate attention to safeguard the workforce (Meyer et al., 2018).

With over 395 million work-related injuries and 2.9 million deaths annually, of which 2.58 million are attributable to work-related diseases and 0.32 million to occupational injuries, the International Labour Organisation (ILO) reports that workplace safety and health remain a concern on a global scale (ILO, 2019; Takala et al., 2024). Additionally, according to HSE (2021) data, 43% of 88,000 British workers who experienced work-related ailments between 2018–19 and 2020–21 had work-related musculoskeletal disorders (WMSD), 41% stress and depression, and 16% other illnesses (HSE, 2021).

In that same year, employment was projected to have contributed 180 million disability-adjusted life years (DALYs), resulting in a loss of economic value equivalent to 5.8% of global gross domestic product. Additionally, according to the International Labour Organisation, the number of deaths from work-related illnesses and injuries has risen by 26% from 2.3 million in 2014 to 2.9 million in 2019 (ILO 2019). These figures highlight the pressing need for all-encompassing approaches to deal with the underlying causes of problems related to workplace safety and health.

Although workspaces are static and built at the time of plant installation, this issue is especially apparent in the manufacturing sectors of developing countries. Because human resources are given more importance in developing countries than technology, workplaces in these countries may put employee well-being ahead of other considerations. Employee turnover, increased costs, lost productivity, and a decline in profitability are all possible outcomes of this. Ergonomic environments and organisational support are crucial for employee performance and efficiency under these circumstances, which affect factory workers' physical and mental health and contribute to work-related illnesses.

Similar difficulties arise in Ethiopian industrial firms, where workplace safety concerns are not adequately considered (Kassaneh & Tadesse, 2019). Due to this neglect, ergonomic risk factors and occupational injuries are quite prevalent in Ethiopia; the estimated yearly pooled prevalence of occupational injuries is 44.66 % (Alamneh et al., 2020). Additionally, manufacturing was responsible for 56.05% of workplace accidents in 2016, according to data from Ethiopia's Ministry of Labour and Social Affairs (MOLSA, 2016; Alamneh et al., 2020). Ergonomic risk factors and occupational injuries are very common in Ethiopian metal production industries, according to studies referenced in Table 1.1. This information emphasises the necessity of preventative safety measures and treatments.

Table 1.1. Prevalence of WMSDs in the Ethiopian Metal Manufacturing Industry

Authors	Number of metal manufacturing industries included in the study	Sample number used	Number of employees affected by WMSDs (the magnitude of the prevalence of WMSDs)
Kifle et al., 2014	4	453	181
Habtu et al.2014	50% of large-scale metal manufacturing firms were selected by a random sampling method	829	489/1000 exposed workers/year.
MOLSA, 2016		25,812	14,468
	Small and medium-scale industry	962	(335/year and 120/two weeks)/1000 exposed employees (stated risk factors: sleep disorder, job dissatisfaction, workload, lack of workplace supervision)
Benti et al., 2019		588	291
Berhan, 2020	89	446	331 (78.07%) sprain, 277 (64.57%) punctures, 269 (61.84%) cases of exhaustion, and 224 (51.97%) cuts in their workplaces.
Tamene et al., 2022	11	422	89 in the head and neck, 144 in the upper extremity, 64 in the lower extremity, and 125 in the spine

A study by Islam et al. (2022) found that 82.9% of work-related injuries occurred rapidly, resulting in a high absenteeism rate (81.1%) among the affected employees. These findings demonstrate how important it is to keep a safe workplace in order to meet employees' needs regarding their health and safety. The importance of taking preventive action is highlighted by the numerous studies that have found that the direct causes of work-related musculoskeletal disorders (WMSDs) include being struck by falling objects, accidents involving machinery, and issues with the use of personal protective equipment. Moreover, while previous studies highlighted ergonomic risk factors, less attention has been given to how these factors affect innovation capability within manufacturing firms.

The majority of businesses used a reactive strategy, mainly depending on administrative controls and personal protective equipment to address the immediate causes of WMSD, according to on-site observations conducted in a few chosen metal production industries. However, there remains a gap in understanding the systematic and immediate ergonomic factors contributing to work-related disorders (WDs), compounded by the lack of a root cause identification framework and proactive tools for ergonomic workplace design. These problems impact the development of proactive tools for designing employee-centric workplaces tailored to the physical and cognitive needs of workers based on their skills, experience, and knowledge.

Significant issues with occupational safety, health, and the frequency of work-related disorders were brought to light during interviews with managers and factory workers at metal manufacturing firms. Concerns were raised by workers regarding the absence of an employee-centric workplace that puts their mental and physical health first. Although safety departments have put safety policies and training into place, there hasn't been much progress in lowering safety concerns in these firms. The lack of established tools and policies that incorporate workers' ergonomic requirements into the workplace is one of the issues about ergonomic workplace design that has been identified. Effective communication and problem-solving are hampered by current top-down management techniques and the absence of employee input in workplace design decisions. To enhance the social sustainability of manufacturing firms, it is imperative to integrate ergonomic workplace design principles into strategies aimed at designing employee-centric, sustainable, and competitive workplaces.

1.4. Research questions

This study is conducted to give an appropriate answer for the following Research Questions: -

1. What are the major ergonomic determinants contributing to work-related disorders in the manufacturing firms?
2. What are the impacts of ergonomic risk factors on the well-being and innovation capability of employees?
3. How does ergonomic workplace design contribute to the development of SCA in the manufacturing industry?
4. What proactive frameworks and design strategies are necessary for creating an ergonomic workplace that enhances employee productivity and well-being while ensuring sustainable competitive advantages in manufacturing firms?

1.5. Objectives of the research

1.5.1. General Objectives

To develop a holistic model for ergonomic workplace design that ensures the well-being and innovation capability of employees, thereby enhancing the development of sustainable competitive advantages in manufacturing firms.

1.5.2. Specific Objectives

- To identify the major ergonomic determinants contributing to work-related disorders in the manufacturing firms.

- To explore the impacts of ergonomic risk factors on the well-being and innovation capability of employees in the metal manufacturing firms.
- To investigate how ergonomic workplace design contributes to the development of sustainable competitive advantages (SCA) in the metal manufacturing firms.
- To develop proactive frameworks and strategies necessary for designing an ergonomic workplace that enhances employee innovation capability and well-being while ensuring the development of sustainable competitive advantages in the metal manufacturing firms.

1.6. Significance of the Study

The title of the dissertation is "Ergonomic Workplace Design for the Development of Sustainable Competitive Advantages in Manufacturing Firms: A Case Study of Selected Metal Manufacturing Firms in Ethiopia." The findings of the study may have significant implications for manufacturing firms. Identifying root causes and conducting proactive ergonomic risk assessments and design strategies will enable workplaces in these firms to be free from work-related disorders that hinder the enhancement of innovation capability and employee well-being.

This research has developed a proactive ergonomic function deployment tool for creating an employee-centric workplace, enhancing an environment of health, comfort, efficiency, effectiveness, and safety through proactive ergonomic workplace design tools. Additionally, when such tools and design strategies are utilized during the design stage, manufacturing firms can ensure their employees' innovation capability and well-being. This research underscores the importance of ergonomic workplace design, advocating for environments that prioritize both the physical and cognitive well-being of employees to sustain competitive advantages in manufacturing firms.

Another ergonomic workplace design strategy has been developed that can be implemented by manufacturing firms to create an employee-centric workplace that ensures health, safety, comfort, efficiency, and effectiveness. This approach promotes sustainable continuous improvement by considering employees as core resources and guiding organizations toward best practices in ergonomics and occupational health.

The findings of this study could also be valuable for other researchers, regulatory bodies, and organizations committed to improving workplace health and safety practices. By emphasizing the application of ergonomic design principles, this study urges manufacturing firms to strategize in ways that guarantee employee well-being, innovation capability, and organizational competitiveness.

Through additional references and insights into problem areas, the research contributes to expanding knowledge, raising awareness, and identifying gaps in the field. It provides a foundation for further research and will inform necessary improvements in workplace ergonomics and occupational health practices.

1.7. Scope and Limitation

Scope

This study deals with the ergonomic design of workplaces in relation to work-related disorders and their respective ergonomic risk factors in metal manufacturing firms. The objective of this study is to identify the impacts of ergonomic workplace design on the development of sustainable competitive advantages in manufacturing firms

In focusing on the metal manufacturing industry, it is readily acknowledged that this is an exceptionally challenging field with a number of hazards and risks, as each day workers are called on to undertake very physical and cognitively challenging tasks. Such a study intends to point out how an employee-centred workplace design forms a proactive strategy toward the prevention of work-related disorders. A necessary reason is that such an environment would ensure working conditions healthier for every employee, which would enhance employee satisfaction, well-being, and overall productivity.

The specific focus of this dissertation is on those aspects of employee-centred workplace design that help to improve the well-being and innovation capability of workers. In such a context, it also intends to illustrate how these changes can be useful in building sustainable competitive advantages in manufacturing firms. It will not only include immediate ergonomic issues but also long-term organisational benefits, which include reduced absenteeism, reduced health care expenses, and better morale among employees.

This study, therefore, hopes to make critical observations and provides useful recommendations on the application of ergonomic principles in the design of workplaces in manufacturing firms. The findings shall emphasize that the design process must consider the participation of employees with respect to their feedback and needs in developing a healthy and productive work environment that will further assist the overall sustainability and competitiveness of the firms concerned.

Limitation of the Dissertation: While the study provides valuable insights into the importance of ergonomic workplace design in the development of sustainable competitive advantages in selected metal manufacturing firms, it is not without limitations. The key limitations of the dissertation are that it requires some hard work in the retrieval of specific data at the workplace, and it also requires appropriate personnel to be present and share information. Moreover, there is a strong dependence on the cooperation of line employees and the clarity of explanation and reassurance provided during the process. In this regard, the research takes various approaches that are aimed at improving data and response quality from the participants. First, there is contact with workers and team members through site visits and face-to-face interviews. This ensured data reliability through direct interaction with workers in their work environment for in-depth insight into better awareness of the ergonomic challenges they experience or are expected to be experiencing in the given context.

The face-to-face discussions were conducted to fill the gaps in data; as such, this approach facilitates open discussions with employees and offers us an opportunity to share various opinions. In this regard, the discussions would allow the research to collect a wide range of information with respect to ergonomic issues and workplace dynamics.

The study also employs the services of personnel with experience and subject matter experts as an alternative mechanism to help in developing the data collection process. These were instrumental in helping contextualize some of these findings and offering further validation for the data collected through the activities of the frontline workers. This way, the research aims at curbing limitations relating to the accuracy of the data in respect of active participation by respondents so as to improve the reliability and validity of the research findings.

It is important to note that the study primarily focuses on evaluating ergonomic needs related to physical and cognitive dimensions, with limited exploration of psychosocial and broader organizational dimensions. Moreover, the study's scope is restricted to data collected from selected manufacturing firms, potentially impacting the generalizability of the findings to other industries such as services, logistics and construction industries.

Organisation of the Thesis

The overall research study consists of eight chapters. The second chapter delves into the related literature reviews. It begins with an introduction and provides a conceptual understanding of the subject matter. It discusses the ergonomic risk factors influencing the prevalence of work-related disorders, the impact of the prevalence of work-related disorders on employees' well-being and innovation capability and development of sustainable competitive advantages. The proactive ergonomic workplace design approaches and gaps identified from the literature review are discussed.

The third chapter addresses the research methodology. It incorporates: the research design, sources of primary and secondary data, sample size determination, research ethical considerations, and data analysis methods and tools.

The fourth chapter focus on data presentation and analysis: It incorporates quantitative data analysis; qualitative data analysis, validity and reliability tests of the data and the practice ergonomic principles in the existing directives, rules and regulation in Ethiopia.

The fifth and six chapters focus on model developments for determining the impacts of ergonomic risk factors on the well-being and innovation capability of employees and the impacts of ergonomic workplace design on the development of sustainable competitive advantages.

Chapters seven and eight focus on proactive frameworks and design strategy for ergonomic workplace design, and conclusions and recommendations, respectively. At the end, the study's reference sources and materials are included.

Chapter Two

Literature Review

2.1. Introduction

This chapter presents a comprehensive review of literature relevant to ergonomic workplace design and its role in achieving sustainable competitive advantages in metal manufacturing firms. It encompasses definitions of key terms, various models, constructs, and formulations, with a critical focus on the current prevalence of work-related disorders and their associated ergonomic risk factors. Furthermore, this chapter explores ergonomic workplace design approaches and methods aimed at proactively preventing work-related disorders. The insights provided herein establish the rationale behind the study and validate the problem statement presented in the previous chapter. This chapter is structured to include theoretical and empirical reviews and a synthesis of key information, identification of literature gaps, and concluding findings.

Moreover, this chapter addresses the following fundamental hypotheses: (1) The innovation capability of employees impacts the development paths of sustainable competitive advantages, (2) The well-being of employees, encompassing both cognitive and physical well-being, influences the innovation capability of employees, and (3) Ergonomic workplace design determines the well-being, innovation capability, and the pathways to sustainable competitive advantages in manufacturing firms.

Definitions of Terms and Concepts

Stress

Transactional models view stress as the interaction between the environment and the individual, emphasizing how an individual's appraisal of situations shapes their responses. According to this approach, stress is defined as "the result of a mismatch between individuals' perceptions of the demands of the task or situation and their perceptions of the resources for coping with them" (Stokes & Kite, 2001). Conversely, the traditional model simplifies stress as a perception that leads employees to feel incapable of coping with work demands, ultimately resulting in fatigue (Harshana, 2018). Based on this, for this study, stress is defined as a reaction to a threat in the workplace (Moussa et al., 2017).

Ergonomics

Ergonomics is defined as the design or modification of the workplace to match human characteristics and capabilities. Its goal is to match the demands and requirements of the job to the abilities and capabilities of the worker (Sluchak, 1992)

Sustainable Competitive Advantages: Competitive advantages (CA) refer to implementing a unique strategy that other organizations do not already utilize (Shebeshe and Sharma, 2024). Sustainable competitive advantages in metal manufacturing firms stem from various factors such as technological expertise, specialized knowledge and skills, quality and reliability, efficient operations, cost control, and intellectual property. These attributes allow firms to consistently outperform their competitors and maintain a superior position in the metal manufacturing industry over the long term (Barney, 1991).

Musculoskeletal Disorders (Physical Strain): Musculoskeletal disorders denote health problems of the locomotors apparatus, i.e. of muscles, tendons, the skeleton, cartilages, ligaments and nerves. This study focuses on musculoskeletal disorders that are induced or aggravated by work and the work environment.

Cognitive disorders (Cognitive Strain): Cognitive strain refers to the subjective experience of mental effort, which can vary significantly among individuals. It is considered a risk factor for work performance, negatively impacting the ability to engage in cognitively demanding tasks. Research identifies three primary categories of cognitive strain: disruptions, interruptions, and information overload, all influenced by the working environment and organizational culture (Veteläinen, 2023).

Occupational Health: Occupational Health is a specialized field within public health that specifically addresses the recognition and mitigation of workplace hazards that have the potential to result in injuries, illnesses, or diseases. It is dedicated to safeguarding and enhancing the physical, mental, and social well-being of workers across various occupations.

Work: It is defined as an activity involving **mental or physical effort done** to achieve a purpose or result (Gallup, 2024).

Workplace: The term "workplace" encompasses any physical setting where work is conducted, including both indoor and outdoor environments, whether temporary or permanent. The concept of a workplace in this study encompasses a working site in the production lines of manufacturing firms.

Exhaustion: Exhaustion, defined as prolonged stress or fatigue lasting over six months, is characterized as an exhaustion disorder (Beser et al., 2014). Therefore, in this study, cognitive disorders affecting employees who have been exposed to prolonged periods of stress and fatigue are classified as exhaustion disorders.

Fatigue: Fatigue is defined as extreme tiredness resulting from mental or physical effort (Phillips, 2015).

2.2. Analysis and Synthesis

To acquire and advance new insights regarding the significance of ergonomic workplace design in shaping sustainable competitive advantages, a systematic literature review was conducted. Analyzing 150 articles through content analysis. This theoretical and empirical review aimed to identify gaps in the existing literature, thereby proposing a conceptual framework for undertaking this research work

2.2.1. Theoretical Review

A theoretical framework seeks to explain a phenomenon through several interrelated concepts, establishing a foundation for understanding the relationships between variables. This framework is crucial for guiding research design and methodology. The following theories are relevant to this study.

Two Factor Theory: Proposed by Herzberg et al. (1959), this theory distinguishes between hygiene factors and motivators in the workplace. Hygiene factors, such as salary and working conditions, can lead to job dissatisfaction if inadequate; however, they do not necessarily motivate employees. In contrast, motivators, such as recognition, achievement, and growth opportunities, are essential for enhancing job satisfaction. This theory is instrumental to the current study as it emphasizes the importance of addressing both intrinsic (motivational) and extrinsic (hygiene) factors, particularly in the context of employee-centric workplace design and its impact on productivity.

Maslow's Hierarchy of Needs: Maslow's (1943) theory provides a framework for understanding human motivation through a five-tier model of human needs, ranging from physiological needs to self-actualization (Maslow, 1943). Ergonomic workplace design aligns with this theory by addressing fundamental needs such as safety and comfort, thereby enhancing employee motivation and productivity.

Sociotechnical Systems Theory: This theory posits that organizations consist of both social and technical components. Effective ergonomic design considers the interaction between employees and their work environment, which is crucial for enhancing productivity and employee satisfaction (Trist, 1981). By optimizing this interaction, firms can achieve improved outcomes in terms of productivity and overall performance. This theory underscores the importance of creating work environments that enhance productivity while promoting employee well-being. This approach highlights the critical relationship between thoughtful workspace design and overall organizational performance, emphasizing the necessity of aligning physical environments with employees' needs to drive long-term success (Sluchak, 1992)

Resource-Based View: Developed by Edith Penrose in her book, *The Theory of the Growth of the Firm* (1959), this perspective emphasizes that an organization's resources, including human capital, are critical for achieving sustainable competitive advantages. Investing in ergonomic workplace design fosters employee well-being and engagement, ultimately enhancing productivity (Penrose, 1959)**.** In summary, the theoretical review gives a broad framework for contextualizing the relationship between ergonomic workplace design and sustainable competitive advantages in metal manufacturing firms.

Competitive Theory: As articulated by Porter (1980), this theory highlights the importance of competitive advantage in business success. It posits that organizations must understand their competitive environment, including industry structure and market dynamics, to create and sustain an edge over their rivals. This theory also suggests that factors such as employee motivation and workplace design significantly influence organizational competitiveness. Hence, ergonomic workplace design can serve as a key differentiator, enabling firms to optimize performance and maintain a competitive edge by enhancing employee productivity and well-being, thereby contributing to organizational competitiveness.

Several theories have been used to inform this study. However, theories have not been perceived as isolated explanations but as an integrated, coherent theoretical framework. Two-Factor theory and Maslow's Hierarchy of needs are two theories that depict how the provision of ergonomic workplace conditions leads to employee well-being. Using these two theories, both hygiene factors and basic physiological and safety needs are fulfilled.

Sociotechnical Systems theory offers another layer of understanding by focusing on the human and technical systems working together and placing the ergonomic aspect as the major point of employee interaction with non-human elements in production companies.

Strategically, the resource-based view and competitive strategy theory show the design of an ergonomic workplace as a company resource that is valuable, rare, and hard to imitate, thus enabling employees' performance, supporting innovation, and leading to sustainable competitive advantage. All four theories, along with the proposed conceptual model, were established. The model shows the linkage between the ergonomic design of the workplace and the three elements: employee well-being, innovation capability, and firm-level competitive outcomes. Hypotheses were formulated from the theoretical base, which integrates different theories and focuses on both employees' innovation capability and the development of sustainable competitive advantages.

2.2.2. Empirical Review

Overview of Sustainable Competitive Advantages (SCA): Among the four perspectives on sustainable competitive advantages—structural approaches, resource-based views, dynamic capability views, and blue ocean strategy(Gowrie et al., 2012)—this study adopts the resource-based view. This perspective emphasizes developing future competitiveness by leveraging existing opportunities and competitive advantages. According to Barney (1991), "a firm is said to have a competitive advantage when it is implementing a value-creating strategy not simultaneously being implemented by any current or potential competitors."

To maintain sustainability, an organization's resources must be valuable, rare, imperfectly imitable, and without substitutes (Barney, 1991). One of the key resources within an organization is its employees. In today's globalized and digitalized business environment, metal manufacturing firms must focus on competition intensity and changing customer expectations to achieve SCA (Wadud et al., 2019). By aligning their resources with industry gaps and opportunities, these firms can anticipate competitors' actions, leading to SCA(Morem da Costa & Horn, 2021).

Strategies such as technological innovation, process optimization, and the integrating of continuous improvement tools such as total quality management (TQM), just-in-time (JIT), and supply chain management (SCM) can be employed by metal manufacturing firms to achieve SCA, resulting in improved product quality, cost reduction, and increased efficiency (Muisyo et al., 2022;(Jiang, et al., 2020). However, organizations must recognize that product innovation and technology alone are insufficient for future success. They must also integrate creativity and the passion of their employees. By addressing organizational and societal challenges, these organizations create significant opportunities for growth, sustained bottom-line results, and motivated individuals eager to contribute to the success of their teams and companies (Oeij et al., 2017).

The next section of this study will reveal the impacts of the well-being of employees on the innovation capability and development paths of sustainable competitive advantages in metal manufacturing firms.

Impacts of Work-related Disorder (WDs): Work-related musculoskeletal disorders (WMSDs) are among the most frequently occurring health problems and occupational disabilities in the manufacturing sector (Rahul et al., 2017; Kee, 2022). These disorders can lead to lost productivity, increased absenteeism, and decreased job satisfaction. WMSDs refer to damage to the musculoskeletal system, including muscles, tendons, ligaments, joints, nerves, and blood vessels (*Ekpenyong and Inyang 2014*). Employees suffering from WMSDs often experience pain, discomfort, and reduced mobility, impairing their ability to perform job duties and leading to decreased job satisfaction and increased costs due to low productivity (Baeka et al., 2017; Buckle & Devereux, 2002).

The impact of WMSDs is significant in the manufacturing industry, affecting productivity and profitability due to increased absenteeism, decreased productivity, and substantial costs associated with medical treatment, rehabilitation, and disability payments(Shahnavaz & Hjelm,2005; Bevan, 2015). In the Ethiopian manufacturing firms, low attention to safety issues and minimal practices for preventing workplace safety problems have resulted in high prevalence rates of WMSDs, with reported figures of 495 (Berhan, 2020) and 333(Kifle et al., 2014) per 1000 exposed employees.

These work-related disorders, often referred to as "silent killers" of productivity and competitiveness in the manufacturing industry, represent critical wastes that negatively impact both the physical and cognitive well-being of employees. They arise from mismatches among the demands of workplace tasks, which can be psychological, physical, or emotional demands (Jan de Jonge et al., 1999). The consequences of WDs include loss of working time, treatment costs, and even fatalities, contributing to reduced productivity and innovation capability and ultimately affecting the sustainable competitive advantages of the metal manufacturing industry.

The literature indicates a strong relationship between musculoskeletal disorders (MSDs), physical well-being, and the innovation capability of employees in metal manufacturing firms. Various studies consistently show that WMSDs are a leading cause of work disability, physical pain, absenteeism, and presenteeism in the workplace, as supported by Melhorn and Gardner (2004), Ansari et al. (2018), Madan and Grime (2015), Erdem and Savas (2023), Wodajeneh et al, (2022), Meyer et al. (2018), Weyh et al.(2020), Elvis et al.(2022); Onawumi et al. (2016) and Bevan (2015). These findings illustrate how WMSDs can negatively affect work-related outcomes, including productivity and performance, for both individual employees and the overall organization (Shreyas & Vinay 2023; Elif et al.,2023, Bevan 2015, Hambali et al. (2019), and Usama & Robert, 2020; Tamene et al., 2022; Karimikia & Singh 2020; Bodin et al., 2012; Duffield et al., 2017).

Moreover, the literature explores the relationship between work-related cognitive disorders (WCDs), cognitive well-being, and the innovation capability of employees in metal manufacturing firms. The reviewed articles consistently indicate that immediate causes of WCDs—such as stress, anxiety, dissatisfaction, suffocation, and fatigue—significantly impact employees' cognitive well-being (well-being of cognitive abilities including learning, memory, perception, concentration, and problem-solving ability) in metal manufacturing firms. This is supported by studies conducted by Vischer (2008), Sohail and Kashif (2016), and Reinhold et al. (2008). WCDs can result in memory loss, difficulties with concentration, and impairments in problem-solving and decision-making abilities, as indicated by research from Andersen and Westgaard (2014) and Taskasaplidis et al. (2024). The review also suggests that cognitive disorders can negatively affect work-related outcomes, including productivity, performance, and job satisfaction, as shown in studies by Medalia & Erlich (2017), Torre et al. (2021) and Qqisar et al. (2018).

Ergonomic Workplace Design and Well-Being of Employees: The literature on ergonomic workplace design explores various studies to understand how prioritizing ergonomics in workplace design can enhance employee well-being. Key themes identified in the review include:

Ergonomics and Well-Being: Ergonomics focuses on designing workspaces, tools, and equipment to fit the capabilities and needs of employees. This approach plays a crucial role in promoting employee well-being by optimising physical comfort, reducing physical strain, and minimizing the risk of musculoskeletal disorders (Realyvásquez-Vargas et al., 2020). An ergonomically designed workplace can lead to improved physical health, reduced discomfort, and enhanced overall well-being.

Physical Well-Being and Ergonomic Design: The literature indicates that ergonomic workplace design positively impacts the physical well-being of employees. Ergonomic interventions, such as workstation set-ups and training, have been shown to reduce physical strain, decrease injury rates, and improve physical health among employees(Ibrahim, 2020; Susuhono & Adiatmika, 2021)

Psychological Well-Being and Ergonomic Design: The relationship between ergonomic workplace design and psychological well-being is also significant. Workspaces that provide privacy, minimise distractions and offer opportunities for personalisation and control have been found to enhance employee satisfaction, engagement, and overall psychological well-being(Kelly & Moen, 2020; Osterman, 2018). One area that remains unexplored is cognitive ergonomics, which focuses on optimising employee interactions with their work environment, considering cognitive processes, mental workload, and human capabilities (Koirala & Maharjan, 2022). Implementing cognitive ergonomics principles can lead to increased job performance, productivity, and the establishment of safer, healthier work environments.

Productivity and Performance Outcomes: The impact of ergonomic workplace design on productivity and performance outcomes is examined in the literature. Studies suggest that ergonomically designed workspaces and tools can lead to increased productivity, efficiency, and accuracy in task performance. By reducing physical and cognitive discomfort and fatigue, ergonomic design helps employees to sustain their effort and perform at their best(Shabani et al., 2021). For instance, De Looze et al. (2010) estimated that 25% of improvements in quality were related to ergonomic changes.

Organisational Benefits: Investing in ergonomics design yields significant organisational benefits, including reduced absenteeism, decreased healthcare costs related to musculoskeletal disorders, and improved employee retention(Sailer et al., 2021; Weng et al., 2021; Bodin et al., 2012; Duffield et al., 2017). A workplace that prioritises employee well-being through ergonomic design fosters a positive organizational culture, enhances employee satisfaction, and improves competitiveness.

Elements Influencing Workplace Design: The review identifies various factors that contribute to workplace design and the prevalence of work-related disorders. Key elements include human and non-human factors, as well as the influence of technology, the environment, and organisational management on workplace outcomes (Papetti et al., 2020; Robertson 2000; Chevez et al., 2014).

Non-Human Elements**:** Non-human elements encompass the physical and cognitive structures of the workplace, including technology (tools, equipment, machinery, and ICT infrastructure), the indoor working environment, organizational management, policies and standards**.** Evidence suggests that technology is critical in creating an employee-centric workplace that enhances well-being and innovation capability (Sorensen et al., 2021). However, poor utilization of technology can negatively impact employee well-being (Wodajeneh et al., 2022). Outdated technology can also pose problems related to occupational safety and health (OSH) (Sileyew, 2020).

Similarly, environmental factors- such as heat, noise, dust, humidity, and chemical exposure - significantly influence employee well-being, productivity, and innovation capability in metal manufacturing firms. Research highlights the need to consider these environmental factors when designing workplaces to foster employee health and innovation (Sorensen et al., 2021; Girma & Kebede, 2019; Wodajeneh et al., 2022).

Human Elements in the Workplace Design**:** The human elements of the workplace, particularly within metal manufacturing firms, are crucial for effective workplace design. Several studies underscore the importance of creating environments that foster employee engagement and productivity (Bridger, 2003; Karhu et al., 1977; Rieker et al., 2023; Jacobo-Galicia et al., 2021). This is also supported by other research findings, which stated that that automation and digitalization cannot be successful without human involvement (Papetti et al., 2020). This review explores the physical and cognitive dimensions of human elements, their impacts on employee well-being and productivity, and the role of ergonomic principles in optimizing interactions between humans and non-human elements.

*Physical Dimensions of Employees***:** The physical dimensions of employees- including body size, shape, skeletal structure, and muscle capabilities – significantly influence workplace ergonomics. Proper consideration of these dimensions is crucial for ensuring employee comfort, safety, and productivity. (Bridger, 2003; Meyer et al., 2018; Kebede & Jema, 2022) highlight the critical role of ergonomic design in creating workspaces that accommodate employees' physical characteristics. These dimensions impact various aspects of workplace ergonomics, including workstation design, equipment placement, and the physical movements required for tasks. Designing the physical structure of the workplace to align with the physical dimensions of employees is vital for maximizing their comfort and productivity.

*Cognitive Dimensions of Employees***:** The cognitive dimensions of human elements encompass employees' cognitive abilities like perceptions, decision-making skills, reasoning capabilities, knowledge, attitudes, and behaviours (Koirala & Maharjan, 2022). It is crucial to understand and consider these cognitive dimensions when designing effective workplace processes. (Koirala & Maharjan, 2022; Dittmar et al., 2021) emphasize the significance of aligning the cognitive aspects of the workplace with employees' cognitive capabilities. The next sub-topics will cover the ergonomic risk factors which are due to the impacts of the mismatches between the dimensions of employees and non-employee elements in the workplace.

Ergonomic Risk Factors due to the mismatches among workplace elements: Ergonomic risk factors are crucial in the onset of work-related disorders. Van Eerd et al. (2003) stress the importance of precise classifications to improve communication and provide a comprehensive review of classification systems for work-related disorders. These disorders stem from the mismatch between employees' needs and the demands imposed by non-human elements in the workplace, a phenomenon particularly prevalent in the manufacturing sector.

Despite the similarity in symptoms, discrepancies exist in the nomenclature of ergonomic factors contributing to work-related disorders. Sandell and Kleiner (2001) acknowledge that work-related disorders are multifactorial, which complicates the establishment of definitive cause-and-effect relationships. The challenges in classifying and identifying ergonomic risk factors stem from the complexities observed in existing literature, underscoring the need for further research to develop a standardised classification system and identify root causes.

Current literature primarily focuses on high-level immediate causes and risk factors associated with the prevalence of work-related disorders. The difficulty in distinguishing broad categories, such as psychosocial and stress factors, often leads to their amalgamation in research (Devereux, 2005).

In this chapter, the categorisation of risk factors influencing work-related disorders among employees in metal manufacturing firms is established based on the reviewed literature. These classifications are discussed as follows:

Physical Ergonomic Risk Factors: Work-related disorders are significantly influenced by physical work factors. The discrepancy between employees' physical capabilities and the physical demands imposed by non-employee elements in the workplace can lead to pain, physical injuries, or accidents, either sudden or chronic (Berlin & Adams, 2017). Evidence that indicates the types of physical factors is further stated in Table 2.1.

Table 2.1: Physical ergonomics risk factors for Work-related Disorders in the metal manufacturing industry

Immediate factors	Intermediate ergonomic risk factors	Evidence	Study suggested
Poor Postures	Prolonged standing or sitting, repetitive motions; ergonomically unsound jobs	*Greggi* et al., (2024); Hanvold et al. (2019); EASHW (2019); Madan and Grime (2015); Gallagher & Schall, (2016); Heiden et al. (2020), Tamene et al. (2022); Berlin & Adams, (2017); Elvis et al.,(2022	Job rotation; Implementing sit-stand workstations and offering stretching exercises can also help.
Frequently exerting high Force	Heavy-lifting or pushing of different materials in the workplace	Brusnahan et al, (2020); Greggi et al. (2024); HSE, (2021)	Providing lifting aids and implementing job rotation
Repetitive task	• Repetitive motion, • performing repetitive tasks,	(Hoe et al., 2018, He, et al., 2021	Job rotation
Vibration	• Using vibrating tools • Exposure to high levels of vibration. • Sitting or standing on vibrating surfaces • Contact with moving machinery	Jaffar et al., (2011) Afata et al. (2024)	Providing anti-vibration gloves and implementing job rotation
Utilisation of ICT facilities	• Repeated exposure to poorly utilised ICT facilities	(Karimikia et al., 2020; Spiezia, 2011; Caputo et al., 2019;(Berlin & Adams, 2017; Yazdani. & Wells, 2018)	

Based on the data presented in Table 2.1, the literature addressed the immediate and intermediate factors for the prevalence of work-related musculoskeletal disorders in metal manufacturing firms.

Intermediate Cognitive Ergonomic Risk Factors: An investigation into workspace design and musculoskeletal pain that solely considers physical ergonomic risk factors and overlooks cognitive ergonomic risk factors would be incomplete (Bridger, 2003). Recent research indicates that different cognitive ergonomic risk factors contribute to the development of work-related disorders in the metal manufacturing industry. The high pace of work, mental load, and pressure to perform can cause stress, leading to increased muscular tension and chronic discomfort (Berlin & Adams, 2017). Additionally, studies conducted by (Taskasaplidis et al., 2024; Kahya et al., 2018; Sherratt, 2018) stated that excessive workload, social interactions, economic factors and environmental factors are triggering factors for work-related stress. Besides these literature reviews, the researcher reviewed additional literature as summarised and shown in Table 2.2.

Table 2.2: Intermediate Cognitive Ergonomic Risk Factors

Authors	Factors for Immediate Cognitive ergonomic risk factors (Stress, fatigue, exhaustion, dissatisfaction and suffocation)						
	Work-Load	Noise	Indoor-environmental condition	Social Factor	Communication among employees	Poor OSH knowledge	ICT utilisation (Techno-stress)
Liu et al., (2021)	*						
Sohail &Kashif, (2016)	*				*		
Choobineh et al, (2021)	*			*			
Makhbul et.al(2013)	*		*				
Benti et al., (2019)	*				*		
Gao et al. (2021)			*	*			
Alavi et al. (2021)				*			
Choobineh,et al(2021)				*	*		
Sailer et al., (2021)		*					
Cantley et al., (2019)		*					
Mithanga et al., 2013		*					
(Nazari & Nodoushan, 2021)		*					
Kahya et al., 2018			*				
Berlin & Adams, (2017)	*						
Taskasaplidis et al., (2024)	*	*	*	*			
Birhan (2020)			*			*	
Alemneh et al., (2020)						*	
Rajak et al., (2021)	*		*			*	
(Borhany et al., 2018).							*

Based on the evidence presented in Table 2.2, excessive workloads and noise in the metal manufacturing firms are the most commonly recorded intermediate causes for the prevalence of immediate causes of cognitive disorders like stress, fatigue, dissatisfaction, exhaustion and suffocation. These factors affect the memory, decision-making abilities, problem-solving abilities, concentration and perceptions of employees working in the metal manufacturing firms.

However, a significant proportion of the studies focused a predominantly proximal, risk-factor-oriented perspective. They solely focused on the immediate and intermediate causes of cognitive disorders without addressing the root causes or emphasizing the significance of cognitive ergonomics in alleviating issues within metal manufacturing firms.

Individual Factors: Individual factors such as age, gender, and educational qualifications significantly contribute to the development of work-related disorders in the metal manufacturing industry. Workplace designers should consider these individual factors when addressing cognitive and physical aspects to reduce the prevalence of such disorders.

Table2.3: Individual factors for Work-related disorders in the metal manufacturing industry

Factor	Evidence	The study suggested
Age	Yang et al. (2023) found that older workers are at a higher risk of developing musculoskeletal disorders. Similarly, Deros et al. (2015), Meyer et al. (2018), and Alemneh et al. (2020) also recognized age as a significant contributing factor. However, Birhan (2020) reported that the majority of work accidents occurred among younger workers, specifically those aged 19-24 (21.29%), 25-29 (18.04%), and 40-44 (15.09%).	Age-specific ergonomic interventions, such as targeted training and job modifications, could help reduce risks for older workers.
Gender	(Kao et al, 2020) found that female metal manufacturing workers faced a higher risk of musculoskeletal disorders compared to males. Studies by Deros et al. (2015), Meyer et al., 2018), and Habtu et al. (2014) also confirmed this. (Berhan, 2020) noted that females were 2.73 times more likely to experience cut injuries.	Gender-specific ergonomic interventions, such as providing ergonomic equipment and modifying tasks, could help reduce risks for female workers.

The information stated in Table 2.3 indicated that all the research findings focused on the reactive approaches for preventing the ergonomic risk factors. None of them stated the proactive approaches for preventing the root causes of the risk factors.

Root Causes of Work-Related Disorders: Much research focuses primarily on identifying the immediate causes of work-related disorders in different organizations, often neglecting the underlying reasons for these causes. Melhorn and Gardner (2004) and(Meyer, et al., 2018) suggest that root causes include a lack of integration of individual ergonomic risk factors and workplace risk factors, as well as systemic design issues that fail to integrate health concerns with business strategy, however, integrating of individual ergonomic risk factors and workplace risk factors did not clearly articulated and addressed very well just to get the root causes of the disorders. Even if the study conducted by Hambali et al.(2019) pointed out that workstation design contributes to awkward postures that adversely affect employee performance, the study focused only on the awkward postures; it did not touch on the cognitive dimensions and other important elements of the workplace.

Furthermore, models have been developed to elucidate the causation of work-related musculoskeletal disorders, such as the conceptual framework, Figure 2.1, introduced by Estill et al. (2002), which emphasizes the impact of arrangement of work procedures, organizational factor, individual factors, temporarily exposure factors, work environments and social contexts on musculoskeletal load and subsequent tissue responses, gaps remain on identifying the root causes for these immediate ergonomic risk factors.

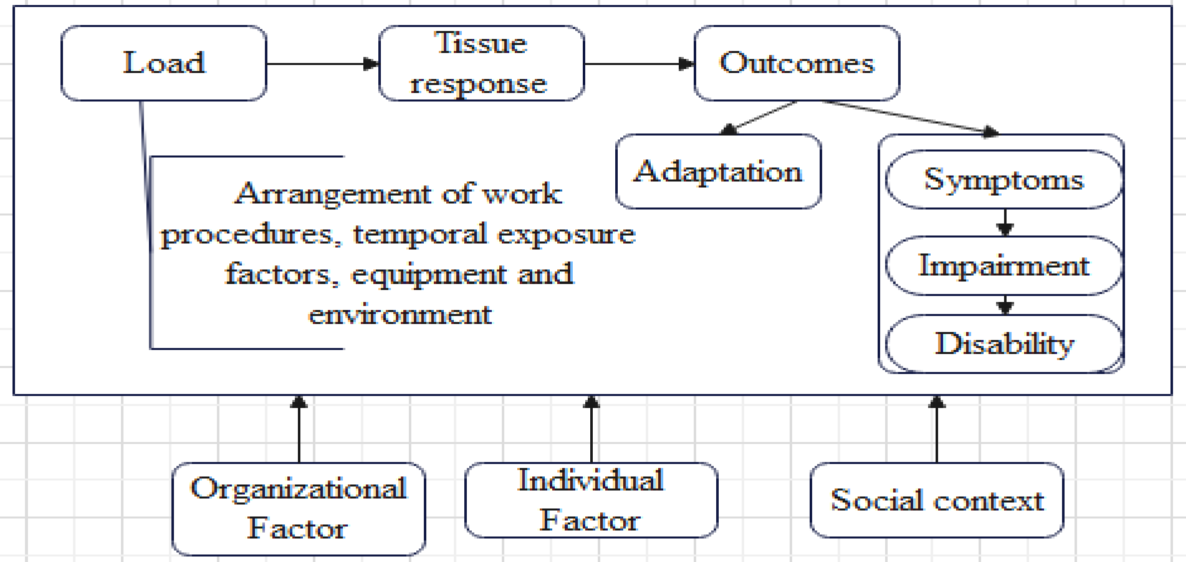


Figure 2.1: Conceptual Model of Factors that may contribute to MSDs (*Adapted from Estill et al., 2002).*

However, these models are also generic and have not adequately addressed the root causes of work-related disorders, which will be synthesised in the next sub-sections of this chapter.

Subsequently, the following sections of this study explore workplace design approaches and tools employed to create an ergonomic and employee-centric workplace.

Proactive Approaches for Designing the Workplace: The literature highlights the importance of integrating human factors and ergonomic principles in workplace design to prevent work-related disorders (WDs) and foster sustainable competitive advantages in the metal manufacturing firms. Previous studies indicate that technological and organizational changes, when implemented without consideration of employee factors and ergonomic criteria, can lead to WDs and significant losses within the production systems (Tytyk and Mrugalska, 2018). These findings support the need for employee-centric approaches and ergonomic principles at every stage of workplace design to mitigate the prevalence of work-related disorders in the metal manufacturing sector.

*Employee-Centric Approaches for Workplace Design***:** The literature underscores the necessity of adopting employee-centric approaches in workplace design. Traditionally, manufacturing industries focused on task-oriented production systems that relegated workers to passive roles (May et al., 2015). However, the advent of Industry 4.0 has introduced technology-centred smart factories, emphasizing efficiency and flexibility through digitalization and technological advancements (Pinzone et al.,2018; Huang,2022). Despite the advantages, Industry 4.0 presents challenges or limitations related to sustainability and workers' well-being(Xu et al., 2021). Therefore, an employee-centred approach is crucial for promoting well-being and innovation while ensuring efficiency. Employees play a significant role in industry development as creators and modifiers of workplace elements, as Knowledge, the foundation of industrial revolutions, originates from humans (Mensch, 1982). Technological innovation relies on knowledge advancements, which are essential for technological change and industrial evolution (Lundgren, 1991).

Emerging as a response to these challenges, Industry 5.0 prioritizes workers' well-being in the production process(Alves et al., 2023), highlighting the importance of employee involvement in designing employee-centric workplaces in metal manufacturing firms (Hoe et al., 2018). Numerous studies advocate for considering human factors in workplace design, identifying challenges related to human well-being and system performance since the industrialisation era (Kadir&Broberg, 2020). A human-centred generative design framework that incorporates human factors in the early design phase is critical (Onan Demirel et al., 2023). Efforts to improve the human factor have led to quality improvements of up to 86% in manufacturing operations (Kolus et al., 2018). The human factor remains a vital contributor to industry development (Wilson, 2000). Studies highlight the need to enhance employees' roles through physical and cognitive support, including managerial and decision-making responsibilities (Romero et al.,2016; Lindqvist, 2024; May et al., 2015).

Ergonomic Assessment Methods: To effectively implement an ergonomic-driven, employee-centric workplace design strategy, a literature survey was conducted to identify appropriate ergonomic assessment and workplace design tools and methods. Identifying the root causes of problems within an organization is the first step in designing effective solutions. For proactive ergonomic workplace design aimed at preventing work-related disorders in metal manufacturing firms, it is crucial to identify both the root causes and immediate factors.

Previous studies have proposed various assessment methods, including RULA, REBA, and the Ovaco Working Posture Analysis System (OWAS), to identify and evaluate unsuitable posture (Karhu et al., 1977; McAtamney & Corlett, 1993; Hignett & McAtamney, 2000). The OWAS method evaluates working posture by coding and recording the percentage of time spent in a specific posture (Karhu et al., 1977). This method can yield reliable and valid results when the assessor is adequately trained. RULA, which is similar to OWAS, offers a more detailed and rapid assessment of upper limb disorders (McAtamney & Corlett, 1993). Validation studies comparing RULA scores with subjective ratings and laboratory tests involving computer data entry operators have demonstrated higher validity for neck and lower arm assessments

Rapid Entire Body Assessment (REBA) builds on RULA and assesses postures, forces coupling, and repetition using diagrams and hypothetical numbers. It considers static, dynamic, or tasks with unpredictable working postures while evaluating overall risk levels, including gravity-assisted upper limb postures (Hignett and McAtamney, 2000). The validity and reliability of REBA results can be confirmed by practitioners; a study involving 14 practitioners assessing 600 tasks indicated an inter-observer agreement of 62-85% (excluding the upper arm). However, this tool was also focused only on assessing the posture analysis; it did not cover the cognitive factors of employees.

Moreover, the Posture Targeting method involves random observations of workers throughout the day, noting job postures, angles, and activities (e.g., holding, pulling, and pushing) related to specific body parts (Corlett et al., 1979). This method allows workplace analysts to identify frequent and potentially stressful job postures for more detailed biomechanical analysis (Chaffin et al., 2006).

According to the results of previous studies, OWAS primarily assesses posture but neglects force considerations, while RULA focuses on upper limb posture during static tasks. The Posture Targeting method is similarly limited to static task assessments. As a result, these techniques cannot be universally applied across various workstation layouts and task types in metal manufacturing firms. In contrast, REBA effectively assesses both static and dynamic task situations and evaluates risk levels for the entire body without requiring input from the workers. Thus, even if it has a limitation in considering the assessment of cognitive factors of employees, the Rapid Entire Body Assessment (REBA) is selected as a suitable method for comprehensive physical ergonomic assessments for this study.

Proactive Ergonomic Workplace Design Methods or Tools**:** Design methods in ergonomic workplace design encompass a range of tools, techniques, and procedures aimed at facilitating effective workplace design. Recently, there has been an increased emphasis on ergonomic workplace design in the metal manufacturing firms to improve worker health, safety, and productivity. Scholars have published various tools and techniques to assess work-related ill-health and accidents, as well as to implement ergonomic interventions for creating a healthy working environment.

Traditionally, work systems in manufacturing were designed using **Industrial Engineering concepts s**uch as work-study, method-study, motion study, and work measurement. However, these approaches primarily focused on productivity while often neglecting the human element within the work system (Rajesh and Srinath, 2016). This oversight has resulted in a disconnect between employee needs and other workplace elements, leading to a higher prevalence of work-related musculoskeletal disorders (WMSDs). To address this issue and reduce the occurrence of WMSDs and work-related cognitive disorders, various participative models and tools have been developed.

Participatory design involves engaging employees in the design process, allowing them to provide feedback and suggestions, and empowering them to take ownership of their workplace environment. This methodology has been shown to enhance employee satisfaction, engagement, job performance, and reduce turnover rates (Wood et al., 2012; Imada, 1988). Literature indicates that metal manufacturing industries have adopted various participatory approaches for assessing ergonomics and understanding the interactions between workplace elements.

The Cube Model, developed by Kadefors in 1993, is an ergonomic assessment model that determines the integrated impacts of force, posture, and time on employee well-being. However, this model only considers three factors related to MSDs and does not take into account other factors such as psychological, social, and cognitive ergonomic risk factors. To address this limitation, *Raghunathan* et al. (2014) proposed a **revised Cube Model** that assesses biomechanical exposure and its impacts on the prevalence of WMSDs. While the revised model integrates biomechanical exposure with force, posture, and time, it still overlooks psychological, social, and cognitive ergonomic risk factors and does not facilitate sufficient worker participation in controlling risks.

The concept of participatory ergonomics has been defined in various ways. Wilson and Haines (2001) describe it as a philosophy, approach, strategy, program, or set of techniques and tools that involve people in analysing, developing, and implementing changes. This approach fosters feelings of ownership and commitment to the changes being made and often involves forming an ergonomics team composed of employees, managers, ergonomists, health and safety personnel, and research experts. Participatory ergonomics can be instrumental in preventing WMSDs by involving employees in planning and controlling their work activities through user-oriented methods.

2.3. Literature Gaps

Building Sustainable Competitive Advantages through worker well-being and innovation capability: The literature consistently argues that SCA in the manufacturing firms depends on translating internal resources - especially workers' well-being and innovation capability - into sustained performance and adaptability (advantages) (Berlin & Adams, 2017; Koirala & Maharjan, 2022; Morem da Costa & Horn, 2021; Zhu et al., 2021; Rajapathirana & Hui,2018). However, these research findings often treat employees' well-being, innovation capability, and organizational productivity as separate inputs rather than as an integrated system that collectively shapes the development of sustainable competitive advantages in metal manufacturing firms. Work-related disorders and ergonomic risk factors have been shown to affect both cognitive and physical health, which can either limit or encourage both incremental and breakthrough innovations. Thus, daily preparedness for innovation practice and employee well-being in the workplace has great potential for organizational responsiveness and sustainable performance (Berlin & Adams, 2017; Generosi et al., 2022; Lawson & Samson,2001; Rajapathirana & Hui, 2018). However, there is limited guidance on how to prioritize and balance these intra-firm contributions to build SCA beyond appeals to 'investing in employees' and adopting new technologies and cost-cutting measures (Rajesh and Srinath, 2016; Barney and Hesterley,2015; Chen et al., 2020).

Boundary conditions and competing explanations: From a technology-centric perspective, sustainable competitive advantage (SCA) primarily originates from the adoption of new technologies and process automation. In this view, human factors are viewed as mediators or moderators, rather than key drivers (Pot and Vaas, 2008; Vinayan et al., 2012). However, in the human-centric view, SCA arises from leveraging employees' innovation capability and well-being to enable flexible, resilient production and continuous improvement (Saunila & Rantanen, 2014; Berlin & Adams, 2017; Borjesson & Elmquist, 2011). The boundary conditions in this study encompass the degree of alignment among ergonomic workplace design, work processes, and management practices. Additionally, they consider the industry context, including the prevalence of ergonomic risks, safety regulations, and workplace cultures within metal manufacturing firms (Koirala & Maharjan, 2022; Zhu et al., 2021).

