IMPACT OF SIT-STAND EXOSKELETON ON WORK PRODUCTIVITY IN METAL INERT GAS WELDING TASK

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Industrial Engineering (Hons.)

By

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DECLARATION

I hereby declared this report entitled "Impact of Sit-Stand Exoskeleton on Work Productivity in Metal Inert Gas Welding Task" is the result of my own research except a cited in reference.

Signature : ……………………………………

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Date : 14/7/2024

APPROVAL

This report is submitted to the Faculty of Industrial and Manufacturing Technology and Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirements for the degree of Bachelor of Industrial Engineering (Hons.). The members of the supervisory committee are as follow:

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DEDICATION

This report is dedicated to my beloved parents, Mr Ahmad Nazri Bin Che Omar and Mdm Rozaiah Binti Che Zakaria, fellow companion and Dr Isa Bin Halim for all the guidance and encouragement.

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In the name of Allah, the most gracious, the most merciful, with the highest praiseto Allah that I manage to complete this PSM smoothly.

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ABSTRAK

Kajian ini menyelidik kesan eksoskeleton duduk-berdiri kepada produktiviti pengimpal kimpalan arka gas logam. Pekerja kimpalan menghadapi risiko ergonomik yang ketara seperti postur yang tidak selesa dan kedudukan statik, yang membawa kepada gangguan otot tulang rangka. Kajian ini bertujuan mengenal pasti risiko-risiko ini melalui penilaian ergonomik, menggunakan eksoskeleton duduk-berdiri yang disesuaikan untuk mengurangkan risiko tersebut, dan menilai keberkesanannya dalam meningkatkan ergonomik dan produktiviti. Metodologi termasuk kajian pemerhatian untuk memahami cabaran ergonomik semasa, pembangunan dan pelaksanaan eksoskeleton yang disesuaikan, serta penilaian kuantitatif menggunakan skor RULA dan metrik produktiviti. Selain itu, metodologi tambahan melibatkan tinjauan kepuasan pekerja dan analisis tugas terperinci untuk memastikan penilaian yang menyeluruh. Keputusan menunjukkan pengurangan risiko ergonomik yang ketara, dengan skor RULA meningkat dari 7 ke 3, dan keempat-empat eksoskeleton sedikit mengurangkan produktiviti. Reka bentuk eksoskeleton duduk-berdiri menunjukkan penurunan produktiviti yang paling ketara sebanyak 58%, menekankan keperluan untuk pengoptimuman reka bentuk. Sebaliknya, eksoskeleton duduk-berdiri tunggal dan eksoskeleton yang dibandingkan menunjukkan penurunan produktiviti yang lebih kecil, menunjukkan potensi untuk penambahbaikan. Secara keseluruhan, eksoskeleton ini meningkatkan kesihatan pekerja tetapi mengurangkan sedikit produktiviti, dan menggalakkan amalan industri yang lestari, menyokong manfaat ergonomik dan ekonomi jangka panjang. Kajian ini menyimpulkan bahawa walaupun eksoskeleton menawarkan kelebihan ergonomik yang ketara, penambahbaikan berterusan diperlukan untuk mengoptimumkan hasil produktiviti.

ABSTRACT

The study investigates the impact of sit-stand exoskeletons in metal inert gas welding environments at. Welders face significant ergonomic risk factors such as awkward postures and static positions, leading to musculoskeletal disorders (MSDs). The study aims to identify these risks through ergonomic assessments, utilize sit-stand exoskeletons tailored to welders' needs to reduce these risks, and evaluate their effectiveness in improving both ergonomics and productivity. Methodologies include observational studies to understand current ergonomic challenges, the development and implementation of custom exoskeletons, and quantitative assessments using RULA scoring and productivity metrics. Additional methodologies involve surveying worker satisfaction and conducting detailed task analyses to ensure comprehensive evaluation. Results show a significant reduction in ergonomic risks, with RULA scores improving from 7 to 3, and all four exoskeletons slightly decreasing productivity. The double-stand exoskeleton design showed the most significant decline in productivity at 58%, highlighting the need for design optimization. Conversely, the single-stand and benchmarked exoskeletons showed smaller productivity declines, indicating potential for refinement. Overall, the exoskeletons enhanced worker health, increased productivity, and promoted sustainable industrial practices, supporting long-term ergonomic and economic benefits. The study concludes that while exoskeletons offer substantial ergonomic advantages, ongoing improvements are necessary to optimize productivity outcomes to the welders in MIG welding.