Therefore, this dissertation aimed to investigate the impacts of ergonomic workplace design on the development of sustainable competitive advantages via the well-being and innovation capability of employees. The core constructs addressed in the study are ergonomic workplace design, ergonomic risk factors, work-related disorders, employee well-being (physical and cognitive), innovation capability, and sustainable competitive advantages (SCA), whose philosophical relationships will be, addressed in chapters 5 and 6 and the conceptual model is presented in Figure 2.7

So, this clear summary indicates that for metal manufacturing companies, having a sustainable competitive advantage isn't just about using new technology; it's also about effectively combining ergonomic workplace design, employee well-being, and their ability to innovate every day within specific organizational and industry limits. Firms should focus on interventions that enhance both physical and cognitive well-being while fostering a daily readiness for innovation. These aspects should be regarded as strategic elements for achieving sustainable competitive advantage.

***Gaps of workplace design elements*:** **Ergonomic workplace design**.

A holistic approach to non-human elements is warranted since cognitive ergonomics are recognized, but there is little systematic implementation in metal manufacturing, while the interplay between the physical and cognitive dimensions remains underexplored, as most studies establish their distinction and study the dimensions separately (Koirala & Maharjan, 2022).

The Integration of Legal and Organizational Policies into ergonomic workplace design is similarly underemphasized, even though evidence indicates the absence of health and safety regulations can lead to increased workplace injuries and calls for embedding governmental and industry policy requirements into design(Benti et al., 2019; Jilcha, 2020; Kelly& Moen, 2020; Osterman, 2018). A holistic approach to human elements is also needed; while (ISO 45001:2018, Article 5.4) highlights employee participation, empirical research work on effectively incorporating into workplace design processes is scarce but essential for an employee-centric environment that supports both physical and cognitive well-being.

Furthermore, despite research showing beneficial effects on conditions and well-being, organizational management practices in terms of commitment and participation are areas in ergonomic design that have not been sufficiently explored (Sorensen et al., 2018; Girma and Kebede, (2019), Jilcha,(2020), Alamneh, et al., (2020); Benti et al., (2019)

In addition, there is a need to provide more details regarding the use of technology in terms of why it is not utilized and how it should be utilized in accordance with the needs and capabilities of the employees to have a positive impact on well-being. All the aforementioned areas provide a basis for a conceptual model (see Figure 2.2) in which there is a link between ergonomic principles, time dynamics, and employee well-being; innovation, and sustainable competitive advantage through the integration of physical and cognitive non-human elements with employees factors through workplace design (Rostami et al., 2022; Caputo et al., 2019; Sluchak, 1992; Berry & Loeb, 2021;Dittmar et al., 2021), considering time dynamics as discussed in Chevez et al. (2014) and Boden et al. (2016) to reflect rapid demand changes and global competition.

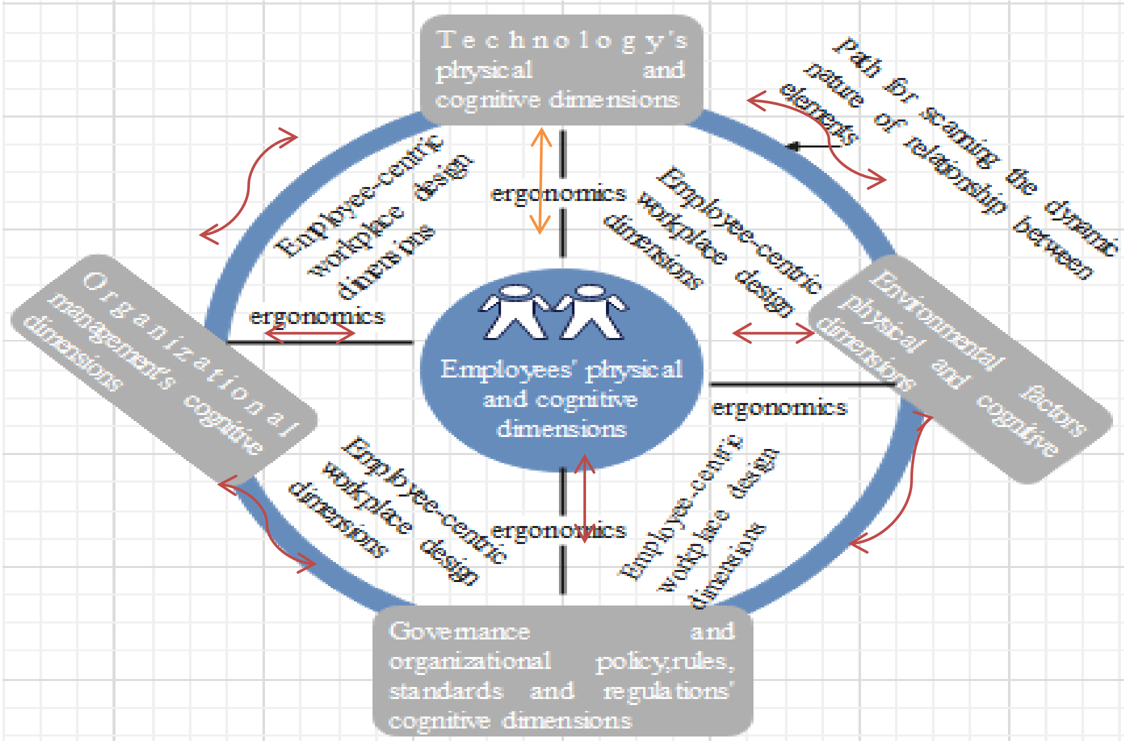


Figure 2.2: Interaction between Elements of the Workplace (Author)

Thus, the framework in Figure 2.2. proposed an ergonomic workplace that maximizes the interaction of technology, environmental factors, governance, organizational policies, rules, standards, and management practices. This framework utilizes employees—one of the key resources of these firms—to build sustainable competitive advantages. Therefore, employees must be regarded as vital assets, and their well-being and innovation capabilities must be prioritised to foster a sustainable development path. This aligns with findings from Ramchandani and Singh (2020), who emphasised that an employee-centric model reinforces the idea that "our people are our best assets," positioning employees as the primary source of competitive advantage for a company. Boosting productivity, creativity, and well-being of employees will be helpful in gaining sustainable competitive advantages in the manufacturing firms.

This supports the assertions made by Rieker et al. (2023) that incompatibility at work may result in unemployment, disorders, and Ramchandani & Singh, (2020) regarding employees as assets in the business. To design an employee-centric workplace with time dynamics to guide proactive decisions in the face of changing demands, the model must be further developed to reveal the underlying causes of work-related disorders and precisely describe the crucial physical and cognitive factors of human elements with those of non-human elements, as depicted in Figure 2.2. In summary, workplace design should focus on ergonomic principles that address employees' cognitive and physical needs. This helps eliminate wasteful practices that lead to work-related disorders and jeopardize sustainable competitive advantages in metal manufacturing. This approach matches the push for employee-focused design (Onan Demirel et al., 2023; Ramchandani & Singh, 2020). It emphasizes putting employees at the center of design by addressing their expectations and needs. The next step is to create a model that identifies the root causes of disorders, determines the key workplace elements for an employee-focused design, and turns those insights into proactive steps that improve well-being, encourage innovation, and enhance productivity.

Gaps related to Ergonomic Risk Factors Analysis: Despite the insights provided by existing research, significant gaps persist regarding the identification of key areas—particularly the stages of workplace design—where engineering interventions could be effectively applied. For example, the study by Hambali et al. (2019) indicated that workstation design contributes to issues with awkward postures, which, in turn, affect employee and organization performance. However, it focused solely on awkward postures without addressing cognitive requirements, organizational needs and management demands of the workplace. Additionally, previous studies have largely overlooked the importance of integrating employee requirements into workplace design, which is crucial for generating employee-centred opportunities, fostering a workplace environment conducive to positive user experiences (Stellwagen & Babul, 1975; Benmoussa et al., 2019).

While previous studies have primarily focused on investigating the immediate and intermediate causes of work-related disorders, there is a notable lack of research aimed at identifying the root causes (the major ergonomic determinants), particularly within the metal manufacturing firms. This gap underscores the necessity for more comprehensive investigations that delve into the foundational issues contributing to these disorders. Understanding the root causes is crucial for developing effective interventions that can mitigate the prevalence of work-related disorders in various settings.

Based on the data sourced from the literature reviews on both the cognitive and physical ergonomic risk factors (as shown in Table 2.1 and Table 2.2) and the prevalence of work-related disorders, the researcher synthesised the root causes (the major ergonomic determinants) for the prevalence of cognitive disorders, as depicted in Figure 2.3. The information revealed in Figure

2.3 highlights that the root causes for the prevalence of cognitive disorders in metal manufacturing firms stem from the mismatches between the cognitive characteristics of employees and the cognitive characteristics (software) of non-employee elements.

Similarly, the intermediate and immediate physical ergonomic risk factors for work-related musculoskeletal disorders are synthesised and presented in Table 2.1. Based on this data, the root causes (the major ergonomic determinants) for these risk factors lie in the mismatches between the physical factors of employees and the physical factors of non-employee elements, such as machinery factors, machinery noise, room temperature, humidity, and others.

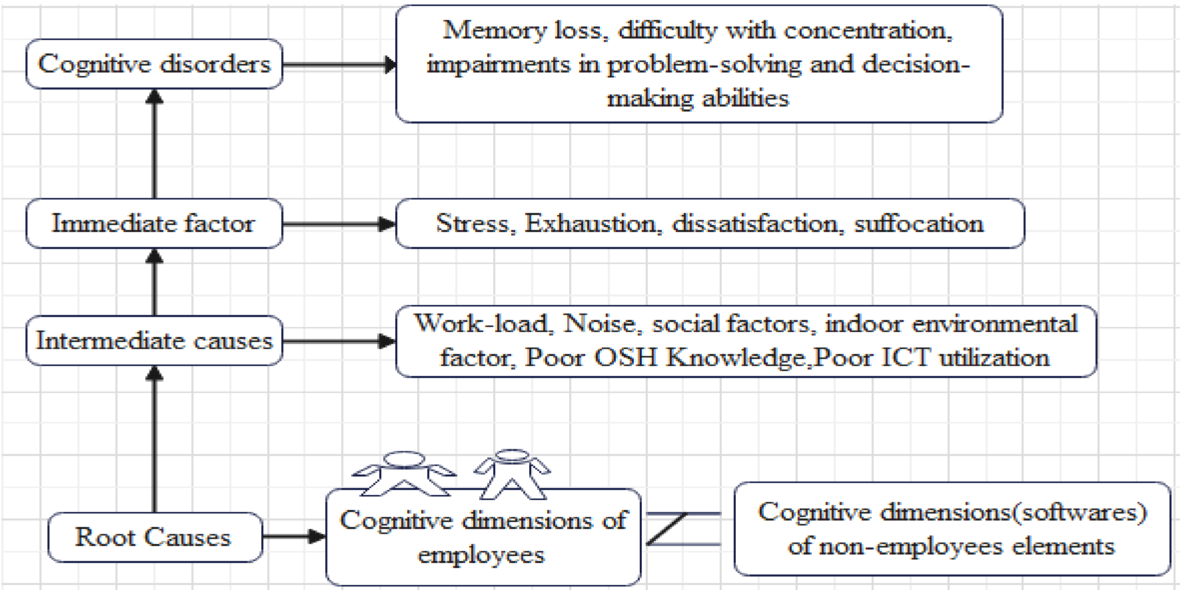


Figure 2.3. Root causes (major ergonomic determinants) for the prevalence of Cognitive disorders (Author)

Building on the synthesized evidence (See Figure 2.3), this gap analysis articulates a coherent conceptual model in which major ergonomic determinants—namely the mismatches between employees' physical and cognitive characteristics and the corresponding non-employee elements (machinery, environment, governance)—drive work-related disorders and, through their effects on well-being and performance, influence innovation capability and competitive advantage. This synthesis lays a concrete, evidence-based foundation for the subsequent development of ergonomic interventions within metal manufacturing contexts.

Subsequently, after identifying the major determinants to work-related disorders, the next crucial step involves conceptualising how these factors of employee and non-employee elements of the workplace (including machinery dimensions encompassing both hardware and software factors) should interact to eliminate the root causes. Although current research findings may not adequately emphasize the importance of incorporating ergonomic principles as a fundamental element of workplace design, this study argues that ergonomic principles should be considered fundamental in the workplace design process, especially within metal manufacturing firms, to facilitate optimal interaction between the two factors. This finding is further supported by various theories, such as the foundation principles of ergonomics established by Wojciech Jastrzebowski (1799-1882), which examine the relationship between humans and work in alignment with the natural law of work (Sluchak, 1992). Additionally, the International Ergonomics Association (IEA, 2000) defines ergonomics as the optimisation of human well-being and overall system performance through a better understanding of interactions between humans and other system elements.

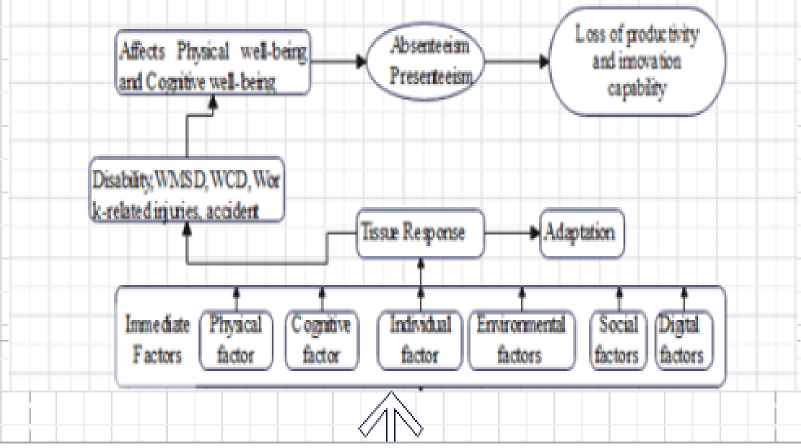
Neglecting the natural law of work in workplace design exposes employees to both physical and cognitive strains. Cognitive strain arises when employees' cognitive capabilities are insufficient to manage work-related stress, potentially leading to strain, workplace accidents, injuries, decreased productivity, and reduced innovation capability of employees. Conversely, if employees' cognitive capabilities surpass the demands of work-related stress and they are not engaged in creative and innovative activities, they may experience dissatisfaction and underutilise their knowledge.

Both physical strain (WMSDs) and cognitive strain, along with knowledge underutilization and dissatisfaction, have detrimental effects on the productivity and innovation capabilities of employees in metal manufacturing industries. To effectively mitigate the risks associated with work-related disorders, it is crucial to have an optimal interaction between the physical and cognitive factors of employees and the corresponding factors of non-human elements when designing workplaces, In light of these identified gaps, this study proposes a conceptual model aimed at showing the possible interaction between the two elements of the workplace and other critical elements of the workplace. The model highlights eight key types of interactions that can lead to these disorders and their consequences, as illustrated in Figure 2.4.

1. Interaction between the physical factors of non-human elements and the physical characteristics of human elements (*PdNHE~PchHE*)
2. Interaction between the physical factors of non-human elements and the cognitive characteristics of human elements (*PdNHE~CochHE*)
3. Interaction between the cognitive factors of non-human elements and the physical characteristics of human elements (*CodNHE~PchHE*)
4. Interaction between the cognitive factors of non-human elements and the cognitive characteristics of human elements (*CdNHE~CchHE*)
5. Interaction of the results of the interaction between cognitive factors of non-human elements and physical characteristics of human elements (*CodIBNHEs~PchHE*)

6. Interaction of the results of the interaction between cognitive factors of non-human elements and cognitive characteristics of human elements (*CodIBNHEs~CochHE*)
7. Interaction of the results of the interaction between physical factors of non-human elements and physical characteristics of non-human elements (*PdIBNHEs~PchHE*)
8. Interaction of the results of the interaction between physical factors of non-human elements and cognitive characteristics of non-human elements (*PdIBNHEs~CchHE)*

The model emphasises that the prevalence of work-related disorders is often linked to mismatches in interactions between employees' factors and non-employee factors, resulting in negative outcomes. Establishing an ergonomic workplace requires ensuring that all interactions yield positive results.



		Dimensions of Non-Human Elements in the Workplace																	
	Elements	Tech(T)		Envt(E)		Orga Ma.(O)		Legal Req(L)		T-E		T-O		E-O		E-L		O-L	
	Dimension	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog
Characteristics of Human-elements	Physical	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
	Cognitive	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
	Behavior	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Figure 2.4: Conceptual Model of Work-related Disorder Analysis MAP (Author)

The proposed model (See Figure 2.4) links the alignment of physical and cognitive factors of employees with the corresponding factors of non-employee elements (machinery hardware/software, environment, governance) through ergonomic principles, and posits that positive interactions reduce cognitive and physical disorders, enhancing well-being, productivity, and innovation, which in turn support sustainable competitive advantage. Hypotheses derived from this model include: holistic ergonomic workplace design improves employees' well-being;

Improve employees' well-being enhance innovation capability of employees, and improvements in well-being and innovation capability mediate gains in development of sustainable competitive advantages.

For this analysis, the study suggests supportive evidence of a "workplace wellness wheel" (see Figure 2.5) where the focus is placed on workplace wellness to examine the impact of each ergonomic risk factor on wellness. Figure 2.5 demonstrates the importance of maintaining a safe and healthy workplace for improving the well-being of employees in metal manufacturing firms. As workplace wellness improves, the prevalence of ergonomic risk factors decreases, and the unhealthy workplace that exposes workers to various work-related disorders is reduced.

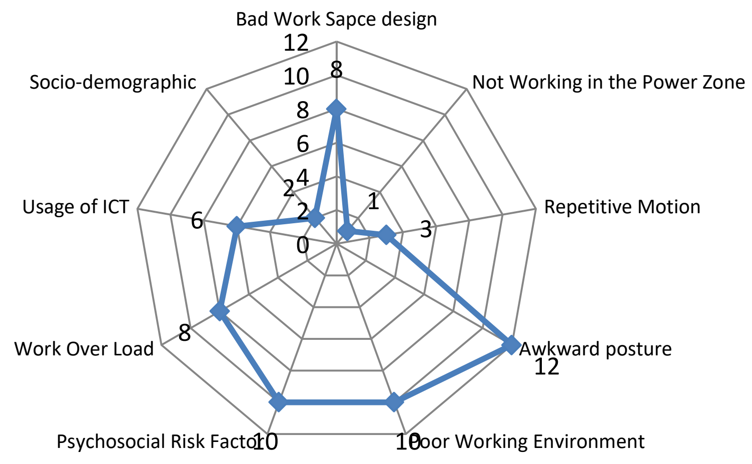


Figure 2.5. The relationship between ergonomic risk factors and workplace wellness (Wodajeneh et al.2022)

Moreover, this workplace wellness wheel (see Figure 2.5) enables tracing work-related disorders—such as WMSDs, depression, stress, anxiety, dissatisfaction, and occupational accidents—back to violations of the natural law of work. These violations occur when there is a mismatch between employees' physical and cognitive requirements and the demands of non-employee elements during workplace design (Wodajeneh et al. 2022).

To address these mismatches, previous research has mainly focused on reactive assessment methods that highlight physical ergonomics. However, there are a few techniques for designing workplaces based on employee preferences. Building on this foundation, researchers have created various participative models, which include tools and techniques, to link employees' characteristics with non-human elements. This study introduces a proactive, multidimensional ergonomic workplace design tool called Ergonomic Function Deployment framework (EFD). EFD framework integrates the physical and cognitive factors of employees with the hardware and software aspects of non-human elements (machinery, the environmental context, and governance structures). It is also flexible enough to adapt to both internal and external changes. The goal of this tool is to guide design thinking in choosing workplace elements that enhance health, safety, comfort, efficiency, and effectiveness. This method is consistent with Tendai and Jerie in (2017), who emphasize the importance of employee-centered interventions in daily operations to tackle the root causes (the major ergonomic determinants) of work-related disorders. By incorporating EFD framework into the workplace design process, the literature suggests that proactive, employee-centered design can create ergonomic workplaces that support well-being and lead to a sustainable competitive advantage in metal manufacturing. Therefore, the workplace design should accommodate both the cognitive and physical needs of employees to adapt to changes from both internal and external forces.

Gaps related to Workplace Design Strategy and Tools: While previous studies have proposed employee-centric workplace design approaches, they often lack a comprehensive classification of employee characteristics and the various elements of the workplace, as well as an explanation of the linking mechanisms. To proactively prevent work-related disorders in the metal manufacturing industry, workplace design must be rooted in the needs and preferences of workers. Prioritising human factors in workplace design is vital for ensuring employees' well-being and enhancing their contribution to sustainable competitive advantages. The employee-centred workplace design process should involve a collaborative approach to designing both employee and non-employee elements of the workplace.

***Ergonomics Approaches for Workplace Design**:* Ergonomic principles play a crucial role in creating an employee-centric workplace, serving as the linking mechanism between employees and the non-employee elements of the workplace(Montoya-Reyes et al., 2020). Ergonomics considers both the physical and cognitive interactions in workplace design. Physical ergonomics focuses on the employee's characteristics and their impact on design, while cognitive ergonomics addresses mental workload and cognitive psychology (Berlin & Adams, 2017). Integrating ergonomic approaches in workplace design reduces the risk of work-related disorders (WDs) and improves employee comfort, job satisfaction, and productivity (Lucas et al., 2024)

There is substantial evidence supporting the importance of ergonomics in workplace design. Studies by Berry and Loeb (2021), Caputo et al. (2019), Hignett et al.,(2021); Kim et al,(2020), Day & Penney et al. (2017), Koirala & Nepal (2022), Heidarimoghadam et al. (2022), Lucas et al (2024), and Susihono & Adiatmika (2021) emphasise the value of investing in ergonomic principles to design employee-centric workplaces and achieve sustainable competitive advantages in the metal manufacturing firms.

Wojciech Jastrzebowski (1799-1882), the founder of ergonomic science, defined ergonomics as the natural law of work that governs the relationship between humans and work(Sluchak, 1992). The International Ergonomics Association (IEA, 2000) defines ergonomics as the scientific discipline focused on understanding interactions between humans and other elements of a system. These definitions highlight ergonomics as the link between employees and non-human workplace elements, encompassing physical and cognitive interactions.

Considering the aforementioned approaches, it is argued that placing employee factors at the core of the workplace and utilizing ergonomic principles as a connection to non-employee elements are vital for proactively preventing work-related disorders in metal manufacturing firms. This study proposes an ergonomic-driven employee-centric approach as a mechanism to prioritise employee well-being and improve innovation capability, leading to the development of sustainable competitive advantages. Additionally, the researcher will also examine the stages at which this **ergonomic-driven employee-centric approach** should be implemented to prevent work-related disorders.

Design Thinking Approach: Design thinking is a proactive methodology for creating an employee-centric workplace. It involves empathising with employees to understand their needs and challenges, defining the problems, generating potential solutions, and testing these solutions through prototyping (Dennerlein et al., 2020). Liedtka (2015) highlights design thinking as a problem-solving approach that prioritizes empathy, experimentation, and collaboration, aiming to address the mismatches between employees' cognitive characteristics and the cognitive factors of non-employee elements.

Considering these insights, the researcher argues that the design thinking approach is highly relevant for developing employee-centred workplaces in metal manufacturing firms. By applying design thinking principles, organisations can identify and eliminate the underlying causes of work-related disorders, thereby promoting employee health and productivity. This approach emphasises the importance of considering employees' needs, capabilities, and well-being when designing work processes and environments.

However, it is important to note that none of the existing studies specifically test the hypothesis that workplace design needs to accommodate ergonomic design thinking, which considers both the cognitive and physical demands of employees to achieve zero prevalence of work-related disorders. To address this complexity, the researcher proposes a proactive, multisided, generic approach customizable to employees' needs, organisational requirements, and technological advancements. Such an approach is essential for preventing work-related disorders, promoting employee well-being, and developing sustainable competitive advantages within the metal manufacturing industry. Effective interventions for reducing work-related disorders require systematic approaches and a combination of measures (Oakman et al., 2016). Consequently, the researcher advocates for an ergonomic-driven employee-centric workplace design approach for metal manufacturing firms.

Proactive, ergonomically driven employee-centric workplace design approach: To transition from a traditional task-centric and technology-centric workplace design approach to a more employee-centric workplace design approach, it is vital to propose a multi-perspective assessment and linkage of workplace elements through the lens of ergonomic science. This proactive ergonomic-driven approach aims to enhance the sustainable competitive advantages of metal manufacturing firms by prioritizing the needs and preferences of employees.

Key to this approach is the establishment of effective linking mechanisms and the implementation of targeted interventions at various design stages. By proactively addressing potential issues, such as work-related disorders, firms can create a healthier and more productive work environment. This is consistent with the findings of Onan Demirel et al.(2023) and Lindqvist, (2024), which emphasizes the development of an employee-centered generative design framework to support concept development and evaluation in the early design stages to have a user-centric system or products.

The proposed design methodology will work out all the physical and cognitive needs of employees, considering factors such as technology requirements, legal obligations at the national and organization levels, organization policies, social relationships among workers, and necessary working environment parameters. All these elements, as shown in Figure 2.6, contribute to an integrated workplace design that enhances employee well-being and effectiveness.

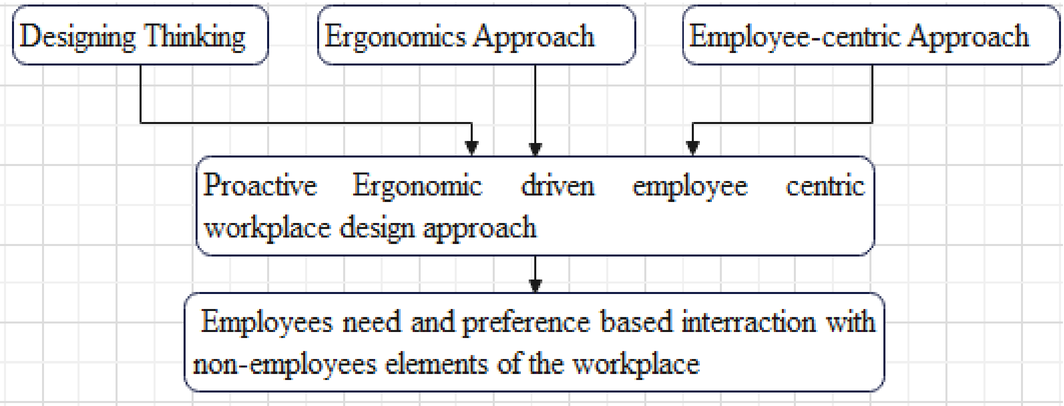


Figure 2.6: Approaches for ergonomic workplace design (Author)

One of the key challenges in this approach is the mismatch between employees' capabilities and non-employee elements, which has led to various work-related disorders among employees in metal manufacturing firms. Effectively managing these increasingly interacting elements within the workplace context is essential for creating an employee-centered environment that ensures competitiveness in the industry. To sustain productive manpower and secure the long-term success of manufacturing industries, it is imperative to address these issues during the design stages to safeguard sustainable competitive advantages. Simply suggesting workplace design strategies based on different ergonomic approaches is insufficient to eliminate work-related disorders. Instead, each stage of design principles must be enhanced with appropriate proactive workplace design tools and techniques that focus on employee-centric approaches. This comprehensive workplace design strategy will include initiatives for preventing musculoskeletal disorders, fostering innovative capabilities, and enhancing productivity for all employees.

Gaps related to Ergonomic Workplace Design Methods and Tools: While **participatory ergonomics programs** have shown promise in reducing the prevalence of work-related musculoskeletal disorders (WMSDs), several gaps need to be addressed to effectively eliminate these disorders:

Focus on Physical Factors: Many participatory ergonomics programs primarily concentrate on physical factors such as posture and force, neglecting psychosocial factors such as job demands, social support, and job control. A comprehensive approach should consider both physical and psychosocial factors.

*Stakeholder Involvement***:** Many programs fail to involve all relevant stakeholders, including workers, managers, and ergonomics experts, in the planning and implementation process. Involving all stakeholders ensures that the program is tailored to the specific needs of the workplace.

Organizational Factors: Existing programs often do not adequately address organizational factors that contribute to the prevalence of WMSDs, such as work organization, job design, and management practices. Addressing these factors is crucial for long-term program success.

Evaluation Plans: Many programs lack a comprehensive evaluation plan to assess effectiveness. Evaluation should be integral to the program to ensure that it meets its intended goals and identifies areas for improvement.

Awareness and Education: There is a need for greater awareness and education about the benefits of participatory ergonomics programs among employers, workers, and other stakeholders. Increased awareness can promote the adoption and implementation of these programs in more workplaces.

Studies by Hanvold et al. (2019) provide evidence on the effectiveness of **participatory ergonomics programs** in reducing ergonomic risk factors and improving musculoskeletal health among workers. However, these studies do not fully address the gaps identified in the design and implementation of these programs. For example, while they assess the effectiveness of the programs in reducing ergonomic risk factors, they ***do not comprehensively consider psychosocial factors or organizational dynamics impacting program success***. Additionally, while these studies involve workers in the planning process, they do not explicitly include other stakeholders such as managers and ergonomics experts.

To address these deficiencies, Oakman and Macdonald (2019) developed the Participative Hazard Identification and Risk Management (APHIRM) toolkit, which involves employees and other interested parties in assessing risk and identifying control actions. This approach helps ensure that the program is tailored to the specific needs of the workplace and increases worker participation and engagement, which are vital for success. However, the APHIRM toolkit does not fully address all gaps in participatory ergonomics programs, particularly concerning psychosocial factors and stakeholder involvement.

The physical demand analysis tools proposed by the Workplace Safety and Insurance Board (2018) and Li et al. (2019) have made significant contributions to participatory ergonomics. However, these tools primarily focus on physical demands without fully considering cognitive requirements and the specific needs of individual employees. Thus, there is a pressing need for more comprehensive and holistic approaches to participatory ergonomics that account for all aspects of the work environment and prioritize worker well-being. Expanding on insights from literature reviews, previous studies have employed various participatory workplace design models, such as the Cube Model and work-study techniques, to create workspaces in manufacturing firms. However, these methodologies have primarily focused on enhancing productivity without sufficiently addressing employee well-being. To rectify these deficiencies and establish an employee-centric workplace, this research proposes the introduction of employee-centric workplace design tools aimed at proactively mitigating the prevalence of work-related disorders.

To tackle the challenge of reducing WMSDs and work-related cognitive disorders, the development of proactive, multi-faceted ergonomic intensive workplace design tools—such as Ergonomic Function Deployment Techniques—is essential. These tools should consider both the physical and cognitive requirements of employees in metal manufacturing firms and adapt to changes from internal and external sources, ultimately enhancing employee health, safety, comfort, efficiency, and effectiveness. This proposition aligns with findings from various researchers, including Tendai and Jerie (2017), who emphasised the importance of employee requirements-based intervention mechanisms during workplace arrangements.

This research argues for the necessity of a proactive, multi-faceted ergonomic intensive workplace design tool to implement design thinking approaches that select the appropriate types and contents of workplace elements. This approach aims to create ergonomic workplaces that ensure employee well-being, ultimately resulting in sustainable competitive advantages for the manufacturing industry. As Bridger noted, considering ergonomic principles in the workplace is vital for ensuring employee safety, health, efficiency, and comfort (Bridger, 2009). Therefore, this research hypothesizes that the physical and cognitive requirements of employees must align with the physical and cognitive demands of non-human elements in the workplace.

The rationale behind this research is grounded in two fundamental philosophies. Firstly, the physical structure of human beings cannot be altered to fit the workplace; thus, workplace design must accommodate the physical needs of employees. Secondly, while cognitive needs can be adapted to fit the workplace, the design must also consider these needs. The workplace design should accommodate both cognitive and physical needs, allowing for adaptability to internal and external changes—similar to the chameleon principle, which adapts its shape in response to environmental changes. This research aims to integrate the physical and cognitive needs of employees with the demands of the workplace to design an ergonomic workplace that promotes employee health, well-being, and productivity.

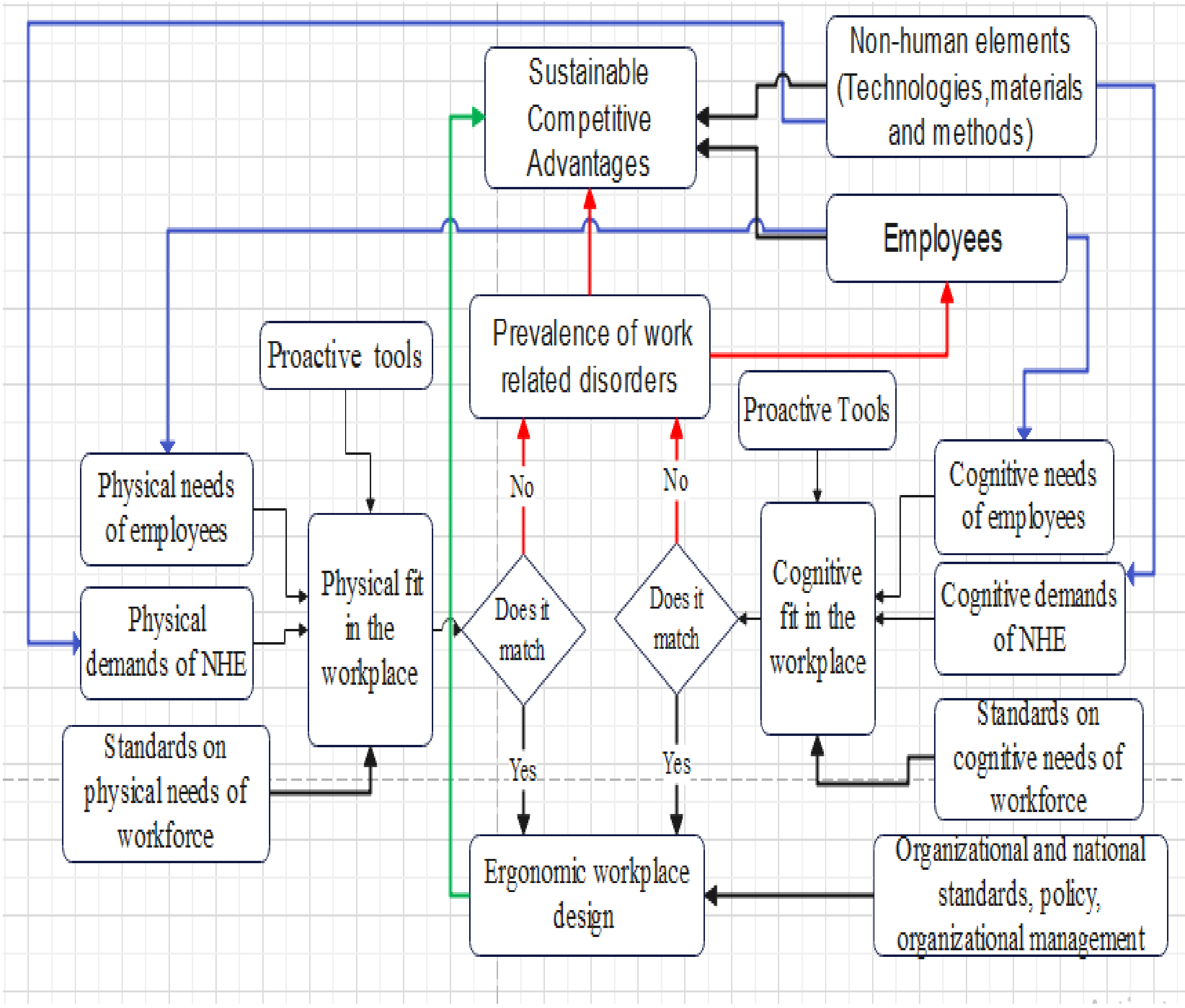
2.4. Chapter Summary:

This chapter conducted a comprehensive literature survey on the theoretical and empirical aspects of ergonomics, the development of sustainable competitive advantages, and ergonomic risk factors in various metal manufacturing firms. It primarily emphasised the significance of ergonomic principles in promoting workplace wellness.

The review of existing literature identified several gaps in previous research, particularly regarding the integration of physical and cognitive demands in workplace design. In light of this review and the proposed detailed conceptual model, a generative framework has been developed, as shown in Figure 2.7. It is evident that there is an urgent need for a model that explicitly links improvements in employee well-being and innovation capabilities with the prevalence of ergonomic risk factors within the metal manufacturing industry. This generic framework provides a foundation for developing a more robust proactive framework and for formulating hypotheses that support the development of sustainable competitive advantages in this sector.

Ultimately, the metal manufacturing industry should transition toward an ergonomic workplace design that addresses the physical and cognitive demands of both employees and machines. This can be achieved through an ergonomic-linking mechanism aimed at establishing sustainable competitive advantages. The proposed model will integrate ergonomic workplace design, elements of employee well-being, innovation capability, and proactive ergonomic interventions within a comprehensive framework tailored for the metal manufacturing industry. Emphasizing ergonomic workplace design, this approach considers both the physical and cognitive needs of employees, aiming to create a safer and healthier workplace while enhancing continuous improvement and productivity.

Transitioning to this conceptual framework will enable the development of targeted strategies and tools that address the specific challenges faced by the industry, ultimately facilitating effective ergonomic design that yields sustainable competitive advantages.



Legend; NHE= non-human elements

Figure 2.7: Generative Framework for Ergonomic Workplace Design for Sustainable Competitive Advantage in the Metal Manufacturing Industry (Author)

Chapter Three

Research Methodology

3.1. Introduction

From the methodological point of view, this research was inclined towards both a qualitative and a quantitative approach. Multiple methods were used for understanding the situations under examination. Scientific theories and analysis were used in directing the collection and analysis of data. The study used a cross-sectional and multi-method approach, whereby survey techniques and case studies were used to induce knowledge from the participants and situations. Within this methodology, initially, a literature review was carried out. Subsequent to this, the study was conducted to identify ergonomic risk factors and the subsequent impacts on the well-being of employees and sustainable competitive advantages of the manufacturing industry (**objectives 1 and 2**). This was followed by a questionnaire survey to identify employees' and other interested parties' requirements for developing a proactive ergonomic workplace design tool to minimize the impacts of MSDs on the well-being of human forces so as to have a competent manufacturing system (**objective 3**). Finally, the prototype framework was developed based on the data extracted from the literature reviews, employees' and other interested parties' interviews and case studies in the industrial settings (**Objective 4**). The overall research methodology is depicted in Fig. 3.1.

3.2. Research philosophical standpoint

This study is rooted in a Critical Realist Constructivist philosophical perspective, in which the referencing scholars like Merriam & Tisdell (2016) and Neuman (2011) guided the development of this research philosophy. From an ontological (reality) standpoint, it assumes that organizational phenomena—such as ergonomic risk factors, employee well-being, innovation capability, and sustainable competitive advantage—exist as real underlying structures and generative mechanisms within manufacturing firms. While these mechanisms do exist, there is no way of observing them physically. Instead, they manifested observable indicators. Structural equation modeling (SEM) makes it possible to estimate latent constructs representing these invisible mechanisms. In this way, SEM is critical realism as latent constructs are seeking structural relationships that explain observable events.

Lastly, from an epistemological (constructivist) perspective, the study accepts that employees' views and interpretations constitute our knowledge of these mechanisms. Therefore, survey instruments capture such constructed representations of the actual working conditions. SEM models are theoretically grounded in structural relationships based on probabilistic associations among latent constructs rather than deterministic or absolute causality.

By incorporating structural modelling with SEM and critical realist constructivism, it is ensured that the approach is both sound in theory and methodology and philosophically sound, while at the same time taking into account the complex interrelationship between ergonomic workplace design and sustainable competitive advantage.

Philosophical foundations of human-system dimensional integration and SCA: Despite significant technological advancements in various sectors, the world continues to face numerous challenges that affect human well-being. Global disruptions, conflicts, accidents, pandemics, and other factors contribute to a troubling increase in human fatalities. Researchers across the globe are striving to address these challenges by developing innovative technologies and systems, connecting individuals and organizations worldwide through the establishment of SMART organizations leveraging digital technologies. In various disciplines, scientists and practitioners are creating non-human-operated technologies to tackle these pressing issues. However, this race for innovation has led to competition among countries, each seeking dominance from both economic and environmental perspectives. Alarmingly, even as technological advancements progress, the incidence of work-related and non-work-related disorders, accidents, and injuries continues to rise, suggesting that current innovations are not effectively addressing the root causes of these problems.

One could argue that while a higher power may have created the world, human beings must adhere to their creator's principles to thrive and attain fulfillment. Unfortunately, many technologies fail to align with the needs of humans, leading to fatalities linked to technological failures that often violate natural laws of work. A critical reason for this disconnects is the insufficient emphasis on social aspects and employees' needs during the design and production of technologies and workplaces. The source of technological innovation, process improvement, and market development lies fundamentally within employee knowledge.

As technology evolves, what is created today will eventually become outdated, necessitating continual human involvement for maintenance and improvement. Thus, technological and process innovations are not isolated phenomena; they are developed and implemented by people (ILO, 2019). Research consistently highlights the pivotal role humans play in achieving sustainable economic growth. For example, Choe et al. (2015) emphasized that eliminating human contributions from manufacturing processes is neither practical nor feasible. Other studies have asserted that continuous innovation and productivity growth cannot be achieved solely through new technologies or cost-cutting measures (Frank, 2017; Frank & Vaas, 2008).

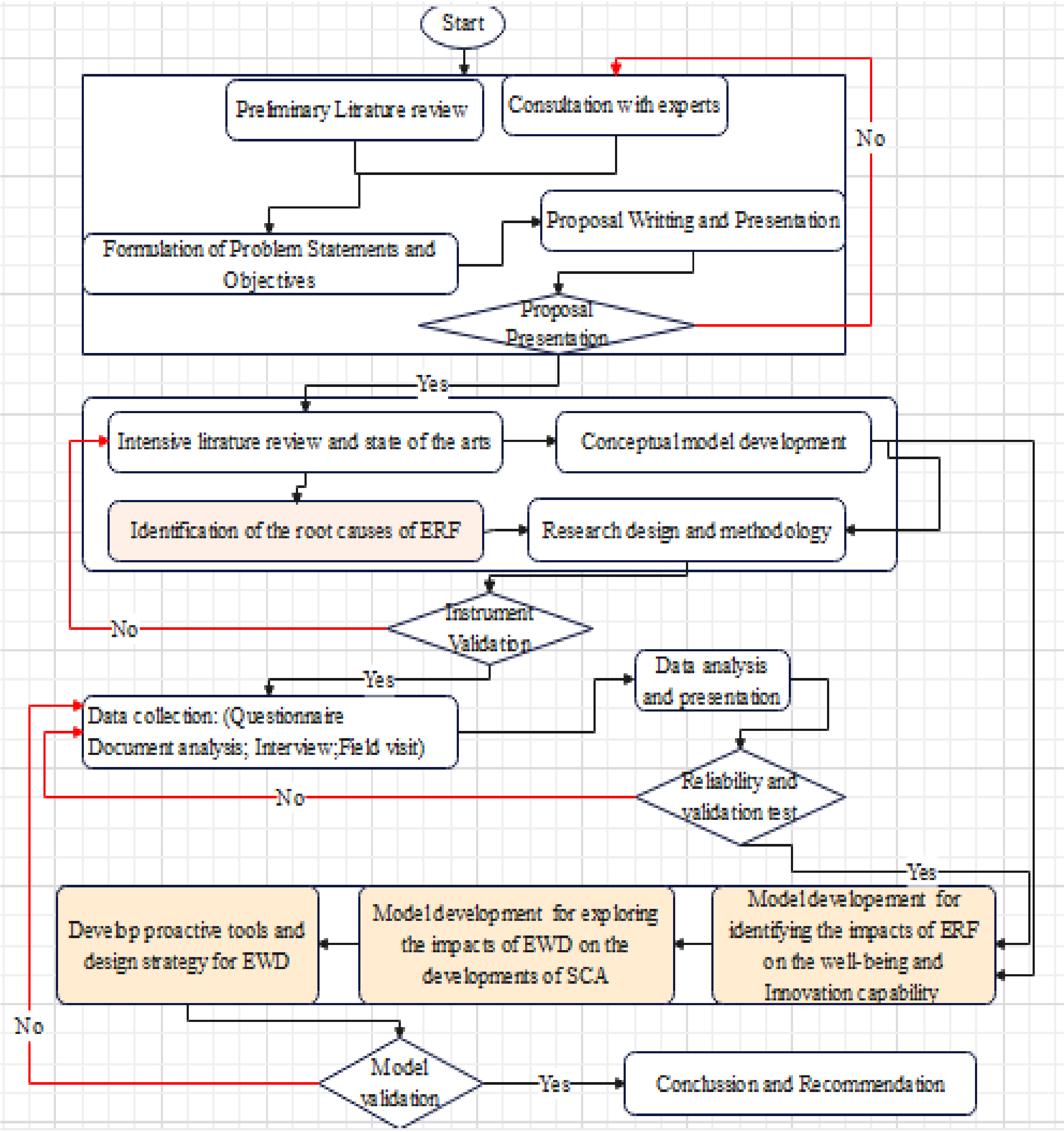


Figure 3.1. Research Design (Author)

Continuous innovation and productivity growth can be associated with the flow of water, which has a source, a path, and a destination. In the context of metal manufacturing, this flow requires a source of knowledge and a pathway for effectively transferring that knowledge into technological and process innovations. If the source of water is disrupted, the overall flow and its destination can be adversely affected. Similarly, if the foundation of industrial development is compromised, the innovation capability and productivity of employees will decline, ultimately undermining firms' sustainable competitive advantages.

Therefore, it is essential to pay special attention to the sources of all development. If the foundation of development is affected, sustainability will falter based on current trends and may cease altogether if the knowledge source fails to generate the engines of progress, as illustrated in Figure 3.2. Previous research underscores this concept; studies Ralf et al. (2016); Chloe et al. (2015); and Mamas (1990) emphasize that technological innovation, process optimization, and market development must be evaluated from both **social value and technical perspectives** to foster a competent organization.

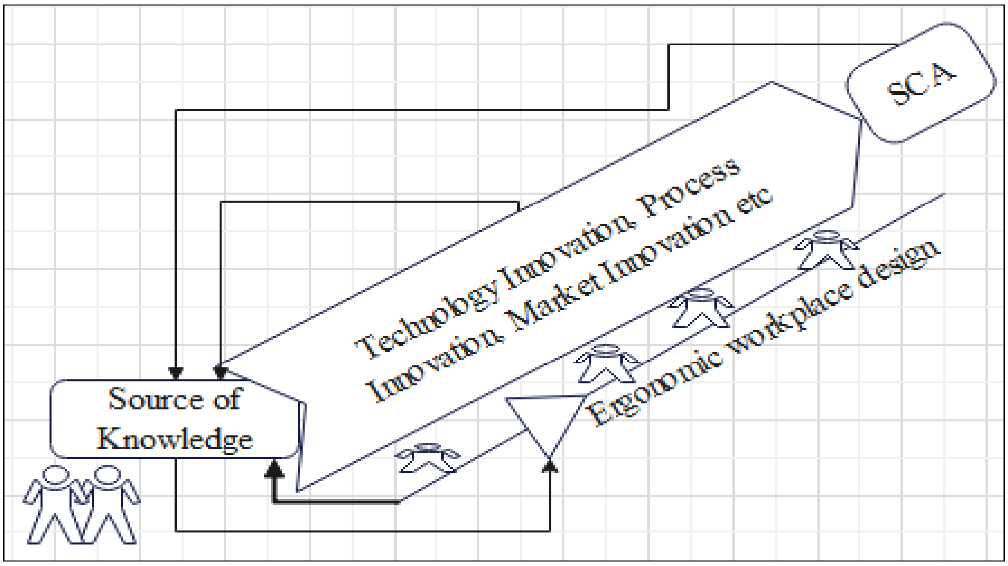


Figure 3.2. Roles of Employees in Building Sustainable Competitive Advantages (SCA) (Author)

The well-being of employees in manufacturing firms is crucial for establishing sustainable competitive advantages. Activities aimed at enhancing employee well-being help balance the exploration and exploitation of organizational knowledge, providing solutions to challenges related to innovation and improvement (Mariachi et al., 2012). The health and well-being of the workforce form the foundation for organizational change, fostering employee satisfaction and motivation while facilitating the extraction of tacit knowledge for innovation and creativity. To enhance both cognitive and physical well-being, workplaces must be free from the causes of Work-Related Musculoskeletal Disorders (WMSDs). As depicted in Figure 3.2, the workforce acts as a conduit for technological processes, market innovations, and other advancements. Therefore, manufacturing firms must implement ergonomically designed, human-centered workplaces to eliminate WMSD causes. This study is grounded in two fundamental philosophies:

1. **Biological Structure**: The physical structure of employees cannot be adjusted to fit the workplace; therefore, workplace design must accommodate the physical needs of employees.
2. **Cognitive Needs**: The cognitive needs of employees-such as knowledge, skills, satisfaction, and perception-can be shaped to align with other elements of the workplace, and vice versa.

Consequently, workplace design must accommodate both the cognitive and physical needs of employees, allowing for adaptation to changes from internal and external forces-akin to the adaptive principles of a chameleon in its environment. This approach emphasizes the integration of employees' physical and cognitive needs with the demands of the workplace, as shown in Fig. 3.3. Influencing factors include technological innovation, global disruptions, demographic changes, workforce requirements, and customer demands.

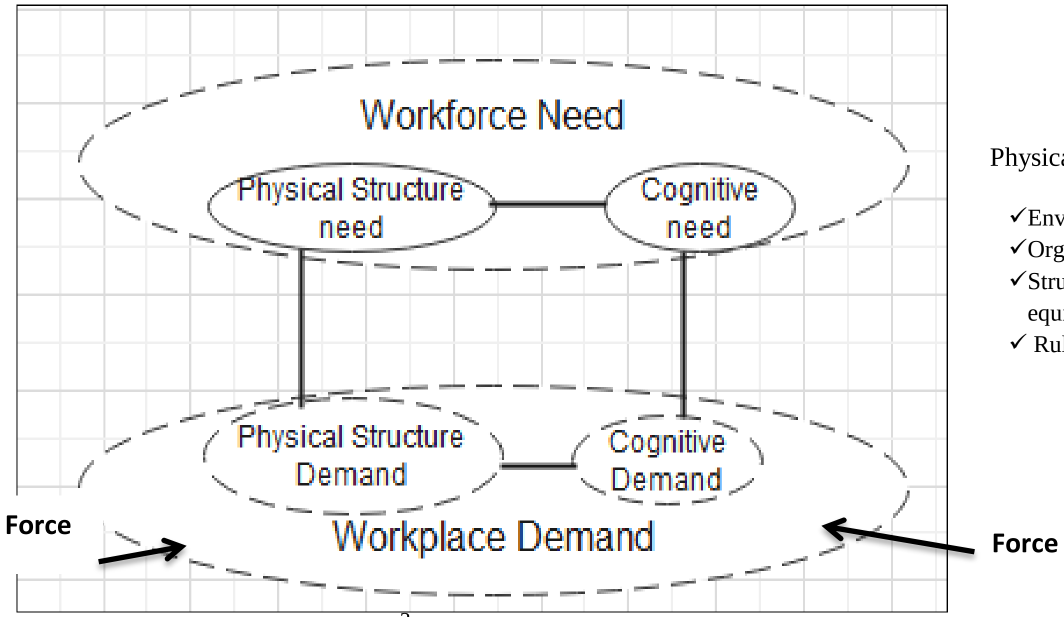


Figure 3.3: The chemistry[2] of ergonomic workplace design (*Source: Developed by author)*

The proposed philosophy advocates for new socio-technical systems within the manufacturing industry that prioritize workforce needs. An ergonomic workplace needs to be designed by considering all factors affecting the development paths of sustainable competitive advantages in the manufacturing sector at every organizational level. Policies, legislation, and standards must be established based on workforce needs, including:

1. Each country should develop its own standards regarding the physical requirements of the workforce and maintain databases on existing cognitive capacities within the manufacturing industry.
2. Standards should be established for the employee-centred physical demands of each workforce element, along with databases on the cognitive requirements of tasks within the manufacturing sector.
3. Management in the manufacturing industry should adopt employee-centred approaches to organizational management, policies, culture, and standards that align with national standards.

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[2] *In this figure, ''chemistry'' refers to the interactions among workplace elements during the design process.*

These measures will enable the metal manufacturing firms and governments to establish employee-centric workplaces capable of adapting to changes in the external environment. Such workplaces can serve as prototypes, tested and verified by experts to ensure they meet the physical and cognitive requirements of the workforce.

This developed methodology will help the manufacturing industry maintain human-centred physical factors for each element of the workplace. Additionally, establishing databases on workforce cognitive needs and task cognitive demands will be essential for implementing new working systems, with cognitive needs enhanced through training and education. Based on these philosophical standpoints, this study employs various research strategies and methodological approaches to address the complex dynamics of ergonomic workplace design.

3.3. Research Strategy

The study used both qualitative and quantitative approaches to obtain broader data for the determination of deep identity, existing ergonomics risk factors, and ergonomic workplace design in the metal products manufacturing firms. According to Christensen (1985), a quantitative survey should be used to describe the strength of the relationship between the dependent and independent variables under consideration.

In qualitative research, non-numerical data were gathered and analysed to better grasp concepts, viewpoints, or experiences. Most industries store secondary data in the form of numeric, textual, and image data. To mitigate the limitations of each approach, a mixed-methods design was employed, combining qualitative and quantitative methods. The mixed-method design is a further philosophical alignment. The quantitative component (SEM-based hypothesis testing) identifies the structural relationships supporting competitive advantage development and employee well-being, ergonomic workplace design, and innovation capacity. In the meantime, the qualitative methods contribute contextual information and illuminate the processes through which such mechanisms operate in metal manufacturing-related environments.

Research Time Horizon: The proposed time horizon for this study is cross-sectional, during which all required data were collected from each selected case firm at a single point in time.

3.4. Literature Review Methodology:

The study adopted a systematic literature review methodology, PRISMA-style, which is an explicit, transparent, and reproducible approach for identifying, evaluating, and synthesizing existing research conducted by scholars and practitioners (Denyer & Tranfield, 2009). The systematic literature review was used to provide a comprehensive overview of the field while minimizing bias, which is shown in Figure 3.4.

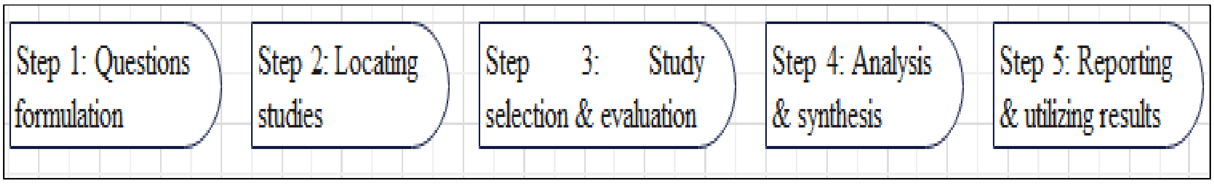


Figure 3.4: SLR method. Source adopted from (Denyer & Tranfield, 2009)

Question Formulation

- What is the root cause (the major ergonomic determinant) contributing to work-related disorders?
- What are the impacts of work-related disorders on employees and firms in terms of productivity, health, and overall well-being?
- What proactive ergonomic workplace design frameworks and strategies are available to prevent the prevalence of work-related disorders?

Locating studies: Locating studies refers to the process of finding and identifying relevant research studies or articles on a particular topic. This includes searching different sources such as databases, journals, and other resources to gather evidence related to the stated research question or area of interest.

Time horizon: Based on a pilot search on selected databases, only academic research papers published starting from the year 2010 were included.

Database selection: The literature for this review was gathered from various reputable sources, including Scopus, Web of Science, MDPI, Google Scholar, and other scientific bibliographic databases.

Journal selection: To ensure the quality of the systematic literature review, scientific articles published in peer-reviewed academic journals were selected.

Report search strings (keywords definition): A comprehensive search was conducted using a set of defined keywords and Boolean operations. The following search keywords were used: "workplace design," AND "ergonomics," OR’’ human factors,’’ OR ‘’employee centric,’’ AND “sustainable competitive advantage," AND "manufacturing industry**.**" The search was performed considering the title, abstract, and keywords of the articles. The "ergonomics" group of keywords encompassed aspects related to human factors, employees' well-being, occupational health and safety, as well as the themes of "human-centered manufacturing" and "human-centered design." Synonyms were selected within each group to ensure a broad coverage of papers published in the existing scientific literature. For a complete list of the keywords used in the search, please refer to Table 3.1.

Inclusion Criteria: The inclusion criteria for reviewing the literature would include the following criteria: *Scientific discipline*: The article's subject area has to be related to occupational health and safety, prevalence of work-related musculoskeletal disorders, workplace design, workplace innovation, and other related areas that prioritize the well-being of employees in metal manufacturing industries. *Document Type:* Only research articles, books, and internationally accredited reports were included, not news. *Language*: The articles written only in the English language were considered in the review.

Table 3.1: Combination of research in the literature review

	Synonymous considered during the searching process
Ergonomics	Cognitive, cognitive strain, human factors, health and safety, mental demand, employee-centric, workload, information load, physical strain, physical demand, physical ergonomics, cognitive ergonomics, well-being of employees
Employees	Operator, worker, human, person, employee
Workplace design	Job design, workspace design, work system design, operation design, and workplace innovation.
Sustainable competitive advantages	Productivity improvement, Innovation capability improvement,

Article Screening: Once the required 250 articles had been collected based on keywords, relevant articles were selected based on the above-stated inclusion and exclusion criteria. The specific steps of the screening process of the collected articles and the flowchart of the articles' selection are shown in Figure 3.5.

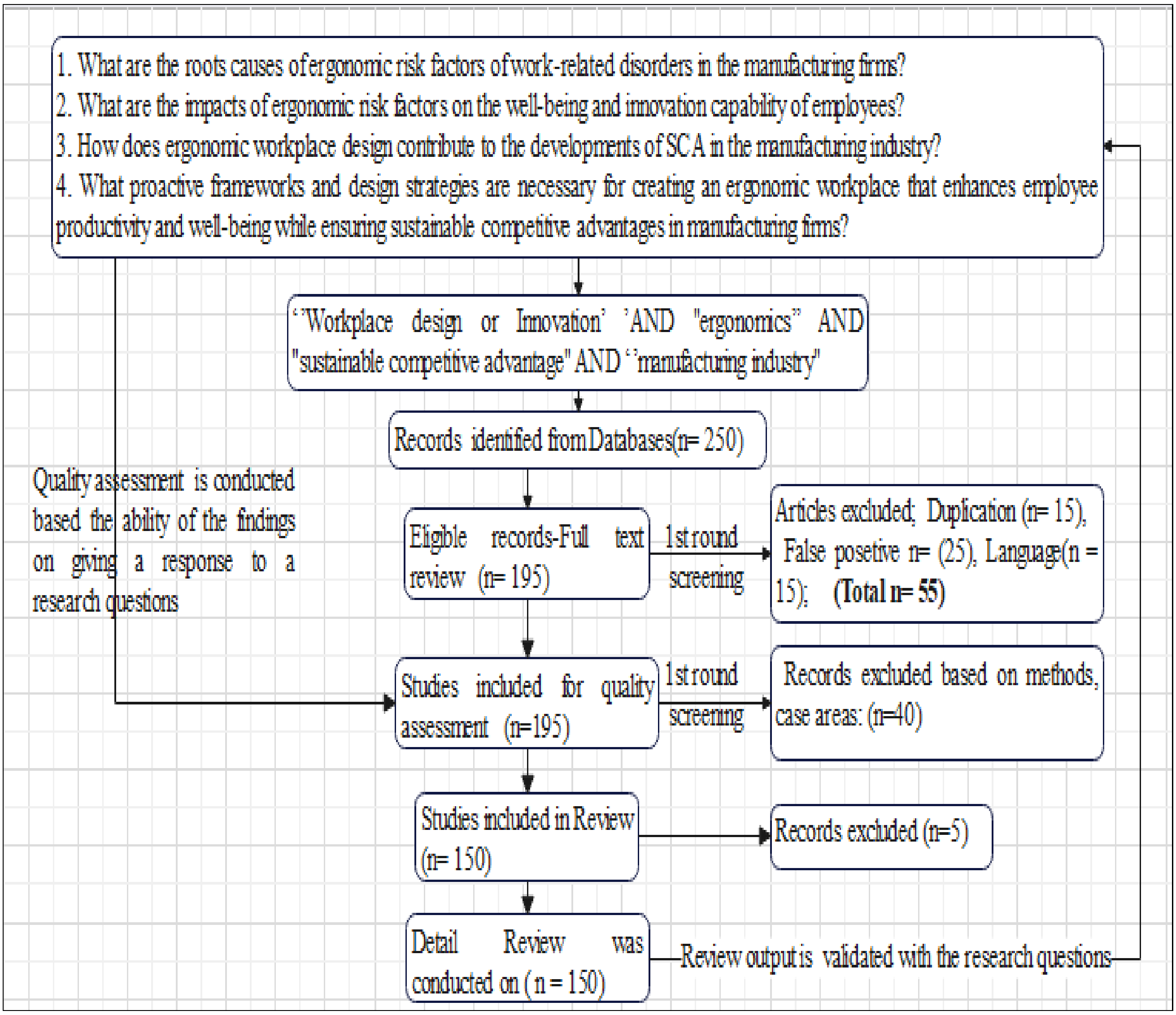


Figure 3.5: Articles Screening Process (Author)

- **First round screening**: evaluate each article based on the title, abstract, and keywords to determine its relevance to the research questions. Sources that meet the inclusion criteria are then selected for further review, while those that do not meet the criteria are excluded.
- **Second round screening**: The selected sources are then reviewed in detail, and the data extracted from them is analyzed and synthesized to provide a comprehensive understanding of the research topic. The data screening section concludes with a summary of the sources selected for the study, including their strengths, limitations, and relevance to the research questions.

Data validation (quality of appraisal): The last 195 screened articles underwent a validation process to determine their suitability for a detailed review. The validation focused on assessing the reliability and relevance of the information presented in the articles to effectively address the research questions posed. As shown in Figure 3.5, 45 articles were excluded, and 150 articles were selected for review.

3.5. Population and Sampling Strategy

Study Population:

The data for this research were based on a cross-sectional survey of manufacturing firms in Ethiopia. The manufacturing industry in Ethiopia is well-suited to the study, as it encountered 56.05% of 25,812 employees who encountered permanent and temporary disability and death (MOLSA, 2016). Many workers in the selected metal manufacturing firms, who are directly engaged in the production process, working at the management level, supervisors, and workers working in different workplaces, were considered in the study population. Other interested parties were also considered in the study population.

Inclusion and Exclusion Criteria: All employees who are directly engaged in the production process in the selected industries and other employees working at the management levels of the manufacturing industry were included. Moreover, experts who were working on policy and strategy development for the manufacturing industry and regulatory bodies were also part of this study. Employees not directly involved in activities related to the manufacturing system were excluded.

Selection of Representative Industrial Sectors: To select representative industries, first, each industry was given a number. These industries are classified based on the Ethiopian Ministry of Industry (MOI) and the Central Statistical Agency (CSA) classification. For this study, a sample size of the stratum was considered for the random selection method to get a representative number of metal and engineering industries from each group.

Sample Size Determination

Sampling is the process of selecting representative individuals or industries from a population to estimate the characteristics of the whole population (Singh & Masuku,2014). Singh and Masuku also informed that the purpose of the study, the population size, the level of precision, the level of confidence or risk, and the degree of variability are the most important criteria for determining the sample size.

In this research, a three-stage sampling method was used to determine the viable number of participants.

Stage one*: Stratification of the metal manufacturing firms.*

The metal manufacturing firms were stratified based on the classification provided by the Ethiopian government, which considers the number of workers and the type of machinery used. The classification includes three main levels of industrial scales: large-scale industries, medium-scale industries, and small-scale industries. This study focused on large- and medium-scale metal manufacturing industries for data collection.

Stage Two: Random selection of firms from each stratum

In this stage, a systematic approach was used to ensure a representative sample of firms for the study. To collect the required information from the case manufacturing firms, random selection of 6 firms from large-scale metal manufacturing firms: Two were from basic iron and steel manufacturing (out of 165), and four were from the manufacturing of fabricated metal products (out of 282 basic metal manufacturing firms, according to Ministry of Industry (MoI) *and Central Statistics Agency (CSA), 2015/2016 (2008 Ethiopian Calendar*)). Additionally, two firms were selected from medium-scale metal manufacturing.

Justification for Selection:

The selection included two firms from basic iron and steel manufacturing and four from metal products manufacturing firms. This allocation enabled a comprehensive understanding of different operational practices and ergonomic risk factors within the industry, ensuring that insights were not limited to a single firm. Moreover, the larger proportion of firms from fabricated metal products reflects the industry's current trends, where this segment has seen significant growth. By including more firms from this category, the study aims to capture current ergonomic practices and ERFs that may influence overall firm performance. The study also included two medium-scale firms, ensuring a balanced perspective on how company size affects ergonomic workplace design practices. This balance was crucial for drawing conclusions applicable to a wider range of firms within the metal manufacturing sector.

Stage Three: Random sampling of employees from each selected firm

The population size was considered heterogeneous data. The population (N) that was estimated using stratified sampling was the population from each stratum, which was from stratum 1 (from basic iron and steel manufacturing firms) and stratum 2 (from fabricated metal manufacturing), which were selected in Stage Two.

Stratum 1: 100 employees were selected from each of the selected basic iron and steel manufacturing firms. A total of 200 employees were selected from the two firms and included in the study.

Stratum 2: 40 employees were selected from each of the selected fabricated metal products manufacturing firms. A total of 240 employees were selected from the four firms and included in the study.

Stratum 3: 20 employees were selected from each of the selected medium-scale metal manufacturing firms. A total of 40 employees were selected from the two firms and included in the study.

Therefore, a total of 480 employees (N=480) were selected randomly from 8 selected metal manufacturing firms.

Sample size determination:

Once the population of employees from each stratum was selected, the next step was to determine the total sample size for the study. The sample size was calculated using the formula provided by Singh & Masuku (2014):

$$n = N/(1 + N(\mathrm{e})^2 \qquad (3.1)$$

Where n = sample size; N = total population (sum of the populations from each stratum); and e = sampling error (e = 0.05) at the 95% confidence level. Hence, the sample size determined for this study was 219 (n = 219), as indicated in Table 3.2.

Sample size of each stratum/metal manufacturing firms.

At this stage, each stratum sample size is directly proportional to the population size of the entire population of strata (N). Hence, each stratum sample size is determined by using the proportionate stratified random sampling formula, ($ni = n(\frac{Ni}{N})$), where n: total sample size, N: total population size, Ni = Stratum population size, n_i = Stratum sample size (Sudeep, 2013)

Table.3.2. Population Size and Sample Size Determination

<table>
<tr><th>S/n</th><th>Types of enterprises</th><th>Number of Population Selected (Population Size), (Ni)</th><th>Sample size of each stratum ($ni = nNi/N$)</th></tr>
<tr><td>1</td><td>Manufacturing of basic iron and steel</td><td>200</td><td>91</td></tr>
<tr><td>2</td><td>Manufacturing of fabricated metal products</td><td>240</td><td>110</td></tr>
<tr><td>3</td><td>Medium scale metal manufacturing firms</td><td>40</td><td>18</td></tr>
<tr><td colspan="2">Total number of populations</td><td>N= 480</td><td rowspan="2">219</td></tr>
<tr><td colspan="3">Based on the total population size (N), the total sample size for the study was computed using $ni = N/(1+N(\mathrm{e})^2$, where (e = 0.05), then, n = 480/ $(1+(480(0.05)^2$ n = 219</td></tr>
</table>

After sampling size determination, the study initially contacted metal manufacturing firms located in different areas of Ethiopia through telephone communication to inform them about the study. Follow-up letters were then sent to the firms, providing additional details and requesting a meeting to discuss their potential involvement. Preliminary meetings were arranged with the interested firms' managers to discuss various aspects of the study, including its objectives, data collection procedures, employee requirements, and the prevalence of work-related disorders such as musculoskeletal disorders and work-related stress disorders.

The selection of specific occupation areas was done in close consultation with the line managers, taking into account the classifications of work characteristics described by Denis et al. (2008). These classifications include workstation layout (stationary layout and variable environment) and the nature of tasks (cyclic and varied work tasks). Based on these classifications, four combinations of workstation layout and nature of tasks were derived: stationary layout and cyclic work tasks, stationary layout and variable work tasks, variable environment and cyclic work tasks, and variable environment and varied work tasks. The aim was to purposively select case study areas (types of occupations) that encompassed these four work characteristics.

Following the meetings with the line managers, the selected workers for the case study areas were informed about the study by their respective line managers. Participation in the study was voluntary, and those who decided to participate communicated their decision to their line managers.

3.6. Data Sources and Collection Methods

Source of Data

The sources of data for this research were

- The ergonomic workplace design practices in the selected metal manufacturing firms
- Employees working in the selected metal manufacturing firms
- Ministry of Labour and Social Affairs.
- Focus on literature review at the international and national level on ergonomic workplace design practice and its impacts on the sustainable competitive advantage of the manufacturing industry.
- Assessments of report output on the occupational health and safety management systems
- Reports on annual production performance of selected metal manufacturing firms
- Different documents, magazines, journals, etc. focus on the well-being of employees working in the manufacturing industry.
- International Labour Organization (ILO) reports

Data Collection Methods

Secondary Data Collection

A database search was conducted to collect data from various sources such as Scopus, Google Scholar, Emerald Publishing, Web of Science, etc., using keywords. The databases were chosen for their coverage of the literature related to ergonomic workplace design, sustainability, competitive advantage, and ergonomics. Moreover, scanning and evaluating the industrial sector’s working documents, manuals, procedures, reports, statistical data, policy documents, regulations, and standards was also used to collect secondary data on the practice of considering ergonomic workplace design approaches in their daily production process.

Primary Data Collection

Field Observations*:* The researcher was conducting a field observation to observe the real practice of metal manufacturing firms on ergonomic workplace design. The data was organized from the field observations through photographs, sound recorders, documents, and video recorders. For conducting this method, based on the objectives of the research, guiding checklists were developed to lead the direction of observation and the other methods. This checklist was clarifying the ergonomic workplace design concepts that must be observed during the research process. The observation was taking place in selected metal manufacturing firms found in different areas of Ethiopia.

Key informant interview*:* Key informant interviews were conducted with the preparation of bench discussions. Operators and managers at all levels were interviewed to reflect their opinion about the intervention of the ergonomic workplace design (workplace innovation) approach through each stage of the design and development process. This technique covered bottleneck factors for implementing an ergonomic workplace design (workplace innovation) framework through each stage of the workplace design and rearrangements, and it also covered the techniques that the firm used to anticipate and include the future needs of the workers and other interested groups during the design and development process of workplaces.

Survey questionnaires: A comprehensive questionnaire was designed and administered to senior experts, managers, and workers in the selected metal manufacturing firms. This design was informed by the findings from the interview techniques and the application of ergonomic principles, workplace design, and work-related management policies. Key areas of focus included the stages of workplace design, the involvement of workers and other stakeholders in decision-making, and adherence to occupational health and safety standards and policies. The investigation aimed to collect valuable and practical information related to ergonomic workplace design practices, critical processes for ergonomic waste minimization, workplace design, process design, and the root causes of waste generated within the manufacturing system.

Questionnaire Design: The questionnaire comprised two common types of survey questions: closed-ended and open-ended. Careful attention was given to the order of the questions, and double-barrelled questions—those that ask two questions in one—were deliberately avoided. Additionally, emotionally charged or biased language was excluded to ensure clarity and objectivity.

It was tailored to collect primary data on the repercussions of inadequate ergonomic workplace design on employees, the effects of musculoskeletal and cognitive disorders, employees' innovation capability, and the impacts of ergonomic workplace design on the development of sustainable competitive advantages in various metal manufacturing firms. To collect subjective responses, Likert Scales, a psychological method introduced by Rensis Likert in 1932, were utilized, enabling respondents to indicate their agreement levels with statements. In this study, scales ranging from five to seven points were employed to measure employees' technique agreement levels across different variables.

To collect relevant information on the prevalence of work-related disorders and their root causes across various occupations, suitable questions were integrated into the questionnaire, designed to capture postural and cognitive-related information smoothly. The Rapid Entire Body Assessment (REBA) technique was utilized to assess overall body risk levels without requiring input from the workers. Furthermore, employees were provided with Whole Body Discomfort (WBD) scales based on Corlett (1990), ranging from 0 (no discomfort) to 6 (extreme discomfort), to self-assess their body discomfort levels and determine whether the discomfort was linked to their work in the workplace. The original scale from Corlett (1990) was maintained without any changes, but the number of body locations was increased to 25 to align with the 15 body regions included in the Nordic Musculoskeletal Questionnaire (NMQ) and the 5 cognitive disorders affecting the employees' well-being and cognitive ability. The questionnaire was developed based on information from the standardized Nordic self-reporting questionnaire (Kuorinka et al., 1987) and insights from literature sources and aimed to measure constructs such as employee-centric workplace design, physical well-being, cognitive health, innovation capability of employees, and the development of sustainable competitive advantages. A six-point scale was employed to measure employee discomfort in physical and cognitive aspects, while a five-point scale was used to evaluate the association of ergonomic risk factors with different occupational roles.

Questionnaire survey determination*:* A subgroup of the population was selected to answer the survey, ensuring that the collected information could be generalized to the broader population of interest. Sample size determination for the questionnaire survey utilized appropriate stratified sampling formulas, with the population size estimated based on statistical agency data. Employees with over one year of industry experience were randomly chosen for questionnaire distribution, following a pre-test by experienced experts to refine and improve the questionnaire based on feedback. The overall data collection methods used for the study are stated in Table 3.3.

Table 3.3. Data Collection Method

	Specific Objectives	Data Source	Data Types	Data Collection Techniques
1	To identify the major ergonomic determinants contributing to work-related disorders in the manufacturing firms	Literature	Secondary/qualitative	Systematic Literature Review
2	To explore the impacts of ergonomic risk factors on the well-being and innovation capability of employees	Literatures	Secondary	Literature review
		Employees, experts, managers, and supervisors	Primary and secondary (quantitative)	Self-reported closed-ended questionnaire
3	To explore the contribution of ergonomic workplace design to the development of sustainable competitive advantages in manufacturing firms	Literature, Case sectors (experts, managers, and supervisors)	Secondary data and primary data from the case company and literature review	Literature review, Key informant Interview, questionnaire
4	To develop proactive frameworks and strategies necessary for designing an ergonomic workplace that enhances employee innovation capability and well-being while ensuring the development of sustainable competitive advantages in manufacturing firms.	Literature, Experts and managers	Results from the data analysis and literature review	Analysis results and literature review

3.7. Data analysis methods and techniques

Data collection by itself could not be a solution to problems. Following the data collection process, the data analysis procedures for analysing data and techniques for interpreting the results of the analysed data were conducted. Data cleaning was also done on organized data to modify incomplete, duplicate, or erroneous data collected. After analysis, data interpretation, and verification took their part. Once the data was visible, the following tools and techniques were used to analyse the collected data to get the required outputs of the research.

Multiple regression model: Prior to SEM analysis, the underlying relationships between ergonomic risk factors and outcome variables were conceptually aligned with multiple regression logic, where multiple independent variables influence a dependent construct (Hair et al., 2021). Based on the problems identified in the literature and case companies, the model has the general specifications stated in equation (4.1) via summarizing the relationship between the dependent variable Y and multiple independent variables X.

$$Y = \beta o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \beta_n X_n + e \qquad (4.1)$$

Where

Y = Sustainable competitive advantage of the manufacturing industry

Bo = Constant

B_1-B_n=Beta coefficients

X_1 = Employees' physical needs interaction with the physical dimension of non-human elements

X_2 = Employees' cognitive factors' interaction with the cognitive dimension of non-human elements of the workplace

X_3 = Organizational rules and regulations

X_n = any interaction of employees with the non-human elements within the workplace

e = error terms

However, given the presence of latent variables and the need to simultaneously assess measurement and structural relationships, structural equation modelling (SEM) was adopted as the primary analytical technique.

Structural equation modelling: Structural Equation Modelling (SEM) is a robust tool utilized to evaluate the alignment between the theoretical covariance matrix and the empirical covariance matrix (Shela et al., 2023). Therefore, in this study, covariance-based SEM was employed to analyse the connection between the theoretical hypotheses developed regarding the relationship between ergonomic risk factors and employees' innovation capability in metal manufacturing firms (objective two) and the data gathered from the case industry.

Furthermore, the study utilized SPSS version 26 alongside an alternative modelling approach of variance-based Partial Least Squares Structural Equation Modelling (PLS-SEM), which aims to predict and estimate the model while maximizing the explained variance of the target constructs (Ramayah et al., 2018). Statistical techniques employed in PLS-SEM offer advantages over covariance-based structural equation modeling (CB-SEM) (Lowry and Gaskin, 2014), especially when the number of respondents is fewer than 200 employees. Therefore, this study employed Structural Equation Modelling (SEM) with PLS version 3 to analyse data collected through questionnaires administered to investigate the impacts of ergonomic workplace design on the development paths of sustainable competitive advantages in metal manufacturing firms (objective three). In this study, the reflective measurement model of PLS-SEM was utilized, with models estimated using regression weights. The arrows indicate the direction from the latent variables to the indicators (measurement items) where the reflective measurements were applied (Shela et al., 2023). Overall, the six logical steps utilized for analysing the collected data using SEM were as outlined by *Fan et al. (2016)*: 1) *Model specification*: in this step, a hypothesized relationship among the variables in an SEM was formulated based on knowledge generated from literature. 2) *Identification*: In this step, the hypothesized model was checked; it's over/just identified. 3) *Parameter estimation*: In this step, the parameter for each constructs was calculated and estimated. 4) *Model evaluation*: It was done using quantitative analysis calculated for the overall goodness of fit. 5) *Model modification*: Modification was done to adjust the model to improve model fit. 6) *Validation*: Validation was conducted to improve the reliability and stability of the model.

Additionally, the other rationale for using both CB-SEM and PLS-SEM was that CB-SEM was used to verify theoretical causal relationships between ergonomic risk factors, employee well-being, and innovation capability, whereas PLS-SEM was used to verify predictive relationships and explained variance of ergonomic workplace design, especially in relation to the development of sustainable competitive advantages.

Source and development of measurement items: The measurement items in this study were developed on the basis of a comprehensive review of existing and peer-reviewed literature. This ensures that content validity is met and that theoretical supporting is established. The development of measurement items in this study is literature-based, ensuring that each construct is theoretically and empirically well-founded.

SPSS Tools*:* The collected data were analysed using the SPSS software. Ergonomic methods such as Rapid Entire Body Assessment (REBA), which builds on Rapid Upper Limb Assessment (RULA) and Whole-Body Assessment techniques, were employed to investigate the interactions between employees and non-human elements within the metal manufacturing firms. These methods were utilized to analyse the factors contributing to the prevalence of work-related disorders, including work-related musculoskeletal disorders (WMSDs), work-related stress disorders, and work-related accidents, in the selected metal manufacturing firms. The summary of the data analysis tools is shown in Table 3.4.

The Likert scales used in the questionnaire were treated as ordinal data, which was consistent with the data type typically associated with Likert scale responses. Responses to a single Likert item are generally considered ordinal because the levels do not have a true numerical value, and the perceived difference between adjacent levels may not be equidistant, particularly when using a limited number of levels, such as five to seven.

Table 3.4. Summary of the tools and techniques used for each specific objective of the study

	Addressed Research Objectives	Theory and models used	Tools and techniques used for data analysis
1	To identify the major ergonomic determinants contributing to work-related disorders in the manufacturing firms	Factors affecting the interaction of employees with other elements of a system, causing work-related disorders.	Systematic Literature review,
2	To explore the impacts of ergonomic risk factors on the well-being and innovation capability of employees	Work-related disorder affects the physical and cognitive well-being of employees.	Covariance-Based SEM Using SPSS and Amos Software
3	To explore the contribution of ergonomic workplace design to the development of sustainable competitive advantages in manufacturing firms	Theories of chameleon leadership style and production management.	Structural Equation Modelling (SEM) with PLS version 3
4	To develop proactive frameworks and strategies that are necessary for designing an ergonomic workplace that enhances employee productivity and well-being while ensuring sustainable competitive advantages in manufacturing firms	Ergonomic Function Deployment Model, along with the application of First Level Fulcrum and algorithms.	

3.8. Triangulation and reliability of the research process

In evaluating the reliability of the data collection methods and data analysis tools, the study employed a combination of triangulation methods and reliability assessments.

Reliability of the Research Process: Reliability pertains to the degree of explicability in a study, under the premise that similar observations should be reproducible by other researchers on different occasions (Easterby-Smith et al., 2002). Despite arguments against achieving identical outcomes through replicated procedures due to organizational variations (Remenyi et al., 1998) and individual researchers' diverse theoretical perspectives, it remains crucial to ensure the robustness of data collection and analysis.

In this research, reliability was ensured through the development of case study protocols and the utilization of various statistical tests such as Cronbach's test. This approach aimed to facilitate easy access to all explicit information used in the study, including maintaining a detailed process of research activities within each case and establishing connections between these lists of activities, company documents, research process reports, and interview transcripts.

Bias reduction strategies*:* While SEM relies on self-reported survey data, triangulation was employed to enhance the validity of the data. This approach included the use of a variety of methods in data collection, for example, observation and in-depth interviews, to explore the evaluation objectives. The use of a variety of methods in data collection promotes reliability and validity of data, especially when data from different sources is consistent. The use of more than one data collector can enhance this reliability. Therefore, during the study period, these data collection techniques were the basis for the research operations.

Participant selection and questionnaire design for model validation: Managers, supervisors, and workers were randomly sampled from a range of manufacturing firms to ensure a comprehensive representation. The perceived importance of the proactive frameworks developed was measured using a 5-point Likert scale questionnaire, with responses ranging from "No importance at all" to "Highly important." They were gathered and analyzed to determine the rating trends between groups of participants to facilitate a comparative analysis of their perceptions of the importance of the tools.

Ethical Clearance: Ethical clearance in the context of the Ethiopian scenario was ensured in the sense that the research followed the principles of non-interventional methods, where the study is based on questionnaire surveys rather than medical interventions for individuals. Further, the emphasis is on voluntary participation with the maintenance of the confidentiality of the participants. For the maintenance of the confidentiality of the participants, several measures were taken. Before the commencement of the study, an official letter was dispatched to the industries and employees from the School of Mechanical and Industrial Engineering at the Addis Ababa Institute of Technology.

3.9. Summary of the Chapter

The approach to research put forth by this dissertation is the critical realist constructivist perspective, based on the premise that reality is socially constructed and contains many dimensions of coexistent realities. Williams and Tisdell (2016), Merriam and Tisdell (2016), and Neuman (2011) informed this approach; therefore, the results of this research were based on interpreting knowledge from various sources. Even with the fastest growing rate of technological advancement globally, we continue to face difficulties with many challenges created due to global crisis events, including, but not limited to, increased loss of life. Thus, there is a need for innovations that are built with a primary focus on meeting human conditions. This research supports developing human-centric workplaces within the metal manufacturing industry by creating workplaces that support the physical and cognitive needs of employees. Therefore, the research presented in this dissertation seeks to develop human-centric workplaces based on the two core constructs of biological design and cognitive function of work to maximally link employee satisfaction with the expectations of the workplace, thereby enhancing fair employment and effective innovation and overall productivity of the workforce. Also, there is a strong level of support in this philosophy for developing socio-technical systems within the workplace, which maximally address the needs of the workforce, specifically in developing ergonomic workplace designs that support long-term competitiveness within the manufacturing sector. The goal of this approach is to create adaptive, human-centric workplaces that address the physical and cognitive needs of the workforce, ultimately supporting continuous improvement and innovative culture within the metal manufacturing sector.

This methodology chapter describes the methodologies utilized in this study. The methodology used in this study followed a socio-technical system framework in its approach to fulfilling the dual objective of addressing both the physical and cognitive needs of employees within their respective work environments.

The research objective is to develop ergonomic work practices that create safe working environments for employees that are healthy and supportive of employees' mental and physical health and well-being, along with promoting innovation among employees in metal manufacturing. Data collection methods consisted of primary and secondary methods such as field observations, interviews with key informants, and survey questionnaires.

The goal of this research design is to better understand the ergonomic risk factors that influence the development of sustainable competitive advantages through the use of a mixed-method approach that incorporates both qualitative and quantitative methods of data collection and overall results analysis. The use of statistical methods such as SEM has provided an understanding of how the presence of ergonomic risks in the workplace affects employee well-being, innovation capabilities, and competitive positions of manufacturing companies.

This chapter discusses the reliability of the research process and provides a detailed description of the measures taken to ensure that the data collected and analysed are reliable. The measures implemented provide information on improving the generalizability and validity of the overall research findings.

Finally, the chapter integrates theoretical considerations with comprehensive data analysis and provides information regarding the benefits of employees who work in organisations that have been designed using ergonomic concepts and how organisations can increase their efficiency through the use of ergonomically designed work environments in the metal manufacturing industry.

Chapter Four

Data Analysis and Presentation

4.1. Introduction

This chapter presents the data analysis and results used as a foundation for the subsequent model development chapters. The analysis covers descriptive statistics, data analysis, and reliability and validity tests. The data analysis presents are used for two different modelling approaches: CB-SEM for analysing the impacts of ergonomic risk factors on the well-being and innovation capability of employees working in the manufacturing firms. The second model is the smart PLS-SEM model for assessing the impacts of ergonomic workplace design on the development of sustainable competitive advantages in manufacturing firms. The survey is based on the data collected through a self-administered questionnaire supported by semi-structured interviews and field observation for validation purposes. The existing practice of ergonomic managements, the prevalence of ergonomic risk factors, the prevalence of work-related disorders, and its connection with the types of occupations were investigated to test models that indicate the impacts of ergonomic risk factors and ergonomic workplace design on the well-being and innovation capability of employees and development of sustainable competitive advantages.

4.2. Data Analysis

In alignment with the research methodology outlined in this study, besides the secondary data from previous studies, a self-administered questionnaire served as the primary data collection tool to measure respondents' perspectives on the identified constructs. The variable incorporated a range of elements, including ergonomic workplace design, the physical and cognitive well-being of employees, various ergonomic risk factors (physical, cognitive, and ICT-related), the prevalence of work-related disorders, and the development of sustainable competitive advantages within metal manufacturing firms.

The questionnaire was structured to cover different areas. Initially, it inquired about demographic details, evaluating respondents' years of service, age, and gender. Subsequently, in part two, the questionnaire investigated the impacts of ergonomic risk factors on the well-being and innovation capability of employees through seven measurement items, self-assessed on a scale from 1 to 5. This part encompassed six constructs: physical ergonomic risk factors, cognitive ergonomic risk factors, ICT usage-related risk factors, musculoskeletal disorders (MSDs), and the enhancement of employees’ innovation capability, each measured using distinct measurement items.

Part three of the questionnaire was designed to assess the impacts of ergonomic workplace design on the development of sustainable competitive advantages in metal manufacturing firms. This section measured five constructs —ergonomic workplace design, physical well-being, cognitive well-being, innovation capability of employees, and the development of sustainable competitive advantages —on a five-point Likert scale. These measurement items were carefully designed to consider the interaction between employees' and non-employees' elements within the workplace.

4.3. Instrument validity and reliability Test

To validate the instrument, the focus shifted towards ensuring its accuracy. Validity, in essence, reflects the extent to which a measurement aligns with its intended purpose. Content validity, a crucial aspect, was not quantitatively assessed. Instead, this involved ensuring that the instrument encompassed all essential items while excluding irrelevant components within a specific domain of constructs. According to Hamed (2016), establishing content validity through a judgmental approach entails thorough literature reviews followed by evaluations from expert judges. In this study, experts' judgments, field observations, and interviews were leveraged to validate the instrument's contents. The researcher contended that as the instrument's contents were meticulously crafted based on an extensive literature review, the items were appropriate for exploring and quantifying the impact of ergonomic workplace design on the development of sustainable competitive advantages. Furthermore, a structured interview (refer to Appendix A) involving 30 employees working at the management, supervisor, team leader, and coordinator levels, was conducted to validate the instrument's contents.

Following the validation and testing processes based on the study sample, 219 questionnaires were distributed, with 209 questionnaires returned. Ten questionnaires were not collected, resulting in a questionnaire return rate of (209/219) * 100 = 95.4%. After a preliminary analysis of the 209 collected questionnaires, nine were rejected due to incomplete responses provided by the respondents. Consequently, 200 of the collected questionnaires were considered suitable for proceeding with the analysis of the second specific objective, which aimed to investigate the impacts of ergonomic risk factors on the well-being and innovation capability of employees. Among these 200 collected questionnaires, 116 respondents met the criteria for the required data to analyze specific objective three (investigating the impacts of ergonomic workplace design on the development of SCA in metal manufacturing firms, specifically respondents with two years or more of work experience), and results from these questionnaires were included in the subsequent analysis phases.

The acknowledgment of potential errors affecting research outcomes arising from measurement inaccuracies is crucial. Typically, assessing the reliability of the instrument, including measurement items and corresponding scales, is a common practice. The reliability of each measurement item for each construct is detailed below:

4.4. Analysis of data for SEM Model results

The analysis of the CB-SEM model aimed to test the impacts of ergonomic risk factors on the well-being and innovation capability of employees in metal manufacturing firms. Constructs and measurement items were developed based on a literature review to measure these impacts. Data were collected through a self-administered questionnaire from employees in steel and iron manufacturing, metal products manufacturing, and medium-scale metal manufacturing firms. CB-SEM analysis was chosen due to the theoretical foundation of the constructs and the size of the viable returned questionnaire (200). Moreover, the PLS-SEM analysis was chosen to investigate the prediction power of ergonomic workplace design on the developments of sustainable competitive advantages and the size of the viable returned questionnaire (116).

Descriptive statistics: Descriptive statistics were used to analyze the prevalence of ergonomic risk factors leading to physical and cognitive disorders. Table 4.1 presents the mean and standard deviations of variables related to physical ergonomic risk factors, cognitive ergonomic risk factors, utilization of ICT infrastructure, overall well-being (MSD risk-free), and innovation capability of employees.

Table 4.1 Descriptive Statistics

Variable	Mean	SD	N
Physical ergonomic risk factors	4.04	0.958	200
Cognitive ergonomic risk factors	4.03	0.914	200
Utilization of ICT infrastructure	4.19	0.844	200
Overall well-being (MSDs risk free) and its prevalence	4.24	0.857	200
Innovation capability of the employees	4.08	0.963	200

Note(s): ICT = *Information Communication Technology*, MSDs=*Musculoskeletal Disorders*, SD= *Standard Deviation, N=Number of Observations*

From 200 observations in Table 4.1, neutral awkward postures show a mean value of 4.04 with a deviation of 0.958 from the mean. Cognitive ergonomic risk factors have a mean value of 4.03 with a standard deviation of 0.914. The utilization of ICT in the workplace has a mean value of 4.19, with a deviation of 0.844 from the mean. Overall well-being (MSD risk-free) demonstrates a mean value of 4.24 and a deviation of 0.857 from the mean. The innovation capability of employees in the workplace has a 4.08 mean value and deviates at 0.963 from the mean.

4.5. Assessment of proactive frameworks and design strategy.

This subsection delves into the evaluation of proactive tools and design strategies within metal manufacturing firms. The researcher conducted assessments to evaluate the implementation and utilization of these tools, using the following key questions:

- What methods do you employ to assess the risks of developing work-related musculoskeletal disorders? Interviewees were presented with options such as RULA, REBA, OWAS, the Body discomfort scale, and other relevant methods.
- Which method(s)/tool(s) do you utilize to formulate specific workplace design solutions aimed at reducing the prevalence of work-related disorders and accidents? Respondents were provided with options including ergonomics guidelines, studying similar cases, making judgments based on experience, fostering innovation, and other relevant tools.

The results from these assessments provided valuable insights. Notably, a significant percentage of respondents (94%) relied on experience-based judgment for developing workplace design solutions, while a minimal proportion (12%) mentioned the use of studying similar cases for specific workplace design. In this assessment, none of the respondents select ergonomic guidelines for workplace design.

Moreover, the evaluation of methods/tools used for assessing the risk of work-related disorders revealed different patterns. A small percentage of respondents, 1.5% and 2.5%, utilized formal methods like REBA and the Body Discomfort Scale respectively, while the majority (96%) did not employ any specific tools for assessing risks related to work-related disorders.

Moving forward, the dissertation delves into the prevalence of ergonomic risk factors across different occupation types within metal manufacturing firms.

***Assessment of cognitive disorder based on types of occupations*:** The analysis of cognitive disorders across various occupations within metal manufacturing firms reveals substantial discrepancies among different job categories, as detailed in Table 4.2.

Table 4.2. Prevalence of cognitive disorder based on types of occupations

<table>
<tr><td>Types of Occupation</td><td rowspan="2">Welding and Metal Cutting</td><td rowspan="2">Machining Operation</td><td rowspan="2">Galvanizing, assembling and other processing operations</td><td rowspan="3">X^2</td><td rowspan="3">p-value</td><td rowspan="3">Kendall’s tau-b</td></tr>
<tr><td rowspan="2">Immediate factors for cognitive disorders</td></tr>
<tr><td>Weighted moving Average (WAM)</td><td>WAM</td><td>WAM</td></tr>
<tr><td>Stress</td><td>4.2</td><td>4.5</td><td>4.2</td><td>39.6</td><td>0.003</td><td>0.102</td></tr>
</table>

Fatigue	4.1	4.2	3.3	37.9	0.00	-0.28
Suffocation	4.1	3.2	3.3	23.8	0.002	-0.201
Exhaustion	4.2	3.9	4.0	5.15	0.74	-0.03
Dissatisfaction	4.4	3.7	3.5	39.7	0.00	-0.07

In welding and metal cutting operations, the most prominent cognitive disorders include work-related stress (mean = 4.2), dissatisfaction (mean = 4.4), fatigue (***mean = 4.1***), exhaustion (mean = 4.2), and suffocation (***mean = 4.1***). The high levels of dissatisfaction and work-related stress suggest that the demanding nature of these tasks, which often involve intense concentration and physical strain, contributes significantly to cognitive distress.

Within machining operations, notable levels of work-related stress (***mean = 4.5***), cognitive fatigue (mean = 4.2), and exhaustion (mean = 3.9) were measured. These results highlight the extreme tiredness and exposure to work-related stress and other factors for a prolonged time that exposed employees to fatigue and exhaustion. Field observations and interviews revealed that many employees in machining operations rely extensively on their cognitive abilities for precision and repetitive tasks over prolonged periods. The mean satisfaction score (*mean = 3.7*) indicates that while dissatisfaction is present, it is overshadowed by the more severe impacts of fatigue and exhaustion.

In other production processes, such as galvanizing and assembling, significant cognitive disorders reported include work-related stress (mean = 4.2), dissatisfaction (mean = 3.5), and exhaustion (mean = 4.0). These findings reflect the physical and mental demands of these roles, where prolonged standing and repetitive tasks can lead to cognitive strain. Fatigue (mean = 3.3) and suffocation (mean = 3.3) are also present, but to a lesser extent, indicating that while they are relevant factors, they do not dominate the cognitive disorder landscape as much as work-related stress, dissatisfaction, and exhaustion.

The statistical analysis supports these observations, with significant chi-square values and p-values indicating strong associations between job types and the prevalence of cognitive disorders. For instance, the chi-square value for work-related stress (39.6), dissatisfaction (39.7), and fatigue (37.9) suggests that these disorders are particularly pronounced in certain occupations. The Kendall's tau-b values, while varying, indicate moderate correlations, particularly in the cases of fatigue, stress, and dissatisfaction.

Overall, the prevalence of cognitive disorders among workers in metal manufacturing firms varies significantly by occupation. The findings highlight the need for targeted interventions to mitigate cognitive stressors, particularly in roles with high reported levels of dissatisfaction, fatigue, and exhaustion. Addressing these issues proactively can lead to improved worker well-being and productivity, ultimately fostering a healthier work environment across the sector.

Analysis of employees' physical body position in metal manufacturing firms: The measurement of employees' physical body positions within metal manufacturing firms aimed to assess the correlation between their body postures and the physical factors of the non-employees' elements, like machinery and other tools.

Employees rated their physical postures on a scale from 0 to 4, indicating the frequency of exposure during their shifts, where 0 indicated a posture not related to the work, 1 indicated rare exposure (1-5% of the shift or 00:08 to 00:40 hrs. of the shift), 2 indicated occasional exposure (6-33% of the shift or 00:48 to 03:04 hrs.), 3 represented frequent exposure (34-66% of the shift or 03:10 to 05:30 hrs.), and 4 indicated constant exposure (05:36 to 08:00 hrs.).

The results of the normality test revealed a significant deviation from normality (Lilliefors Sig = 0.000, <0.05), indicating a non-normal distribution of the data. To assess whether there were significant differences in the measured values across different categories, the Kruskal-Walli's test was conducted, which revealed significant differences ($p < 0.05$) in employees' physical body positions across various workstations.

The highest mean value for trunk position was recorded in the 20^0-60^0 flexion categories, indicating frequent exposure during the time period of 03:10 to 05:30 hours of the shift. The next highest mean values were observed in the categories of 0^0-20^0 flexion and 0^0-20^0 extension, both indicating occasional exposure during 6-33% of the shift (00:48 to 03:04 hours), while the upright trunk position reflected rare exposure in the metal manufacturing firms.

In terms of ***upper arm position***, the highest mean value was recorded for the 45^0-90^0 flexion categories, indicating occasional to nearly frequent exposure. The second highest mean value was observed in the >20^0 extension, *20^0-45^0 flexion category*, indicating occasional to frequent exposure. Positions greater than 90^0flexion were rated with a mean frequency value of 1.51, indicating rare to nearly occasional exposure.

For the ***lower arm***, maximum exposure was recorded at positions less than 60^0 flexion or greater than 100^0 flexion, with a mean frequency value of 2.45, indicating occasional to frequent exposure. The position of the lower arm at 60^0-100^0 flexion had a mean frequency value of 2.42, indicating occasional to nearly frequent exposure. The highest exposure for the legs was documented for the position of bilateral weight bearing, walking, or sitting, with a mean frequency value of 3.04. This was followed by the position of unilateral weight bearing, featherweight bearing, or an unstable posture, which had an average frequency value of 1.31.

The analysis provides insights into employees' physical body positions within metal manufacturing firms, highlighting exposure levels associated with different postures. The findings can aid in assessing ergonomic factors and potential risks linked to employees' physical positions in the workplace.

The table showcasing the summary statistics and test results for physical body factors can be found in Appendix A: Analysis of Employees' Physical Body Position in Metal Manufacturing Firms.

The researcher conducted an assessment of the clustering of measurements for employees' physical body positions based on the operations they performed. This clustering analysis facilitates the comparison of body positions across various operational tasks within the metal manufacturing firms, aiming to identify patterns and discrepancies in posture. The figure visually illustrates the variations in physical body positions concerning specific tasks or operations, aiding in the identification of prevalent postures and potential ergonomic challenges associated with different operations.

From the data depicted in Figure 4.3, it is evident that the trunk position at 20^0-60^0 flexion and $>20^0$ extension exhibited the highest exposure during welding and metal cutting occupations, with an average exposure frequency of 3.14. The upper arm position at greater than 45^0-90^0 flexion had a mean exposure frequency of 2.92. Similarly, the lower arm position at less than 60^0 flexion or greater than 100^0 flexion recorded the highest mean value, with an average exposure frequency of 2.56. Furthermore, the leg position at bilateral weight bearing, walking, or sitting showed a mean exposure frequency of 2.72 in welding and metal cutting operations.