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LIST OF ABBREVIATIONS

MIG	-	Metal inert gas
RULA	-	Rapid upper limb assessment
GDP	-	Gross domestic product
WMSD	-	Work-related musculoskeletal disorder
NIOSH	-	National Institute of Occupational Safety and Health
SDN BHD	-	Sendirian Berhad
ERF	-	Ergonomics risk factors
GMAW	-	Gas metal arc welding
CTS	-	Carpal tunnel syndrome
HOQ	-	House of quality
RPN	-	Risk priority number

LIST OF SYMBOLS

cm	-	Centimeter
m	-	Meter
%	-	Percent

CHAPTER 1

INTRODUCTION

Chapter 1 briefly describes the introduction of a study beginning with the background of study, thereafter, the problem statements of this case study will be presented in this chapter from the beginning of the study. Followed by the objectives, scope of the study, significance of study and summary of the chapter.

1.1 Background of Study

Malaysia's manufacturing industry is essential to the country's economy, contributing considerably to GDP and jobs. It is distinguished by a wide spectrum of industries, including electronics, automotive, manufacturing, and chemicals. Malaysia has emerged as a significant manufacturing hub, with several global businesses establishing facilities there. The government has developed policies to encourage investment, research and development, and innovation in the manufacturing sector, positioning it as a vital driver of Malaysia's economic growth and development. Furthermore, the country’s strategic position, well-developed infrastructure, and trained people add to its allure as a Southeast Asian manufacturing destination.

Welding is a fundamental and integral part of various manufacturing industries. It involves joining materials, typically metals, by melting and fusing them together, creating strong and durable connections. Welding is essential in manufacturing because it enables the efficient and long-lasting integration of materials, allowing the construction of complex structures and products that fulfil specific design and technical criteria. To ensure quality and safety, Malaysian welders and welding firms comply to international standards and qualifications. Furthermore, vocational, and technical training programs are provided to train and certify welders, therefore contributing to the growth and sustainability of Malaysia’s welding sector. Figure 1.1 shows examples of metal inert gas welding.

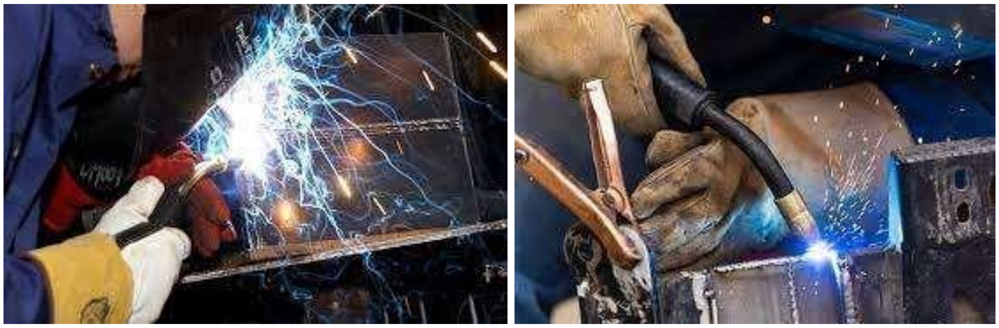


Figure 1.1: Examples of metal inert gas welding (Sild, 2023)

A prevalent welding method is metal inert gas (MIG) welding, where an electric arc is generated between a consumable electrode and the workpiece, leading to the melting and fusion of materials, typically metals. This technique, alternatively known as Gas Metal Arc Welding (GMAW), is versatile and extensively employed across various industries, including construction, manufacturing, and maintenance. Welders have manual control over the positioning of the welding gun and the intensity of the arc, providing precise control and adaptability to diverse materials and project specifications. Due to this process that requires welders to handle it manually, they often suffer various types of health issues such frequent back pain, muscle soreness etc. Those who work in factories are prone to MSDs due to ergonomic factors such as repetitive activities (Azlidah et al., 2023). Welders are exposed to various risk factors as a result of prolonged standing, awkward and static posture. Figure 1.2 shows an example of sit-stand exoskeleton design used in metal inert gas welding.

Figure 1.2 : Example of sit-stand exoskeleton design used in metal inert gas welding.

The aim of this study is to analyse the impact of sit-stand exoskeleton on work productivity in metal inert gas welding. The existence of sit-stand exoskeletons are able to significantly help minimize ergonomic issues in metal inert gas welding by providing support and reducing the physical strain on welders. Metal inert gas welding can be physically demanding, requiring welders to hold heavy tools and maintain uncomfortable positions for extended periods. Sit-stand exoskeletons can support the weight of the welding equipment, reducing the strain on the welder's arms, shoulders, and back, which can help prevent fatigue and musculoskeletal disorders.

Exoskeletons technology has a profound impact on productivity by reducing worker fatigue, enhancing precision, and improving overall task efficiency in Wentel Engineering Sdn. Bhd. Our exoskeletons designs provide physical support, enabling welders to sustain higher energy levels and focus on tasks, leading to increased output and reduced downtime due to fatigue. Additionally, they assist in maintaining stable and precise movements, resulting in fewer errors and higher-quality work. This transformative technology offers the potential to boost workforce productivity significantly, making it an asset in the Wentel Engineering team.

1.2 Problem Statement

The problem statements of this study are:

1. In today's market, the efficacy of exoskeleton products in enhancing productivity and in the workplace remains largely unverified and uncertain. This unresolved issue presents a multifaceted challenge, encompassing various aspects that require thorough investigation and evaluation. One of the central problems is the lack of conclusive evidence regarding the extent to which exoskeletons genuinely improve productivity. While these wearable devices are designed to augment human capabilities and potentially expedite tasks, the specific impact on different job functions, industries, and work environments is inadequately understood.

Figure 1.3 : Metal inert gas welding process at Wentel Engineering Sdn. Bhd.

2. Welders especially in Wentel Engineering Sdn. Bhd. as shown in Figure 1.3, in the course of their duties, confront a spectrum of physical challenges and ergonomics risk factors primarily stemming from extended periods of standing and the need to maintain awkward postures during welding operations. This issue presents a multifaceted set of concerns, necessitating comprehensive examination and potential solutions to improve the well-being and safety of welders. These ergonomics risk factors put excessive strain on various muscle groups and joints, leading to musculoskeletal disorders (MSDs) as shown in Figure 1.4. Welders are particularly vulnerable to conditions like back pain, neck pain, shoulder injuries, and carpal tunnel syndrome due to repetitive movements and postures which will reduce their productivity and efficiency.

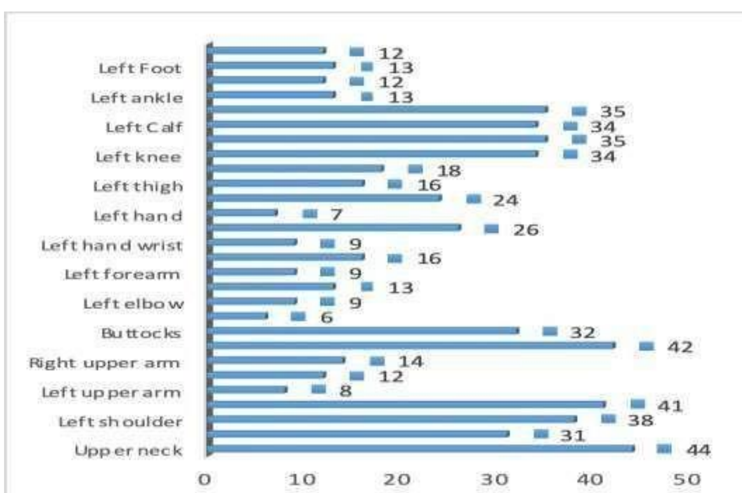


Figure 1.4 : Musculoskeletal complaints by the welder (Susihono et al., 2020)

i) Unproven effectiveness of exoskeleton products existed in the current market onproductivity and ergonomics.

ii) Welders face various physical challenges and health risks due to prolongedstandings and awkward posture.