The figure presenting the summary statistics and test results for the clustering of Measurements for physical body positions in metal manufacturing firms is displayed in Appendix A:

4.6. Qualitative Data Analysis

In the qualitative data analysis section, interviews were conducted with company managers, supervisors, team leaders, and randomly selected employees from various metal manufacturing firms to validate the results of the self-reported questionnaire. An interview guide, divided into three sections, was utilized during these interviews. The first section aimed to gather job-related information, the second focused on participants' awareness of work-related disorders, cognitive issues, and ergonomic risks, while the third section assessed the implementation of proactive tools and design strategy involvement in workplace design decisions.

Thirty participants (working as managers, supervisors, team leaders, and selected employees**)** working at different levels from the *case-selected* metal manufacturing firms were interviewed based on the prepared guide. Additionally, interviews were conducted with managers, production heads, and visual assessments were carried out in the working environments of these firms.

Noteworthy observations emerged during the analysis of responses provided by industry managers regarding ergonomic risk factors, workplace safety, and design.

- ✓ Concern about work-related disorders: 40% of managers expressed worries about the potential impact of work-related musculoskeletal disorders and stress disorders on their organization, showing significant awareness.
- ✓ Actions to reduce risks: Only 20% of managers are considering taking action to reduce work-related musculoskeletal and stress problems in their workplace.
- ✓ Clarity of mitigation plans: 6.7% of managers have clear plans to mitigate work-related disorders, indicating a lack of concrete strategies among the majority.

In section 3, which focused on involvement in task design decisions, valuable insights were obtained:

- ✓ Participation in specifying jobs and equipment: 16.7% of managers are engaged in specifying jobs and equipment, with most not actively involved in this process.
- ✓ Impact on decision-making: Those involved rated their impact between 2 and 8 on a scale of 1-9, indicating a moderate to high level of impact.
- ✓ Awareness of ergonomics guidelines: Only 16.7% of managers are aware of ergonomics guidelines, with the majority lacking specific knowledge in this area.

These findings underscore the importance of stakeholder collaboration to ensure that workplace design and equipment specifications align with ergonomic principles, prioritizing employee well-being. Field observations highlighted operational strategies focusing on material and machinery utilization, market competitiveness, and quality management systems. The workplace layout was primarily based on planned production capacity, machinery types, and adherence to standard operating procedures (SOP). Notably, none of the observed industries demonstrated a trend of considering human factors during the workplace design phase. Through document analysis and field observations, it was noted that numerous large-scale metal manufacturing industries had developed Job Analysis Documents (JAD) outlining the number of employees, required skills, and knowledge at each production stage following SOP. However, the utilization of JAD was limited to only a few medium-scale metal manufacturing firms. Furthermore, the researcher examined industries utilizing JADs to determine their update frequency, revealing that many metal manufacturing firms did not regularly update their JADs.

Additionally, the lack of dedicated policies aimed at safeguarding employee well-being was observed, leading to potential hazards such as awkward postures, noisy environments, high-vibration machinery, and dusty workplaces. This emphasizes the necessity for proactive measures to address ergonomic concerns and enhance workplace safety. The researcher further explores the awareness within the country regarding the significance of implementing ergonomic risk factors in metal manufacturing firms in the upcoming sections.

Existing proclamations in Ethiopia regarding occupational health and safety:

The governance of occupational health and safety (OHS) in Ethiopia dates back to the 1940s with Proclamation No. 58/1945, evolving to address the country's industrialization needs. This legal framework was influenced by International Labour Organization (ILO) conventions, emphasizing labour inspection principles. Subsequent regulations, such as Proclamation No. 232/1964, aimed to enhance occupational safety and health management, aligning with changing industrial dynamics and adapting European models to Ethiopia's unique industrial landscape and labor administration system.

Recent legislative efforts have worked towards modernizing Ethiopian laws in line with international standards, resulting in more comprehensive legal instruments for OHS. The Constitution of the Federal Democratic Republic of Ethiopia, endorsed on August 21, 1995, emphasizes decent work conditions, including safety, health, and the working environment. Notably, *Article 9* prioritizes the Constitution's power and the integration of ratified international agreements, including ILO conventions, into national law. *Article 10* underscores the inviolable nature of human rights, particularly in labor contexts.

Proclamation No. 377/06 stands out as a comprehensive labour law in Ethiopia, governing all aspects of labour relations to ensure fundamental rights and obligations. This law mandates employers to maintain safe and healthy workplaces, including compliance with OHS requirements, employee training on workplace hazards, and the establishment of safety committees. While these regulations address general safety, they lack a specific focus on ergonomic principles crucial for preventing work-related disorders.

The Ethiopian OSH Directive-2008 provides detailed guidelines for occupational safety and health, emphasizing risk assessment, hazard mitigation, and the provision of personal protective equipment by employers. The directive aims to foster a safe work environment, protect against occupational hazards, and promote employee well-being, though with limited focus on ergonomic principles.

Labour Proclamation No. 1156/2011 and Labour Proclamation No.1156/2019 outline employer obligations related to OSH, stressing the maintenance of a safe working environment and workers' rights. However, these proclamations do not explicitly address ergonomic practices vital for enhancing workplace efficiency and preventing musculoskeletal issues.

Moreover, Ethiopia ratified the Occupational Safety and Health Convention, 1981 (*ILO Convention No. 155*) in 1991, providing a framework for national policies to promote OHS and enhance working environments.

In conclusion, while Ethiopia boasts a robust legislative framework for occupational health and safety, there exists a notable gap in integrating ergonomic principles. Emphasizing ergonomic workplace design is imperative for proactively preventing work-related disorders and cultivating a safer, more productive environment, particularly within the metal manufacturing sector.

4.7. Chapter Summary

In this chapter, the data analysis and results prepare us for the next sections on model development. The analysis includes descriptive statistics and data assessments for CB-SEM and PLS-SEM modelling methods. The data were collected through a customized questionnaire, semi-structured interviews, and field observations to support the findings stated in the study. The research looked at current ergonomic risk factor management practices, work-related disorders, and their effects across different jobs in the metal manufacturing firms.

The CB-SEM model analysis examined how ergonomic risk factors impact employee well-being and innovation capability in metal manufacturing environments. Data gathered from questionnaires filled out by employees was analysed, specifically looking at the prevalence of ergonomic risk factors related to physical and cognitive disorders. The smart PLS-SEM model assessed how ergonomic workplace design predicts the development of sustainable competitive advantages in metal manufacturing firms.

Moreover, the assessment of cognitive disorder based on types of occupations was conducted and found that stress, dissatisfaction, suffocation, exhaustion, and fatigue are the prevalent intermediate factors for cognitive disorders in the metal manufacturing firms. The results found from the assessment of employees' physical body position in metal manufacturing firms are also used as a benchmark for conducting further analysis on their impacts on the innovation capability and development of sustainable competitive advantages in metal manufacturing firms. Qualitative data analysis included interviews with management and observational studies in metal manufacturing environments. It revealed a lack of ergonomic focus in workplace practices and gaps in policies related to employee well-being and safety. Ethiopia's laws on occupational health and safety meet international standards but do not include the specific ergonomic principles needed to prevent work-related disorders. To fix the problems with current rules and practices, the metal manufacturing industry needs to put more emphasis on ergonomic workplace design to boost productivity, safety, and well-being.

Chapter Five
Model development to determine the impacts of ergonomic risk factors on well-being and innovation capability of employees

5.1. Introduction

In chapter four, the prevalence of ergonomic risk factors in selected metal manufacturing firms is discussed; however, the main focus of this chapter is to present the impacts of ergonomic risk factors in the selected manufacturing firms. This chapter primarily focus on investigating the impacts of ergonomic risk factors on the well-being and innovation capability of employees in the selected manufacturing firms. Moreover, this chapter proposed a model for investigating the impacts of ergonomic risk factors on the well-being and innovation capability of employees in selected manufacturing firms.

Investigating the impacts of ergonomic risk factors on employees' well-being and innovation capability is vital for developing the right types of frameworks for proactively preventing the occurrence of the root causes instead of focusing only on the immediate causes of ergonomic risk factors in the selected manufacturing firms.

5.2. Conceptual Model Development

The overall well-being of employees leads to innovation capability improvements.

In the workplace, the overall well-being of employees is integral to enhancing innovation capability. Musculoskeletal disorders (MSDs) represent the most common work-related health issues in manufacturing sectors, often arising from the nature of work tasks and the workplace environment (Rahul et al., 2017; EASHW, 2019). These disorders lead to work disability, sickness, absenteeism, and reduced productivity among employees (Bevan, 2015; Madan & Grime, 2015). Moreover, working in ergonomically unsound jobs, physical factors at the workplace, such as frequent or prolonged work, inadequate postures, and exposure to vibration, result in different MSDs (Madan & Grime, 2015). Addressing MSD prevalence not only impacts employee well-being but also influences corporate productivity, highlighting the importance of mitigating these issues to foster employees' innovation capability (Bevan, 2015). In developing countries, the neglect of MSDs as critical workplace concerns poses challenges to both employee innovation capability and overall productivity in the manufacturing sector, emphasizing the necessity for proactive measures (Gosselin et al., 2020).

The complexities surrounding MSD development stem from challenges in integrating employees' and non-employees' demands, showing the need for a holistic approach to sustain innovation practices(Melhorn & Gardner, 2004). Researchers advocate for the elimination of MSD prevalence due to its positive correlation with improvements in employees' innovation capability (Awan & Sroufe, 2020). This forms a basis for a hypothesis that physical well-being from MSD risk significantly impacts the innovation capability of employees in the manufacturing industry (H1).

Cognitive well-being emerges as a critical factor influencing innovation capability. Cognitive well-being, essential for workplace quality, is often compromised in industrial settings due to workplace stresses, management issues, and excessive work demands (Vischer, 2008; So hail & Kashif,2016). Cognitive pressures faced by employees give rise to psychosomatic musculoskeletal disorders whose effects could hinder performance, making psychological well-being a potentially positive impact on employee well-being and innovation capability (Reinhold et al., 2008; Andersen & Westward, 2014). Researchers contend that cognitive well-being within the workplace positively correlates with employee well-being and innovation capability, forming the foundation for the hypothesis that cognitive ergonomic risk factors affect the physical well-being and innovation capability of employees in manufacturing environments (*H_2).*

Furthermore, the prevalence of ergonomic risk factors, such as awkward postures, significantly contributes to the global burden of occupational diseases, impacting employee performance and well-being (IOE, 2019; Ansari et al., 2018; Hambali et al., 2019). Correcting ergonomic issues like awkward postures can enhance employee physical well-being and innovation capability, leading to the hypothesis that reduced physical ergonomic risk factors in the workplace are positively associated with improvements in both physical employee well-being and innovation capability (***H_3*).**

Effective utilization of Information and Communication Technology (ICT) infrastructure emerges as a critical factor for innovation capability. However, poor utilization of ICT facilities at the workplace affects the well-being of employees. Studies have shown that poor ICT utilization can lead to techno-stress and physical discomfort among employees, ultimately affecting their well-being and performance (Spiezia, 2011; Curbano, 2019; Karimikia et al., 2021). To know the effects of the utilization of the ICT infrastructure on the innovation capability of employees within their workplace, the researchers argue that alleviated poor utilization of ICT infrastructure at the workplace influences both employee physical well-being and innovation capability, highlighting the necessity for optimized ICT strategies to support employee health and innovation (*H_4).*

This study aims to develop a comprehensive model to investigate the impacts of ergonomic risk factors on the well-being and innovation capability of employees in the selected manufacturing firms, utilizing covariance-based Structural Equation Modeling (SEM) techniques to analyze the intricate relationship between ergonomic factors, innovation capability, and well-being at work

(Kiraz et al., 2020; Lomax and Schumacker, 2012). The proposed conceptual model seeks to elucidate how ergonomic factors intersect with employee well-being and innovation capability within metal manufacturing firms, encapsulating this interplay in Figure 5.1.

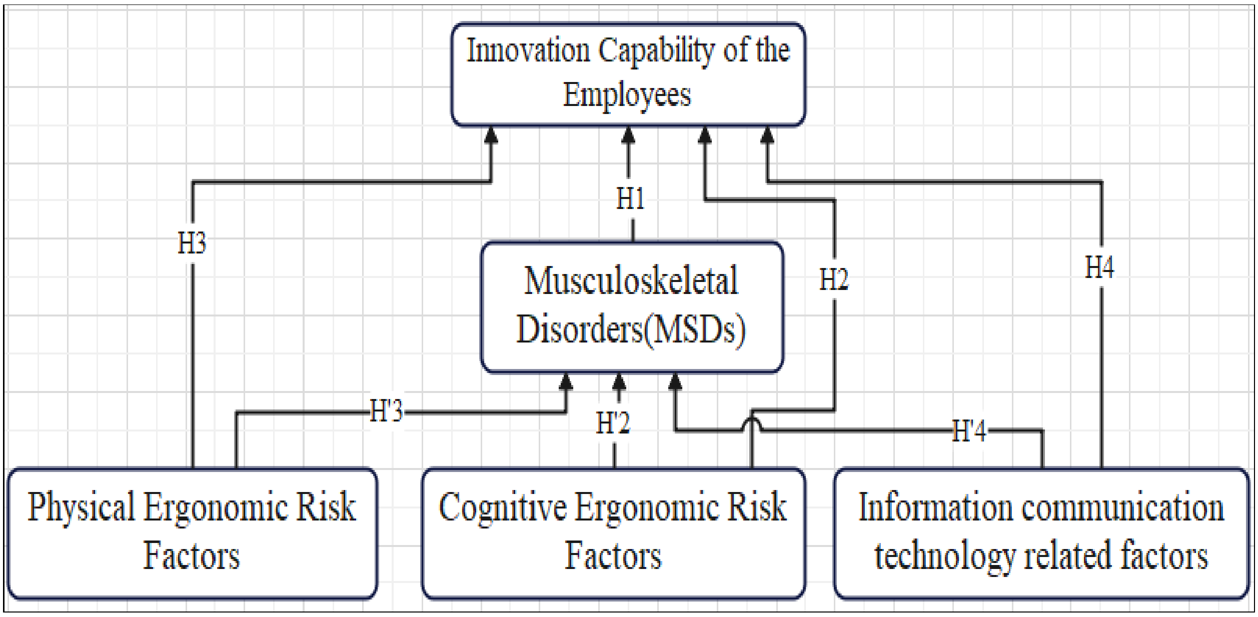


Figure 5.1: Hypothetical model of the ergonomic factors influencing the well-being and innovation capability of the employees (source by the author).
Note: H= hypothesis 1 to 4

5.3. Assessments of the measurement model:

Among various empirical reliability testing methods, internal consistency analyses evaluate result consistency across factors within a test. Cronbach's alpha, a prevalent measure of internal consistency, provides an overarching assessment of this reliability aspect (Hajjar, 2018). Consequently, in this study, the internal consistency of the constructs was gauged using cronbach's alpha, supplemented by structured interviews, existing research insights, and researchers' judgments and observations.

The internal consistency analysis was conducted both for the overall instrument scale and individually for the distinct constructs within groups. In analyzing the impact of ergonomic risk factors on employee well-being and innovation capability, the cronbach's alpha based on standardized items for each constructs is depicted in Table 5.1. Following Ravand and Baghaei's (2016) study, a cronbach's alpha of 0.70 or higher supports indicator homogeneity. The findings in Table 5.1 illustrate that the cronbach's alpha for each construct surpasses 0.90, indicating high acceptability levels. Moreover, the convergent reliability of each measured construct is also greater than 0.90, which indicates acceptable reliability.

In evaluating the well-being and innovation potential of employees within metal manufacturing firms, cognitive ergonomic risk factors (coded as PS_1–PS_7) were identified following an extensive literature review. These factors comprise mental exhaustion or feeling drained by the end of the workday, cognitive overload experienced in the workplace, feeling overwhelmed by the volume of mental processing, unclear instructions or miscommunication at work, limited discussions with supervisors regarding mental workload, restricted involvement in decision-making processes, and workplace distractions. These identified factors are instrumental in assessing the cognitive ergonomic risk factors that impact the well-being and innovation capacities of employees in the metal manufacturing industry.

Furthermore, the measurement unit employed to assess physical ergonomic risk factors, coded as AW_1-AW_7, encompasses a range of elements, such as working in improper postures, engaging in static positions, enduring prolonged periods of standing, extended periods of sitting, adopting bending postures in the workplace, performing repetitive movements, and tilting the head forward and sideways. These metrics play a critical role in evaluating the physical ergonomic factors that influence the physical well-being of employees in the metal manufacturing sector.

Table 5.1. Instrument Reliability and Validity Test

Items to be measured	Code	Cronbach's Alpha (α)	CR	(AVE)
Physical ergonomic risk factors	AW_1-AW_7	0.913	0.932	0.66
Cognitive ergonomic risk factors	PS_1 – PS_7	0.917	0.935	0.67
Utilization of ICT	ICT_1- ICT_7	0.910	0.929	0.65
Musculoskeletal Disorders	MS_1- MS_7	0.938	0.95	0.73
Innovation capability of employees	INO_1–INO_7	0.954	0.963	0.787

The quality of a measurement model can also be inspected by checking convergent validity, which shows the amount of variance the indicators have in common. The average variance explained is greater than 0.64, which is greater than the average variance extracted (AVE) (>0.5), which is an indication of convergent validity (Ravand and Baghaei, 2016).

The detailed explanations for each construct are shown in Table 5.2. In Table 5.2, all the questions, the latent variables, and the number of questions used to measure each latent variable are presented in brief. The study conducted by Malkanthie (2018) stated that it is hard to get the model to have a good fit in the initial run. Hence, the model fit indices need to be modified to get a better fit by reducing the overall chi-square by adding covariance on indicators. Moreover, Table 5.2 also shows the Amos outputs of the final measurement model fit parameters like the chi-square, the comparative fit index (CFI), the Tucker-Lewis coefficient (TLI), the Incremental Fit

Index (IFI), the Factor Loading, the Average Variance Extracted (AVE), and the Composite Reliability (CR) of the final SEM reliability and validity of each construct.

The quality of a measurement model can also be inspected by checking convergent validity, which shows the amount of variance the indicators have in common. High factor loadings (>0.7) and average variance extracted (AVE) (>0.5) are an indication of convergent validity (Ravand and Baghaei, 2016). As Table 2 shows, except for the seventh indicator, ICT_7 (factor loading = 0.534), and the cognitive ergonomic risk factor (PS_7) (factor loading = 0.636), the entire factor loadings of the indicators are > 0.70. Accordingly, the AVE values of each measurement model are > 0.60, which is above the acceptable 0.50 value. Both of these tests showed that the model is well fit for the data.

The Chi-square (X^2) test for all measurement models *presented* in Table 5.2 is ideal since the value of p>0.05 since the Chi-square test would be ideal with p>0.05 (Spiezia, 2011).

Table.5. 2: Observed and Latent Variables used in the Model

Variable	Measurement Items	FL	AVE	CR	A (cronbach alpha)	X^2(p)	TLI	CFI	IFI	RMSEA
Reduced physical ergonomic risk factors	AW_1	0.787	0.66	0.932	0.913	17.762(0.059)	0.983	0.992	0.992	0.062
	AW_2	0.873								
	AW_3	1								
	AW_4	0.928								
	AW_5	0.794								
	AW_6	0.717								
	AW_7	0.703								
Cognitive ergonomic risk factors	PS_1	0.794	0.67	0.935	0.917	13.58(0.193)	0.992	0.996	0.996	0.042
	PS_2	0.869								
	PS_3	0.991								
	PS_4	1.000								
	PS_5	0.923								
	PS_6	0.759								
	PS_7	0.636								
Alleviated poor utilization of ICT at the workplace	ICT_1	0.807	0.65	0.929	0.910	13.583(0.193)	0.992	0.996	0.996	0.042
	ICT_2	0.881								
	ICT_3	1								
	ICT_4	0.934								
	ICT_5	0.871								
	ICT_6	0.784								
	ICT_7	0.534								
Reduced risks of Musculoskeletal Disorder	MS_1	0.878								
	MS_2	1.000								
	MS_3	0.933								
	MS_4	0.936								

	MS_5	0.934	0.73	0.95	0.938	17.479 (0.064)	0.986	0.993	0.993	0.061
	MS_6	0.782								
	MS_7	0.751								
Innovation Capability of Employees in their workplace	INO_1	0.901	0.787	0.963	0.954	24.799(0.06)	0.978	0.989	0.989	0.070
	INO_2	0.938								
	INO_3	0.959								
	INO_4	1.000								
	INO_5	0.932								
	INO_6	0.924								
	INO_7	0.866								

Note(s): α = cronbach alpha, $AW_{1\text{-}7}$= *Awkward posture measurement items from one to seven*, AVE= Average Variance Extracted, CFI=*Comparative Fit Index*, CR=Construct reliability, FL=Factor Loading, $ICT_{1\text{-}7}$=*Information Communication Technology measurement items from one to seven*, IFI= *Incremental fit index*, $INNO_{1\text{-}7}$=*Innovation Capability measurement items from one to seven*, X^2 =Chi-Square, $MSD_{1\text{-}7}$=*Musculoskeletal Disorder measurement items from one to seven*, $PS_{1\text{-}7}$=*Psychological Risk Factor measurement items from one to seven*, RMSEA= *Root Mean Square Error of Approximation*, TLI= *Tucker-Lewis Index*

The correlation assessment has also been done to gain an initial overview of the correlations of the constructs. Hence, the bivariate correlations of the constructs are calculated. Table 5.3 shows some of the information from the correlation matrix among constructs for measuring the impacts of ergonomic risk factors on the well-being and innovation capability of employees working in their workplace.

Table 5. 3. Correlation matrix of the latent variables

Variable	Physical ERFs	Cognitive ERFs	Alleviated poor utilization of ICT facilities	MSD
Cognitive ergonomic risk factors	0.481**			
Alleviated poor utilization of ICT facilities	0.178*	- 0.235**		
MSD	0.268**	- 0.207**	0.370**	
Innovation capability	0.325**	- 0.127**	0.278**	0.345**
**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).				

Note(s): ICT = *Information Communication Technology*, MSD = *Musculoskeletal Disorder*

The correlation value presented in Table 5.3 indicated that reduced physical ergonomic risk factors within the manufacturing firms have a strong positive relationship with cognitive ergonomic risk factors (β=0.481, p<0.01), reduced risks of MSDs (β = 0.268, p<0.01), the innovation capability of employees (β =0.325, p<0.01), and alleviated poor utilization of ICT facilities in the workplace with (β =0.178, p<0.05). From this result, it is concluded that a unit increase in an awkward-posture-free working environment within the manufacturing industry will bring a 0.325-unit increase in the innovation capability of employees at the workplace.

Moreover, the positive strong relationship between the cognitive ergonomic risk factors of employees and other variables in the model indicates that a unit increase in the mechanisms used for decreasing the cognitive ergonomics risk factors in the workplace will bring a 0.235-unit increase in effective utilization of ICT facilities and a 0.207-unit increase in the physical well-being of employees within the manufacturing industry. It also increases the innovation capability of employees at the workplace (β = 0.127, $p<0.01$). A unit increase in the mechanisms that decrease the prevalence of cognitive ergonomic risk factors at the workplace will bring a 0.127-unit increase in the innovation capability of employees at the workplace.

Furthermore, employees in manufacturing firms that have a unit increase in effective utilization of ICT facilities are more likely to increase reduced risks for MSD of employees (β =0.370, $p<0.01$) and increase the innovation capability of employees at the workplace (β =0.278, $p<0.01$). Reduced risks of MSD of employees at the workplace have a strong relationship with the innovation capability of employees (β=0.345, $p<0.01$). This indicates that to improve the innovation capability of employees at the workplace, industries need to work on keeping the physical well-being of employees working within the industry. Since a unit increase in the improved ergonomics and reduced physical ergonomic risk factors will bring a 0.345-unit increase in the innovation capability of employees at the workplace.

Suitability of the Correlation Matrix

Raw data is suitable for conducting a factor analysis of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) if it is > 0.6.

The KMO and Bartlett's Test is designed to test whether the sample correlation matrix differs significantly from an identity matrix, with 1's on the primary diagonal and 0's on the off-diagonal (Field, 2018). Due to that, the value in the correlation matrices of this sample on the diagonal is 1, and on the off-diagonal is zero. Moreover, based on the information stated in Table 5. 4, the p-value of Bartlett's Sphericity Test in this output is significant ($p<0.001$). The overall KMO MSA addresses the adequacy of the measured variables for carrying out principal component analysis (PCA). In this output, the overall KMO value is 0.649, which is consistent with the assertion that it is appropriate to carry out PCA on the data (in the ''mediocre'' range) (*Backhaus et al., 2006*).

Table 5. 4. KMO and Bartlett's Test

Kaiser-Meyer-Olin Measure of Sampling Adequacy.		0.649
Bartlett's Test of Sphericity	Approx. Chi-Square	147.848
	Do	10
	Sig.	<0.001
a. Based on correlations		

Note(s): do = *degree of freedom*, KMO = *Kaiser-Meyer-Olin measure*, Sig = *Significance*

Once the suitability of the correlation matrix is tested, anti-image matrices that rely on the decomposition of the two variances are conducted for evaluating whether or not the individual constructs should be included in the factor analysis. In the output of this analysis, as shown in Table 5.5, the anti-image correlation matrix off-diagonal elements are close to 0.

The Measures of Sampling Adequacy (MSA's) for each variable on the principal diagonal all fall between 0.601 and 0.719. The value of each variable is > 0.60, which indicates that all variables can be included in the factor analysis. Based on this result, there have not been any problems with the analysis of this correlation matrix in terms of sampling adequacy.

Table 5. 5: Anti-Images Matrices

	Reduced physical ergonomic risk factors.	Cognitive ergonomic risk factors	Alleviated poor utilization of ICT facilities	Reduced risks of MSD	Innovation capability
Reduced physical ergonomic risk factors	0.607[a]	-0.451	0.034	-0.113	-0.260
Cognitive Ergonomic risk factors	-0.451	0.601[a]	-0.164	-0.055	0.090
Alleviated poor utilization of ICT facilities	0.034	-0.164	0.691[a]	-0.279	-0.168
Reduced risks of MSD	-0.113	-0.055	-0.279	0.719[a]	-0.225
Innovation capability	-0.260	0.090	-0.168	-0.225	0.673[a]

Note(s): *'a'= Superscripts that show the measure of sampling adequacy of each item, ICT= Information Communication Technology, MSD= Musculoskeletal Disorder*

Total Variance Explained: With the principal component analysis, the number of components extracted equals the total number of measured variables. In these analysis five components having a total of 35 variables are included, as shown in Table 5.6;

Table 5.6: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Physical ERFs	2.130	42.597	42.597	2.130	42.597	42.597
Cognitive ERFs	1.023	20.456	63.053	1.023	20.456	63.053
Alleviated poor utilization of ICT facilities	0.784	15.685	78.739			
Reduced risks of MSD	0.613	12.269	91.007			
Innovation capability of employees	0.450	8.993	100.000			
Extraction Method: Principal Component Analysis.						

Note(s): ICT= Information Communication Technology, MSD = Musculoskeletal Disorder

In Table 5.6, the 'Total' column contains the eigenvalues associated with each component. In principal component analysis, the eigenvalues reflect the amount of variation in the measured variables accounted for by each component. Based on this output, the first part, reduced physical ergonomic risk factors, has a range of 2.130 of the original variables and 42.597% of the variation.

The second extracted component, the cognitive ergonomic risk factors in the workplace, has an eigenvalue of 1.023, meaning that it accounts for as much variation as 1.023 of the original variables. Moreover, the percentage of variance accounted for is 20.456%. Cumulatively, having physical ergonomic risk factors and cognitive ergonomic risk factors in the workplace accounted for ***63.053%*** of the variation of the causes for the innovation capability of employees.

5.4. Assessment of the Structural Model

Figure 5.2 shows the initial SEM for evaluating ergonomic risk factors affecting the well-being and innovation capability of employees working in metal manufacturing firms. The default model has a chi-square of 1184.366, the degree of freedom is 551, and the probability level is 0.000. Hence, the value of chi-square divided by the degree of freedom (CMIN/DF) = 2.149 shows an acceptable fit between the hypothetical model and sample data. Since the value, CMIN/DF < 3 indicates an acceptable value (Marsh & However, 1985). The regression weights and goodness of fit measures of the initial model are shown in Table 5.7 and Table 5. 8, respectively.

Table 5.7: Regression Weights for the Measurement Variables in the Initial Model

Measurement Variables	Regression weight	Measurement Variables	Regression weight
Reduced risks of musculoskeletal disorder <-- Reduced Physical ERFs	0.208	ICT5	0.981
Reduced risks of musculoskeletal disorder<--alleviated poor utilization of ICT	0.387	ICT_4	0.940
Reduced risks of Musculoskeletal disorder<-- Cognitive ERFs	0.016	ICT3	1.000
Innovation capability <--reduced risks of Musculoskeletal disorder	0.384	ICT2	0.943
Innovation capability <--Reduced Physical ERFs	0.306	ICT1	0.854
Innovation capability <-- Cognitive ERFs	-0.208	ICT6	0.908
Innovation capability <--Alleviated poor utilization of ICT	0.291	ICT7	0.670
MS_4	0.934	INO4	1.000
MS_3	0.919	INO5	0.953
MS_2	1.000	INO3	0.978
MS_1	0.897	INO2	0.990

Measurement Variables	Regression weight	Measurement Variables	Regression weight
MS_5	0.976	INO1	0.954
MS_6	0.833	INO6	0.958
MS_7	0.785	INO7	0.868
PS3	1.000	AW4	0.965
PS1	0.868	AW3	1.000
PS_2	0.947	AW2	0.900
PS_4	0.986	AW1	0.828
PS_5	0.861	AW5	0.871
PS_6	0.758	AW6	0.824
PS_7	0.668	AW7	0.796

Note(s): AW1, 3, 4-7= List of physical ergonomic risk factors' measurement items, INO 1-6= List of Innovation capability measurement items, ICT 1, 2, 3-7= List of Information communication technology measurement items, MS1-7= List of musculoskeletal disorder measurement items, PS 1-6= List of cognitive ergonomics risk factors measurement items

Based on the evaluation, as shown in the regression weights of the latent variables in Table 6.7, the factor loading for all latent variables except (cognitive ergonomic risk factors---> Innovation capability of employees) in the prediction of the dependent variables and measurement items are significantly different from zero at the 0.001 level (two-tailed). The factor loading for cognitive risk factors in the prediction of innovation capability of employees in their workplace is significantly different from zero at 0.05 levels (two-tailed). Therefore, the p-value of all standard regression weights is significant. However, the relationship between cognitive risk factors and innovation capability is negative. In the context of this analysis, the negative sign suggests that as cognitive ergonomic risk factors such as stress and work-loads, increase, the innovation capability tends to decrease.

Table 5. 8. The goodness of fit measures of the initial model

Goodness of Fit Measures of the Structural Equation Model	Parameter Estimate	Minimum Cut-off Recommended by [Marsh and However, 1985]
Root Mean Square Error of Approximation (RMSEA)	0.07	<0.07
Incremental Fit Index (IFI)	0.89	>0.90
Tucker Lewis Index (TLI)	0.88	>0.90
Comparative Fit Index (CFI)	0.89	>0.90

Based on the information in Table 5.8, the RMSEA, CFI, TLI, and IFI values are nearly approaching the minimum cut-off value, and the result shows the model can still be considered valid.

However, to have a better model fit, the researcher decided to remove measurement items that have a small number of factor loadings. During the model fitting, the measurement item two (IT2), which states the effects of ICT not fit for the work at the workplace on the health and innovation capability, was removed. The cognitive ergonomic risk factor measurement item seven (PS7), *lack of discussion with supervisors on mental workload*, which has the minimum number of the factor loading, was also removed from the initial model. Moreover, the reduced physical ergonomic measurement item two (AW2), which has almost the same capacity as measurement item one (AW1) to measure reduced awkward posture, was removed for better model fit.

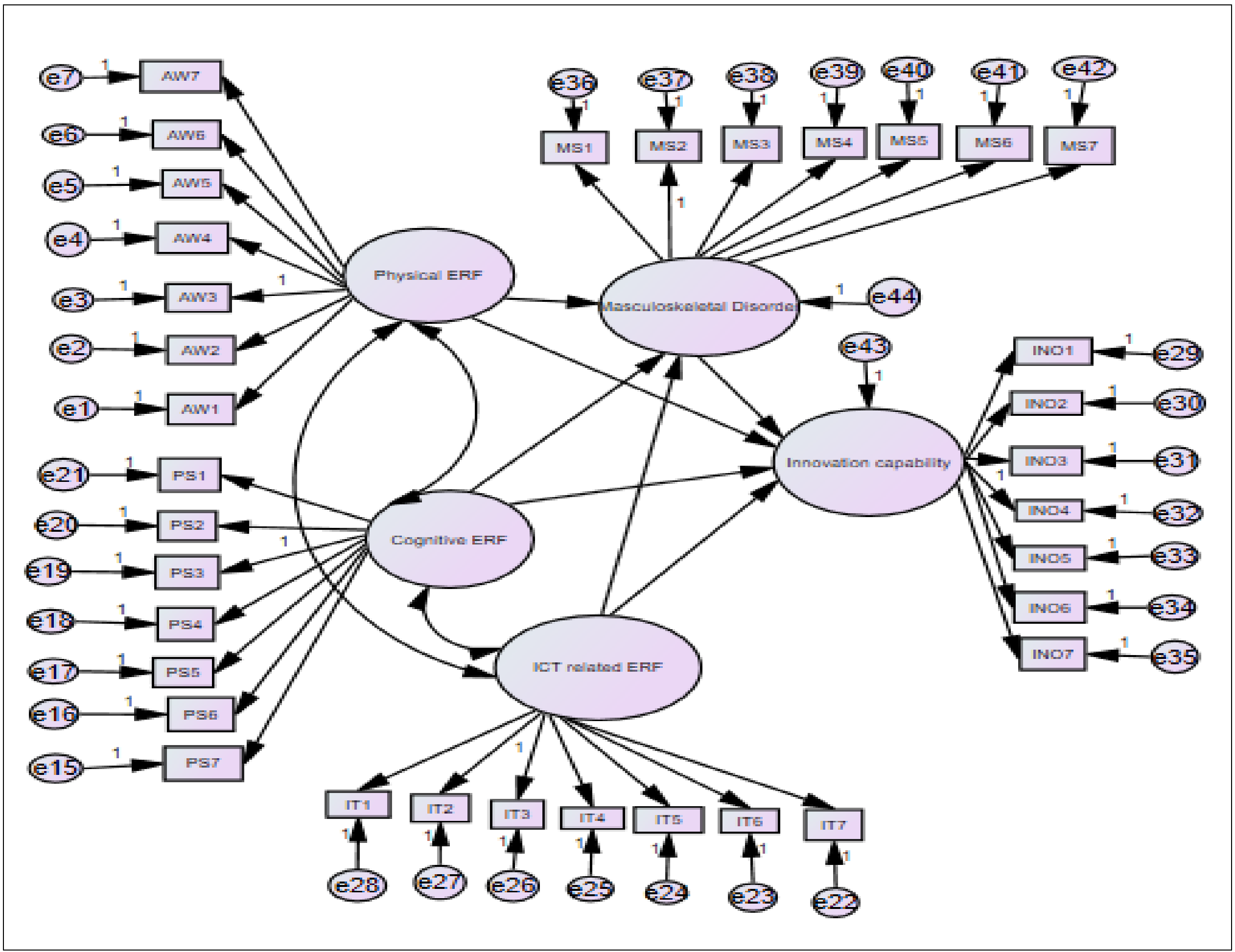


Figure 5. 2: Initial SEM for evaluating ergonomic risk factors on employees' well-being and innovation capability in their workplace (source by the author)

Note: AW=reduced awkward posture, INO=innovation capability, IT=information communication technology, MS=reduced risk of musculoskeletal disorder, PS=Cognitive ergonomic risk factors, e= error, 1= factor loading of the path from each of the latent variables to an indicator is fixed to 1 to provide a measurement scale for the latent factor.

After performing indices modification and removing the three measurement items from the three latent variables, the final chi-square was a reduced model with a better fit. After the above iteration, Table 5.9 shows the factor loading of each measurement item and Table 5.10 shows the regression weight of the latent variables in the final modified model.

Table 5.9: Factor loading of the measurement variables in the modified model

Measurement Variables	Regression weight	Measurement Variables	Regression weight
Musculoskeletal disorder <-- Reduced physical ERFs	0.255	ICT5	1.000
Musculoskeletal disorder<--Alleviated poor utilization of ICT infrastructure	0.369	ICT_4	0.924
Innovation capability <--Reduced risk of musculoskeletal disorder	0.378	ICT3	0.965
Innovation capability <--Reduced physical ERFs	0.325	ICT1	0.798
Innovation capability <-- Cognitive ERFs	-0.211	ICT6	0.930
Innovation capability <--Alleviated poor utilization of ICT	0.287	ICT7	0.684
MS_4	0.934	INO4	1.000
MS_3	0.919	INO5	0.953
MS_2	1.000	INO3	0.978
MS_1	0.897	INO2	0.989
MS_5	0.976	INO1	0.954
MS_6	0.833	INO6	0.958
MS_7	0.785	INO7	0.868
PS3	1.000	AW4	0.999
PS1	0.859	AW3	1.000
PS_2	0.948	AW1	0.828
PS_4	0.972	AW5	0.941
PS_5	0.846	AW6	0.900
PS_6	0.734	AW7	0.858

Note(s): AW1, 3, 4-7= List of reduced physical ergonomic risk factors measurement items, INO 1, 2, 3, 5, 6,7= List of Innovation capability measurement items, ICT1, 3-7= List of alleviated poor utilization of information communication technology measurement items, MS1-7= List of reduced risks of musculoskeletal disorder measurement items, PS1-6= List of cognitive ergonomic risk factors measurement item

The summary of the standardized direct effect, standardized indirect effect, and standardized total effects of each latent variable on the dependent variables are shown in Table 6. 11.

The structural equation model shown in Figure 5.3 is tested and investigated. Moreover, the covariance was created between two errors /predictors of the innovation capability of employees. The outputs of Amos' analysis of the fitness parameters are shown in Table 5.10. Based on the research outputs of the scholars, the value of chi-square (CMIN) divided by degree of freedom (DF) < 3 indicates an acceptable fit between the hypothetical model and sample data (Hair et al., 2021); moreover, the value of CMIN/DF < 5 indicates a reasonable fit (Marsh and Hocevar,1985). The finding in this study shows that the modified final model has a chi-square (CMIN) of 906.608, a degree of freedom (DF) of 454, and a p=0.000. Therefore, the value

(CMIN/DF=1.997) < 3 indicates that it is an acceptable fit between the hypothetical model and sample data.

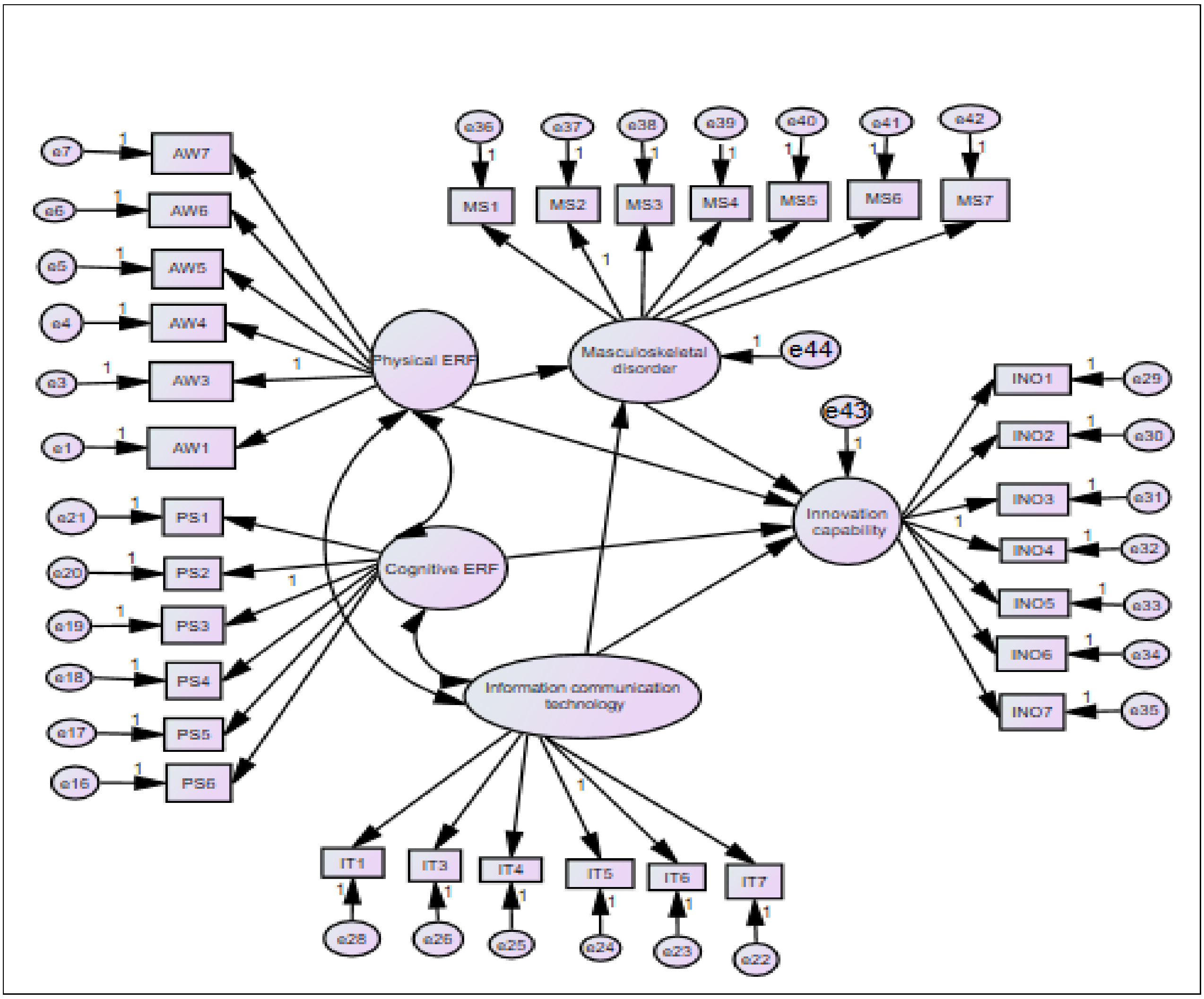


Figure 5.3: The Final SEM Model for investigating the impacts of ergonomic risk factors on the well-being and innovation capability of employees in their workplace (source by the authors).

Note: AW=Awkward Posture, INO=innovation capability, IT=information communication technology, MS=Musculoskeletal disorder, PS=Psychological risk factor, e= error, 1= factor loading of the path from each of the latent variables to an indicator is fixed to 1 to provide a measurement scale for the latent factor.

Table 5. 10 show the model goodness-of-fit measures such as IFI, TLI, CFI, and RMSEA of the final model. The study conducted by Hair et al. (2014) recommended categorical outcomes and reported that the cut-off values, such as RMSEA < 0.07, TLI > 0.90, CFI > 0.90, and IFI > 0.90, are reasonably large. The findings of this study, as presented in Table 5.10, indicated that the listed variables met the minimum cut-off value. Therefore, the model is valid.

Table 5.10. The Goodness of Fit measures of the Final Structural Equation Model

Goodness of Fit Measures of the Structural Equation Model	Parameter Estimate	Minimum Cut-off Recommended by Hair et al, (Hair et al,2014)

Root Mean Square Error of Approximation (RMSEA)	0.063	<0.07
Incremental Fit Index (IFI)	0.913	>0.90
Tucker Lewis Index (TLI)	0.904	>0.90
Comparative Fit Index (CFI)	0.912	>0.90

5.5. Effects Analysis

The multivariate analysis findings, as presented in Table 5.11, show the effects of exogenous variables (physical ergonomic risk factors, cognitive ergonomic risk factors, utilization of ICT facilities) on endogenous variables (innovation capability of employees and overall well-being) in metal manufacturing firms. The direct and indirect effects of ergonomic risk factors on employee innovation capability and well-being are explored in this analysis. The exogenous variables, i.e., the ergonomic risk factors in the metal manufacturing firms, have a direct effect, which means that the influence of exogenous variables (the ergonomic risk factors) on the endogenous variable (Innovation capability of employees) is not mediated by the overall well-being of employees in the model and has an indirect effect as those influenced by the overall well-being of employees. The total effects, comprising both direct and indirect effects, of these exogenous variables on the endogenous variables are summarized in the Table 5.11.

Table 5.11. Standardized effects (β) of Constructs from the final Structural Equation Model

	Reduced physical ergonomic risk factors	Reducing Cognitive ergonomic risk factors	Alleviated poor utilization of ICT facilities	Reduced risk of MSD
a. Standardized Direct Effect				
Reduced risk of MSD	0.246	0.00	0.344	0.00
Enhancing Innovation capability of employees	0.299	-0. 202	0.241	0.336
b. Standardized Indirect effect				
Reduced risk of MSD	0.000	0.00	0.000	0.00
Enhancing Innovation capability of employees	0.089	0.00	0.116	0.00
c. Standardized Total Effect				
Reduced risk of MSD	0.264	0.00	0.357	0.00
Innovation capability of employees	0.387	-0.202	0.387	0.336

Note(s): ICT= *Information Communication Technology*, MSD=*Musculoskeletal Disorder*

The results of this analysis support the hypothesis (H_3) that a reduction of physical ergonomic risk factors or a reduction of awkward posture in the workplace, in the working environment, positively affects the well-being and innovation capability of employees working in the metal manufacturing firms. According to the results, a neutral awkward posture or reduction of the physical ergonomic risk factors in the workplace within the manufacturing firms directly impacts the well-being (*β=0.246, P=0.00*) and innovation capability (*β=0.299, P=0.00*) of employees. Additionally, an awkward posture-free workplace (reduction of the prevalence of physical ergonomic risk factors) has an indirect effect (*β = 0.089, P = 0.00*) on employees' innovation capability.

Therefore, maintaining a neutral posture at the workplace has a medium effect (β=0.264, P=0.00) on physical well-being and a large effect (β=0.387, P=0.00) on the innovation capability of employees. According to Faze (2022), effects between 0.15 and 0.35 are considered medium, while values greater than 0.35 indicate a large effect. This finding is consistent with previous studies (Ansari et al., 2018; Hambali et al., 2019; Susuhono & Adiatmika, 2021) that state the positive effects of ergonomic interventions on the reduction of the negative impact of awkward posture (physical ergonomic risk factors) on employees' performance and well-being.

The prevalence of cognitive ergonomic risk factors in the workplace (*β = -0.202, P=0.00*), including stress, workload, exhaustion, suffocation, and work-related fatigue among employees in the manufacturing firms, is associated with a decline in innovation capability. This finding shows that the prevalence of cognitive ergonomic risk factors has a medium effect on employees' innovation capability within the manufacturing firms. These findings support hypothesis (H_2/H'_2), suggesting that cognitive ergonomic risk factors have an impacts on employees' innovation capability, indicating that the prevalence of cognitive ergonomic risk factors has an opposite impact on the innovation capability of employees in manufacturing firms. However, the hypothesis (H'_2) stating that cognitive ergonomic risk factors have an impact on musculoskeletal disorders suggests a relationship between the two constructs. However, the results indicate that while a correlation exists, cognitive ergonomic risk factors do not have a statistical significant direct effect on musculoskeletal disorders (MSDs). Consequently, we dismiss H'2, which asserts that cognitive ergonomic risk factors influence the physical health of employees in manufacturing settings.

So, when designing a workplace, manufacturing companies should think about cognitive ergonomic interventions to improve how the cognitive aspects of non-employees' elements and employees work together. This suggestion is in line with Koirala & Maharjan, (2022), research, which shows how cognitive strain affects how well people do their jobs and how productive they are overall. Additionally, the study by Stedmon, et al., (2012) stated the importance of considering the cognitive skills and knowledge in job design to optimize the interaction between employees and non-employees' elements in the workplace.

Furthermore, effective utilization of ICT facilities in the metal manufacturing firms' workplace has a significant direct effect *(β=0.344, p=0.00)* on the physical well-being and a medium significant effect *(β=0.241,* P=*0.00)* on the innovation capability of employees. Alleviating poor utilization of ICT also has a significant indirect effect (*β=0.116, 95% confidence interval)* on employees' innovation capability. Therefore, a policy promoting effective utilization of ICT in the workplace can have a large effect on the well-being and innovation capability of employees. These results support the hypothesis ($H_{4/}$ H'_4) that the effects of effective utilization of ICT facilities on employees' well-being and innovation capability are positive, consistent with previous studies (Karimikia et al., 2021; Marsh & Hocevar, 1985) emphasizing the impact of inefficient ICT utilization on employee performance and well-being.

The study also explores the correlation between work-related musculoskeletal disorders and the innovation capability of employees in metal manufacturing firms. The results show a significant relationship (β=0.336, p=0.00) between physical well-being and innovation capability, indicating that an improvement in employees' physical well-being could result in a large effect on the innovation capability of employees. These findings support the hypothesis (H_1) that employees' physical well-being at the workplace positively influences their innovation capability. This finding is in line with previous research (Karimikia and Singh 2020; Kumpikait, 2007) stated that employees' physical well-being contributes to increased productivity and quality of life in the workplace. Furthermore, research by Oo (2021) stated that the physical well-being of employees at work can increase performance and overall productivity.

Mediation effect: The CB-SEM results indicate that physical ergonomic risk factors exert a statistical meaningful indirect effect (β = 0.089) on innovation capability through musculoskeletal disorders, indicating that physical ergonomic risk factor exposure on innovation capability operates primarily via employees' musculoskeletal health. Similarly, the use of ICT shows a positive indirect effect (β = 0.116, 95% confidence interval) on innovation capability, mediated by musculoskeletal disorders, suggesting that ICT-related workplace design contributes to innovative performance by reducing musculoskeletal disorders.