1.3 Objectives

The objectives of this study are: -

i) To identify ergonomics risk factors and productivity issues faced by the weldersin metal inert gas welding at Wentel Engineering Sdn. Bhd.

ii) To utilize sit-stand exoskeleton to minimize ergonomics risk factors and productivity issues in metal inert gas at Wentel Engineering Sdn. Bhd.

iii) To evaluate the effectiveness of sit-stand exoskeleton on ergonomics and productivity of metal inert gas welding.

1.4 Relationship Between Problem Statement and Objectives

An issue or problem that has to be resolved immediately in order to make things better is described in a problem statement. The project's objective was to address the current situation of the issue. The relationship between the project's objectives and problem statements is displayed in Table 1.1 below.

Table 1.1 : Relationship between problem statements and problem statements

Problem Statements	**Objectives**
Welders especially in Wentel Engineering Sdn Bhd, in the course of their duties, confront a spectrum of physical challenges and ergonomics risk factors primarily stemming from extended periods of standing and the need to maintain awkward	To identify ergonomics risk factors and productivity issues by the welders in metal inert gas welding at Wentel Engineering Sdn Bhd.

postures during welding operations. This issue presents a multifaceted set of concerns, necessitating comprehensive examination and potential solutions to improve the well-being and safety of welders. These ergonomics risk factors put excessive strain on various muscle groups and joints, leading to musculoskeletal disorders (MSDs). Welders are particularly vulnerable to conditions like back pain, neck pain, shoulder injuries, and carpal tunnel syndrome due to repetitive movements and postures which will reduce their productivity and efficiency.	To utilize sit-stand exoskeleton to minimize ergonomics risk factors and productivity issues of welders in metal inert gas welding at Wentel Engineering Sdn Bhd.
In today's market, the efficacy of exoskeleton products in enhancing productivity and in the workplace remains largely unverified and uncertain. This unresolved issue presents a multifaceted challenge, encompassing various aspects that require thorough investigation and evaluation. One of the central problems is the lack of conclusive evidence regarding the extent to which exoskeletons genuinely improve productivity. While these wearable devices are designed to augment human capabilities and potentially expedite tasks, the specific impact on different job functions, industries, and work environments is inadequately understood.	To evaluate the effectiveness of sit-stand exoskeleton on ergonomics and productivity of metal inert gas welding.

1.5 Scope of Study

This study discusses the impact of exoskeleton on work productivity in metal inert gas welding. To make sure the study's goals can be met, a number of scopes are mentioned.

The first objective of this study is to comprehensively identify the ergonomic risk factors and productivity issues faced by welders engaged in metal inert gas welding processes at Wentel Engineering Sdn Bhd. Through a thorough examination of the work environment, task demands, and employee experiences, the study aims to identify specific areas where ergonomic considerations and productivity issues intersect. By establishing a baseline understanding of the current challenges, this project seeks to lay the foundation for the development and implementation of effective interventions to enhance the overall working conditions for welders at Wentel Engineering Sdn Bhd.

The second objective of this study will delve into the utilization of a sit-stand exoskeleton that focuses on the lower limb part as a targeted intervention to address the identified ergonomic risk factors and productivity issues. The focus will be on the development and utilize the existed exoskeleton tailored to the needs of metal inert gas welders at Wentel Engineering Sdn Bhd. This involves collaboration with experts in biomechanics and engineering to ensure the design is not only ergonomic but also practical for the specific demands of metal inert gas welding. The implementation phase will include the integration of the exoskeleton into the workplace, providing 6 welders with a tool designed to minimize the impact of ergonomic risk factors on their well-being and simultaneously enhance productivity.

The final objective of the project involves a comprehensive evaluation of the sit-stand exoskeleton's effectiveness in mitigating ergonomic risk factors and improving productivity in the context of metal inert gas welding. This evaluation will encompass both quantitative and qualitative assessments, incorporating metrics such as worker satisfaction, task completion times, and physiological measurements. Comparison will be made before and after usage of sit-stand exoskeleton to identify the existence of any significant difference of productivity of welders Through this evaluation, the project aims to provide evidence-based insights into the viability and impact of sit-stand exoskeletons as a solution for enhancing the ergonomic conditions and productivity of metal inert gas welding processes at Wentel Engineering Sdn Bhd.

1.6 Significance of Study

This research is significant as it aims to investigate the impact of sit-stand exoskeleton on work productivity in metal inert gas welding task. This study will indirectly improve their workplace health and safety by reducing ergonomic issues and enhances work productivity. Moreover, the collection of dataset and forecasting model of productivity for exoskeleton, contributes to knowledge transfer, and future research opportunities, benefiting both Wentel Engineering and NIOSH. Essentially, this research combines practical improvements for welders with valuable insights and resources for the field of ergonomics and product design.

1.7 Summary

Chapter 1 revolves around the core objective of identifying ergonomic issues and productivity in Wentel Engineering Sdn Bhd. The study is carried out in order to relate the impacts of sit-stand exoskeleton on productivity in metal inert gas welding.

1) Identify ergonomic issues and productivity in metal inert gas welding - The goal of the study is to quantify Wentel Engineering Sdn. Bhd's productivity and create a normative dataset. The project's goal in collecting this data is to offer an established framework for further studies and design initiatives.
2) Utilize exoskeleton design to improve ergonomic issues and productivity of welderin metal inert gas welding – This study's main goal is to investigate how different exoskeleton affect Wentel Engineering Sdn Bhd welders' productivity. Enhancing these welders' comfort and efficiency in their job is

the goal here, which will eventually increase their production as a whole.

3) Evaluate the effectiveness of each exoskeleton design by using time study analysis – Time study is particularly useful for evaluation of effectiveness and productivityin each design when there are relationships between variables that can be quantified and measured. These tools are able to offer insights into how these factors influence welders' productivity, contributing to a deeper understanding of the subject.

To summarize this chapter, this study intends to solve ergonomic issues faced by welders, particularly in metal inert gas welding, with the goal of making a significant contribution to this field. This study also emphasizes productivity as a quantitative measureto evaluate the performance of the welders before and after the usage of sit-stand exoskeleton.

CHAPTER 2

LITERATURE REVIEW

This chapter presents pertinent material concerning the study, encompassing the analysis, synthesis, and evaluation of the literature review that establishes the relevance of the current project. Within this chapter, you will find definitions of associated terms, theoretical or foundational aspects of the knowledge base, experimental procedures, and the research gap, serving as a reference for the ongoing investigation. All information in this chapter is derived from reputable sources, such as books, credible internet resources, journal articles, and conference proceedings. The organization of these sources aligns with the study's goals. Additionally, the comprehensive nature of the literature review underscores the thorough exploration of existing scholarship, contributing to a robust foundation for the current study. The meticulous arrangement of these sources reflects a deliberate effort to align with the study's objectives, ensuring a coherent and purposeful presentation of the research landscape.

2.1 Literature Review on Effect of Body Posture on Musculoskeletal System

Figure 2.1: A man suffer from MSD (Kaare Iverson, 2023)

The impact of body posture on muscle fatigue is a crucial consideration in occupational settings and daily activities. Prolonged or awkward body postures can exert mechanical strain on specific muscle groups, leading to increased fatigue as shown in Figure 2.1. When individuals maintain positions that require sustained muscle contraction or unusual joint angles, it can result in muscle imbalances, where some muscles become overused while others are underutilized. This imbalance contributes to fatigue as the muscles struggle tomaintain optimal function. Additionally, poor body posture can impede blood flow to muscles, limiting the delivery of oxygen and nutrients essential for sustained muscle activity. The increased muscle activation required to support uncomfortable postures accelerates the depletion of energy stores within the muscles, hastening the onset of fatigue. The stress on joints associated with poor posture also plays a role, as muscles work harder to providestability, contributing further to fatigue. Moreover, neuromuscular fatigue may occur due to prolonged postures, affecting the communication between nerves and muscles and impairing overall muscle coordination. Psychological factors, such as discomfort and mental fatigueinduced by poor postures, can further compound the physical effects, creating a reciprocal relationship between mental and physical fatigue. Employing proper ergonomic practices, including maintaining neutral postures, taking regular breaks, and incorporating stretching exercises, is crucial to mitigate the adverse effects of body posture on muscle fatigue and promote overall musculoskeletal well-being.