In conclusion, to enhance employees' innovation capability and well-being in manufacturing firms, it is crucial to identify and control the root causes of ergonomic risk factors. Developing proactive ergonomic mechanisms to eliminate these root causes, which are the mismatches between employees' and non-employees' elements of the workplace, during workplace design stages, can mitigate issues hindering employees' well-being and innovation capability. Investigating the impact of ergonomic workplace design on employees' well-being, innovation capability, and the development of sustainable competitive advantages in manufacturing firms warrants further exploration.

These findings have managerial implications for manufacturing firms. Managers in these firms should focus on identifying root factors influencing employees' innovation capability and well-being, eliminating identified ergonomic risk factors, and developing an ergonomic-intensive proactive mechanism for reducing causes that hinder the well-being and innovation capability of employees within the manufacturing industry.

5.6. Chapter Summary

This chapter presents the findings from the structural equation modeling (SEM) analysis conducted to investigate the impacts of ergonomic risk factors on employee well-being and innovation capability within manufacturing firms. The results, summarized in Table 5.11, highlight standardized direct, indirect, and total effects of various latent variables on the dependent variables.

The modified SEM model, illustrated in Figure 5.3, demonstrates a strong fit with the sample data, as indicated by a chi-square (CMIN) value of 906.608, a degree of freedom (DF) of 454, and a CMIN/DF ratio of 1.997, which is below the acceptable threshold of 3 (Hair et al., 2021). The goodness-of-fit measures presented in Table 6.10 confirm that all fit indices (RMSEA, IFI, TLI, and CFI) meet the recommended cut-off values, establishing the validity of the model.

The analysis reveals that ergonomic risk factors, including reduced physical ergonomic risk factors (awkward posture), cognitive ergonomic risk factors, and the alleviated poor utilization of information communication technology (ICT), significantly affect employees' well-being and innovation capability. The findings support the hypothesis that reduced physical ergonomic risk factors positively influence both physical well-being ($\beta=0.246$, $p=0.000$) and innovation capability ($\beta=0.299$, $p=0.000$). Similarly, the presence of cognitive ergonomic risk factors in the workplace negatively impacts innovation capability (β= (-0.202, p=0.000)).

Alleviating poor utilization of ICT facilities within the manufacturing firms emerges as a critical factor, demonstrating a direct positive effect on physical well-being ($\beta=0.344$, $p=0.000$) and innovation capability ($\beta=0.241$, $p=0.000$), alongside an indirect effect on innovation capability ($\beta=0.116$, $p=0.000$). Furthermore, a significant relationship ($\beta=0.336$, $p=0.000$) exists between physical well-being and innovation capability, underscoring the importance of physical well-being in enhancing employee innovation capability. Looking ahead, the well-being and innovation capability of employees is increasingly integral to manufacturing processes, particularly with the rising popularity of employee-centric practices (Lihui, 2022). Establishing an ergonomic, risk-free workplace is realized by designing an employee-centric workplace that enhances both innovation capability and well-being. The research

In conclusion, the findings in this chapter emphasize the close connection between ergonomic risk factors and the pathways to improving innovation capability and well-being in the metal manufacturing industry. Hence, the manufacturing firms should work on the mechanisms that prevent the mismatches between the dimensions of non-employee elements and employees in the workplace. Therefore, based on these findings, the researcher suggests further exploration of the impacts of ergonomic workplace design on employees' well-being and innovation capability, fostering sustainable competitive advantages in the metal manufacturing firms. These insights have important managerial implications, urging managers to identify the mechanisms for preventing the root causes of each ergonomic risk factor to establish a healthier and more productive work environment.

Chapter Six

Models for determining the impacts of ergonomic workplace design on the development path of sustainable competitive advantages

6.1. Introduction

Employee-centric workplace design, as an evidence-based practice, nurtures a workplace that enhances the health, creativity, and innovation capacity of employees in metal manufacturing firms (Frank et al., 2016). Neglecting ergonomics principles can lead to mismatches between non-human and human elements, resulting in work-related musculoskeletal and cognitive disorders.

The aim of this chapter is to examine the relationships between employee-centric workplace designs, physical and cognitive health, and innovation capability to shed light on pathways to sustainable competitive advantages in metal manufacturing.

The findings presented in this chapter provide valuable insights for enhancing employees' health and innovation capability in metal manufacturing firms, fostering the development of sustainable competitive advantages, and guiding future research endeavors in this domain.

6.2. Conceptual Model Development

To remain competitive, metal manufacturing firms must achieve Sustainable Competitive Advantage (SCA) (Wadud et al., 2019). This enables them to forecast competitors' moves by aligning their resources with market gaps and opportunities (Morem da Costa & Horn, 2021). Strategies for achieving SCA include technological innovation, process optimization, and market development, which enhance product quality while reducing production costs, making products more affordable (Jiang et al., 2020). However, sustainable innovation requires maximizing human capital, making employee welfare a critical aspect of building SCA in the metal manufacturing sector (Pot and Vaas, 2008).

Internal resources, such as the innovative abilities and problem-solving skills of workers, can provide a competitive edge (Vinayan et al., 2012). These competencies are essential for organizational revitalization and growth, leading to the development of sustainable competitive edge creation (Rajapathirana & Hui, 2018). Establishing employee-centric workplaces that enhance innovation capability and well-being presents challenges but significantly boosts adaptability, innovation, and problem-solving skills within the industry (Berlin & Adams, 2017 ; Generosi et al., 2022).

Two-Factor Theory (Herzberg et al., 1959) describes the twofold relation of hygiene factors, like a safe working environment, to motivators, such as recognition and opportunities for growth that affect work satisfaction. A truly productive workplace maximizes employee satisfaction, and productivity requires both factors. In the ergonomic design of the workplace, ensuring that everyone is safe and that well-being is encouraged has the effect of increasing job satisfaction and driving productivity.

Also, Maslow's Hierarchy of Needs (1943) gives a framework that shows how the gratification of fundamental needs-for example, safety and comfort-motivates and raises the efficiency of workers. Meeting these basic needs through ergonomic design can help the organization develop a more motivated workforce, which is essential for sustaining competitive advantages.

The sociotechnical systems theory by Trist (1981) describes organizations as consisting of both social and technical elements. In designing proper ergonomics, there should be a relationship between employees and the work environment in such a way that systems are optimized for both productivity and employee satisfaction. Integration is, therefore, important in achieving better results in productivity and overall performance.

Despite these theoretical foundations, the literature has not comprehensively investigated how innovation capability, along with the physical and cognitive well-being of employees and employee-centric workplace design, affects the sustainable development paths of metal manufacturing firms. Interventions that affect employees' intentions to address sustainability are particularly important, highlighting the need for a deeper understanding of these dynamics (Haider et al., 2019). Comparative insights from Batat 2021 into sustainability practices across different sectors further strengthen these principles for metal manufacturing. Additionally, Blouch et al. (2023) propose suggestions for more ergonomic or employee-centered practices that could enhance organizational performance. Thus, further research is required to explore the potential alignments between sustainable competitive advantage, innovativeness capability, physical and cognitive well-being, and ergonomic (employee-centric) workplace design. Thus, the following hypothesis is posited for investigation in this direction:

Hypothesis 1 (H_1): *The development path of sustainable competitive advantages is positively impacted by the innovative capability of employees.*

In the context of physical well-being and its role in competitive advantages within the metal manufacturing sector, studies have shown that work-related musculoskeletal disorders significantly impact employee well-being and innovation capability. In supporting that WMSDs hamper employees' well-being and hurt their innovative capabilities, a study by Melhorn & Gardner (2004) and Ansari et al. (2018) affirms it. Additionally, it was documented that evidence of other effects may impact productivity and performance that are harmful not only to the organization but also to the workers as individual workers(Shreyas & Vinay 2023; Elif et al., 2023; Kelly & Moen, 2020; Osterman, 2018). Despite the significance of physical well-being in the development of the performance of the firms, none of the reviewed studies specifically addressed the relationship between physical well-being, the innovation capability of employees, and the development of sustainable competitive advantages. To address these gaps, the following hypotheses are proposed: To address these gaps, the following hypotheses are proposed:

Hypothesis 2 (H2): The physical well-being of employees positively impacts their innovation capability.

Hypothesis 9 (H9): The physical well-being of employees affects the development pathways to sustainable competitive advantages in metal manufacturing firms.

This section examines the relationship between work-related cognitive disorders (WCDs), cognitive well-being, and the innovation capability of employees in metal manufacturing firms. Research shows that work-related cognitive disorder (WCDs)-such as stress, anxiety, dissatisfaction, and depression-significantly impact employees' cognitive well-being. As supported by the research of Vischer (2008) and Sohail and Kashif (2016), cognitive disorders have been proven to have negative effects on memory, concentration, and, thus, overall cognitive function. Also, cognitive disorders can manifest in memory loss, problems with concentration, and poor problem-solving skills, as well as affect job-relevant outcomes like productivity, performance, and job satisfaction (Andersen & Westgaard, 2014; Taskasaplidis et al., 2024; Medalia & Erlich, 2017; Torre et al., 2021; and Qqisar et al., 2018). While it can, according to current evidence, be understood how cognitive well-being might relate to work outcomes, the relationship between innovation capacities and, thus, competitive advantage was, however, not yet clearly assessed; hence, the hypotheses are stated to be as follows:

Hypothesis 3 (H3): Employees' capability for innovation is positively impacted by their cognitive well-being.

Hypothesis 8 (H8): The development path of sustainable competitive advantages in metal manufacturing firms is positively impacted by employees' cognitive well-being.

Regarding ergonomic workplace design (employee-centric workplace design), ergonomics is about the well-being of workers. Ergonomics is helpful in designing such a workplace that would take into account the appropriate needs of workers. An effective ergonomic design would minimize chances of MSDs and yield maximum physical comfort (Realyvásquez-Vargas, et al., 2020). Most research outputs indicate that ergonomic intervention might improve physical health, reduce physical discomfort, and improve an individual's well-being (Ibrahim, 2020; Susuhono & Adiatmika, 2021). Cognitive ergonomics would also improve job performance, as it would optimize the interactions taking place between employees and their working environments (Shabani et al., 2021). Ergonomics in design not only create the two aspects of physical and cognitive well-being but also increases productivity. It makes an environment rich in capabilities for innovation which is considered crucial to remain competitive within the sector of metal manufacturing. Thus, the following hypotheses have been proposed to examine the aforementioned impacts of an employee-centric workplace design on physical well-being, cognitive well-being, innovation capability, and the developing paths of sustainable competitive advantages:

Hypothesis 4 (H4): Employee-centric workplace design positively impacts the physical well-being of employees in metal manufacturing firms.

Hypothesis 5 (H5): Employee-centric workplace design positively impacts the cognitive well-being of employees in metal manufacturing firms.

Hypothesis 6 (H6): Employee-centric workplace design enhances the innovation capability of employees.

Hypothesis 7 (H7): Employee-centric workplace design contributes to the development paths of sustainable competitive advantages in metal manufacturing firms.

Figure 6.1 illustrates the purpose of these studies, which is to examine and validate the hypotheses derived from the literature.

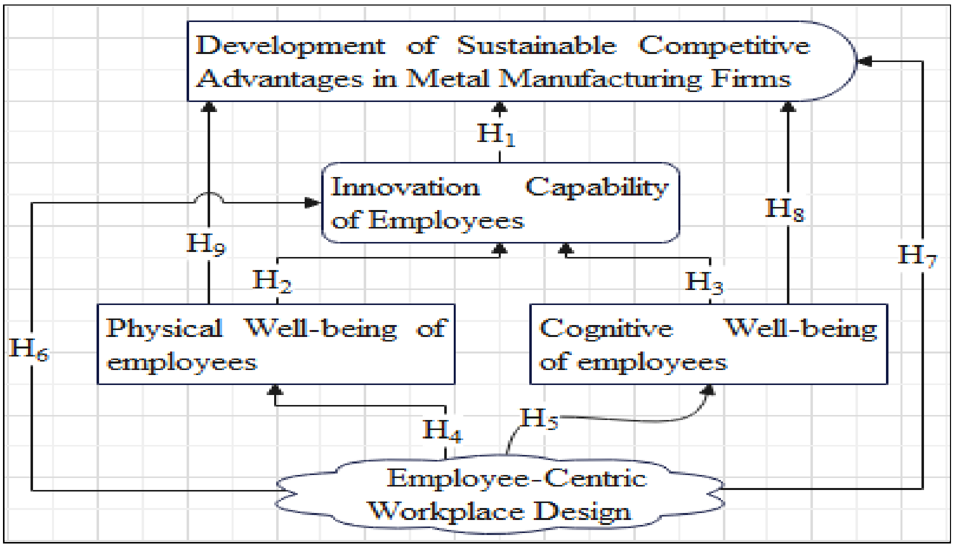


Figure 6.1: Hypothesised Relationships

To evaluate the impacts of ergonomic workplace design on sustainable competitive advantages, the researcher conducted assessments of the measurement and structural models. The results of these assessments are detailed in the subsequent sections.

6.3. Analysis of SMART PLS-SEM Model Results

Smarts-SEM is used for analyzing the impacts of ergonomic workplace design on the development paths of sustainable competitive advantages in the metal manufacturing firms. This data analysis tool was selected due to the number of respondents who were asked to fill out this self-administered questionnaire, who were employees who have more than 2 years of industry experience and have at least shift leader experience. The other factor that made the researcher choose these tools was the nature of the study, which is more exploratory than confirmatory research. Due to these two reasons, the tool is selected. Hence, the test results of the reliability and validity of the measured constructs are shown in Table 6.1.

Reliability of the Constructs: SmartPLS-SEM was utilized to analyse the impacts of ergonomic workplace design on the development paths of sustainable competitive advantages in metal manufacturing firms. The tool was chosen due to the nature of the study and the sample characteristics. The reliability and validity of the measured constructs were assessed, and the results are presented in Table 6.1.

The measurement items utilized to assess the cognitive well-being construct (CogWellB1 – CogWellB7), drawn from various sources in the literature, include understanding new tasks or machine operations, the ability to handle multiple tasks simultaneously during work, making rapid decisions under time pressure, such as unexpected machine failures or production errors, maintaining concentration on workstations, retaining memory for task sequences or work procedures at workstations, reliance on memory over written guidelines for complex tasks, and engagement and motivation in tasks at workstations.

Furthermore, the measurement items utilized to assess the ergonomic workplace design construct (EWD_1–EWD_6) encompass a range of elements, including work arrangements that afford employees ample time for critical thinking and informed decision-making, considerations regarding workplace distractions such as noise, machine alarms, and interruptions, workstation design strategies targeting the reduction of mental strain, emphasis on workstation design to minimize physical strain, clear display of safety instructions and operational guidelines within the workplace area, provision of access to tools or technology that streamline physical and mental processes and decision-making, and fostering a workplace environment that promotes social interaction and offers opportunities for such interactions.

The measurement items employed for evaluating the construct of physical well-being, coded as $PhysWellB_1$ – $PhyWellB_7$, encompass assessments of various aspects of physical health, including the well-being of the neck, upper back, lower back, legs, fingers, hands, and shoulders.

Table 6.1: Reliability Measures from SmartPLS (PLS-SEM)

Construct	Codes of the measurement items	Cronbach's Alpha (α)	(CR)	AVE

Cognitive well-being	$CogWellB_1 – CogWellB_7$	0.842	0.888	0.54
Innovation Capability of Employees	$INNOVATION_1$- $INNOVATION_7$	0.833	0.882	0.60
Ergonomic Workplace Design	$EWD_1 – EWD_6$	0.863	0.896	0.58
Physical Well-Being	$PhysWellB_1$ –$PhyWellB_7$	0.781	0.849	0.61
Sustainable Competitive Advantages	SCA_1- SCA_7	0.842	0.887	0.65

The results indicated in Table 6.1 indicate that all constructs' Cronbach's Alpha (α) values fall between 0.781 and 0.863, which is considered acceptable. The SmartPLS-SEM analysis of the measurement model shows that the composite reliability (CR) values for each construct range from 0.849 to 0.896. Notably, physical well-being has the lowest CR value (0.849), and ergonomic workplace design has the greatest CR value (0.896). Given that all CR values are higher than the generally accepted cut-off of 0.7; these findings suggest that each construct significantly contributes to monitoring the development process (Javari, 2018).

Construct Validity: Convergent validity was evaluated through measures such as average variance extracted (AVE) to assess how well constructs relate to the creation of long-term competitive advantages in metal manufacturing companies. The findings reveal that all constructs in the PLS-SEM model demonstrate convergent validity, with AVE values exceeding the suggested cut-off of 0.50**.** All research constructs have AVE, as shown in Table 6.1, measures greater than 0.53, which is in line with the suggested cut-off of 0.50 (Hadwiansyah and Latief, 2022).

6.4. Assessment of Model of Measurement

The measurement model's fit was evaluated based on criteria for discriminant validity, convergent validity, and reliability. T-values, obtained through bootstrapping with 5,000 subsamples, along with the factor outer loading of the measurement units, were used to assess the homogeneity of these units in the initial phase. A significant correlation between an indicator and its latent variable is indicated by T-values greater than 1.96 (Hadwiansyah and Latief, 2022). A model is considered reasonably reliable when the factor loading is 0.7 or above, provided that the variance between a structure and its indices exceeds the measurement error (Sarhadi and Rad, 2020). Consequently, two questions related to the evolution of sustainable competitive advantages and one question about ergonomic workplace design were excluded from this study due to their low outer loading values.

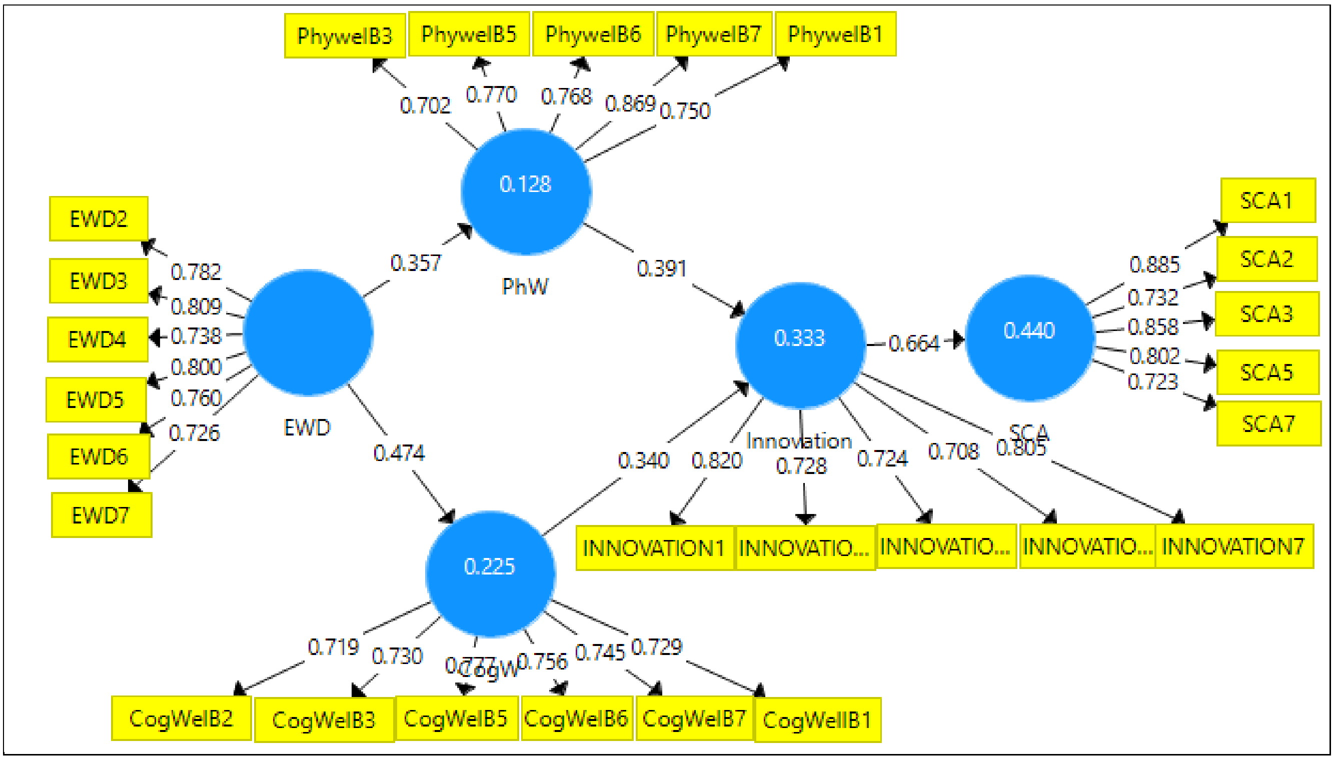
Additionally, to investigate the relationships between the constructs—cognitive well-being, physical health, innovation ability of the workforce, and ergonomic workplace design—and the development of sustainable competitive advantages in metal manufacturing firms, the researcher assessed the outer loadings. The outer loadings for each construct indicator were evaluated at the first stage using SmartPLS 3.0.

In the first assessment, the measurement items that have outer loading values less than 0.5 are not significant, and the researcher decided to eliminate these measuring items from the model. The remaining measurement items demonstrate that the outer loading values for all constructs surpassed 0.5, as shown in Table 6.2, confirming their reliability as measuring items (Hair et al., 2019). Based on the information stated in the table below, the outer loading of the measurement items is reliable since the outer loading of the item is >0.50 (Hair et al., 2012)

Table 6.2 Outer loading of measurement items

Measurement Item	Outer loading	p-vale	Measuring Item	Outer loading	p-vale
CogWellB1	0.73	0.000	INNOVATION5	0.72	0.000
CogWellB2	0.72	0.000	INNOVATION6	0.71	0.000
CogWellB3	0.73	0.000	INNOVATION7	0.80	0.000
CogWellB4	0.845	0.000	PhyWellB1	0.75	0.000
CogWellB5	0.78	0.000	PhyWellB2	0.618	0.000
CogWellB6	0.76	0.000	PhyWellB3	0.70	0.000
CogWellB7	0.74	0.000	PhyWellB5	0.77	0.000
EWD7	0.73	0.000	PhyWellB6	0.77	0.000
EWD2	0.78	0.000	PhyWellB7	0.87	0.000
EWD3	0.81	0.000	SCA1	0.89	0.000
EWD4	0.74	0.000	SCA2	0.73	0.000
EWD5	0.80	0.000	SCA3	0.86	0.000
EWD6	0.76	0.000	SCA5	0.80	0.000
INNOVATION1	0.82	0.000	SCA7	0.72	0.000
INNOVATION3	0.73	0.000			

To assess how unique each component was, a discriminant and convergent validity test was also carried out. This was accomplished by evaluating the average variance extracted (AVE) of each latent variable as shown in Table 6.3. Moreover, to test discriminant validity, the suggestion put forth by the Fornell and Lacker (1981) model was utilized (Gye-Soo, 2016). This suggestion proposes that the square root of the average variance extracted (AVE) in each latent variable can be employed to establish discriminant validity. This criterion is met when this value surpasses the other correlation values among the latent variables (Wong, 2013). The constructs utilised for discriminant validity, such as AVE and cross-loadings, are shown in Table 6.3 (Hair et al., 2016).



Note: *PhyWellB = physical well-being measurement unit; CogWellB = cognitive well-being measurement unit; SCA = sustainable competitive advantage measurement unit; EWD=ergonomic workplace design unit for measuring ergonomic workplace design.*

Figure 6.2. Structural model of the development paths of sustainable competitive advantages in metal manufacturing (Source: by Author).

The results shown in Table 6.3 show that the AVE values for every construct fall between 0.54 and 0.65. Sustainable competitive advantage is the component with the highest AVE value, while cognitive well-being has the lowest value (AVE=0.54). Crucially, every AVE value for every construct is higher than the suggested cutoff of 0.5 (Kamis et al., 2020). The fact that each latent variable's square root of the AVE is larger than the correlations between the latent variables provides additional evidence for the proposed model's excellent validity.

Table 6.3: Validity Measures from SmartPLS (PLS-SEM)

Construct	AVE	1	2	3	4	5
Cognitive well-Being [1]	0.54	**0.728**				
Ergonomic Workplace Design (2)	0.60	0.47	**0.768**			
Innovation Capability of Employees (3)	0.58	0.44	0.36	**0.755**		
Physical Well-Being [4]	0.61	0.24	0.36	0.47	**0.775**	
Sustainable Competitive Advantages [5]	0.65	0.39	0.27	0.66	0.31	**0.80**

Based on all of the previously indicated measurement outcomes, the measurement model assessment is therefore considered satisfactory. After that, the researcher assessed the structural model.

6.5. The Structural Model Assessments

Variance Inflation Factor (VIF) was utilized as a metric to assess collinearity within the structural model (Sandoval & Ramos-Diaz, 2018). VIF is calculated as (1 / (1 - R^2)) and was estimated by the researchers to determine the extent of collinearity (Wong, 2013). In the path model based on Partial Least Squares (PLS), Table 6.4 presents the VIF values for the indicators on the path diagram. The VIF values shown in Table 6.4 are all below the threshold of 5 (Wong, 2013), indicating a lack of significant collinearity. Thus, the VIF values demonstrate strong correlations among the constructs in metal manufacturing organizations, including ergonomic workplace design, employees' physical and cognitive well-being, employees' capacity for innovation, and the development of sustainable competitive advantages.

Table 6.4: Indicator's VIF results on the PLS-SEM model

Indicators	VIF	Indicators	VIF	Indicators	VIF
CogWellB1	1.74	SCA6	1.766	SCA7	1.61
CogWellB2	1.94	EWD2	1.85	Innovation5	1.75
CogWellB3	1.85	EWD3	2.12	Innovation6	1.54
CogWellB5	1.91	EWD4	2.11	Innovation 7	1.75
CogWellB6	1.95	EWD5	2.24	PhyWellB1	1.77
CogWellB7	1.72	EWD6	2.02	PhyWellB3	1.60
SCA1	2.63	EWD7	2.05	PhyWellB5	1.87
SCA3	2.46	Innovation1	1.67	PhyWellB6	1.87
SCA5	2.04	Innovation3	1.58	PhyWellB7	2.19

Upon determining that the VIF values are valid, the model must be assessed in order to identify the appropriate models within the constructs.

R-squared (R^2): To assess the variation explained by the model's constructs, the researcher analysed the R-squared values. The goodness of fit of the model is indicated by the coefficient of determination (R^2), which shows the amount of explained variation for each construct (Gotz et al., 2010). The R^2 values for the four constructs presented in the route diagram are summarized in Table 6.5. The R^2 index values range from 0.13 to 0.44, indicating the amount of variance explained. Notably, the development of sustainable competitive advantages achieved a value of

0.44, indicating moderate explanatory power, while the physical well-being of employees exhibits the lowest value at 0.13.

Cognitive well-being and innovation capability of employees account for 23% and 33% of the explained variance, respectively. The 0.44 R^2 value demonstrates a substantial impact that employees' capability for innovation has on the development of long-term competitive advantages in metal manufacturing companies, this indicating that innovation capability at work accounts for 44% of the variation in the development of sustainable competitive advantage. Furthermore, 33% of the variance in overall physical and cognitive well-being can be attributed to employees' capability for innovation. Within metal manufacturing firms, ergonomic workplace design accounts for 22% and 13% of the variation in employees' cognitive and physical well-being, respectively.

According to Joseph et al. (2017), R^2 values of 0.67, 0.33, and >0.19 represent strong, moderate, and weak levels of endogenous constructs. The R^2 value of 0.13 is greater than the minimum of 0.01 as recommended by Falk and Miller (1992), which shows that the explanatory value is low but acceptable. This is similar to the idea of cognitive well-being, which scored 0.23, being a small but important difference that the model can detect. The analysis of the R^2 values indicates that the model has good predictive validity for relevant constructs. At the same time, this analysis points to areas for further research and improvement to make employees happier and give the metal manufacturing industry a competitive edge.

Predictive relevance (Q^2): To assess the predictive relevance of the model, the researcher utilized cross-validation techniques for model prediction assessment. In this stage, the researcher employed a 10-fold cross-validation (k=10) to ensure reliable and generalizable predictions in the PLS framework. Subsequently, the researcher evaluated the predictive relevance (Q^2) to gauge the model's ability to make accurate predictions by comparing its out-of-sample predictive accuracy with the baseline model (Enis and Geisser, 1974).

Table 6.5. Results on the prediction power of the PLS-SEM model

Constructs	**R^2**	**RMSE**	**MAE**	**Q^2_predict**
Cognitive Well-Being	0.22 (p=0.00)	0.91	0.68	0.20
Innovation Capability of Employees	0.33 (p=0.00)	0.95	0.77	0.12
Physical Well-being	0.13 (p=0.05)	0.98	0.74	0.10
Sustainable Competitive Advantage	0.44 (p=0.00)	0.98	0.81	0.06

The results indicate that the highest value is presented by cognitive well-being (0.20), followed by innovation capability (0.12), physical well-being (0.10), and the development of sustainable competitive advantages (0.06). These findings support the relevance of the predictive model based on the independent variables in the model. According to Fauzi (2022), a Q^2 value of 0 or greater indicates relevance, thereby reinforcing the predictive model's effectiveness in this study. Overall, the analysis of predictive relevance corroborates the model's ability to accurately forecast the relationships between the constructs, aligning well with the established benchmarks in the field.

Moreover, to test the predictive power of the model, the PLS model's predictive result is contrasted with the root mean square error (RMSE) values in the linear regression model (LM model), as shown in Table 6.6. According to the test results, the model has a modest level of predictive potential, which is consistent with the research done by Rodrigo & Horn (2021). Only one out of the twenty-two indicators included in the PLS-SEM research produces greater prediction errors than the benchmark inexperienced **linear regression model** (LM). Three measurement items have equal prediction error.

Table 6.6. Summary of the prediction of measuring items (indicators)

	PLS		LM		PLS-LM (RMSE)		PLS		LM		PLS-LM (RMSE)
Indicators	RMSE	Q²_predict	RMSE	Q²_predict		Indicators	RMSE	Q²_predict	RMSE	Q²_predict	
CogWelB7	0.68	0.18	0.68	0.0	0.00	INNOT5	0.68	0.05	0.73	-0.08	-0.05
CogWelB2	0.83	0.07	0.87	-0.03	-0.04	PhywelB7	0.80	0.08	0.84	0.04	-0.04
CogWelB3	0.77	0.11	0.80	0.03	-0.03	PhywelB3	0.90	0.02	0.92	0.00	-0.02
CogWelB6	0.76	0.07	0.79	-0.03	-0.03	PhywelB1	0.90	0.05	0.89	0.09	0.01
CogWellB1	0.82	0.04	0.85	-0.08	-0.03	PhywelB5	0.85	0.05	0.86	0.01	-0.01
CogWelB5	0.76	0.13	0.78	0.03	-0.02	PhywelB6	0.90	0.04	0.91	0.03	-0.01
CogWelB4	0.77	0.06	0.79	0.02	-0.02	SCA5	0.69	0.04	0.69	0.05	0.00
INNOVAT1	0.76	0.08	0.78	0.03	-0.02	SCA7	0.57	0.04	0.57	0.03	0.00
INNOVAT3	0.70	0.08	0.71	0.03	-0.01	SCA3	0.65	0.03	0.68	-0.07	-0.03
INNOVAT6	0.73	0.01	0.77	-0.13	-0.04	SCA2	0.69	0.03	0.72	-0.06	-0.03
INNOVAT7	0.63	0.08	0.67	-0.06	-0.04	SCA1	0.69	0.06	0.72	-0.06	-0.03

6.5. Effect Analysis:

In analysing the mediation, the first step is to determine the significance of the indirect and specific indirect effects. This was done through a bootstrapping procedure with 5,000 subsamples to determine the path coefficient, t-statistics, and confidence intervals. The results of the direct and indirect effects tests, including the path coefficients, significance levels, and t-statistics of the hypotheses that passed the PLS-SEM analysis, are presented in Table 6.7.

Table 6.7: Structural model results total direct effects using t-values and with 95% confidence interval (n=5000 subsamples)

	Path (β)	95% confidence interval		t =	P	Hypothesis
Cognitive well-being -> Innovation Capability of Employees	0.34	0.22	0.49	4.87	0.000	H_3
Ergonomic Workplace Design -> Cognitive well-being	0.47	0.33	0.63	6.13	0.000	H_5
Ergonomic Workplace Design -> Physical well-being	0.36	0.19	0.54	4.06	0.000	H_4
Innovation Capability of Employees -> Sustainable Competitive Advantage Development	0.66	0.56	0.77	12.10	0.000	H_1
Physical Well-being -> Innovation Capability of Employees	0.39	0.24	0.49	6.01	0.000	H_2

Furthermore, the significance of the test values is evident, with P-values below 0.001 and T-statistics exceeding 1.96, indicating significance at the 0.05 level (Wong, 2013). The result demonstrates the significant direct effects of ergonomic workplace design (EWD) on employees' cognitive well-being (β = 0.47, t = 6.10, P = 0.000), demonstrating a large effect size as defined by Fauzi, (2022). In comparison, the impact of EWD on physical well-being (β=0.36, t=5.43, P=0.000) reflects a medium effect size. This suggests that metal manufacturing firms must prioritize ergonomic workplace design and employee well-being to develop an employee-centric workplace that provides for their needs and preferences. This approach enables them to enhance their innovation capability. These findings align with previous research by Berry & Loeb (2021), Caputo et al. (2019), and Peruzzini et al.(2017) supporting the notion that ergonomic workplace designs enhance workers' mental and physical well-being. This finding further reinforces the study's hypotheses (H4 and H5) regarding the impacts of ergonomic workplace design on the well-being of employees in metal manufacturing firms.

Additionally, the direct relationship between innovation capability and sustainable competitive advantage (SCA) exhibits a large effect size (*β=0.66, t=12.1, P=0.000*), indicating a strong connection between these constructs. Cognitive well-being positively influences innovation capability (β=0.36, t=5.14, P=0.000) with a large effect size, while physical well-being also contributes to Innovation capability (β=0.36, t=5.54, P=0.000), demonstrating a large effect size as well. Collectively, these results reinforce the notion that effective ergonomic design and employee well-being are vital in fostering a productive and innovative workforce within metal manufacturing firms. This finding is supported by the research conducted by Rodrigo & Horn (2021) and Vinayan et al. (2012), emphasizing the critical role of employees' innovation and problem-solving abilities in gaining a competitive advantage over environmental factors available to all competitors. Moreover, the findings are also consistent with the study of Berlin and Adams(2017), Birhan and Endawoke (2023), Docherty et al. (2008), and Hedge (2016), who emphasize that employees who feel safe and whose well-being is valued are more likely to be motivated, and productive in their roles.

Furthermore, the indirect effect analysis was performed to determine the significant indirect effects among each construct. Moving to Table 6.8, the results present significant indirect effects across all relationships tested. Notably, cognitive well-being, physical well-being, and ergonomic workplace design significantly impact the pathways towards sustainable competitive advantages. The findings highlight the significant indirect influence of ergonomic workplace design on employees' innovation capability (β=0.30, 95% [0.20, 0.42]) and the development of sustainable competitive advantages (β=0.20, 95% [0.13, 0.30]). These results provide empirical support for H_7 and H_6, which state that ergonomic workplace design has an important impact on the innovation capability of employees and on the development paths of sustainable competitive advantages in metal manufacturing firms. This finding is supported by Vladenska and Permana (2023), emphasizing the critical role of occupational health and safety (OSH) in enhancing individual and organizational performance.

Table 6.8: Structural model results of total indirect effects using t-values and with 95% confidence interval (n=5000 subsamples)

Relationship	Effect (β)	95% confidence interval		*t*	*p*	Hypothesis
Cognitive Well-Being -> Sustainable Competitive Advantage Development	0.23	0.14	0.34	4.51	**0.000**	H_8
Ergonomic Workplace Design -> Innovation Capability of Employees	0.30	0.20	0.42	5.22	**0.000**	H_6
Ergonomic Workplace Design -> Sustainable Competitive Advantage Development	0.20	0.13	0.30	4.63	**0.000**	H_7
Physical Well-being -> Sustainable Competitive Advantage Development	0.26	0.15	0.34	5.47	**0.000**	H_9

The coefficients (β) indicate positive relationships between the constructs. Notably, cognitive well-being (β=0.23, 95% [0.14, 0.34]) and physical well-being (β=0.26, 95% [0.15, 0.34]) have a significant indirect impact on the pathways towards sustainable competitive advantages.

Moreover, the specific indirect effect of each construct on innovation capability and the development of sustainable competitive advantages in metal manufacturing firms is assessed, and the results are shown in Table 6.9.

Table 6. 9. Specific indirect effects of each construct

Relationship	Effect (β)	95% confidence interval		t	p
Ergonomic Workplace Design -> Cognitive Well-Being->Innovation Capability of Employees	0.17	0.09	0.27	3.73	**0.00**
Ergonomic Workplace Design -> physical well-being-> Innovation capability	0.13	0.06	0.23	3.05	**0.00**
Cognitive Well-Being->Innovation Capability of employees->Sustainable Competitive Advantage development	0.24	0.15	0.34	4.78	**0.000**
Ergonomic Workplace Design -> Cognitive well-being->Innovation Capability of Employees->Sustainable competitive advantage development	0.11	0.06	0.18	3.57	**0.000**
Physical Well-being -> Innovation Capability of Employees-> Sustainable Competitive Advantage Development	0.24	0.16	0.34	5.03	**0.000**
Ergonomic Workplace Design -> Physical Well-being->Innovation Capability of Employees-> Sustainable Competitive Advantage Development	0.09	0.04	0.16	2.79	**0.01**

The results in Table 6.9 revealed that the cognitive well-being and physical well-being of employees via the innovation capability of employees have **moderate** specific indirect effects on the developments of sustainable competitive advantages. Moreover, ergonomic workplace design via the well-being of employees also has a positive specific effect on the innovation capability of employees.

Lastly, the total effects presented in Table 6.10 demonstrate the overall influence of the constructs on employees' innovation capability and the development of sustainable competitive advantages. The results highlight that ergonomic workplace design has a large effect on the cognitive well-being (β = 0.47, t = 6.10, p = 0.00) and physical well-being (β = 0.36, t = 4.09, p = 0.00) of employees. While it has a medium effect on the innovation capability of employees (β = 0.30, t = 5.43, p = 0.000).

Table 6.10.Total effect of each construct

	Effect (β)	95% confidence interval		**t**	**p**	Hypothesis	Effect
Cognitive Well-Being -> Innovation Capability of Employees	0.36	0.22	0.49	5.14	**0.000**	**H_3**	**Large**
Cognitive Well-Being -> Sustainable Competitive Advantage Development	0.24	0.15	0.34	4.78	**0.000**	**H_8**	**Medium**
Ergonomic Workplace Design -> Cognitive Well-Being	0.47	0.33	0.63	6.10	**0.000**	**H_5**	**Large**
Ergonomic Workplace Design -> Innovation Capability of Employees	0.30	0.21	0.42	5.43	**0.000**	**H_6**	**Medium**
Ergonomic Workplace Design -> Physical Well-being	0.36	0.19	0.54	4.09	**0.000**	**H_4**	**Large**
Ergonomic Workplace Design -> Sustainable Competitive Advantage Development	0.20	0.13	0.29	4.73	**0.000**	**H_7**	**Medium**
Innovation Capability of Employees -> Sustainable Competitive Advantage Development	0.66	0.56	0.77	12.1	**0.000**	**H_1**	**Large**
Physical Well-being -> Innovation Capability of Employees	0.36	0.24	0.49	5.54	**0.000**	**H_2**	**Large**
Physical Well-being -> Sustainable Competitive Advantage Development	0.24	0.16	0.34	5.03	**0.000**	**H_9**	**Medium**

In the context of the statistical analysis presented in Table 6.10, the strength of the relationship between cognitive well-being (t=5.14), physical well-being (t=5.54), and the innovation capability of employees is relatively high, indicating a strong level of statistical significance for the relationships between employees' well-being and innovation capability. The difference in the t-values (*5.54 - 5.14 = 0.40*) is not particularly large. Typically, a larger t-value suggests a stronger relationship between the independent variables and dependent variables (Wong, 2013). In this case, the slightly higher t-value for physical well-being compared to cognitive well-being may indicate that the relationship between physical well-being and innovation capability is slightly stronger than the relationship between cognitive well-being and innovation capability.

Specifically, ergonomic workplace design demonstrates a significant indirect effect (*β = 0.2, 95% [0.13, 0.29]*) on the development of sustainable competitive advantages in metal manufacturing firms.

Path Coefficients (Hypothesis Testing): The goodness of the structural model was also tested via the path coefficient test. In this test, the model's path coefficients were tested based on the following conditions: the model's p-values must be below 0.05, and the confidence interval's limits must not cross zero (Fauzi, 2022). All the hypotheses were considered statistically significant and acceptable, which validates the relationships proposed in the study, as shown in Table 6.10.

Hence, these findings indicate that ergonomic workplace design significantly influences development of sustainable competitive advantages through the mediating roles of well-being and innovation capability. The results also indicate that ergonomic workplace design plays a crucial role in establishing sustainable competitive advantages within the metal manufacturing firms. These findings are supported by previous research conducted by Berry & Loeb (2021), Caputo et al. (2019), and Peruzzini et al. (2017), reinforcing the idea that ergonomic workplace designs enhance the mental and physical well-being of workers. It is evident that the innovation capability of employees plays a pivotal role in establishing sustainable competitive advantages within metal manufacturing firms. With its favourable effects on well-being and capacity for innovation, ergonomic workplace design shows a high degree of performance in supporting the development of sustainable competitive advantages in metal manufacturing firms.

For instance, in countries like Ethiopia, the government has a national plan to enhance the performance of manufacturing industries for import substitution. While this plan aims to boost innovation and creativity among educated citizens, it frequently overlooks the well-being and innovation potential of employees in metal manufacturing firms. Innovation and creativity hubs are typically established within higher education institutions, neglecting the wealth of tacit knowledge and skills possessed by employees in the metal manufacturing firms. Regrettably, the presence of work-related disorders and the absence of organizational and national policies supporting employee innovation enhancement programs often lead to the wastage of valuable internal resources. To tackle this challenge, metal manufacturing firms in developing nations should prioritize the efficient utilization of their internal resources as a fundamental strategy for developing competitive advantages, rather than solely relying on ideas and products from developed countries.

Hence, metal manufacturing firms should give due emphasis to the design of the workplace to focus on the needs and preferences of employees working within the metal manufacturing firms. By focusing on these aspects, metal manufacturing firms should prioritize their resources (skills and knowledge of their employees) efficiently rather than depending exclusively on concepts and goods from industrialized nations as a crucial tactic for creating competitive advantages. To achieve this, metal manufacturing firms should focus on the proactive tools and designing strategies that enable them to assess the root causes affecting employees' well-being. The metal manufacturing firms should aim to design an ergonomic workplace that addresses both the cognitive and physical needs of their employees. This recommendation is in line with previous research conducted by Pot and Vaas (2008) and Hasanain (2024), who stated that sustainable innovation and productivity growth necessitate the optimal utilization of the workforce rather than solely depending on adopting new technologies and cost-cutting measures to ensure the development of sustainable competitive advantages. Therefore, metal manufacturing firms should implement ergonomic workplace design for developing sustainable competitive advantages.

Although this work offers important reflections on the link between ergonomic workplace design, employees' well-being, innovation capability of employees, and sustainable competitive advantage, it is not without limitations. First, the lower R^2 values for constructs measuring well-being indicate that other variables possibly related to physical and cognitive well-being might have been missing in our models. Second, we do note that the embrace of a narrow set of eight metal manufacturing companies and the small sample size could restrict the generalizability of our results. It should be noted that the conclusions are to be applied with great caution to more general contexts.

Future research should explore additional predictors, such as external stressors—like technological factors and work-life balance—to provide a more comprehensive understanding of employee well-being. Longitudinal studies are also suggested to confirm causal connections and understand the long-term effects of the ergonomic workplace design of the workplace on employees' innovation potential and the development of sustainable competitive advantages.

In addition, the sample size should be larger and more heterogeneous for future studies to support our results. If the scope is extended to cover different industries and geographic areas, the robustness of the conclusions drawn from this study will be strengthened. In general, these aspects will lead to a better understanding of ergonomic workplace design's broader outputs to well-being and innovation capacity.

6.6. Summary of chapters

The findings in this chapter underscore the importance of developing a model to evaluate the effects of ergonomic workplace design on employees' well-being, innovation capability, and the establishment of sustainable competitive advantages in metal manufacturing firms. These findings suggest that implementing an ergonomic workplace design strategy within manufacturing firms significantly influences the development of sustainable competitive advantages. By giving priority to ergonomic workplace design, manufacturing firms can improve employee well-being and innovation capability, essential internal resources for cultivating sustainable competitive advantages. Thus, the findings indicate that ergonomic workplace design plays a pivotal role in fostering sustainable competitive advantages through its substantial impact on the well-being and innovation capability of employees in manufacturing firms. The study focused on the proactive prevention of ergonomic risk factors affecting employee well-being, innovation capability, and the necessity of taking preventive measures to address their root causes.

According to the study's findings, the interaction among workplace elements in manufacturing firms notably affects employees' physical and cognitive well-being, as well as their contributions to the company's success. Designing an ergonomic workplace is crucial for enhancing employees' innovation capabilities and their physical and cognitive well-being, both of which can influence the development of long-term competitive advantages. This study enriches the literature by constructing a model that elucidates the connection between ergonomic workplace design and the cultivation of sustainable competitive advantages.

Drawing from the insights presented in this chapter, the researcher recommends that manufacturing firms adopt an employee-centric approach to workplace design strategies, in addition to task and technology-centric approaches, to develop a sustainable competitive advantage. This recommendation aligns with prior research on strategies that metal manufacturing firms can implement to attain sustainable competitive advantages, encompassing technological innovation, process optimization, and the integration of improvement tools like supply chain management, just-in-time practices, and total quality management (Muisyo et al., 2022; Jiang et al., 2020). Hence, to operationalize these findings, the study proposes a set of proactive ergonomic assessment and design strategies to design an employee-centric workplace.

Chapter Seven

Proactive Tools and Design Strategies for Designing Ergonomic Workplaces

7.1. Introduction

In this chapter, the researcher discusses proactive tools and strategies for designing ergonomic workplaces in metal manufacturing firms. The focus of this chapter is on proposing a multi-perspective assessment and linkage of workplace elements through the lens of ergonomic science. This proactive, ergonomic-driven methodology aims to heighten the sustainable competitive advantages of metal manufacturing firms by prioritizing employees' needs and preferences.

At the heart of this new paradigm is the need to develop effective linking mechanisms and the use of specific ergonomic needs interventions at different design phases of the workplace. In this way, potential problems such as work-related disorders can be addressed, and metal manufacturing companies can develop a healthier and more efficient workplace. This methodology resonates with the insights from Onan Demirel et al.'s study in 2023, which underscores the importance of a human-centred generative design framework for concept creation and evaluation in the early design phases.

Moreover, in this chapter, proactive assessment framework are developed for assessing the mismatch between employees' capabilities and the non-human elements' dimensions, which has been a significant factor contributing to work-related disorders in metal manufacturing firms. A conducive workplace is essential for maintaining workers' well-being and optimizing their performance capabilities. However, when ergonomic risk factors are not adequately addressed, they can lead to significant challenges that compromise both employee health and productivity (Berlin & Adams, 2017; EASHW, 2019).

Chapters 4 and 5 discuss the types of ergonomic risk factors that contribute to the prevalence of work-related disorders and examine the impacts of these risk factors on employee well-being and innovation capabilities. Chapter 6 explores how employee-centric workplace design can foster sustainable competitive advantages in metal manufacturing firms. The study identifies that many industries currently adopt a reactive approach to ergonomics, addressing issues only after they escalate. This undermines employee health and overall productivity. Therefore, transitioning to a proactive, employee-oriented ergonomics framework is critical.

This chapter aims to address existing gaps by developing a proactive ergonomic risk factor assessment framework and a workplace design tool that can manage the mismatches between employees' factors and factors of non-employee elements within the workplace environment. It is crucial for fostering an employee-centred setting that ensures industry competitiveness. To sustain a productive workforce and secure long-term success in manufacturing industries, it is imperative to tackle these issues during the design phases to safeguard sustainable competitive advantages.

7.2 Ergonomic Tools and Techniques

This section delves into various ergonomic tools and techniques that can be utilized to assess and improve workplace design. The discussion is centred on the design of an Ergonomic Function Deployment (EFD) framework and Workfit-Lever, which promotes employee involvement in evaluating the workplace design and the relationship between employees and non-employee factors in the metal manufacturing industry. The proposed framework is intended to provide innovative solutions for the design of employee-focused workplaces that take a proactive approach to solving the underlying causes of ergonomic issues, thereby improving employee health, innovation capability, and the creation of sustainable competitive advantages in the metal manufacturing companies.

7.2.1. Work-Fit Lever: A Novel Ergonomic Assessment Tool for Workplace Balance.

Traditional ergonomic assessment tools such as RULA (McAtamney & Corlett, 1993), REBA (Hignett & McAtamney, 2000), and OWAS (Karhu et al., 1977) have been widely used to evaluate posture-related risks and musculoskeletal disorders. Despite their effectiveness in assessing physical strain, these tools exhibit critical limitations:

- *Focus Solely on Human Postures* –Existing tools primarily assess employee postures but fail to evaluate the ergonomic compatibility of non-human workplace elements, such as workstation dimensions, tools, and machines.
- *Limited Interaction Analysis* –They do not account for the dynamic interaction between employees and workplace elements, leading to potential mismatches in workspace design.
- *Neglecting cognitive ergonomics*: Mental workload, decision-making, and perceptual ergonomics are not adequately addressed, despite their role in workplace efficiency (Rajendran & Sen, 2024; Wilson, 2000).

To address these limitations, a new ergonomic assessment framework, the workfit-lever, is introduced in this chapter. This framework provides context and additional information for existing ergonomic principles on employee versus non-employee element dimension balance in a workplace. To ensure conceptual rigor, methodological robustness, and practical relevance within the manufacturing firms, the Workfit-lever was developed according to the following core design requirements:

A. Conceptual Basis for developing Workfit-Lever: To develop this concept, numerous scientific, theoretical benchmarks, and industries standards were referenced.

The *scientific foundations* used for developing the *Workfit-Lever concept* are derived from the Law of the Lever and *Newton's First Law of Motion*, which states that equilibrium occurs when net torque is zero. This principle, originally described by *Archimedes (287–212 BC),* explains a lever as a simple machine that balances forces around a pivot (fulcrum) point.

The Existing Theoretical Benchmarks: The concept used for developing the *Workfit-Lever* concept is aligned with key ergonomic and biomechanical principles, including concepts such as the *Biomechanical Load Distribution Theory,* which is rooted in Chaffin & Anderson's (2006) biomechanical approach, focusing on force equilibrium in workplace design. The other theoretical concepts that were used as a benchmark for developing this work fit lever is systems ergonomics, which integrates principles from Karwowski (2005), which considers workplace interactions beyond individual postures.

Moreover, *Cognitive Load Theory* plays a significant role, drawing inspiration from Sweller (1988) to integrate mental workload into ergonomic assessments. This aspect addresses decision-making processes and task complexity, serving as a foundational theoretical benchmark for the Work Lift-Lever.

Industry Standards for Ergonomic also used as a benchmark for developing Work fit-Lever concept. This concept is designed to align with international ergonomic standards and workplace safety regulations such as ISO guidelines, including ISO 9241-210 (2019), which recommends the importance of ergonomics for human-centred design for interactive systems in the workplace (*IOS: 2019*). Moreover, the theory on National Institute for Occupational Safety and Health (NIOSH) Lifting Equation (Waters et al., 1993), which focuses on investigating the risk of work-related injury with manual handling and lifting activities in the workstation, complements the Workfit-Lever's integration of employees' dimensions and non-employees' dimensions balancing.

B. **Key contribution of the Workfit-lever and its application***:* The Workfit-Lever surpasses traditional ergonomic models by conducting physical fit assessment, analysing workplace interaction, and assessing cognitive capability.

This concept is developed by customizing a lever system where the force applied at one point of the lever is referred to as the effort (E), while the force applied at the second point is considered the weight (W). A lever is defined as a rigid bar capable of movement about a fixed axis called the fulcrum (F)(Hazari et al., 2021).

In this context, the lever represents work, the effort arm (E) represents employee physical capability (reach, strength, posture) and cognitive capability (memory, understanding, problem -solving skill, concentration, knowledge, and skill), and the weight arm (W) represents the machinery constraints (fixed factors, accessibility, adjustability, software, etc.). The fulcrum position represents the ideal ergonomic balance point between employees' factors and workplace design. The researcher suggests that work acts as a rigid bar connecting employees and non-human elements of the workplace. This claim is supported by Ichniowski et al. (1996), who noted that innovative workplace practices can increase performance primarily through systems of related practices that enhance worker participation and make work design less rigid.

Thus, the approach emphasizes the importance of utilizing ergonomic principles as a fulcrum to balance employees and machinery and other equipment in workplace design, ultimately making work less rigid. By adhering to the natural laws of work and ensuring that the physical and cognitive characteristics of machinery align with those of employees working on it, the Work-Fit Lever Techniques help in preventing physical and cognitive strain. This approach helps in reducing workplace accidents, work-related musculoskeletal disorders (WMSDs), injuries, and the depletion of human skills and knowledge. This finding aligns with the findings of Docherty et al. (2002), which posit that the disparity between the factors of employees and non-employee elements in the workplace leads to a depletion of human resources within the organization. This depletion occurs when workers afflicted by WMSDs are less capable of fulfilling their job responsibilities. Such depletion stands as a primary reason why many systems today lack sustainability at individual, organizational, and societal levels (Docherty et al., 2002).

The Work-Fit Lever, which is shown in Figure 7.1, illustrates the imbalance between the physical factors of workplace elements, highlighting the negative consequences of violating the natural laws of work. When the physical and cognitive factors of machinery and other tools do not synchronize with those of employees' physical factors, physical strain can lead to work-related musculoskeletal disorders (WMSDs), accidents, and injuries, subsequently affecting employee innovation capability and productivity.

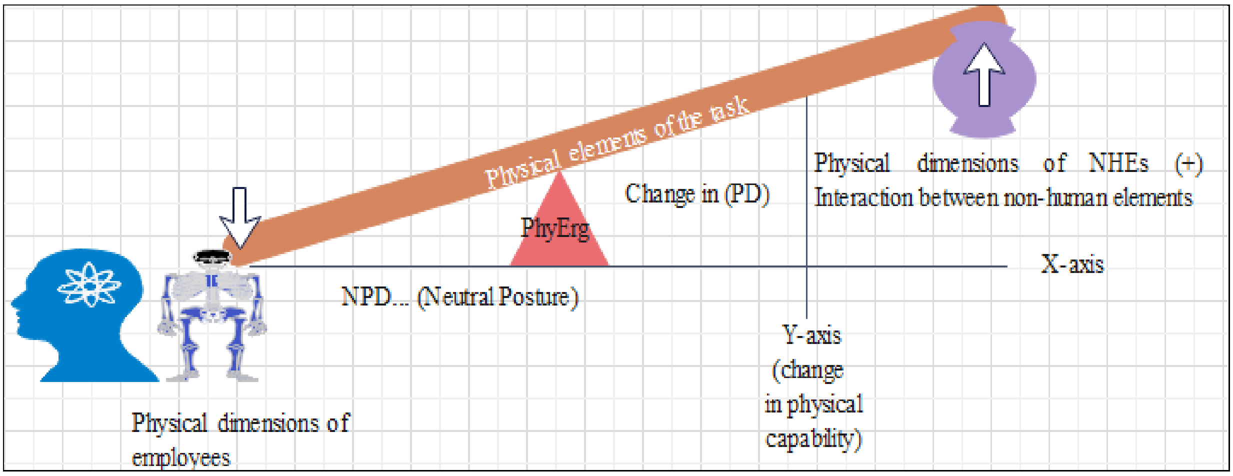


Figure 7.1: Work-Fit Lever for assessing physical strain development (Author)

In Figure 7.1, the effort arm represents the physical characteristics of employees performing a task and is applied to one end of the lever (work). The load component represents the physical factors of machinery and other tools in the workplace and is located at the opposite end of the lever (work) from the employees' physical dimension. For the case metal manufacturing firm, the machining operation embodies the work, acting as a rigid lever. The effort pertains to the physical and cognitive capabilities of the machining operator, while the load encompasses the factors of machines (fixed factors, accessibility, adjustability, etc.) utilized for the task, such as lathe, milling, etc., along with the cognitive factors involved in the operation. The cognitive factors of the machinery are operating procedures, manuals, software, maintenance procedures, and other software in the machinery.

This technique aims to enhance the interaction between effort (employee factors) and the load (machine dimension) through ergonomic principles. Any deviation from this optimization can adversely affect the physical interaction between employees and the machinery. This technique aligns with the guidelines of the International Ergonomics Association, emphasizing the importance of ergonomic principles in achieving optimal interactions between humans and all systems within the workplace (IEA, 2000).

C. Quantitative operationalization requirement: The Workfit-Lever will generate objective numerical outputs through a mathematically defined strain computation model. The framework enables measureable assessment rather than subjective ergonomic judgment. Deviated physical factors refer to the differences between the physical factors of machinery and the natural (neutral) postures of the employees. The formula for calculating the deviated physical factors (ΔPD) is as follows, stated in equation 7.1:

$$Deviated\ Physical\ dimensios(\Delta PD) = (Physical\ dimensions\ of\ the\ design\ of\ machineries) - (Natural(neutral) posture\ of\ the\ human\ elements)\ \ldots\ldots\ldots\ldots.\ (7.1)$$

By utilizing this formula (7.1), the total impacts of deviations in physical factors can be computed, providing a quantitative assessment of mismatches and their potential effects on employees and employee-machine interactions.

To quantify physical and cognitive strain, the researcher develops a concept based on the fundamental formula for computing engineering strain in mechanical properties. Engineering strain (ε) is calculated by dividing the change in length (ΔL) of a material by its original length (L_0), represented mathematically as: $\boldsymbol{\varepsilon = (\Delta L / L_0)}$.

By applying this concept, work-related strain (**physical or cognitive strain)** can be calculated by measuring the change in the muscle's posture relative to a neutral posture (Lo). Therefore, the formula for calculating the physical or cognitive strain is expressed as

Physical/cognitive strain = Change in muscles posture / neutral posture... (7.2)

This formula enables the evaluation of physical and cognitive strain experienced by employees based on changes in their muscle posture relative to a neutral posture.

In the visualization of work-related physical strain, a lever system, shown in Figure 7.1, is used by utilizing a fulcrum, which represents the principles of physical ergonomics (PhyErg), which are crucial for assessing the optimal interaction between employees and non-employees' elements in the workplace. A mathematical model is established to calculate the physical strain (Xi) on various body parts, providing insights into how machinery factors affect employee body factors.

Physical Strain (Xi) = (Deviated physical factors) / (Neutral or natural physical factors of human elements) ……………. (7.3)

The physical strain on body part j (Xj) can be calculated using the formula:

$$\text{Physical Strain on body parts j } (X_j) = \frac{\text{Deviated physical factors } \mathit{during\ the\ interaction\ of\ body\ parts\ j\ with\ each\ dimension\ of\ NHE}\ (\Delta\,\text{PDi})}{\mathit{Netural\ posture\ of\ body\ part\ j}\ (NPDj)}$$

The average physical strain on each body part (Xj) can be computed by summing the interactions between that body part and each dimension of the non-human elements in the workplace. The formula for calculating the average physical strain is

$$\textit{The average physical strain on each body parts } (X_j) = \frac{(\sum_{i=1}^{n} \Delta\,\text{PD(i)} / NPD(j)}{n} \qquad (7.4)$$

Where ΔPDi indicates the deviation of physical factors of each non-human element concerning each anthropometric dimension of the body of the workforce (NPD_j), and n represents the type of interaction.

Equation (7.4) enables workplace designers to assess and predict the impact of physical strain in metal manufacturing firms, determining how each physical dimension of non-human elements affects the body factors of human workers.

Multidimensional ergonomic coverage requirement: The WorkFit-Lever can incorporate a comprehensive assessment that evaluates different types of interacting dimensions of ergonomic mismatch, including anthropometric discrepancies between employees' body dimensions and non-human elements geometry, cognitive workload mismatches where task complexity affects human-system interaction, and postural deviations from neutral posture alignment.

By implementing the Work-Fit Lever approach, metal manufacturing firms can effectively address and correct discrepancies in the physical aspects of their workplace. This complete arrangement of a workstation, equipment functionality, usability, and ergonomic factors will provide a productive and safe environment for optimal performance and comfort.

Likewise, cognitive strain can be assessed using the Work-Fit Lever technique, considering the inconsistencies of cognitive characteristics of elements in a work environment, as depicted in Figure 7.2. The implementation of the 3S principles alongside the 5S principles is recommended for metal manufacturing firms to ensure safety practices(S), foster the spirit of employees at each workstation (S), and address the waste of skills and knowledge (S), which can negatively impact both employee performance and overall factory productivity. This finding is supported by the study conducted by Purnomo et al., (2020), which noted that cognitive disorders, such as fatigue, are common workplace issues that can adversely affect productivity. By understanding these impacts, organizations can implement preventive measures to minimize cognitive strain and its negative effects on employees' cognition, well-being, and overall performance in the workplace.

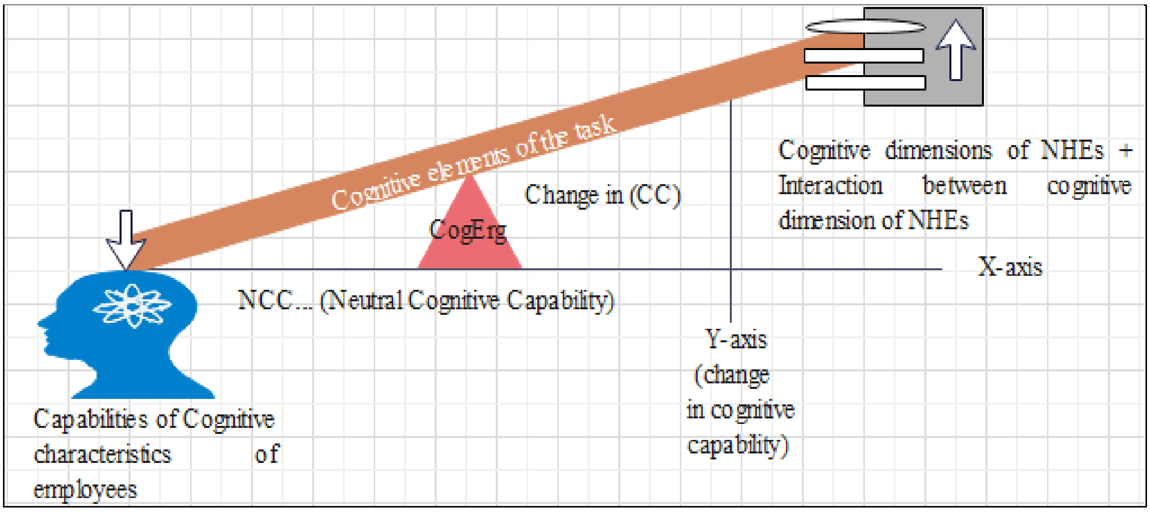


Figure 7.2: Framework for accessing the prevalence of cognitive strain developments(Author)

Step-by-Step application procedure for implementing Workfit-Lever

To assess the interaction between employees and non-employees' elements within metal manufacturing firms' workplaces, the Workfit-Lever is applied following the following 8 steps:

Step 1: Define the production system boundary: Firms must identify the following production system boundary in which the framework is ready for testing: Identify specific workstations, such as welding stations, machining stations, metal cutting stations, etc.; define employee categories, like welder, machinist, painter, etc.; identify task characteristics, like static welding, repetitive cutting, heavy lifting, etc.; and also define the performance outputs of the workstation to set the production system boundary.

Step 2: Measure Employees' Dimensions: Once defining the production system boundary, the firms should collect relevant data of their employees, like anthropometric data (elbow height (both standing and sitting), popliteal height, forward reach distance, and grip strength (important in metal or tool handling tasks)) and cognitive demand (knowledge and skills to operate the machine monitoring complexity).

Step 3: Measure non-employee dimensions: The firms should measure machine and other non-human element dimensions such as machine table height, welding bench height, tool positioning, material storage height, vibration exposure, load weight handled, cognitive demand (machine monitoring complexity), etc.

Step 4: Compute dimensional mismatch/deviations: Once the database of employees' dimensions and non-employees' dimensions are ready in the defined production system boundary, the next step is the assessment of the mismatches between employees' and non-employees' elements using the formula stated in 7.1.

Step 5: Calculate overall Strain developed: Once the mismatches/deviations are computed, the next step is the determination of the strain developed using the formula stated in 7.2.

Step 6: Interpret Lever Imbalance: Using the Workfit-lever analogy and the value of the strain developed in step 5, the experts can determine the severity of the interaction between employees and non-employee elements of the workplace. If the computed strain is high, then the expert goes to step 7.

Step 7: Generate design optimization parameters: For high-strain workstations, the expert can give recommendations for the workstation adjustment of the non-human element dimensions, redesign the workstation layout, introduce adjustable features, improve material handling design, etc.

Step 8. Recalculate post-redesign strain: if the expert recommends general design optimization parameters, the expert should check the deviation and strain development on the improved element interaction. This demonstrates measurable ergonomic improvement and supports the development of sustainable competitive advantages in metal manufacturing firms.

The Workfit-Lever is the primary instrument used to detect and evaluate mismatches in terms of ergonomic needs between employees and non-employees. It provides an objective evaluation of the degree and direction of mismatches in terms of metal manufacturing workstation design through its mathematical model of strain computation. Although Workfit-Lever provides an understanding of the degree and structure of mismatches in terms of ergonomic needs, it does not, by itself, provide a structure for the translation of this information into an engineering context.

In order to implement corrective actions, the Ergonomic Function Deployment (EFD) framework is proposed as a complementary mechanism for design translation.

7.2.2. Ergonomic Function Deployment Framework:

In the realm of Ergonomic Function Deployment Framework, the preceding chapters (5 and 6) have underscored how discrepancies between employee factors and machinery factors in the workplace impact well-being and innovation capability, thereby shaping the sustainable competitive advantages in metal manufacturing firms. Additionally, existing literature points to a concerning lack of awareness regarding the value of ergonomics, leading to underutilization of its potential (Isabel, 2015). Ergonomic considerations and risk assessments during the design phase are often overlooked, with corrective actions postponed to the production phase, resulting in escalated intervention costs (Dul and Neumann, 2009). This trend is exacerbated by organizations prioritizing productivity and quality performance over worker health (Meyer et al., 2017), with health and safety concerns receiving inadequate attention in national development agendas (ILO, 2010). Such issues within the metal manufacturing sector create an imbalance between worker capacity and system demand.

Building on the insights from the previous chapters, the establishment of an employee-centric workplace design is pivotal for mitigating imbalances and reducing the prevalence of work-related disorders that impact employee well-being and innovation capability—essential elements for sustaining competitive advantages in metal manufacturing firms. To ensure employee engagement, Ergonomic Function Deployment (EFD) is advocated to incorporate employees' perspectives during workplace design, akin to Quality Function Deployment's (QFD) role in integrating customer feedback throughout product planning and manufacturing stages (Chen & KO, 2008; Hsu et al., 2007). Consequently, the Ergonomic Function Deployment emerges as a suitable tool for aligning employee requirements with other workplace elements to foster ergonomic workplace design.

This proposed Ergonomic Function deployment (EFD) framework delves into addressing the physical and cognitive needs of employees comprehensively, taking into account technology requirements, legal obligations at national and organizational levels, internal policies, social dynamics among workers, and essential working environment parameters. This study introduces the comprehensive procedures (Figure 7.3) for applying the EFD framework to proactively prevent work-related disorders in metal manufacturing firms via designing an ergonomic workplace. To establish a workplace that prioritizes employee needs, effective collaboration among physical and cognitive subsystems, organizational standards, regulations, and management is essential. The framework underscores the importance of engaging employees in the workplace design process, placing their requirements and tasks at the forefront, ultimately leading to the creation of a human-centred workplace. Leveraging an ergonomic function deployment (EFD) tool can facilitate this process, fostering a harmonious collaboration between employee requirements and the various elements within the workplace.

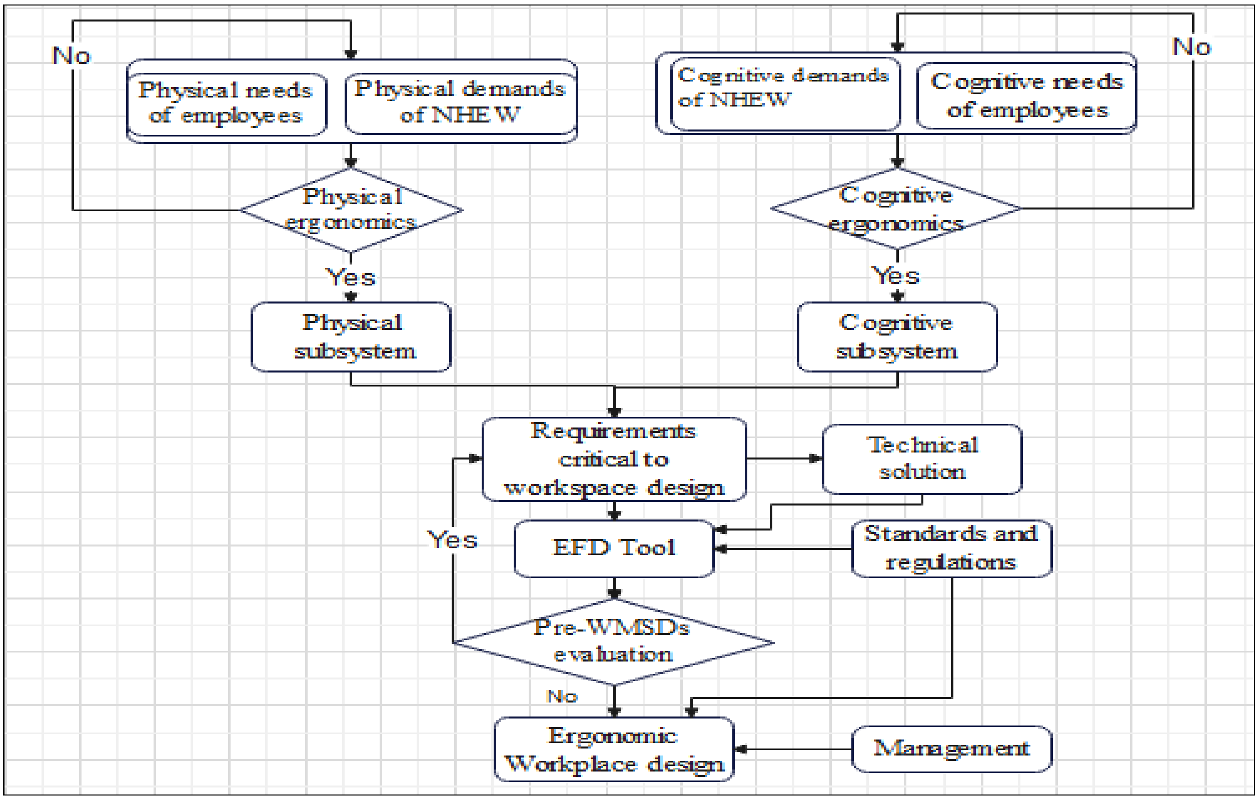


Figure 7.3: A procedure for designing an ergonomic workplace (Author)

Elements of the design framework (EFD)

In the endeavour to eliminate the root causes of work-related disorders within the metal manufacturing systems, the adoption of an ergonomic function deployment framework throughout the workplace design process is deemed crucial. The framework's elements are delineated as follows:

Step 1: Identify Working Environment Requirements: The study's findings underscore the necessity to consider the design of the workplace and space based on the factory's mission and vision. Notably, the study reveals a lack of consideration for working environment demand analysis during workplace design, emphasizing the need to determine working environment characteristics early on for an ergonomic workplace design. Hence, to have an employee-centric workplace, the characteristics of the working environment need to be determined at the first stages of the workplace design process using the template in Table 7.1, which is developed based on the results found in the existing metal manufacturing firms. In this template, both the physical and cognitive factors of each element should be identified.

Table 7.1: Workplace Demand Analysis Template

Demand types of the workspace elements	Factors for the demands
Physical demands	Layout of the workplace (height, width, and length of buildings; types of buildings; and roof types)
	Layout of the workspace (height, width, and length of the workspace)
	Types of processes used in the production (welding, galvanizing, etc.)
	Physical demands of indoor environment infrastructure (light, humidity, room temperature, etc.)
	Aisle distances and the types of materials, machines, tools, and equipment used)
Cognitive demands	Communication system design
	Required skill and knowledge for operating different elements of the workplace (machinery, tools, equipment, software, etc.).
	Required skills and knowledge for social and environmental interaction
	Required decision-making skills and knowledge

Step 2: Ergonomic Needs of Employees*:* After establishing the working environment requirements, the focus of the framework transitions to identifying the ergonomic needs of employees for each aspect of the working environment. At this stage, it is crucial to pinpoint the ergonomic requirements of the employees who currently work or are planned to work in the workstation. The physical and cognitive factors of the employees, as the end-users of the workplace, must be meticulously identified and documented to ensure comprehensive consideration during the workplace design process. It is essential to incorporate the feedback and input of employees regarding their cognitive and physical needs at this stage to mitigate work-

related disorders, which are often silent productivity killers. To perform this step, metal manufacturing firms should utilize Table 7.2 as a template to determine employees' physical and cognitive requirements and involve them in designing an ergonomic workspace.

Table 7.2. Workforce requirement analysis template

Types of requirements	Factors for the requirements
Physical requirements	Height of the employee Weight of the employees Width of the employees, etc.
Cognitive (skills and knowledge required) for	Mental processing Decision-making Social learning Ease of use Perception, etc.

These efforts align with the conclusions drawn in the study by Tendai and Jerie (2017), which emphasized the importance of integrating employees' requirements into the daily operations of the company to reduce the incidence of Work-Related Musculoskeletal Disorders (WMSDs). Furthermore, this step finds support in the research conducted by Charisi et al.(2025) highlighting workplace mental health as a critical social issue with profound human and economic implications.

Step 3. Determining requirements critical to workplace design (RCWD):

Once the factors of the employees at step two and the factors of the non-employees' elements (at step1) are identified, the next step should be identifying the optimal interaction area between the two to eliminate the imbalance between the employees and the non-employees' elements using the Workfit-Lever techniques. In this study the researcher advocates that the set of requirements critical to ergonomic workplace design is the feasible common values of the sets of work environment requirements (factors of non-employees' elements), and the ergonomic needs of employees are determined using the following formula shown in 7.5:

$$\{RCWD\} = \{\, Dimensions\ of\ Non - employees\ elements\} \cap \{dimensions\ of\ employees\}$$

(7.5); Where, ∩ is intersection

A sample template is developed based on the data found from the case metal manufacturing firms, as shown in Table 7.3

Table 7.3. Template for determining critical requirements for welding workspace design

	Demands of welding workspace	
	Physical (dimension *of machines, tools, equipment, raw*	Cognitive(*skill and knowledge demands for design, operation*

		materials, dimension of welding space, etc.)	*procedure, and management)*
Ergonomic needs of employees	Physical capability (*physical dimension of employees)*	+	+
	Cognitive capability (skill *and knowledge of employees on design, operation*, reading drawing, etc.)	+	+

Note: + indicates positive impacts on the well-being of employees.

Table 7.3's template identifies variables that positively impact employee well-being and are critical to identifying requirements critical to workplace design. Once identified, the requirements are prioritized based on their impact on WMSD prevalence.

Step 4: Prioritizing Requirements Critical to Workplace Design (RCWD)

To simplify the workspace design process, critical requirements for workplace design (RCWD) must be prioritized based on their respective impacts on the physical, cognitive, environmental, and social well-being of employees. This study determined feasible RCWD using a **hexagonal model** (equation 7.6) with six factors (risk factors) for WMSDs: muscular force, awkward posture, work overload, social impacts, environmental factors, and exposure time. The model integrates the effect of each risk factor on employee well-being to select a set of critical requirements for workplace design.

$$\text{Feasible RCWD} = \min\{(f * t) + (Awkp * t) + (PsyS * t) + (\ Ef * t) + (Si * t)\} \quad (7.6)$$

Where the value of each variable is between 1 to 3

Where 1 is the list effect on the well-being of employees

2 is the medium effect on the well-being of employees

3 is the highest effect on the well-being of employees

F is force exertion, t is exposure time, PsyS is psychological stress, E_f is environmental factor, and Si is social impacts

It can also be computed mathematically using the formula (7.7):

$$RCWD = \min\{\textstyle\sum_{i=1}^{n} X_n \ \ t_n\}$$

$$\text{Subjected to; } X_n \ \leq EI_n \quad (7.7)$$

Where X is the impact of workspace design requirements on the ergonomic needs of employees, t_n is the exposure time for the impacts, n is the number of interactions between X and t, and EI is the accepted ergonomic index for each ergonomic risk factor.................. (*Model by Author)*

In this context, exposure time is calculated as follows:

$$t_n = \frac{\text{Task duration}}{\text{shift duration}}$$

For example, this formula can be used to prioritize the reach distance employees need based on its impacts on different dimensions of employee well-being. By analysing how reach distance affects employees across various aspects, we can identify the following dimensions and their corresponding impacts:

Well-being dimensions	**Impacts of excessive reach distance**
Physical	Shoulder load, MSDs, fatigue
Cognitive	Reduce focus
Social	Lower morale
Environmental	Inefficient workspace
Organizational	Lower productivity

Based on this impact, the workplace design experts can identify reach distance requirements critical to workplace design based on its summative impacts on the well-being of employee and the firm as well.

This study's findings align with previous research by Sperling et al. (1993) and *Raghunathan* et al. (2014) that suggests using a Cube Model to determine work posture, force, and repetitive demands for a proper workplace design. The authors' model can be used to establish realistic physical and cognitive requirements for workspace design, guiding the creation of an ergonomic function deployment model to achieve an employee-centred workspace in metal manufacturing firms.

Step five*: *Determining the interaction between non-employees' elements of the workplace: Once feasible requirements for an ergonomic workplace design are established, they should be recorded using the house of ergonomic function deployment. In workplaces with multiple non-employee elements, the impact of their interactions on employee well-being must be assessed by utilizing the matrix provided in Table 7.4. This matrix maps the requirements of one element against another to evaluate their impacts on employee well-being. Managers can utilize this matrix to mark significant interactions with ''HS,'' conflicting solutions with ''C,'' or leave the cell blank if both solutions stand alone. This process aids in eliminating the root causes of Work-related disorders and highlighting potential conflicts between non-employees' elements in the workplace.

Table 7.4 Interaction Matrix

		Demands of NHE_2	
		Physical	Cognitive
Demands of NHE_1	Physical	HS	C
	Cognitive		

Table 7.5 illustrates the criticality of considering the impacts of interactions between non-employee's elements in an ergonomic workplace design for the metal manufacturing industry. For example, the machinery requirement versus indoor environment factors matrix requires careful consideration of factors such as power consumption, heat, humidity, and air quality. Decisions should incorporate the needs and preferences of employees who will operate the machinery. If an interaction between two factors is suitable for employees, it should be marked as "HS." Conversely, any contradictions should be labelled as "C." This approach ensures a secure and comfortable work environment that minimizes the risk of work-related disorders.

Table 7.5 Sample of interaction between machineries and indoor environment

		Machinery		
		Heat generated	Space requirement	Power consumption
Indoor environment	Electric installation			
	Air quality			
	Humidity			

Step 6: Selecting Acceptable Non-employee elements of the workplace: After identifying a set of feasible requirements crucial to workplace design, technically unviable solutions should be screened out based on the hierarchy of control to mitigate hazards and diminish occupational health and safety risks. The proposed framework for selecting and proposing suitable technical solutions is depicted in Figure 7.4, incorporating the hierarchy of controls to determine which technical requirements to be included. This methodology aligns with ISO 45001 standard article 8.1.2 on hazard and risk control. Requirements of non-employee elements of the workplace should be tailored to the employee's ergonomic needs and should not introduce new workplace risks beyond the organizational context. The hierarchy of controls will serve as a guide for amending technical requirements that might result in new work-related disorders.

Subsequently, once technically feasible non-employee elements are identified for ergonomic workplace design, the next step involves establishing organizational-level management standards based on the physical and cognitive specifications of the workplace. This process ensures that management practices and policies are aligned to establish a safe and comfortable work environment that mitigates the risk of work-related disorders.

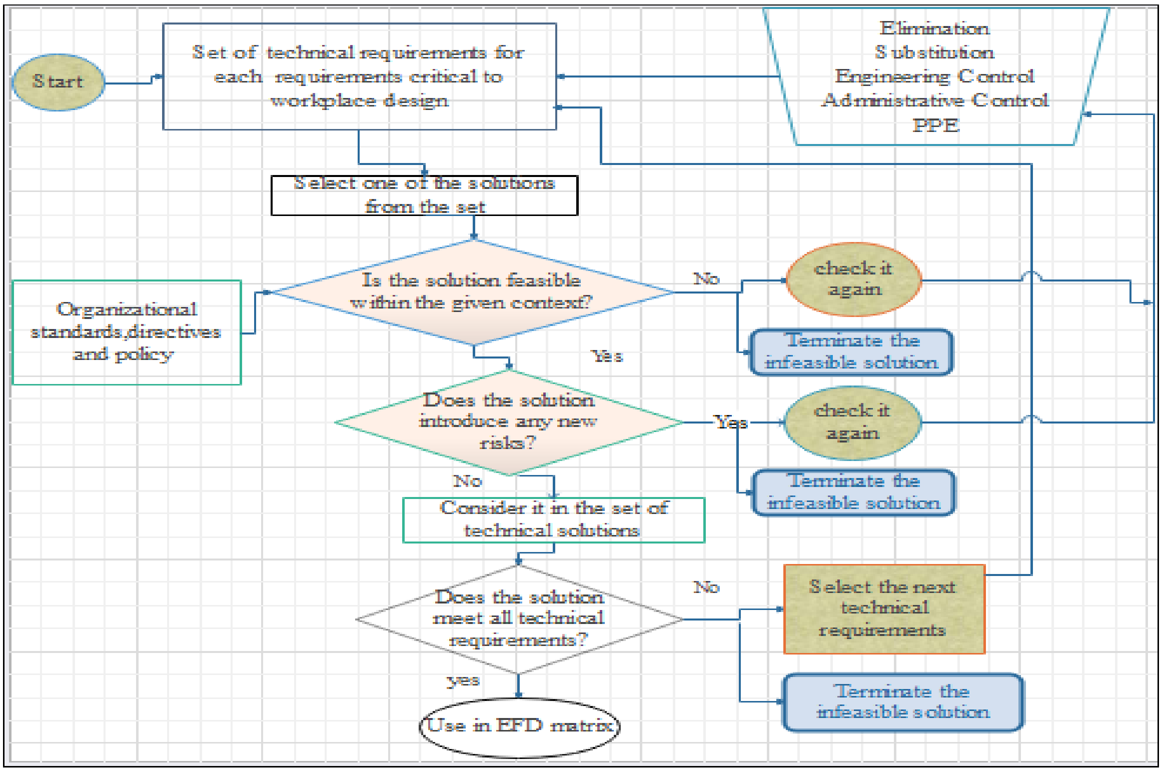


Figure 7.4 Framework for selecting acceptable technical requirements (by author)

Step seven*: Determining employee-centred operation and management factors:* Addressing the root causes of work-related disorders, requires identifying human-centered operation and management requirements based on feasible physical and cognitive workspace specifications. Utilizing the template provided in Table 7.6, these requirements include workload, production methods, rotating work schedules, compensation practices, and management strategy. It is imperative that these requirements align with the employee-centric physical and cognitive workspace specifications to determine employee-centric operation and management subsystem's factor. This process is vital in establishing a safe and comfortable work environment while minimizing the risk of work-related disorders. Subsequently, the physical and cognitive specifications are prepared for final implementation.

Table 7.6. Template for determining the employee-centered operation management factors

Specification of the workspace	Operation and Management Requirements				
	Workload	Method of production	Rotation of the working schedule	Management strategy	Incentive mechanisms
Physical Specification	Dimensions for employee-centric workplace design				
Cognitive specification					

Legal Requirements (LR): Legal requirements focusing on employees' needs play a crucial role in addressing the root causes of work-related disorders and establishing an employee-centred workplace. Organizational legal requirements, such as standards concerning physical and mental demands and anthropometric data, should be developed and integrated into all stages of the production process to prevent work-related disorders. However, the literature reveals a lack of policies in many countries that incentivize firms to target the elimination of these root causes, with organizations often relying solely on personal protective equipment, which is a reactive and less effective solution. The findings from Ethiopia also showed that the country has developed various directives and legislation related to occupational health and safety (OHS) that are not yet fully implemented in many manufacturing firms, as stated in *Chapter Four* of this study. Moreover, these standards do not address ergonomic workplace design. Therefore, to minimize the root causes of work-related disorders, it is essential for top management to demonstrate commitment and take responsibility for developing and implementing organizational and national legal requirements in each workplace design that prevent work-related disorders and ensure safe and healthy workplaces. This finding aligns with ISO 45001 Clause 5.1, which emphasizes leadership and commitment in preventing work-related injuries.

Step eight: Developing Relationship Matrix: A relationship matrix is used to evaluate the feasibility of non-human elements in the workplace concerning RCWDs and human-centred legal requirements, as shown in Figure 7.5. Feasible non-human element requirements are used to create a workspace design specification with physical and cognitive parts based on human-centred legal requirements. The physical and cognitive specifications are determined by intersecting the requirements critical to workspace design with the physical and cognitive requirements of technical solutions. Note that the relationship values will be assigned based on expert consensus supported by ergonomic standards. The left and right columns of the matrix list the physical and cognitive requirements critical for workspace design and their corresponding ergonomic indices measurements.

The ergonomics indices measure the level of work-related disorders related to force, stress, posture, indoor working environment, social impacts, and workloads in the workplace. The Ergonomic Index is an objective benchmark showing whether workplace conditions meet acceptable limits (e.g., posture flexion > 200 indicates risk).

The set of physical and cognitive non-human elements that match each RCWD and legal requirement are selected based on the framework shown in Figure 7.5 and listed in the EFD framework's top row.

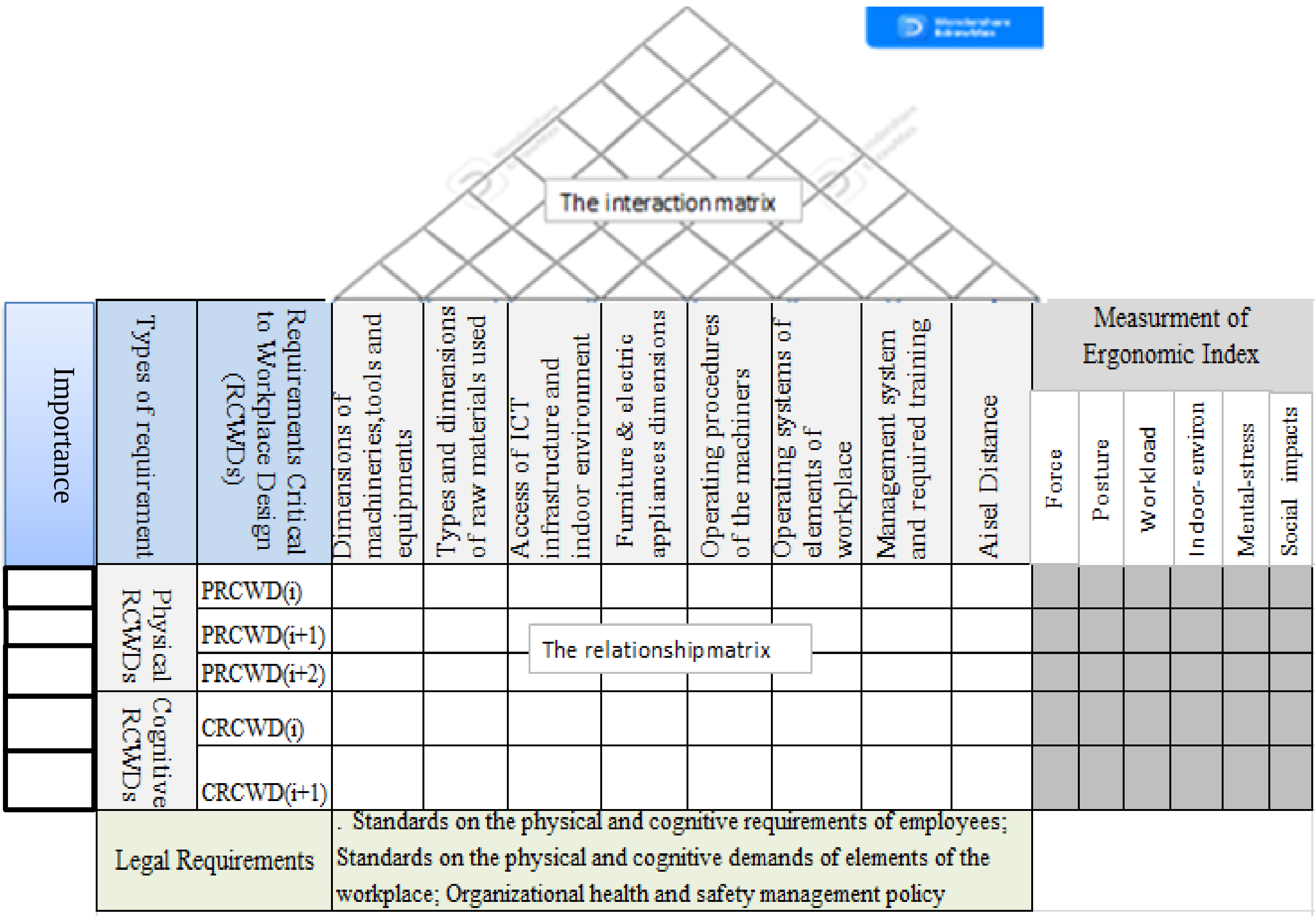


Figure 7.5 House of ergonomic function deployment framework (by Authors)

Validation of the frameworks: In order to further enhance the robustness and applicability of the developed ergonomic function deployment (EFD) framework and the Workfit-Lever, an expert review was performed. The expert review was conducted in an attempt to validate the conceptual validity, clarity, and applicability and relevance of the proposed tools in the manufacturing industry. The expert review was conducted by inviting experts with experience in industrial engineering, mechanical engineering, production management, and manufacturing engineering to review the models. In addition, the expert review was conducted by involving participants from different levels of the organization to ensure a balanced and practice-oriented validation of the proposed tools. Specifically, 59 frontline workers and 8 senior experts with experience at different levels of management were involved in the expert review process. The involvement of the frontline workers provided information on the applicability, usability, and clarity of the EFD framework and Workfit-lever from the operational level, while the involvement of the senior experts ensured a strategic, technical, and managerial assessment of the models.

The involvement of participants from different levels of the organization increased the credibility of the expert review by including both hands-on experience and decision-making perspectives.

The importance was rated using a 5-point Likert scale (1 = not important at all to 5 = highly important), and the results are presented in Table 7.7 and Table 7.8, demonstrating the practical relevance important and content validity of the EFD framework and Workfit-Lever.

Table 7.7. Summary of rating for the Ergonomic Function Deployment Tool

Respondents	Rating scales given by experts				
	Not important at all	Neutral	Low impact	Moderate	Highly important
Managers and supervisors				2	6
Percentage of response				25%	75%
Workers			2	17	40
Percentage of response			3.4%	28.8%	67.8%

Table 7.7 shows that nearly all management-level experts support the relevance of the Ergonomic Function Deployment Tool in designing ergonomic workplace design aimed at reducing workplace risks and hazards. Specifically, 75% of managers and supervisors recognize that this framework significantly supports the manufacturing firms via decreasing the incidence of work-related disorders. Furthermore, 96.6% of experts agree that involving workers in the workplace design process lowers the incidence of work-related disorders. Only 3.4% of experts expressed low regard for the impact of employee needs involvement, attributing their concerns to insufficient management support for employee-centered changes.

Table 7.8. Summary of rating for the Importance of Workfit-Lever

Respondents	Rating scales given by experts				
	Not important at all	Neutral	Low impact	Moderate	Highly important
Managers and supervisors				3	5
Percentage of response				37.5%	62.5%
Workers				18	41
Percentage of response				30.5%	69.5%

The analysis of responses from managers, supervisors, and workers regarding the importance of the Workfit-Lever ergonomic assessment tool yielded interesting findings. Among managers and supervisors, 37.5% rated it as having a moderate impact, while 62.5% considered it to be of high importance for assessing the mismatches between employees' dimensions and dimensions of non-employee elements of the workplace. In contrast, workers displayed a stronger inclination towards its significance, with 30.5% perceiving it as having a moderate impact and a substantial 69.5% recognizing its high importance.

The rating gap between supervisors/managers and workers suggest a variation in perception of the importance of the element under evaluation. Though most supervisors and managers value its importance to some extent, the majority of employees value its broad impact. Such a difference in perception can arise from variations in the level of direct interaction and exposure to the element within the work environment.

The higher endorsement of the significance of this component by employees indicates a reflection of direct experience or perception of its impact on their responsibilities and obligations. The more conservative style of certain supervisors and managers, in turn, could reflect that there should be more explanation regarding the significance and potential benefits associated with this component.

These results highlight the importance of considering diverse viewpoints within the organizational framework in evaluating significant factors, highlighting the need for proper communication and coordination to reconcile views and develop a common understanding of significant factors influencing workplace operations and dynamics. Based on feedback from experts, an Importance column was added to the EFD framework to enhance its quality.

7.3. Ergonomic Workplace Design Strategy:

The findings of this study, as discussed in the literature and Chapter Six, highlight the impact of cognitive ergonomic risk factors on the well-being and innovation capabilities of employees working in metal manufacturing firms. The results indicate that these ergonomic risk factors have significant relationships with employee well-being and innovation capability, revealing that metal manufacturing firms should focus on eliminating the root causes of these ergonomic risk factors rather than relying solely on reactive approaches.

Moreover, the results presented in Chapter Seven indicate a significant relationship between employee well-being, ergonomic workplace design, innovation capability, and the development of sustainable competitive advantages in metal manufacturing firms. This suggests that these firms must ensure the well-being and innovation capabilities of employees by designing ergonomic workplaces to foster sustainable competitive advantages. To achieve this, metal manufacturing firms should prioritize preventive approaches over reactive ones.

Additionally, the results of this study, derived from document analysis, indicate that national legislation, policies, and directives in Ethiopia focus primarily on occupational health and safety management without addressing ergonomic workplaces. This highlights the need for all manufacturing firms to adopt prevention strategies, as outlined in the Ethiopian Occupational Safety and Health (OSH) Directive of 2008 and other relevant documents.

Therefore, these findings serve as a call to action for the development of sustainable competitive advantages, which is an on-going process that requires prioritizing employee well-being. The researcher advocates that this process is akin to a road that is always under construction—a progressive path rather than a final destination. This road must be safe and comfortable for both the users (employees) and builders (metal manufacturing firms) of sustainable competitive advantages.

From a philosophical standpoint, the key to building sustainable competitive advantages within metal manufacturing firms lies in establishing a "highway" for the continuous flow of knowledge, as depicted in Figure 7.6. To create an employee-friendly highway, experts and stakeholders need to consider the needs and preferences of the employees working within the firm. Employees serve as the source and gatekeepers of development within the organization. Their ability to generate new knowledge, innovation, and creativity significantly enhances the technological, process, and marketing capabilities of the manufacturing firm they are associated with. However, for employees to fully utilize their potential, they need to operate within a safe and healthy working environment—a well-designed highway. If the workplace fails to provide a healthy environment, employees may not feel free, satisfied, or motivated to generate new knowledge and improve the firm's innovation capabilities. Moreover, they can also be exposed to different work-related disorders that affect their well-being and cause them to be absent from work and make errors in their workplace.

Consequently, designing an employee-centric highway (workplace) serves as the foundation for leveraging the knowledge and innovation capabilities of employees in driving success within metal manufacturing firms. The primary source of power for these firms to develop sustainable competitive advantages stems from specialized knowledge and innovation, which can only be derived from satisfied and comfortable employees. Hence, metal manufacturing firms must consistently adhere to a strategy known as the "development of sustainable competitive advantages formula".

The concept of the development of the sustainable competitive advantages formula is derived from the analogy of a continuous water supply. Just as a secure, sufficient, and high-quality water source is essential to have a continuous water supply, the continuous development of sustainable competitive advantages in metal manufacturing firms relies on a secure source —the intangible resources, skills, and knowledge of employees.

The initial step of this formula involves identifying the specific area, product, or excellence in which the firm aims to develop sustainable competitive advantages to compete at both national and international levels. The subsequent step entails taking actions that differentiate the firm from its competitors. This involves implementing initiatives that enhance the well-being and innovation capabilities of employees, thereby facilitating the generation of new ideas and products that contribute to the development of sustainable competitive advantages. Healthy, satisfied, and motivated employees can effectively apply their knowledge and skills to research solutions and generate new product ideas within the firm. Investing in research and development and fostering new product development is instrumental in achieving sustainable competitive advantages (Chen et al., 2020; Madero-Gómez et al., 2023).

To take action in building safe and comfortable highways for employees, metal manufacturing firms must adhere to the natural laws of work, including ergonomic principles that optimize interactions between employees and other non-employees' elements in the workplace. This adherence to the law of work should be considered a critical requirement in constructing an employee-centric highway (workplace) within metal manufacturing firms. Since the impacts of work-related disorders are seen as system problems rather than employee problems, and their solution is seen to lie in designing a better system of work (R. Bridger, 2003) rather than in the adoption of new technologies and employee management.

The third step involves developing sensory perception to recognize the responses and outcomes arising from different types of workplace design and promptly assessing whether or not these actions bring the firm closer to the goals established in step one. During this stage, the production and ergonomic management department should gather feedback from the marketplace and the various workspaces within the firm regarding the well-being and innovation capabilities of employees, as well as the progress made in developing sustainable competitive advantages within the identified target areas.

In collaboration with the research and development office of the metal manufacturing firms, the production and ergonomics management department should engage in discussions and communication with employees at each stage of the production system to facilitate further improvements and remedial actions. Thus, in order to maintain a continuous path of sustainable development and establish an employee-centric workplace with ergonomic design, a detailed framework has been developed in this study, as outlined in the subsequent subsections.