2.1.1 Analysis of Literature Review on Body Posture

The study conducted by Guo et al. (2020) constitutes a comprehensive exploration into the effects of passive sit-to-stand exoskeletons on the biomechanics and muscle activity of metal inert gas welding workers. This investigation aimed to assess the impact of a sit-to-stand exoskeleton on the posture and muscle engagement of welders during their tasks. The research yielded noteworthy results, demonstrating a significant reduction in static muscle activity, particularly in the lumbar spine, neck, and shoulders, when welders utilized the exoskeleton. This reduction in muscle activity suggests that the sit-to-stand exoskeleton contributed to alleviating strain in these crucial body regions, potentially enhancing postural comfort for welders. Additionally, the study implies that the observed decrease in muscle activity may correlate with a reduction in overall fatigue among metal inert gas weldingworkers. In essence, Guo et al.'s findings suggest that the incorporation of passive sit-to-stand exoskeletons shows promise in improving the working conditions for welders, fostering more ergonomic postures, and ultimately mitigating the risk of fatigue-related issues in this occupational context (Guo et al., 2020).

According to Kee et al. (2014), biomechanical factors, such as awkward postures, repetitive motions, and heavy loads, are recognized as significant risk factors for work-related musculoskeletal disorders (WMSDs). Awkward postures manifest when joints are not in a neutral position, for example, during activities like lifting heavy products or reaching for materials. These postures have the potential to induce muscle fatigue and elevate the overall risk of developing WMSDs. Figure 2.2 shows an example of welder's working posture and CAD model illustration of welder's joint while Table 2.1 illustrates degree of freedom of different joint. As comparison, Figure 2.3 shows welder's working posture in Wentel Engineering Sdn. Bhd.

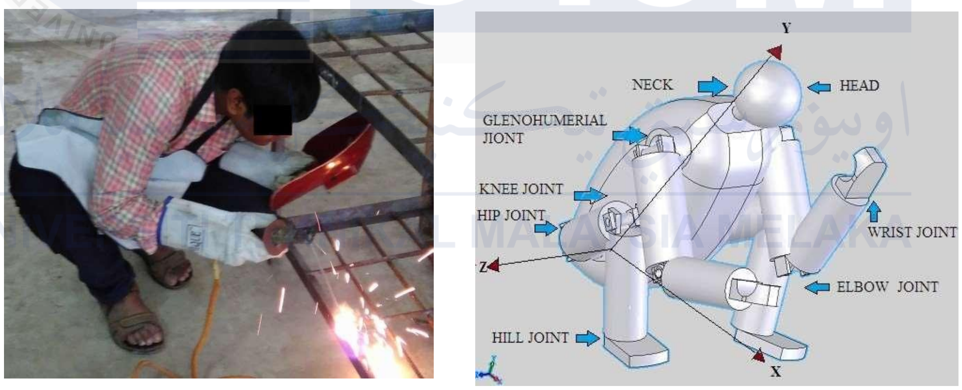


Figure 2.2 : Working Posture of Welder and CAD model of welder's joint (Suman et al, 2018)

Table 2.1 : Degree of Freedom of different joints (Arpeet et al, 2022)

Name of the Joint	**Degree of Freedom**
Neck	3
Each Shoulder Joint	2
Pelvis Joint	3
Each Elbow Joint	1
Each Wrist Joint	2
Each Hip Joint	2

Figure 2.3 : Working Posture of Welder in Wentel Engineering Sdn Bhd

Injuries and illnesses of welders now a day are due to overexertion and constant statictype of work. It is reported from studies that high rates of carpal tunnel syndrome (CTS) have been observed among workers in welding trade and similar types of work. The awareness andergonomic intervention in the unorganized sector are very low. So, the MSDs are always present in small and mediumscale enterprises where manual activities are carried out. The lower back, neck, shoulder, forearm, and hands are the most commonly affected body regions due to that reason. Most of the work-related MSDs are cumulative trauma disorders which result from exposures to high or low intensity loads acting over a longperiod of time repeatedly (Mukherjee S. et al., 2018).