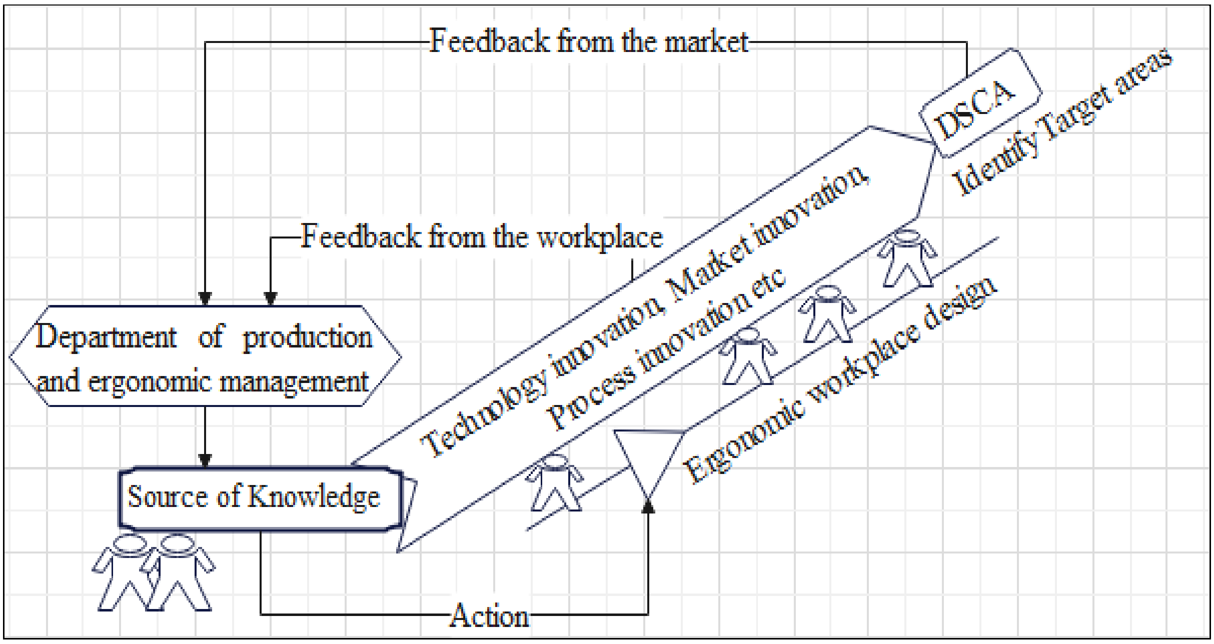


Figure 7.6. Formulas of Development of Sustainable Competitive Advantages (DSCA) (*Source: Developed by Author)*

Thus, the formula for developing sustainable competitive advantages (SCA) in manufacturing firms indicates that manufacturing firms should have a strategy that integrates and prioritizes ergonomic workplace design as the foundation for any production system aiming to cultivate sustainable competitive advantages, as illustrated in Figure 7. 7. For instance, if manufacturing firms aim to eliminate waste in their production process, they may consider implementing different production philosophies like lean philosophy for minimizing the seven wastes. However, for successful implementation, manufacturing firms should synergize ergonomic principles with other production principles, for example, with lean principles and others. This integration of ergonomics with other production concepts should start with the employee-driven workplace design that prioritizes ergonomic requirements. It is essential to prioritize both employee productivity and well-being when designing the workplace and working procedures. Just as a strong and high-quality foundation is necessary for building construction, a manufacturing firm cannot produce competitive products without a conducive working environment. Therefore, for example, in lean concepts, the foundation for removing Mura and Muri, which lead to the occurrence of Muda and work-related diseases, is ergonomic workplace design. This strategy mitigates ergonomic risks, acknowledging that ergonomics is the cornerstone of lean transformation (Brito et al., 2020; Kim, 2017). Furthermore, the study by Brito et al. (2019) supports this conclusion by stating that enhancing worker safety and work conditions can minimize waste, as Muri and Mura are the main causes of waste.

Building Blocks: Ergonomic-Driven Lean Tools and Techniques: To address the root causes of ergonomic and lean wastes at every stage of the production system, it is essential to develop ergonomic-driven lean tools and techniques as foundational elements. These tools and techniques are designed to optimize workflow, minimize unnecessary movements, and enhance the overall efficiency and ergonomics of workstations. By integrating ergonomic considerations into lean practices, the production system can effectively tackle waste reduction and ergonomic risk factors, resulting in improved productivity and the well-being of workers. This finding is supported by the study by Aqlan et al. (2013), which confirms that ergonomics supports lean transformation, resulting in a reduction of ergonomic risks and lean wastes.

Interior Spaces: Workflow and Value-Adding Tasks: Organizing and optimizing the interior spaces of the production system is crucial to minimize waste and maximize productivity while considering ergonomic principles. The interior spaces of the production system represent the workflow and value-adding tasks performed during the production process.

Roof: Developments of Sustainable Competitive Advantages (DSCA): The roof of the "house" symbolizes increased production and favourable work environments for developing sustainable competitive advantages in metal manufacturing firms. Creating a culture of practicing an employee-centric continuous improvement, employee engagement, and empowerment is essential for achieving increased production and favourable work environments. By encouraging creativity and innovation in a conducive work environment, employees become active participants in identifying and resolving ergonomic and lean issues. This collaborative approach fosters a sense of ownership and responsibility among workers, contributing to their overall well-being and the success of the production system.

Truss: Ensuring Highest Quality, Lowest Cost, Shortest Lead Time, and Employee Wellbeing: The truss of the roof symbolizes the commitment to achieving the highest quality, lowest cost, shortest lead time, and prioritizing the well-being of the workforce. By integrating ergonomics with lean principles, the production system can effectively work towards these goals by minimizing waste, optimizing processes, and giving utmost importance to the wellbeing of employees.

Remedial Actions: Empowering Employees and Establishing Ergo-Lean Teams: To put the concept into practice, the factory must empower and motivate employees, encouraging them to apply their innovation and creativity to solve problems at their workstations. Furthermore, the establishment of an ergo-lean team becomes necessary to identify ergonomic and lean issues at every stage of the manufacturing process and effectively implement suitable solutions.

Supporting Pillars: The framework (Figure 7.7) for synergizing ergonomics with lean principles incorporates eight principles that form the supporting pillars for achieving an ergo-lean production system (ELPS). Two key principles within this framework are

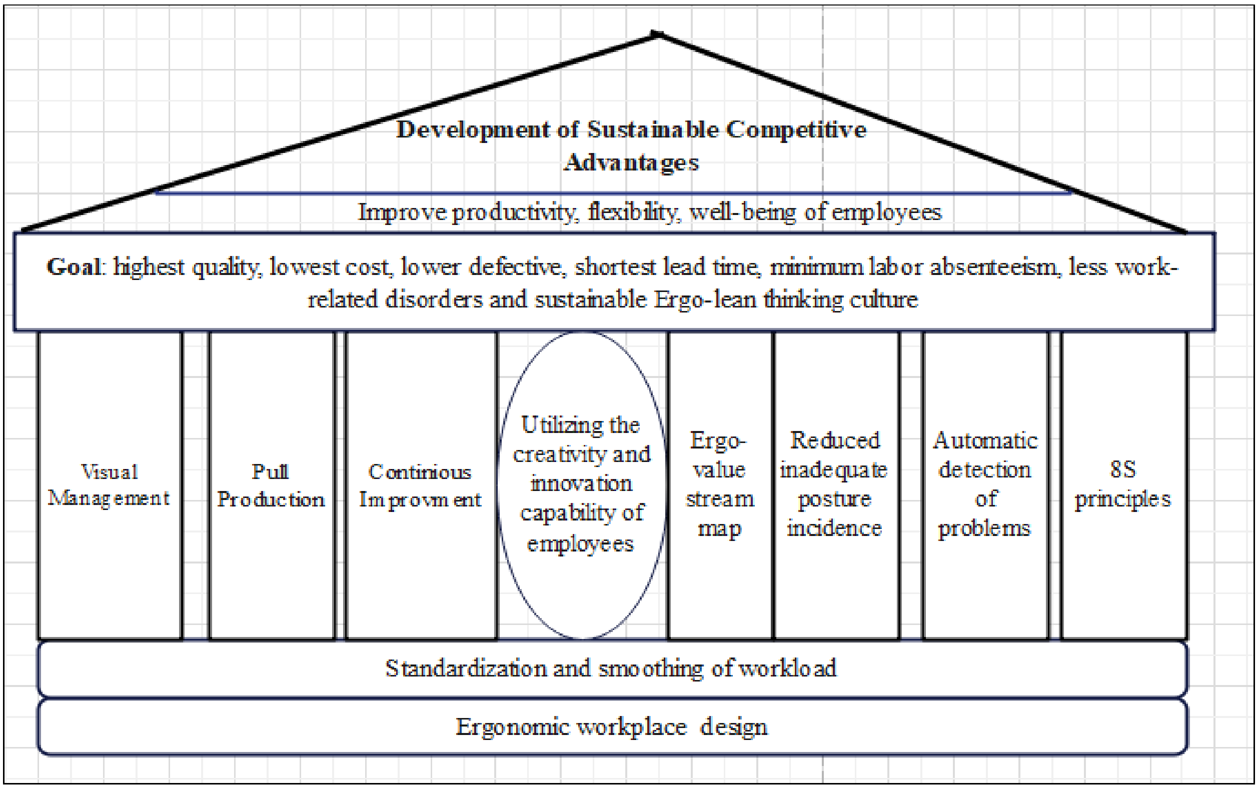


Figure 7.7. Strategy for Synergizing Ergonomic workplace design with other production system(Author)

(1) *Pull Production*: The pull production principle aligns production with downstream process demands while prioritizing employee well-being. By responding to actual customer and employee demand, this approach minimizes waste and optimizes resource utilization, preventing overproduction and reducing strain on workers for a smoother and more efficient workflow.

(2) *Automatic Detection*: Automatic detection is a vital principle in the framework, involving the implementation of systems that promptly identify quality issues and injuries at their root causes. This proactive approach helps maintain product quality, mitigate risks, and safeguard employee well-being by resolving issues before they escalate.

Ergonomic-Lean 8S principles: Integrating ergonomic principles with lean principles to establish an ergo-lean 8S system presents a valuable approach for addressing both lean and ergonomic wastes in the manufacturing industry. By incorporating additional S principles that specifically target wastes affecting employee well-being, such as Safety, Spirited and Inspiring Situations, and *Skills Utilization*, the 8S system aims to eliminate ergonomic wastes that contribute to work-related disorders. The ultimate goal is to create a work environment that prioritizes employee well-being, reduces the risk of injuries, and improves overall productivity and efficiency. Steps to Implement Ergo-Lean 8S Principles in the Manufacturing Industry: ***Sort:*** This principle emphasizes removing unnecessary items and organizing the workplace. In the ergo-lean 8S system, ergonomic considerations ensure only essential tools, equipment, and materials are present, reducing clutter and minimizing the risk of ergonomic hazards from unnecessary items. *Set in Order:* This principle focuses on organizing items systematically. In the ergo-lean 8S system, ergonomic principles are incorporated into the arrangement of tools, equipment, and workstations. This includes optimizing placement, providing ergonomic storage, and designing workstations to support proper posture and movement. *Shine:* The shine principle highlights the significance of maintaining a clean work environment in the Ergo-Lean 8S system. Cleanliness is essential for visual management and preventing ergonomic hazards like slips and falls. Regular cleaning ensures equipment is in good condition, reducing the risk of ergonomic issues. *Standardize:* Standardization is crucial to maintain improvements in the ergo-lean 8S system. Establishing and documenting ergonomic standards ensures consistency in practices, including workstation setup, equipment usage, and work techniques. This reduces variations and promotes a safer, more ergonomic work environment. *Safety:* This stage focuses on minimizing or eliminating workplace risk factors and ensuring appropriate safety protective equipment is available. The goal is to reduce causes for accidents and injuries in the workplace, aligning with the aim of creating a safe and ergonomic work environment. *Spirited and Inspiring Situations*: This stage emphasizes the significance of cultivating a positive work environment that prioritizes employee well-being and morale. It aligns with the goal of preventing ergonomic risks and work-related stress. Gull and Doh (2004) support the idea that a spiritually oriented workplace benefits managers, workers, and society. *Skills Utilization: It* recognizes the importance of optimizing employees' skills and minimizing wastage to enhance the culture of innovation in the manufacturing firms. Effectively utilizing skills within manufacturing firms enables them to develop sustainable competitive advantages. This finding is also supported by the 2024 World Manufacturing Report, which states that developing and maintaining skills to foster innovation, such as creativity, adaptability, and entrepreneurial thinking in the leadership team and workforce, is crucial for driving innovation at the core of manufacturing transformation[3]. By providing opportunities for employees to contribute their expertise, the 8S system fosters engagement and maximizes potential, resulting in improved efficiency and quality. Afonso et al. (2021) support this finding, noting untapped human potential as a cause of waste in production. *Sustain:* The sustain principle in the ergo-lean 8S system focuses on maintaining and improving the system. This involves continuous monitoring, training, and communication to address ergonomic issues. By integrating ergonomic and lean principles, the system prioritizes employee well-being, reduces

[3] *2024 World Manufacturing Report – New Perspectives for the Future of Manufacturing: Outlook 2030: World Manufacturing Foundation*

waste, and enhances productivity. By embracing these concepts, the production system merges lean and ergonomic principles, prioritizing workers, enhancing productivity, and improving efficiency. It minimizes waste, optimizes processes, and prioritizes employee well-being, fostering success and a positive workplace culture. Bassam's (2024) study provides compelling evidence for incorporating human factors and ergonomics in sustainable manufacturing practices, recognizing the pivotal role of workers.

Therefore, employee involvement in the design process of the workplace can have significant benefits. By including employees in the decision-making and seeking their feedback through surveys and other means, a sense of ownership and engagement can be fostered. This employee-centric approach ensures that their perspectives and preferences are taken into account, leading to a workspace that better meets their needs. Since co-creation or design allows employees to provide feedback, contribute ideas, and participate in the design process (Prahalad & Ramaswamy, 2004; Bennett, 2025)

Specifically, when implementing new non-human elements in the workplace, it is crucial to engage employees and inform them about the benefits and opportunities that these elements can bring. Employees' perception of upcoming changes is influenced by their involvement in the process and their understanding of the positive impact that non-human elements can have. By involving employees in the implementation of these elements and communicating the advantages they offer, organizations can enhance acceptance and facilitate a smoother transition (Ciccarelli et al., 2023).

Overall, employee involvement in the design process and keeping them informed about the benefits of introducing non-human elements contribute to creating a more inclusive and engaging workplace environment. This approach acknowledges the importance of employees' perspectives and ensures that their needs are considered, ultimately leading to higher levels of employee satisfaction and productivity.

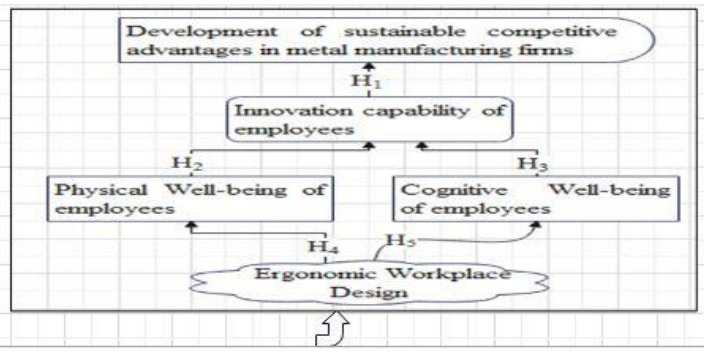
Continuous Improvement: An ergonomic workplace should embrace a culture of continuous improvement. Regularly soliciting feedback from employees, conducting workplace assessments, and implementing necessary changes based on the feedback received can lead to an on-going process of enhancing the workplace environment and addressing employee needs.

By considering these strategies stated in Figure 7.7 and customizing the workplace design to cater to the specific requirements of metal manufacturing firms, organizations can establish an employee-centric environment that fosters well-being, engagement, and optimal performance.

In the following sections, detailed engineering approaches for designing an ergonomic workplace that aligns with the aforementioned key factors will be discussed. The initial consideration in designing an ergonomic workplace involves determining the appropriate factors of the workspace.

Factors for ergonomic workplace design: Based on the information presented in Figure 7.6, it is evident that creating an employee-centric workplace is crucial for establishing sustainable competitive advantages within the metal manufacturing firms. Such a workplace prioritizes employees' well-being, innovation capabilities, and sense of responsibility. Therefore, when designing an employee-centric workplace, it is essential to determine the factors of the workspace based on the needs and preferences of the workers. The industrial sector should place employees' needs and interests at the core of the production process, focusing on enhancing employees' capabilities and designing a safer and more fulfilling work environment, rather than replacing them on the shop floor (Ciccarelli et al., 2023).

The interaction between the factors of the elements within the workplace should not be a cause for work-related disorders as depicted in Figure 7.8. It should prevent physical hazards and psychosocial stressors (cognitive hazards) that can result in work-related disorders that affect the well-being and innovation capability of employees. As discussed in the philosophical standpoint of this study, physical hazards arise from mismatches between the physical factors of human elements and non-human elements in the workplace. Similarly, psychosocial stressors (cognitive hazards) arise from mismatches between the cognitive factors of non-human elements and human elements.



	Dimensions of Non-Human Elements in the Workplace																		
	Elements	Tech(T)		Envt(E)		Orga Ma.(O)		Legal Req(L)		T-E		T-O		E-O		E-L		O-L	
	Dimension	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog	Phy	Cog
Characteristics of Human-elements	Physical	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
	Cognitive	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
	Behavior	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

Phy = physical factors, Cog= cognitive factors, T-E= technology interaction with environment, T-O = technology interaction with organizational management, E-O= environment interaction with organizational management,

Figure 7.8. Frameworks for ergonomic workplace design (Author)

To determine the factors of an ergonomic workplace, the workplace designer should establish ergonomic-centric physical and cognitive factors that proactively prevent mismatches between workers' characteristics and the characteristics of non-human elements, thereby preventing the occurrence of work-related disorders. Based on the results found in this study, the root causes of work-related disorders stem from a lack of employee-centric interactions among the elements of the workplace in metal manufacturing firms. To proactively prevent these causes, the researcher proposes a framework for determining factors for designing an ergonomic workplace (an employee-centric workplace) within metal manufacturing firms.

The dimensions of ergonomic workplace design (DEWD) should minimize physical and cognitive strains during the interaction between employees and non-employees. These dimensions can be determined using a mathematical framework described in Equation (7.8). This finding is consistent with the findings presented by Kalakoski et al., 2020), which stated that cognitive ergonomics practices support work performance via reducing cognitive strain.

$$DEWD = \min \{\text{physical strains, cognitive strains}\} \quad \ldots\ldots\ldots\ldots\ldots.. \quad (7.8)$$

Here, physical strains and cognitive strains represent the strains resulting from interactions between the dimensions of non-employee elements and the characteristics of employee elements in the workplace. The values of these strains can be determined using equations (7.2) and (7.3 & 4).

Physical factors for an ergonomic workplace design

To create an employee-centric workplace with ergonomic design, it is crucial to analyse employees based on their characteristics. The first step in determining the physical dimensions of an ergonomic workplace is to conduct an anthropometric characterization of employees. This involves identifying critical anthropometric dimensions that should be considered in the workplace design. Relevant anthropometric data can be collected using various data capture systems such as sensors, video/image motion capture, and body scanning. Table 7.9 provides examples of some anthropometric dimensions to consider.

The next step is conducting a task analysis to determine the physical functional capacities of employees working or planned to work in metal manufacturing firms. This analysis focuses on the general force capacity needed to perform physical tasks in daily work (May et al., 2015). Examples of physical capacities are also shown in Table 7.9. Task analysis is also useful for identifying the physical dimensions of non-human elements in the workplace. Critical physical dimensions for workplace elements can be determined using this analysis.

Table 7. 9: Workplace elements, physical factors

	Task Analysis	Laws used

Anthropometric characterization	Physical functional capabilities	Physical factors of the machinery and other tools	for task analysis
1. Standing height 2. Elbow height 3. Sitting height 4. Shoulder height (sitting) 5. Shoulder height (standing) 6. Elbow height (sitting) 7. Shoulder (bi-acromial) breadth 8. Hip breadth 9. Popliteal height 10. Button-abdomen depth (sitting), etc.	1. Raising a weight, 2. Carrying a weight, 3. Hold a tool, 4. Grip strength, 5. Standing balance, 6. Bending over, 7. Pushing or pulling objects, 8. Frequency of repetitive motions, 9. Sitting, 10. Walking, 11. Standing, etc.	1. Height 2. Width 3. Thickness 4. Weight 5. Length 6. Surface finish 7. Roughness 8. Shape 9. Sharpness 10. Outer cover 11. Height (after installation) Etc.	Physical ergonomics: which is used for determining the optimal relationship between employees' anthropometric characteristics with physical dimensions of NHE

Table 7.9 present the physical characteristics of workplace elements, including anthropometric characterization, task analysis, physical functional capabilities, and physical dimensions of non-human elements. The physical dimensions of an ergonomic workplace should consider the anthropometric characteristics of employees, their physical functional capacities, and the physical dimensions of non-human elements. These dimensions are crucial for establishing an optimal relationship between employees' anthropometric characteristics and the physical dimensions of non-human elements, based on the principles of physical ergonomics.

By considering the information presented in Table 7.9, the physical dimensions of an ergonomic workplace can be determined, taking into account the interactions among anthropometric characteristics, physical functional capacities, and the physical dimensions of non-human elements. This approach ensures that the workplace design is tailored to the employees' needs, resulting in an employee-centric and ergonomic environment (Figure 7.9).

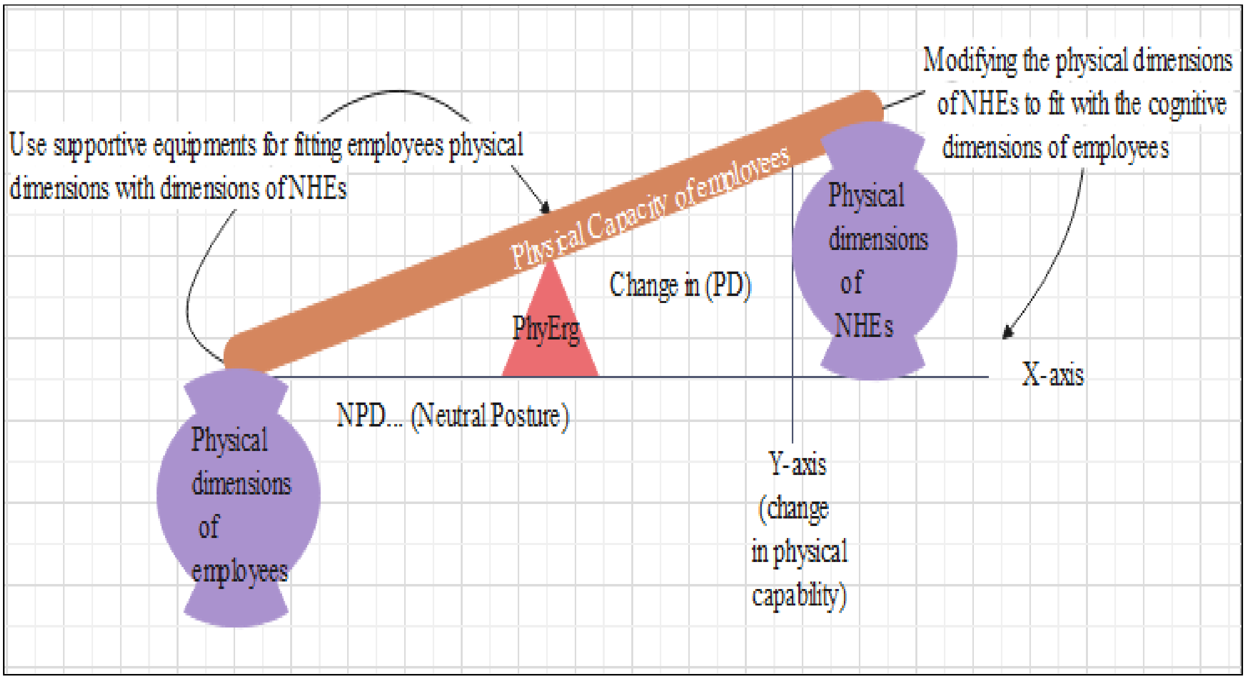


Figure 7.9. Optimizing Mechanisms in Physical Ergonomics (*Source: Developed by Author*)

Having employee-centric physical dimensions is crucial for preventing the development of physical strain and work-related musculoskeletal disorders among employees in metal manufacturing firms. Equation (7.1) and Figure 7.9 present a model for understanding the impacts of physical strain on employees' body parts. To address this, workplace designers, practitioners, and other stakeholders should apply the principles of physical ergonomics as intervention mechanisms based on natural laws of work.

Physical ergonomics (PhyErg) principles serve as a natural law for identifying mismatches between employees' physical dimensions and the design of non-human elements. These principles help to proactively prevent the root causes of work-related musculoskeletal disorders. The physical natural law of work (PhyErg) serves as a fulcrum for determining the physical dimensions required to design an ergonomic workplace. The physical natural law of work is employed to assess the optimal interaction between human body parts and non-human elements. Optimal interactions, which fall within the allowable range of physical strain, are considered for determining the set of physical dimensions in ergonomic workplace design (EWD).

The determination of physical factors for ergonomic workplace design is based on the interactions between different body parts of employees and various parts of non-human elements within the workplace (i.e., i, r, z dimensions).

In this study, an algorithm was developed to determine the optimal physical dimensions for ergonomic workplace design (Figure 7.9).

Algorithmic Application:

The proposed algorithm for designing an ergonomic workplace consists of three components: inputs, processing, and outputs.

1. *Inputs:* the algorithm considers various factors related to both employees and non-employees. These include fixed dimensions of machinery, accessibility, adjustability, and other relevant parameters.
2. Processing: The processing section of the algorithm identifies mismatches between current workplace conditions and ergonomic standards. It calculates optimal design adjustments to enhance comfort and efficiency.
3. Outputs: The outputs of the algorithm are workplace design recommendations. These may include suggestions for machine height, adjustability features, and modifications to seating arrangements to improve overall ergonomics.

Steps for developing the algorithm

The algorithm for determining optimal physical and cognitive factors for designing an ergonomic workplace consists of several steps aimed at optimizing the interactions between physical and cognitive elements of workplace design.

Steps for Determining Optimal Physical Factors for Ergonomic Workplace Design:

Step One: Identify Anthropometric Data: In this step, the goal is to identify the physical dimensions, also known as anthropometric parameters, of employees working in each section of the metal manufacturing firms. These dimensions play a crucial role in designing ergonomic workspaces that can accommodate a diverse workforce. The researcher uses the notation (j ... m) to represent different types of physical dimensions.

To gather this information, a database of anthropometric dimensions for different postures needs to be prepared. This includes measurements such as standing height, hand length, chest breadth, and more. By collecting these data points, designers can gain insights into the distribution of body measurements within the employee population. Having an anthropometric database allows designers to determine appropriate dimensions for workstations, seating arrangements, and other elements in the workspace. By considering the range of body measurements, designers can create ergonomic solutions that cater to a variety of individuals, promoting comfort, safety, and overall well-being.

*Step Two: Task Analysis***:** Understanding the task performed in the workspace is crucial for designing effective ergonomic solutions. In this step, the focus is on conducting a thorough task analysis to gain insights into the nature of work and its associated requirements. Algorithms are used to consider various factors, including the nature of work, required movements, frequency of tasks, and duration of work cycles.

Task analysis plays a vital role in identifying potential ergonomic risks that workers may face during task execution. By carefully examining the tasks involved, designers can pinpoint areas where ergonomic interventions are needed. This analysis guides the design of workstations, tools, and equipment to support efficient and comfortable task execution. The goal of task analysis is to ensure that the workspace is designed in a way that minimizes physical strain, reduces the risk of musculoskeletal disorders, and promotes productivity. By understanding the demands of the job and the movements required, designers can create ergonomic solutions that enhance worker well-being and performance.

By integrating task analysis into the design process, designers can tailor the workspace to meet the specific needs of the workers, allowing them to perform tasks effectively and comfortably. This step serves as a foundation for developing ergonomic solutions that align with the requirements of the job and the capabilities of the individuals performing it.

Step Three: Identify physical dimensions of non-human elements (machinery and other tools):

In this step, the focus is on identifying the physical dimensions of the existing or to-be-designed non-human elements in each workstation of the metal manufacturing firms. These non-human elements include equipment, tools, machinery, and other objects that workers interact with during their tasks. To facilitate the identification and representation of these physical dimensions, the notation (.i... r...z) is used. Each part or component of the non-human element is denoted by a specific notation to capture its dimensions accurately.

By identifying and understanding the physical dimensions of these non-human elements, designers can assess their compatibility and interaction with the human workers. This step is crucial for ensuring that the dimensions of the non-human elements align with the anthropometric parameters of the workers, promoting ergonomic compatibility and reducing the risk of discomfort or injury.

Considering the physical factors of non-human elements is essential for creating a workspace that supports efficient and safe task execution. It allows designers to optimize the layout, placement, and design of equipment and tools to enhance user comfort, accessibility, and overall productivity. By integrating the physical dimensions of non-human elements into the design process, designers can create a workspace that promotes ergonomic harmony between humans and their work environment.

Step Four: Determine the Interaction between Physical Dimensions:

In this step, the goal is to determine the interaction between each physical dimension of employees (j...m...n) and the physical dimensions of the non-human elements design (.i...r...z...) that require the employees' physical dimensions for effective operation.

To assess the compatibility and effectiveness of the interaction between these factors, the researcher utilizes Figure 7.9 and Equation 7.1. Figure 7.10 provides a visual representation or reference to understand the relationship between different physical factors. It helps designers visualize and analyse how the dimensions of employees' and non-employees' elements may interact. Equation 5.3, on the other hand, is an equation or formula used to calculate and quantify the changes required in physical factors. This equation enables designers to determine the necessary adjustments needed to optimize the interaction between the dimensions of employees and non-human elements. *In this step, the two interactions should be determined: the interaction between human physical characteristics and physical factors of non-employees' elements like machinery, seating chairs, and others in the workplace, and the interaction between employees' physical dimensions and the interaction among non-employees' elements (ir...iz...rz), where ir is the interaction between (non-employees' element)$_i$ and (non-employee element)$_r$.*

By considering both the visual representation and the mathematical equation, ergonomic workplace designers can make informed decisions about modifying the physical dimensions of the non-employees' elements to ensure ergonomic compatibility with the employees. The goal is to find a balance that minimizes physical strain, promotes efficiency, and supports safe and comfortable task execution.

Step Five: Determine the Values of Physical Strain: In this step, the focus is on determining the values of the physical strain developed on employees' physical body parts, as shown in matrix 7.9. The physical strain (X) reflects the level of stress or discomfort experienced by employees due to the interaction between the physical dimensions of employees (j...m...n) and the physical dimensions of the non-human elements (i...r...z).

Matrix 7.9 represents the set of physical strains (X) developed for each interaction between the dimensions. Each element in the matrix corresponds to a specific combination of employee physical factors (j...m...n) and non-human element factors (i...r...z). To evaluate the physical strain, the algorithm compares the values in matrix 7.9 with the acceptable range. If the physical strain for a particular interaction is greater than 1 or less than 0, it indicates that the interaction exceeds the acceptable limits and requires a physical ergonomics intervention.

In such cases, designers may need to optimize the physical dimensions of the non-human elements or modify the design of tasks to reduce strain and improve ergonomics. This can involve revising the dimensions of the non-human element design or developing supportive tools or products to assist employees in accommodating their physical dimensions.

On the other hand, if the physical strain for each interaction is within the range of 0 to 1, it indicates an acceptable interaction betwe Parts on non-human element cases, the algorithm proceeds to step 6, as the interaction meets the ergonomic criteria. By evaluating the physical strain values, designers can identify problematic interactions that require intervention and take appropriate measures to optimize the workspace design. The goal is to create a work environment that minimizes physical strain, promotes employee well-being, and enhances overall productivity.

$$\text{Set of physical strains developed} = \text{Body parts} \begin{bmatrix} X_{j,i}; & X_{j,r} & \dots & \dots & \dots\dots\dots & X_{j,z} \\ \dots & \dots & \dots\dots & \dots\dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ X_{m,i}; & X_{m,r} & \dots & \dots & \dots. & X_{m,z} \end{bmatrix} \quad (7.9)$$

Step Six: Select the Interaction with Minimum Physical Strain:

In this step, the focus is on selecting the interaction that has the minimum physical strain from the set of physical strains developed. The goal is to identify the combination of employee physical dimensions (j...m...n), and non-human element dimensions (i...r...z) that results in the least amount of physical strain (X). By analysing the set of physical strains (X), the algorithm identifies the interaction with the lowest physical strain value. This interaction is considered to be the most ergonomic, as it minimizes the stress and discomfort experienced by employees.

Once the interaction with the minimum physical strain is determined, a set of physical dimensions can be prepared for designing an ergonomic workplace. These dimensions should be included in the databases of physical dimensions (PhyD) specifically tailored for ergonomic workplace design in metal manufacturing firms.

Matrix 7.10 represents the set of physical dimensions (X) for designing an ergonomic workplace (EWD). Each element in the matrix corresponds to a specific combination of employee physical dimensions (X) that contributes to the optimal interaction with the non-human elements. At this step, the algorithms may suggest optimal placement of machinery, tools, and other equipment within the workspace. They may also recommend suitable heights and angles for work surfaces to ensure ergonomic compatibility and minimize physical strain.

By incorporating the selected physical dimensions into the ergonomic workplace design databases, designers can access and utilize this information to create work environments that are tailored to the needs and dimensions of the employees. This promotes comfort, safety, and overall well-being, leading to improved productivity and job satisfaction.

Parts on non-human elements

$$\text{Physical dimensions for EWD} = \text{Body parts} \begin{bmatrix} X_{j,i};\ X_{j,r}\ \dots\ \dots\ \dots\dots\dots\ X_{j,z} \\ \dots\ \dots\ \dots..\ \dots\dots\ \ ..\ \ \dots \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ X_{m,i};\ X_{m,r}\ \dots\ \ \dots\ \ \dots.X_{m,z} \end{bmatrix} \quad (7.10)$$

Step Seven: Workspace design: In this step, the focus is on designing the workspace to support optimal posture and reduce musculoskeletal disorders, occupational illness, and biomechanical overload. The workspace design needs to be designed to support posture and reduce both physical and cognitive disorders in employees. The layout of the workspace should be designed to minimize physical ergonomic risk factors that affect the well-being and innovation capability of employees in the metal manufacturing firms. Like workspace design should incorporate dimensions that minimize the causes for physical strain on employees.

Step Eight: Feedback and Iteration: In this step, the focus is on the feedback and iteration process in ergonomic workplace design algorithms. These algorithms provide designers with the opportunity to input parameters and constraints and receive recommendations or simulations of the workspace design. This iterative process allows designers to evaluate and refine the design based on the algorithm's output, ensuring that it meets ergonomic criteria and employees' needs. Since a continuous feedback loop with employees is critical for understanding their evolving needs and improving the workplace accordingly (Rust and Huang, 2014). Designers can utilize the algorithm to generate recommendations for the optimal physical dimensions of the ergonomic workplace design. This feedback helps in identifying areas for improvement and designing workspaces that are tailored to the specific needs and dimensions of the employees.

To facilitate the implementation of the algorithm, a flowchart (Figure 7.10) has been developed to illustrate the steps involved in determining the optimal physical dimensions for ergonomic workplace design.

The algorithm serves as a tool to assist workplace designers in creating optimal working spaces. However, it is essential to combine the algorithm's output with the expertise of employees, particularly in the area of cognitive ergonomics, to ensure that the design fulfils their needs and preferences.

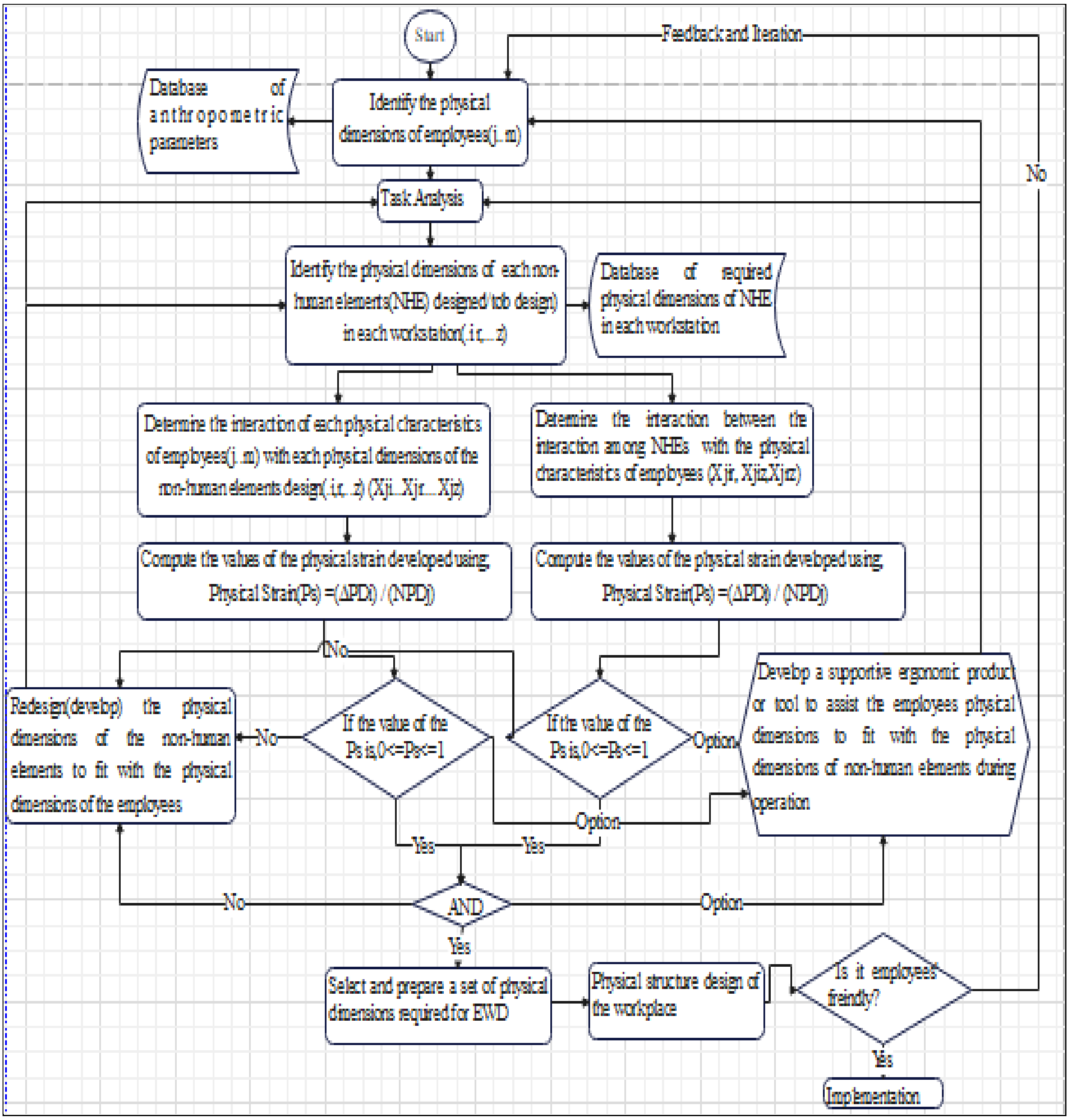


Figure 7.10. Algorithm for determining optimal PhyD for EWD (*Source: Developed by Author*)

Regular evaluation and adjustment of the workspace design based on user feedback and ergonomic assessments are crucial for maintaining an ergonomic and healthy work environment. This iterative process allows for continuous improvement and adaptation to changing user requirements. It is worth highlighting the importance of considering anthropometric parameters in the design process. Neglecting to account for these parameters can result in disproportionate dimensions in the designed workstation or product, leading to potential ergonomic issues (Zanwar et al., 2023).

Additionally, the workplace designer can experimentally determine the dimensions that have an optimal interaction between each body part and a single part of the non-human elements within the workplace (7.11). For each body part (j), the experiment (i) is conducted multiple times (n) to identify the dimensions that result in the minimum physical strain. By selecting the interaction with the minimum physical strain for each body part, the workplace designer can ensure an ergonomic design.

$$\text{Set of PhS with iteration on each part of NHE} = \min \; \underset{\text{Body parts}}{\overset{\text{Number of interaction}}{\begin{bmatrix} X_{j,i}; & X_{j,i+1} & \cdots & \cdots & \cdots & X_{j,i+n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{m,i}; & X_{m,i+1} & \cdots & \cdots & \cdots & X_{m,i+n} \end{bmatrix}}} \quad (7.11)$$

For example, in the case of designing an ergonomic working position for operations that require standing postures, the dimensions that have an optimal interaction with the standing height of employees can be determined through tests. The optimal standing height dimension (StangH) for designing an ergonomic working position can be obtained by selecting the interaction with minimum physical strain from various tests involving the standing height (x1) and the height of the working bench (wb), as shown in (7.12).

$$\text{Optimal StangH} = \min \overset{\textit{Number of interactions}}{\left((X_1 \; Wb)_1, \quad (X_1 \; Wb)_{2,} ; (X_1 \; Wb)_3 \ldots (X_1 \; Wb)_n \right)} \quad (7.12)$$

Based on this, the algorithm serves as a valuable tool in this process, allowing designers to optimize the physical dimensions and promote healthy working postures in the workplace.

The cognitive dimensions for an ergonomic workplace design

The findings of this study, as discussed in the literature and in Chapter Six, highlight the impact of cognitive ergonomic risk factors—such as stress, dissatisfaction, suffocation, fatigue, and other intermediate factors like noise, workloads, social interactions, and communication among employees—on the well-being and innovation capabilities of employees in metal manufacturing firms. Furthermore, the results presented in Chapter Seven indicate that cognitive well-being significantly influences the development of sustainable competitive advantages in these firms.

These findings serve as a wake-up call for metal manufacturing firms to develop proactive preventive mechanisms aimed at eliminating the root causes of mismatches between cognitive dimensions within workplace elements. To effectively prevent these issues, it is essential to design cognitive dimensions of the workplace based on the needs and preferences of employees. Creating an employee-centric cognitive framework for workplace design is vital for promoting employee well-being and fostering sustainable competitive advantages in metal manufacturing firms. A healthy and satisfied workforce yields clear benefits for businesses, including increased productivity, improved employee retention, reduced sickness absence, and greater employee resilience (Hulls et al., 2021; Bevan, 2010). Therefore, addressing cognitive strains and promoting mental well-being are crucial aspects of designing an ergonomic workplace in metal manufacturing firms.

By proactively considering employees' needs and preferences and incorporating appropriate cognitive dimensions, designers can create a workplace environment that supports employee well-being, enhances innovation capability, and fosters sustainable competitive advantages. This research contributes to the growing body of literature that recognizes the positive impact of workplace interventions on mental well-being, as discussed by Pieper et al. (2019).

Similar to the process used for determining physical dimensions, analysing employees' factors is necessary for identifying cognitive dimensions. The first step in determining the cognitive factors of an ergonomic workplace is to assess the cognitive characterization of employees. This involves gathering data through interviews and tests, and reviewing employees' certificates and other relevant documents. By understanding the critical cognitive factors that should be considered in the workplace design, designers can create an environment that supports employees' cognitive well-being.

Table 8.2 provides an overview of some of the cognitive dimensions that should be taken into account during the workplace design process. It serves as a reference for identifying and incorporating the relevant cognitive dimensions into the design of an ergonomic workplace.

The next step in designing an ergonomic workplace is conducting task analysis. This step involves determining the cognitive functional capacities required by employees working or planned to work in metal manufacturing firms. Cognitive capacities are important because they represent the mental processes through which sensory inputs are transformed, elaborated, and utilized in problem-solving. These cognitive processes include attention, working memory, language comprehension and production, calculation, and reasoning, problem-solving, and decision-making (May et al., 2015).

Table 7.10 provides a list of critical cognitive dimensions for workplace elements. These dimensions represent the cognitive characteristics or soft skills that are essential for employees. The task analysis helps identify the specific cognitive functional capabilities necessary for performing the tasks associated with these cognitive dimensions. Additionally, the table also includes the cognitive dimensions of the non-human elements present in the workplace.

Table 7.10: Workplace elements Cognitive dimensions

Cognitive characterization(soft	**Task Analysis**		Laws used for cognitive dimensions of
	Cognitive functional capabilities	Cognitive dimensions of the non-human elements	

skills)			task analysis
1. Knowledge (welding, types of welding, etc.) 2. Skills 2.1.Reading 2.2.Writing 2.3. Communication 2.4. Social interaction, etc.)	1. Memory 2. Perception 3. Language 4. Analytical thinking 5. Problem solving 6. Decision-making 7. Responsibility 8. Cooperation (working with others) 9. Capacity for concentration 10. Understanding writing, reading, drawing 11. Calculating 12. Pattern recognition	1. Operating procedure 2. Software 3. Working manual 4. Workloads 5. Standards 6. Organizational management 7. Culture on social interaction 8. Teamwork 9. Information flows between different levels 10. Shifts start, shift duration 11. Availability of weekend work 12. Number of operations	Cognitive ergonomics: This is used as a law for designing an optimal interaction between the cognitive characteristics of employees and the cognitive dimensions of NHEs.

To determine the cognitive dimensions of an ergonomic workplace, it is important to consider the principles of cognitive ergonomics, which govern the optimal interaction between the cognitive characteristics of workers and the cognitive dimensions of non-human elements. This interaction is crucial for creating an environment that supports employees' cognitive well-being and enhances their performance.

Figure 7.11 illustrates the adjustment of either the cognitive characteristics or the cognitive dimensions of non-human elements to their optimal points, based on the principles of cognitive ergonomics. By using these principles as a guide, designers can ensure that the cognitive dimensions of the workplace are aligned with the cognitive capacities and needs of employees. Cognitive ergonomics, as a field concerned with the mental processes that affect interactions between humans and other elements of a system, serves as a foundation for designing optimal cognitive interactions (Koirala & Maharjan, 2022)

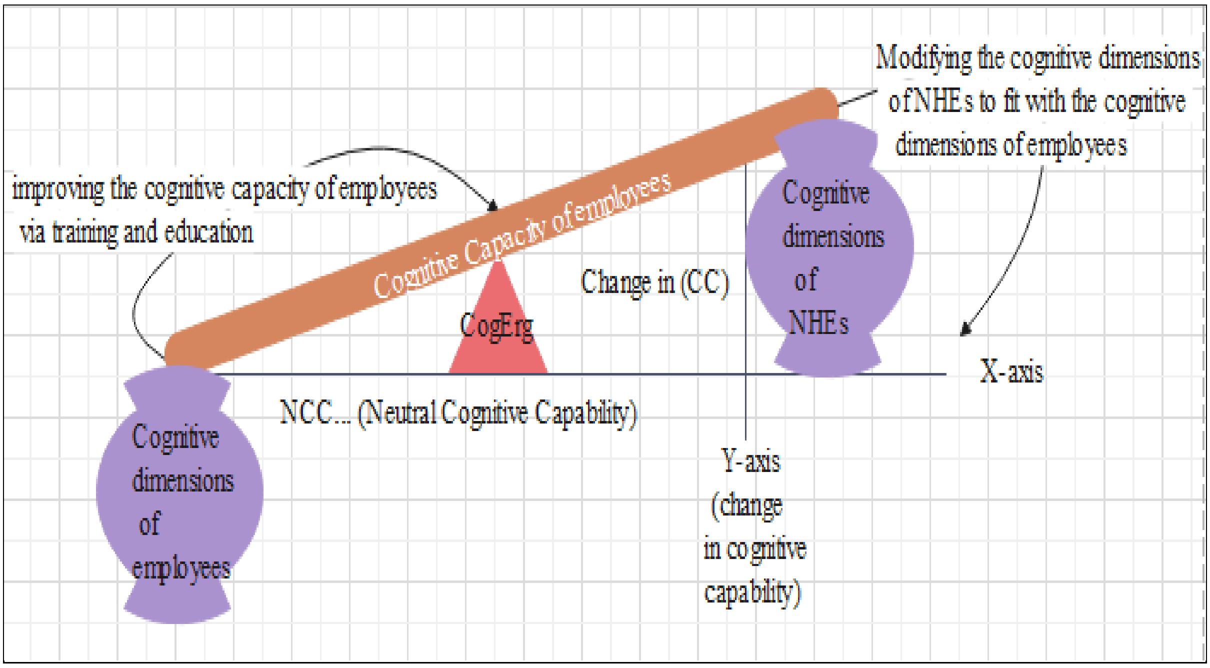


Figure 7.11. Cognitive dimensions optimizing mechanisms (Source: Developed by Author)

Having employee-centric cognitive dimensions in the design and arrangement of workplaces for employees in metal manufacturing firms is essential for preventing the development of cognitive strain, such as stress, suffocation, interruptions, disruption, anxiety, and work overload. The model presented in equation (5.4) and Figure 7.11 serves as a framework for assessing the impacts of work-related cognitive disorders on employees in these firms. Similarly, to identify optimal ergonomic workplace dimensions, workplace designers, practitioners, and other stakeholders should utilize the cognitive natural law of work as an intervention mechanism, as shown in Figure 7.11.

In order to achieve an optimal interaction between the cognitive functional abilities of employees and the cognitive dimensions of the non-human elements, cognitive ergonomic principles should be employed. This is in line with the findings by Kalakoski et al., (2020), which state that cognitive ergonomics intervention will improve workflow and productivity and decrease cognitive strain, in comparison to an active control group and a passive control group. This approach takes into account the specific cognitive characteristics of employees, including the knowledge needed for operation, management, decision-making, and social interaction, as well as the necessary skills and commitment for innovation and development. Notations such as (i...r...z) can be used to represent the various activities performed by the human elements of the workplace that require cognitive abilities in relation to the non-human elements.

In this chapter, an algorithm is proposed to determine the optimal cognitive factors for designing an ergonomic workplace, as shown in Figure 7.12.

Steps for Determining Optimal Cognitive Factors for Ergonomic Workplace Design:

Step one: Identify the cognitive characteristics and functional capabilities of employees working (or planned to work) in each section of the metal manufacturing firms. In this study, the researcher used the notation (j...m) to represent the different types of cognitive dimensions employees possess, such as knowledge, skill, perception, commitment, attitude, and more**.**

Step Two: Conduct a task analysis to understand the nature of work and its associated requirements. Consider factors such as the type of work, required skills and knowledge, task complexity, and work cycle duration.

Step Three: Identify the cognitive dimensions associated with each non-human element of the workplace or the cognitive dimensions that rely on employees' cognitive abilities to be effective. In this study, the researcher denoted the cognitive dimensions of non-human elements as (i... r...z) that necessitate the cognitive abilities of employees.

Step Four: Determine the interaction between each cognitive dimension of employees (j...m) and each cognitive dimension of the non-human elements design (.i...r...z) that relies on employees' cognitive capabilities. Moreover, the interaction between the cognitive dimensions of employees and the interaction among the cognitive dimensions of non-human elements need to be determined. For example, the interaction between the rules and regulations set by the organization and the operating procedures of the machinery and the interaction with the cognitive abilities of employees needs to be determined. In this step, changes in cognitive dimensions are assessed and evaluated.

Step Five: Determine the cognitive strain values (represented as Xji, Xjr ... Xjz) developed or potentially developed on employees' cognitive aspects using matrix (7.6). If the cognitive strain for each interaction is greater than 1 or less than 0 (Xji > 1 or Xji < 0), it indicates the need for cognitive ergonomics intervention. This intervention can involve optimizing the cognitive dimensions of employees through training and education. Alternatively, it may require revising and redesigning the cognitive dimensions of the non-human elements based on the cognitive abilities of employees. However, if the cognitive strain values (such as Xji, Xjr, ... Xjz) for each interaction fall within the range of 0 to 1 (0 ≤ Xii...XMZ ≤ 1), it indicates an acceptable level of interaction between the two dimensions, and the process can proceed to the next step.

Activities require cognitive abilities (i, .r...z)

$$\text{Set of cognitive strain developed} = \text{Cognitive abilities} \begin{bmatrix} X_{j,i};\ X_{j,r}\ \dots\ \dots\ \dots\dots\dots\ X_{j,z} \\ \dots\ \dots\ \dots..\ \dots\dots\ \quad ..\quad \dots \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ X_{m,i};\ X_{m,r}\ \dots\ \dots\ \dots.X_{m,z} \end{bmatrix} \quad (7.13)$$

Step Five: Step Five: Select the interaction with the minimum cognitive strain and compile a set of cognitive dimensions for the workplace that should be considered during the design or arrangement process. The interactions between cognitive dimensions that fall within acceptable ranges of cognitive abilities need to be identified and included in the database of cognitive dimensions for ergonomic workplace design in metal manufacturing firms.

These dimensions should be organized and presented in matrix form, as shown in Equation (7.14):

Interaction within acceptable range of cognitive abilities

$$\text{Cognitive dimensions for EWD} = \begin{matrix}\text{Cognitive}\\ \text{abilities}\end{matrix} \begin{bmatrix} X_{j,i}; & X_{j,r} & \dots & \dots & \dots\dots\dots & X_{j,z} \\ \dots & \dots & \dots\dots & \dots\dots & .. & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ X_{m,i}; & X_{m,r} & \dots & \dots & \dots . & X_{m,z} \end{bmatrix} \qquad (7.14)$$

In this matrix, each element represents an interaction between a cognitive dimension of employees (j...m) and a cognitive dimension of the non-human elements (i...r...z) within the acceptable range of cognitive abilities. These dimensions serve as a foundation for designing and arranging the workplace, ensuring that it aligns with employees' cognitive capabilities and promotes a productive and ergonomic environment.

Step Six: Feedback and Iteration: This step emphasizes the feedback and iteration process in the design algorithms for cognitive ergonomic workplace dimensions. These algorithms enable designers to input parameters and constraints and receive recommendations or simulations of workspace designs. Through this iterative process, designers can evaluate and refine the design based on the output of the algorithm, ensuring that it meets ergonomic criteria and fulfils the needs of employees. The feedback loop allows for continuous improvement and optimization of the workplace design, promoting a more effective and ergonomic environment.

Figure 7.10 illustrates the algorithm for determining the optimal cognitive dimensions for ergonomic workplace design.

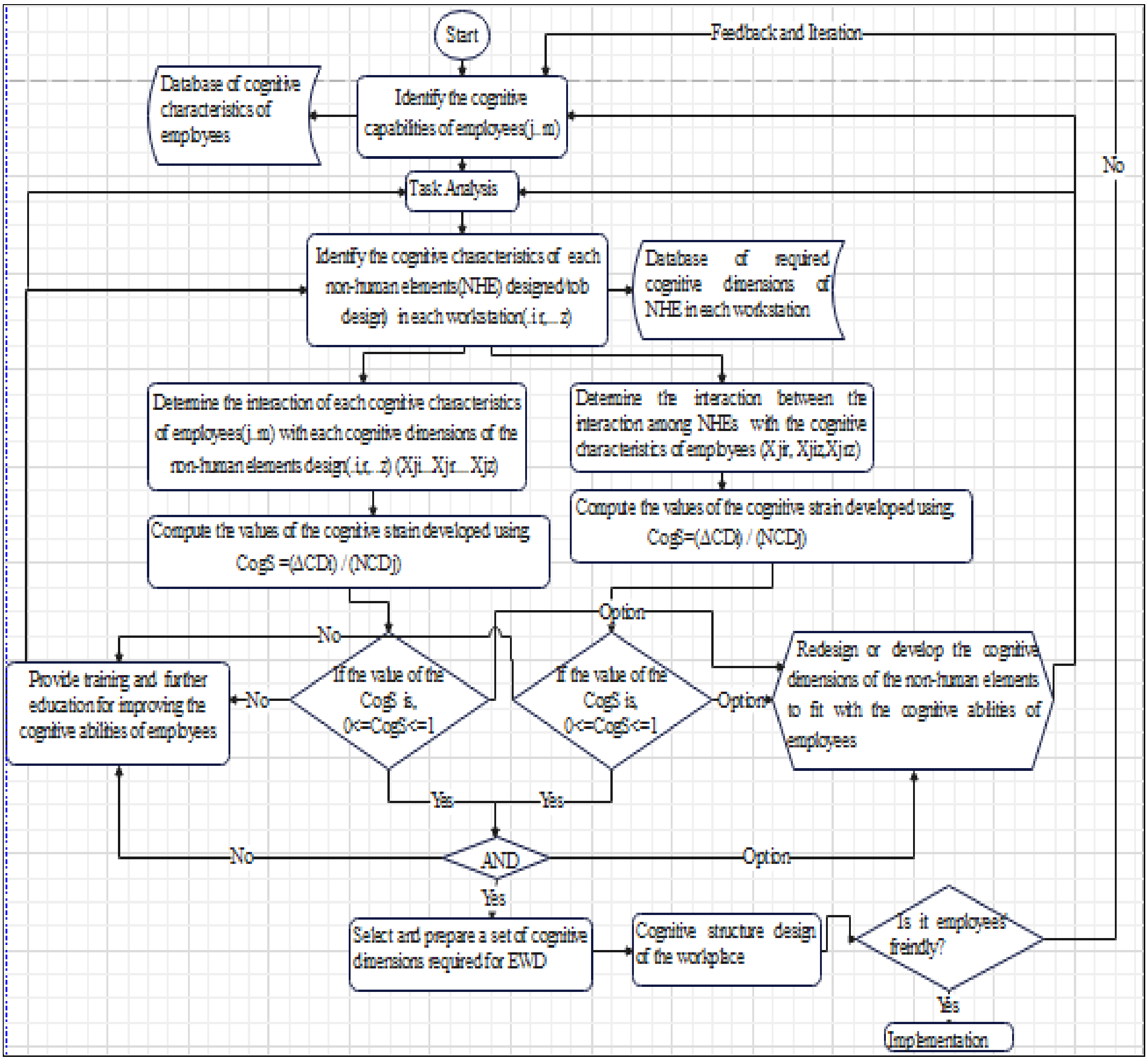


Figure 7.12. Algorithm for determining optimal CogD for EWD (Source: Developed by Author)

Based on the data from the metal manufacturing firms' case, the cognitive dimensions required for designing the workstation for welding operations are determined using the algorithm stated in (Figure 7.12). The cognitive characteristics and functional capabilities of employees working in the welding workstations are identified as shown in Table 7.11.

Table 7.11: Cognitive dimensions and Functional Capabilities of Employees

Cognitive Dimensions	Cognitive functional capability
Knowledge on types of welding, welding operation, welding design, Operation management, Time management, Occupational risk management, Skill on welding operation, cutting metal, and maintenance of equipment and tools	Understanding writing, reading, drawing, perception, problem-solving skills, decision-making and, cooperation,

The cognitive dimensions of non-human elements that require the cognitive functional capability of employees for safe and efficient operations within the welding workstations are as follows:

Knowledge of Welding Process (KWP): Understanding different welding processes such as MIG, TIG, and stick welding, as well as knowledge of welding parameters and troubleshooting common welding issues.

Material Knowledge (KM): Familiarity with the types of metals and alloys commonly used in welding, their properties, and how they behave during the welding process. This knowledge helps in selecting the appropriate welding techniques and materials for specific welding tasks.

Safety Procedures (SP): Knowledge of safety protocols and procedures associated with welding, including the use of personal protective equipment (PPE), handling and storage of welding gases, fire safety, and proper ventilation in the workstation.

Blueprint Reading and Interpretation (BRI): Ability to read and interpret technical drawings, blueprints, and welding symbols. This includes understanding welding symbols, dimensions, and tolerances specified in the drawings.

Equipment Operation and Maintenance (EOM): Proficiency in operating welding equipment, such as welding machines, torches, and auxiliary tools. Knowledge of equipment maintenance and troubleshooting common issues is essential for efficient and safe operation.

Weld Quality Standards (WQS): Familiarity with welding quality standards, codes, and regulations set by industry organizations and government agencies. Adhering to these standards ensures the production of high-quality welds that meet the required specifications.

Spatial Awareness and Hand-eye Coordination (SAH-EC): Good spatial awareness and hand-eye coordination are crucial for accurately positioning the welding torch or electrode, controlling the welding arc, and achieving precise welds.

Problem-solving Skills (PSK): Ability to identify and troubleshoot welding-related problems, such as welding defects, inadequate penetration, or distortion. Problem-solving skills help in finding effective solutions to maintain weld quality.

Communication and Collaboration (CC): Effective communication skills to interact with team members, supervisors, and other stakeholders. Collaboration is essential for coordinating tasks, ensuring safety, and maintaining a productive work environment.

Continuous Learning (CL): Willingness to stay updated with the latest advancements in welding technology, techniques, and safety practices. Continuous learning ensures professional growth and the ability to adapt to evolving industry standards.

Based on these input data, the workplace designer needs to determine the optimal cognitive dimensions for designing and arranging a workspace for welding operations using the matrix presented in Table 7.12 and matrix (7.14).

Table.7.12. Interaction of Knowledge (K) of employees with the required knowledge in the welding station

Cognitive characteristics of employees	Knowledge of employees ($K_{j.m}$)	Cognitive dimensions of non-human elements (welding machines, etc.)									
	Welding types										
	Welding design										
	Operation management										
	Time management										
	Occupational risk management										
	Ergonomics management										

Based on the algorithm stated in Figure (7.12), the optimal knowledge dimensions (OKD) to be considered while designing a workplace for employees working or required to work in welding operations should fulfil the union of the optimal interaction with each type of required knowledge. The results of these dimensions need to be determined and presented in matrix form, as shown in Equation (7.8). The optimal knowledge dimensions in the welding workstation for ensuring the well-being and innovation capability of employees are developed by either providing training for the employees working within the workstation to have all the required skills and knowledge.

$$\text{OKD}=[(K,KWP)\quad(K,KM);\ (K,SP);(K,BRI).(K,EOM),(K,WQS),(K,SAH),(K,PSK),(K,CC),(K,CL)]$$

(7.14)

This matrix indicates the interaction between the two dimensions and determines the strain level developed on employees due to the mismatches.

Cognitive-physical integration for ergonomic workplace design

In this study, it is argued that the hybrid of physical and cognitive ergonomics principles can be referred to as "cognitive-physical ergonomics" or "cognitive-physical integration." Needs to be considered to have an employee-centric workspace in the metal manufacturing firms. This term signifies the integration and consideration of both physical and cognitive aspects in the design and evaluation of work systems, tasks, and environments. It acknowledges the interplay between physical factors (such as posture, movement, and ergonomics of physical workstations) and cognitive factors (such as mental workload, decision-making, and information processing) in optimizing human performance, well-being, and overall system effectiveness.

To ensure that the final workspace is truly ergonomic, it is necessary to evaluate and design it from two perspectives, considering the human-centric aspects. The algorithm for assessing and creating an ergonomic workplace is depicted in Figure 7.10 and Figure 7.12. The purpose of representing the algorithm in figures is to provide a visual representation of the interactions between various elements of the workplace. This visual representation enhances the understanding of how different components interact and influence each other, leading to the creation of an employee-centric environment. By following the algorithm, designers can systematically evaluate and optimize the workplace design to prioritize the well-being, comfort, and productivity of the employees.

Implementing an employee-centric approach in the workplace design not only considers the physical aspects but also takes into account the cognitive requirements of the employees. By considering both cognitive and physical interactions, the resulting workplace promotes efficiency, safety, and overall satisfaction among the workforce.

7.4. Chapter Summary

The primary objective of this chapter is to develop proactive ergonomic workplace design tools and strategies to prevent mismatches between employees and non-employee elements in the workplace, impacting the well-being and innovation capability of employees within the metal manufacturing sector. Through a comprehensive literature review, it became evident that the physical and cognitive needs of workers often do not align with the requirements of other non-employee elements of the workplace in the manufacturing industry, leading to the widespread occurrence of work-related disorders.

Furthermore, the findings from the data analysis of this study highlighted the detrimental impact of ergonomic inefficiencies, such as work-related disorders and labour absenteeism, on the productivity and sustainable competitive advantage of metal manufacturing firms. Past research has emphasized the necessity for proactive interventions to address the root causes of work-related disorders and enhance overall industry and employee productivity. Consequently, the development of ergonomic risk factor assessment tools and workplace design tools within metal manufacturing firms emerges as a critical step in mitigating ergonomic risk factors.

This chapter has introduced a pivotal lever for assessing ergonomic risk factors and a proactive Ergonomic Function Deployment (EFD) framework tailored to translate employee needs into critical requirements essential for workplace design and technical solutions aimed at fostering a human-centric workplace. Diverging from previous studies that primarily adopted reactive strategies to address the prevalence of work-related disorders in an effort to enhance employee well-being and productivity within metal manufacturing firms, this study offers a novel mathematical model for identifying critical requirements for workplace design. Moreover, it has established a proactive EFD framework dedicated to ergonomic workplace design with the explicit goal of eradicating the root causes of ergonomic risk factors.

Looking ahead, further research is imperative to explore the implementation of the EFD framework throughout all levels of manufacturing industry management and employee cohorts. Additionally, there is a need to develop an Ergonomic Social Index to measure the extent of EFD's impact on social well-being within these settings. These initiatives will play a crucial role in advancing the field of ergonomic workplace design and enhancing the well-being and productivity of employees across the manufacturing industry.

Chapter Eight

Conclusion and Recommendation

8.1. Conclusion

In conclusion, it is vital for metal manufacturing firms, especially in emerging economies, to place strong emphasis on fostering employees' well-being by promoting both physical and cognitive well-being and by providing an employee-centric work environment. Employee well-being is also vital for improving employees' innovation capability, which, in turn, is used to build sustainable competitive advantages in manufacturing firms. By identifying and addressing work-related disorders and implementing employee well-being and innovation capability-supporting policy and programs, metal manufacturing firms can effectively leverage their strengths and develop sustainable competitive advantages.

The research found that physical and cognitive ergonomic risk factors and the utilisation of ICT facilities in metal manufacturing firms play a crucial role and must be regulated for efficient and effective use of human assets. A workplace free from ergonomic risk factors and their causes improves employee well-being and boosts employees' innovation capability. This study's focus on the relationship between ergonomic risks and employees' innovation capability adds to the existing knowledge and complements earlier work on competitiveness through physical, cognitive, and social well-being (Nderitu et al., 2019).

Furthermore, the study demonstrates that EWD is not merely a risk control mechanism but a strategic design lever that enhances employee well-being, innovation capability, and ultimately sustainable competitive advantages. By ensuring that the use of ergonomic workplace design is a priority and strategy in any production system, metal manufacturing companies can improve the physical and mental well-being of their employees, which will help in the development of innovation capability and ultimately influence the directions of sustainable competitive advantages that are hard to copy by competitors. This is supported by previous research (Birhan & Endawoke, 2023), which showed that a workplace culture that values well-being is a motivation for employees.

Furthermore, the study shows the importance of developing a framework to evaluate the impacts of mismatches between the physical and cognitive dimensions of the workplace and employee characteristics in metal manufacturing firms. Addressing these mismatches can enhance employee well-being and innovation capability, crucial for building sustainable competitive advantages. Mismatches in workplace dimensions can lead to cognitive and musculoskeletal disorders, negatively impacting employee performance and satisfaction. By employing a Workfit-Lever, Ergonomic Function Deployment (EFD) framework, and ergonomic workplace design strategies, metal manufacturing firms can proactively identify and mitigate physical and cognitive strains, fostering a productive work environment.

In summary, this research shows the significance of considering ergonomic workplace design for enhancing employee well-being and innovation capability as foundational elements in developing sustainable competitive advantages for metal manufacturing firms. By investing in ergonomic workplace design, metal manufacturing firms can unlock their internal potential and achieve long-term success in the competitive market landscape. Additionally, the study notes the limitations in the empirical validation of the developed models, work fit lever, Ergonomic Function Deployment (EFD) framework, and developed algorithms. It recommends that future research concentrate on validating these findings to improve the effectiveness and applicability.

8.2. Recommendations and Future Research

Based on the findings, the researcher forwarded the following recommendations for relevant stakeholders:

For the government

- It is imperative for policymakers to closely monitor the presence and implementation of organisational ergonomic workplace design policies that influence manufacturing firms. These strategies must aim to proactively manage factors impacting workers' well-being and innovation capability.
- Governmental bodies should actively support the development of organisational and national policies related to ergonomic workplace design that enhance employees' well-being and innovation capability to drive sustainable competitive advantages.
- It is recommended for the government to follow the implementation of proactive tools and design strategies for designing ergonomic workplace design across various industries.

For Universities

- Universities should develop a curriculum focused on ergonomics for workplace design and product design, expanding beyond existing occupational health and safety management to provide a holistic approach to design.
- Conduct applied research in ergonomic design of products and workplaces across various industries in developing countries to reduce dependence on foreign technology and foster local innovation.

For Industries

Drawing from the study's insights, the following managerial implications are recommended for managers in metal manufacturing firms facing challenges related to employee innovation and well-being:

1. **Root Cause Analysis:** Managers in industrial sectors should develop ergonomic management strategies to identify fundamental factors impacting employees' innovation capability and well-being.
2. **Ergonomic Risk Mitigation:** Leveraging the study's findings, managers should prioritise the elimination of ergonomic risk factors to enhance both employees' innovation capability and overall well-being.
3. **Occupational Health and Safety:** To guarantee the well-being of manufacturing firms' employees, it is recommended that managers of the firms should set up an ergonomic-centric occupational health and safety management system.

For Researchers

Further research is essential in order to enhance our knowledge of the interrelation between ergonomic design of workplaces, employee well-being, innovation capability, and the development of sustainable competitive advantages in metal manufacturing companies. Future research should include:

- ✓ Longitudinal research that aims to investigate specific aspects of each of the ergonomic risk factors and their effects on well-being, creative potential, and sustainable competitive advantage of metal manufacturing companies.
- ✓ Investigation of indoor-environmental and social ergonomic risk factors affecting employee well-being and innovation capabilities in manufacturing firms.
- ✓ Validation of the models developed in this dissertation, particularly the Workfit-Lever framework, the Ergonomic Function Deployment (EFD) framework, and algorithms for developing a socially sustainable working environment.

The research recommendations and directions offered above provide a solid foundation for metal manufacturing organizations to incorporate ergonomic workplace design strategies in their organizational goals with the aim of satisfying employees while creating sustainable sources of competitive advantage.

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Appendix A

Survey Questionnaire

Survey Questionnaire to access the Impacts of work-related disorders on Employees' Well-being and Innovation Capability in their work place

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Hello,

I am conducting research on "Ergonomic Workplace Design and Sustainable Competitive Advantages of Metal Manufacturing Industry" as my Ph.D. dissertation for fulfilment of my Ph.D. at Addis Ababa Institute of Technology, Addis Ababa University, Ethiopia. The purpose of this survey is to gather information on the effects of ergonomic risk factors and human-centred workplace design on improving employees' well-being and innovation capability in the metal manufacturing industry, resulting in improving sustainable competitive advantages. We kindly ask for your participation and contribution to this research by filling out the questionnaire below.

Please forward this questionnaire to those in your circle of influence that have experience working in metal manufacturing industries as operators, supervisors, engineers, quality inspectors, maintenance technicians, team leaders, etc., so that they can also fill and submit the form.

The questionnaire consists of three parts: ***Part one*** is about information about the workplace, ***Part Two*** is on measurements constructs developed for measuring the impacts of ergonomic risk factors on the well-being and innovation capability of employees. ***Part Three*** is on measurements of constructs for the assessment of the Impacts of ergonomic workplace design on employees' well-being, innovation capability, and building SCA in metal manufacturing firms

Thank you for your contribution!

With best regards

Shemelis Nesibu (Ph.D. Candidate, AAiT, AAU), Mobile: 0939027547

Part One 1.0. Information ***about workers***

1.1. Gender: 1. Male ☐ 2. Female ☐

1.2 Educational Background: *Diploma* ☐ *First degree* ☐ *Second degree* ☐ *other* ☐

1.3. Your height: __________; Weight (Kg):______________

1.4. Age: Less than 22 ☐ 22-28, ☐ 29-35 ☐ 36-42 ☐ 43-50 ☐ > 50 ☐

1.5. Types of your Occupation: Welding ☐ metal cutting ☐ product assembling ☐ Working on lathe machines ☐ working on milling machine ☐ workers in maintenance ☐ Moulding ☐ Heat treatment ☐ Galvanizing ☐ Metal fabrication/processing ☐

Other please specify: ____

1.6. Did you participate on your working space arrangement decisions? 1. Yes ☐ 2. No ☐

1.7. Years of experience: 1. 1 year to 2year ☐ 2. 3 to 5 years ☐ 3. 5 to 10 years ☐ 4. more than 10 years ☐

1.8. Position in your Company (if any)________________, please specify if any other___________________

Part Two: measurements of the constructs

In the following tables, lists of questions are provided to investigate the impact of ergonomic risk factors (Awkward Posture, Psychosocial (Cognitive Ergonomic) Risk Factors, and ICT-related Risk Factors) on the well-being and innovation capability of employees at their workstations. The variables outlined in each table allow us to assess the effects of each ergonomic risk factor on the prevalence of Musculoskeletal Disorders and the innovation capability of employees in the workplace.

Furthermore, Table 2.3 contains a list of questions designed to measure the impact of musculoskeletal disorders on the innovation capability of employees. Additionally, Table 2.4 presents measurement items that assess the innovation capability of employees in the workplace. Your professional contribution is essential for the success of this dissertation work. Therefore, based on your work experience, you are cordially invited to complete this questionnaire and evaluate the impacts of each variable by marking the provided space: 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree. (Mark with a tick (✓) in the black box next to each variable)

2.1 ***Physical ergonomic risk factors***

S.N	Variables	1	2	3	4	5
1	Maintaining proper posture in my work place enhances my health and innovation capacity.					
2	Working in a dynamic position(not static) improves my health and increase my innovation capacity in the workplace					
3	Avoiding prolonged standing in the workplace positively affects my health and supports my innovation capability					
4	Not Sitting for extended periods while working promotes my health and enhances my innovation capability.					
5	Avoiding excessive bending (More than 20^0 extensions (20-60)0 flexion in the workplace helps prevent musculoskeletal disorders and improves my health and innovation capability.					
6	Minimizing repetitive movements in my workplace contributes to my health and positively influences my innovation capability.					
7	Keeping my head in a neutral position (avoiding Tilting head forward (> 20^0 flexion or in extension) for a prolonged time) supports my health and enhances my innovation capability.					

2.1. Cognitive Risk Factors

S.N	Variables	1	2	3	4	5
1	Insufficient skill and knowledge related to my work negatively impact my health and hinder my innovation capability.					
2	Work place stress adversely affects my health and innovation capability.					

3	Lack of involvement in decisions making at work diminishes my health and reduces my innovation capability					
4	Unclear instructions and miss-communication in the workplace detrimentally affect my innovation capability and over all well-being					
5	Experiencing mental exhaustion or feeling drained by the end of my shift negatively impacts my well-being and innovation capability.					
6	Distraction in the workplace (such as unbalanced noise, poor ventilation, inadequate lighting, or humidity etc) negatively affect my health and my capacity to innovate					
7	A Lack of discussion with supervisors about mental workload detracts from my well-being and inhibits my innovation capability					

2.2.ICT related Risk Factors

S.	Variables	1	2	3	4	5
1	A well-designed ICT infrastructure in the workplace enhances my health and improves my innovation capability.					
2	Using ICT that is fit for purpose in the workplace positively impacts my health and supports my innovation capability.					
3	Technologies that are well- suited for workplace use contribute to my health and enhance my innovation capability					
4	Well-designed ICT visual displays in the work place improve my health and increase my innovation capability.					
5	Having knowledge of the benefits and drawbacks of ICT usage in the workplace positively affects my health and innovation capability.					
6	Effective information communication in the workplace supports my health and enhances my innovation capability					
7	Having adequate ICT resources in the workplace positively influences my health and innovation capability					

2.3. Musculoskeletal Disorders(MSDs)

	Variables	1	2	3	4	5
1	Poor Ergonomic designed workplace exposed me for Musculoskeletal disorder(MSD) (like upper and lower back pain, head ache, eye and ear pain etc)					
2	Having a bad working environment in the workplace exposed me for MSD(like, asthma, eye pain, ear pain etc)					
3	Having inadequate posture in the workplace exposed me for MSD (like ,head ache, back pain, wrist pain, etc)					
4	Cognitive ergonomic risk factors in the workplace exposed my for MSD, like stress, depression, anxiety etc.					
5	Lack of good ICT infrastructure in the workplace exposed me for MSD like, eye pain, ear pain, stress, depression etc.					
6	Poor rest and recovery in the work place exposed me for work-related disorders like depression, stress, head ache, etc)					
7	Hopelessness in the work place exposed me for different musculoskeletal disorder.					

2.4. Improve Innovation Capability of the Employees

S.N	Variables	1	2	3	4	5
1	Cognitive well-being improves my innovation capability in the work place					
2	Having organizational innovation atmosphere within the company improves my innovation capability.					

3	Having good social capital in the work place improves my innovation capability.					
4	Having well-deigned ICT infrastructure in the workplace improves my innovation capability					
5	Having ergonomic corrected work place design improves my innovation capability in the work place.					
6	Having healthy working environment in the workplace improves my innovation capability.					
7	Having enough rest and recovery time in the work place improves my innovation capability.					

Note: Dear respondents, the following section of this data collection instrument is intended for individuals with a minimum of 2 years of industry experience. Thank you for your participation**.**

Part Three*. Impacts of interaction among workplace design dimensions on employees' well-being, innovation capability and development of sustainable competitive advantages*

The researcher has identified the interaction among the cognitive and physical dimensions of the workplace elements determine the quality of the workplace in the metal manufacturing firms. Moreover, these interactions and the quality of the workplace determine the contribution of employees for building SCA of the firms where they are employed. Your professional input is sought to evaluate the impacts of these factors on your well-being, innovation capability, and your contributions to building SCA within your workplace.

3.1. Ergonomic Workplace Design

You are invited to fill out a questionnaire where you will rate the impacts of each factor on a scale of 1 to 5, with 1= strongly disagree, 2=disagree, 3=neutral, 4= agree, 5= strongly agree

S	Variables	1	2	3	4	5
1	Work which allows me enough time to think critically and make me well-informed decision for improving my well-being, innovation capability and contribution to build SCA.					
2	Workstation designed in a way that minimizes mental strain improves my well-being, innovation capability and contribution for building SCA of the firm.					
3	Workplace distraction (noise, machine alarms, and interruptions) affects my well-being, innovation capability and Contribution to SCA.					
4	Workstation designed in a way that minimizes physical strain improves my well-being, innovation capability and contribution to build SCA.					
5	Workplace that gives freedom for social interaction improves my well-being and contribution for building SCA of the firm.					
6	Clearly displayed safety instructions and operational guidelines in my workplace area improves my well-being, innovation capability, and contribution for building SCA of the firm					
7	Workplace that allows me to get access for technology, new information improves my well-being, innovation capability and contribution for building SCA of the firm.					

3.2. Interaction between the Cognitive dimensions of the workplace elements

The researcher has identified cognitive strain as the mismatch between employees' cognitive dimensions (such as skill, knowledge, perception, attitude, etc.) and the cognitive dimensions of non-human elements designed in the workplace (including operating procedures of machinery, tools, equipment, workload, information load, etc.). This mismatch can lead to work-related stress, fatigue, dissatisfaction, impacting the quality of life in the workplace and employees' contributions to building Sustainable Competitive Advantages (SCA) for the firm.

Professionals like you are invited to provide input to assess the impacts of these factors on your quality of life and your contributions to building SCA within the firm where you are employed. Your insights are crucial in evaluating these factors (scale of 1 to 5, with 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree).

	Variables	1	2	3	4	5
1	Understanding new tasks or machine operations increase the quality of my life in the workplace and my contribution to building SCA of the firm.					
2	Ability to handle multiple tasks simultaneously during work increases the quality of my life in the workplace and my contribution to building SCA of the firm.					
3	Making rapid decisions under time pressure, such as unexpected machine failures or production errors, increase the quality of my life in the workplace and my contribution to building SCA of the firm.					
4	Maintaining concentration on workstations in the workplace determine the quality of my life in the workplace and my contribution to building SCA of the firm.					
5	Retaining memory for task sequences or work procedures at workstation increases the quality of life in the workplace and my contribution to building SCA of the firm.					
6	Reliance on memory over written guidelines for complex tasks in my workplace affects my quality well-being and contribution to building SCA of the firm					
7	Engagement and motivation in tasks at workstations affects my health, innovation capability and my contribution to building SCA of the firm.					

3.3. Interaction between physical dimensions of the workplace elements

The researcher has identified physical strain as the mismatches between the physical dimensions (anthropometric parameters) of employees and the physical dimensions of non-human elements (such as machineries, tools, equipment, etc.) designed in the workplace, exposing employees to work-related musculoskeletal disorders that affect their well-being and their contributions to building Sustainable Competitive Advantages (SCA) for the firm.

The researcher is seeking input from professionals like you to evaluate the impacts of these factors on the quality of your life in your workplace and your contribution to building SCA within the firm where you are employed. Your insights are crucial in evaluating these factors (scale of 1 to 5, with 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree).

S/	Variables	1	2	3	4	5
1	The mismatches of my physical body factor with the design of the physical dimensions of the machineries (height, width, length, thickness, etc) in my workplace affects my well-being, innovation capability, and my contribution for building SCA of the firm.					
2	The mismatches of the physical dimensions(height, back support, length, etc) of furniture with my physical dimensions in my workplace affects my quality of life in the workplace and my contribution for building SCA of the firm					
3	The mismatches of the physical dimensions (like height, weight, width, thickness, etc.) of equipment with my physical dimensions capabilities affects my well-being, innovation capability, and my contribution for building SCA of the firm					
4	The mismatches of my physical dimensions with the ICT materials in my workplace affects my well-being, innovation capability and contribution for building SCA in the firm					
5	Excessive workforce in my workplace affects my well-being, innovation capability and contribution for building SCA in the firm.					
6	Repetitive motion in my workplace affects my well-being, innovation capability and contribution for building SCA in the firm.					
7	Feeling of pain on my physical body parts affects my well-being, innovation capability and contribution for building SCA in the firm.					

3.4. Innovation Capability and developments of SCA

The researcher is seeking input from professionals like you to evaluate the impacts of these factors on your innovation capability, and your contribution to building SCA within the firm where you are employed. Your insights are crucial in evaluating these factors (scale of 1 to 5, with 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree).

S.	Variables	1	2	3	4	5
1	Engagements in different innovative activities in the company enhance my contribution on development of SCA in the firm					
2	Giving values for my innovation in the workplace enhance my contribution on developments of SCA in the firm.					
3	Getting support from my company on my innovation activities enhance my contribution on developments of SCA in the firm					
4	Having effective mechanisms in place to implement employee-generated innovations enhance my contribution on building SCA in the firm					
5	The workplace that fosters a culture that encourages and rewards employees innovation enhance my contribution on building SCA in the firm					

3.5.Measurement items for Developments of SCA

S.N	Variables	1	2	3	4	5
1	Employee-driven innovations have a measurable impacts on the success and growth of my firm					
2	Employee innovation and well-being are recognized as a critical factor for maintaining competitive advantages in metal manufacturing firms					
3	The metal manufacturing firms can adapt quickly to market changes if they give value for their employees innovation and well-being					
4	Considering sustainable competitive advantages as a key focus of strategic planning in my firm improves the competitiveness of my firm					
5	The firm I have been working in prioritizes sustainable competitive advantages in the competitive market.					
6	Employee innovation capability directly contributes to the development of sustainable competitive advantages					
7	Ergonomic workplace design has an impact on the development of sustainable competitive advantages.					

Part Four: Evaluation of physical demand of the job in your workstation

The researcher is seeking input from professional like you to evaluate the current physical demand of the job in your workstation. You have been invited to fill out a questionnaire, where you will rate the position of your body parts while doing your task on a scale provided in the table

Strength Demands of your Job/ Physical demands of the job/						
Activity	Comments(description of handled objects, coupling	FORCE/LOAD (Kg)		FREQUENCY	MOVING DISTNACE	Time
		Avg.	Max	N/R/O/F/C	Centimetre	Second
Lifting						
Low level lifting						
Waist Level Lifting						
Above shoulder Lifting						
Carrying						
Front Carry						
Side Carry-Right Hand						
Side Carry-Left Hand						
On Shoulder						
Pushing/Pulling						
Pushing tools/objects						
Pulling tools/objects						
Grasping and Pinching						

Hand use (Dominant, Non-dominant)						
Forceful Gripping (Dominant, Non-dominant)						

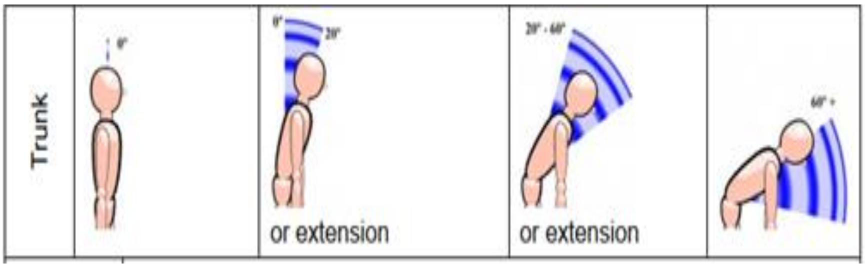
N=Not Required, R, Rare(1-5% of shift),O; Occasional(6-33%) of shift);F; Frequent(34-66%) of shift), C: Constant (67-100% of shift)

Body Posture Frequency

Activity	Comments(description of handled objects, coupling	***Frequency of Workday***				
		Not required	Rare	Occasional	Frequent	Constant
Mobility						
Walking	(terrain/surface)					
Standing	(flooring/surfaces)					
Sitting	(type of seat/chair)					

Evaluation of your Physical body position in your workplace

Trunk		
Movement	Score	Change score: +1 if twisting or side flexed
Upright	1	
$0^0 - 20^0$ flexion $0^0 - 20^0$ extension	2	
$20^0 - 60^0$ flexion $> 20^0$ extension	3	
$> 60^0$ flexion	4	



N=Not Required, R, Rare(1-5% of shift),O; Occasional(6-33%) of shift);F; Frequent(34-66%) of shift), C: Constant (67-100% of shift)

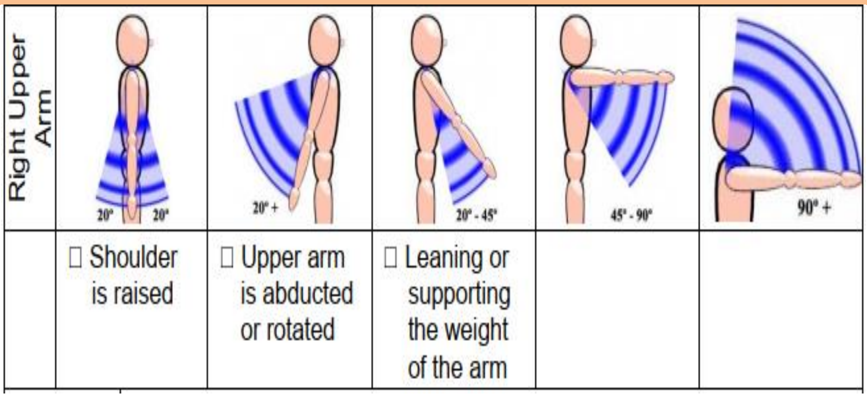
Based on the position of your Trunk while doing your work relative to the figure please fill the score		*Frequency*				
		N	***R***	***O***	***F***	***C***
Trunk Score						

Trunk side-bend Evaluation

	N	R	O	F	C
Trunk side-bend					

Upper Arm Evaluation

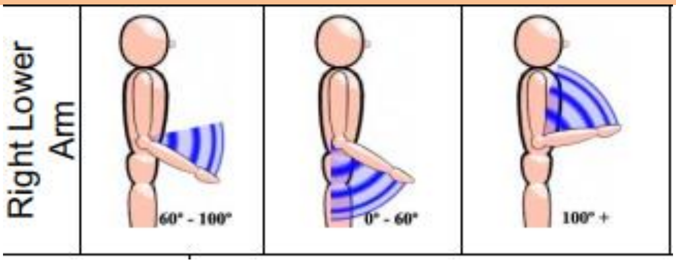
Upper arms		
Position	Score	Change score:
20^0 extension to 20^0 flexion	1	+1 if arm is abducted or rotated
$> 20^0$ extension $20^0 - 45^0$ flexion	2	+1 if shoulder is raised
$45^0 - 90^0$ flexion	3	-1 if leaning, supporting weight of arm or if posture is gravity assisted
$> 90^0$ flexion	4	



Based on the position of your upper arm while doing your work relative to the figure please fill the score		**Frequency**				
		N	**R**	**O**	**F**	**C**
Score						

Lower Arm Evaluation

Lower arms	
Movement	Score
$60^0 - 100^0$ flexion	1
$< 60^0$ flexion or $> 100^0$ flexion	2

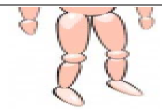


Based on the position of your arm while doing your work relative to the figure please fill the score		Frequency				
		N	R	O	F	S
Score						

Muscle Use [ ] posture is mainly static, e.g. held for longer than 1 minute or repeated more than 4 times per minute

Leg Position Evaluation

Legs		
Position	Score	Change score:
Bilateral weight bearing, walking or sitting	1	+1 if knee(s) between 30^o and 60^o flexion
Unilateral weight bearing, featherweight bearing or an unstable posture	2	+2 if knee(s) are $> 60^o$ flexion (not for sitting)

Legs		Bilateral weight bearing, walking or sitting.		Unilateral weight bearing, featherweight bearing or an unstable posture

Legs Position in your workplace	Score	N	R	O	F	S

Part Five: Evaluation of cognitive disorder in your workstation

Cognitive disorder		No exposure				High exposure			Frequency		
		0	*1*	*2*	*3*	*4*	*5*	*6*	*Low*	*Middle*	*High*
1	Stress										
2	Fatigue										
3	Suffocation										
4	Exhaustion										
5	Dissatisfaction										
other	______________										

Other questions

1. What methods do you use to assess the risks for developing work-related MSDs?(select all that apply) (REBA, ULBA, OWAS, Targeting Methods, Whole body assessment other):___________________
2. What method(s)/tool(s) do you use to help develop specific workplace design solutions to reduce the prevalence of work-related disorder and accidents? (Select all that apply)

   (Ergonomics guidelines Study similar cases Experience-based judgements Innovation

   Other (please explain)

Thank you for taking the time to fill out this survey. Your responses will be kept confidential and will only be used for research purposes. If you have any questions or concerns, please contact the researcher at the email and mobile number provided above.

Thank you for your contribution!!

Interview for industry Managers and Team leaders

Interview Questions: For Industry Managers

Investigators

Researcher **Supervisor**

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Section 1: Job information

1. ***What is your job title? ____***
2. For how long have you been working in the above capacity? _____________________
3. Can you please explain what your job assignments are? ____
4. For how long have you been working in this sector? ____

Section 2: Awareness of Work related disorders (WMSDs and Work-related stress disorder) (Put √ in front of your choice)

1. Are you concerned about the risk of Work-related disorders (WMSDs and WSDs) in your organization?

   Yes (1) ___ *No (2)* _____
2. Are you thinking about taking action to reduce the risk of work related musculoskeletal (stress) problems in the next 6 months?

   Yes (1) ____ *No (2)* _____
3. Do you have a clear idea of what you are going to do to reduce the risk of work related disorders (musculoskeletal problems) in your company?

   Yes (1) ______ No (2) ______
4. Are you concerned about the impacts of ergonomic risk factors on the innovation capability of employees?

   Yes (1) ______ No (2) ______
5. Do you think that the workplace in your company safe for employees working in?

   Yes (1) ______ No (2) ______
6. Do you think that the workplace design in your company consider the needs of employees? NO............................Yes
7. Are you concerned about employee needs based workplace design important for developments of sustainable competitive advantages in your company?

   No:_________________ Yes:________________

Section 3: Involvement in the task design decision

3. The company has to design new tasks; workplaces; order new equipment from time to time. Do you take part in the specification of jobs and equipment in any way?

   Yes (1): _______ _____ No (2):____ ______

   If no, answer questions 9, 10 and 11. If yes, answer all the rest of the questions.

4. What exactly is your involvement in the workplace and/ or equipment specification or ordering process?

   ____
5. Rate on the 1-9 scale, your impact on the overall decision according to your understanding

No impact at all						Very high impact		
1	2	3	4	5	6	7	8	9

6. What is the procedure that you normally follow in selecting equipment and arranging working place that your organisation need?

   ____
7. Are you aware that there are ergonomics guidelines and standards available to help protect workers from musculoskeletal troubles?

   Yes (1) _______ No (2) __________

   If no continue at question 9. If yes, answer questions 6, 7 and 8 too

8. Are there any ergonomic guidelines and standards are available to you? If so, what are they? _______________all of them said _____________________________there is no ergonomic guidlines____
9. How do you use these guidelines and standards in job and/or equipment specification? ____
10. From where do you have access to ergonomic guidelines and standards? ____
11. According to your knowledge, who gets involved in obtaining specifications for workplace design and/ or equipment for your organization? Name the people who get involved including consultants if any;

____
12. Does your organization involve shop floor level workers in the workplace design and/or equipment specification process to derive specifications for new workplace and equipment?
Yes (1) ________ No (2) ___all of them said no________
13. Can you please give reasons for the answer you provided for the previous question?
14. They donot have awareness about this and____

Thank you so much for participating in this study and hope you would help in the future too

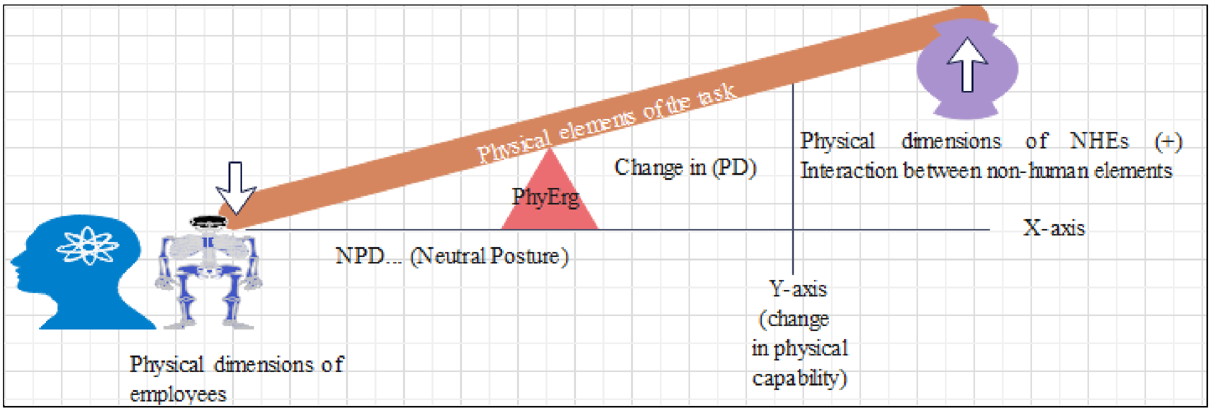
III. *Validation of Proactive Workplace Design Frameworks*

In this section, the researcher needs to validate two of the developed proactive ergonomic workplace design frameworks. The first framework, depicted in picture A, is an ergonomic assessment framework, which is used for assessing the mismatches between the dimensions of employees and the dimensions of non-human elements of the workplace. The second tool, shown in picture B, is an Ergonomic Function Deployment Framework, which is used to design an ergonomic workplace by translating employees' needs into technical requirements for workplace design.

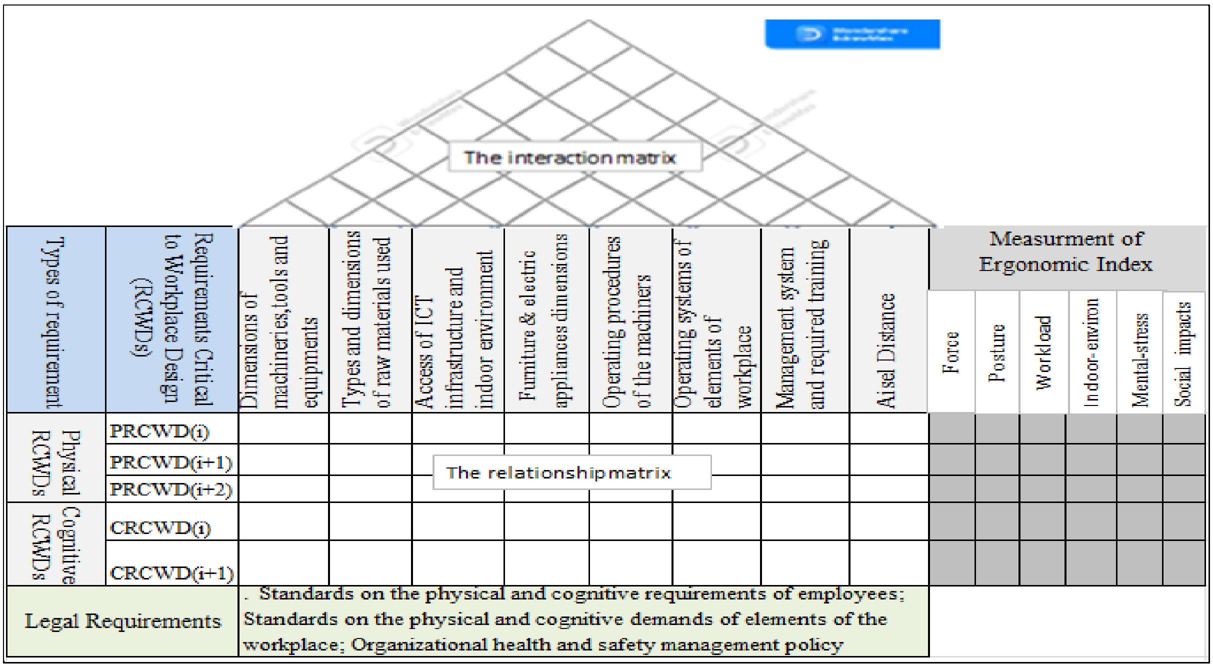
1. Information about the respondent

1.1.Academic Background:__________________, 1.3. Responsibility/Position/:______________

1.2.Age:____ 1.4. Gender:____ 1.5. Experience:___________ 1.6. Place of work:__________



A) *Figure 7.1: Work-Fit Lever for assessing physical strain development (Author)*



B. Figure 7.5 House of ergonomic function deployment framework (by Authors)

Questionnaire to Validate the Developed Tools:

1. ***Tool Importance Assessment***:

1.1. How crucial do you believe these tools are in identifying the root causes of work-related disorders and designing an ergonomic workplace? Please rate their importance on a scale of 1 to 5, where: 1- Not Important; 5 - Highly Important

A. Work Fit-Lever

Not important → Highly Important				
1	2	3	4	5

Please provide an explanation for your rating.

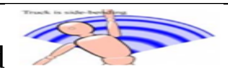
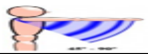
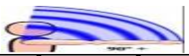
B. Ergonomic Workplace Design Tool

Not important → Highly Important				
1	2	3	4	5

Please provide an explanation for your rating

Appendix B.

Table 4.2. Summary Statistics and Test Results for Physical Body Dimensions

Body Part	Position of the body Parts in the workplace	Mean	Kolmogorov-Smirnov Test		Kruskal Wallis Statistic Test	
			Z value	Asymp.Sig	Chi-Square	Asymp.Sig
Trunk	Upright 	0.06	5.4	0.000	8.7	0.013
	0^0-20^0 flexion,0^0 – 20^0 extension 	2.28	2.5	0.000	13.4	0.001
	20^0-60^0 flexion, > 20^0 	3.01	3.8	0.000	11.2	0.004
	Greater than 20^0 flexion 	2.04	2.6	0.000	14.4	0.001
	Trunk-side bend 	0.94	2.7	0.000	12.3	0.002
Upper-Arm	20^0 extension to 20^0 flexion 	0.54	3.8	0.000	8.4	0.015
	> 20^0 extensions ,20^0 – 45^0 flexion 	2.11	2.4	0.000	10.8	0.004
	45^0-90^0 flexion 	2.74	3.5	0.000	10.5	0.005
	>90^0 flexion 	1.51	2.5	0.000	10.97	0.004
Lower-Arm	60^0 to 100^0 flexion 	2.42	3.0	0.000	15.8	0.000

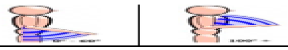
	Less than 60^0 flexion or greater than 100^0 flexion 	2.45	2.2	0.000	23.4	0.000
Leg	Bilateral weight bearing, walking or sitting 	3.04	3.6	0.000	9.3	0.010
	Unilateral weight bearing. featherweight bearing or an unstable posture 	1.31	3.5	0.000	10.4	0.006

Figure 4.3. Association of Prevalence of WDs with Types of Occupation