2.1.1.1 Body Posture as Factor Associated with Musculoskeletal Symptoms

It is observed that musculoskeletal symptoms in different body regions are significantly associated with working posture and working time. Patients with musculoskeletal disorders may experience body posture as a potential etiologic factor (Zonnerberg et al., 1996). The development of musculoskeletal issues, such as pain or discomfort in the muscles, bones,and joints, can be associated with poor posture. The musculoskeletal system may experience acute or chronic problems as a result of the misalignment and strain caused by poor posture (Li, 2022). Discussing the major ergonomic factors associated with musculoskeletal problems aims to develop guidelines for improving working posture and reducing postural stress in welding workstation design.

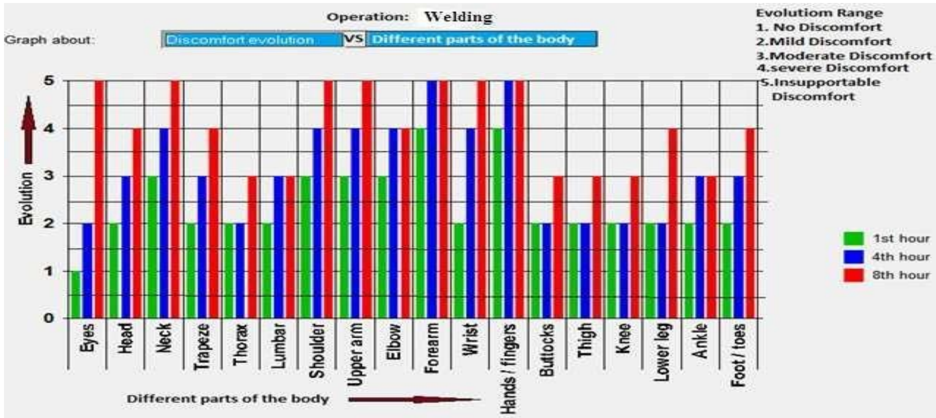


Figure 2.4 : Discomfort Evolution in Different body parts (Banerjee et al., 2018)

Figure 2.5. : Discomfort Frequency in Different body parts (Banerjee et al., 2018)

The working postures of the welders, representing the positions of the neck, trunk, hands, and legs during work, are shown in Figure 2.4 and Figure 2.5. With the increase in working hours and experience, a significant rise in pain in the neck, back, wrists, hips, shoulders,and arms is evident. The lack of adjustability in welding workstations appears to be a primary cause of constrained and challenging postures, particularly concerning ground welding operations where the job table becomes a determinant factor for neck, shoulder, and arm postures. This limitation also emphasizes the significance of addressing workstation adjustability, especially in ground welding operations, where the job table significantly influences workers physiological condition. Unfortunately, there has been a lack of attention to the adjustability and easy rotation of the job table, and no specific seat for welders during operations has been provided (Suman et al, 2020).

2.1.2 Synthesis of Literature Review on Body Posture

The investigation by Guo et al. (2020) offers a thorough exploration of the impact of passive sit-to-stand exoskeletons on the biomechanics and muscle activity of metal inert gas welders. Focused on assessing posture and muscle engagement during welding tasks, the study revealed a significant reduction in static muscle activity, particularly in crucial areas such as the lumbar spine, neck, and shoulders, when welders utilized the exoskeleton. This reduction suggests that the sit-to-stand exoskeleton played a beneficial role in alleviating strain in these key body regions, potentially enhancing postural comfort for the workers. The observed decrease in muscle activity implies a potential correlation with a reduction in overall fatigue among metal inert gas welders, suggesting that the incorporation of passive sit-stand exoskeletons holds promise for improving working conditions, promoting ergonomic postures, and mitigating the risk of fatigue-related issues in this occupational context (Guo et al., 2020).

In parallel, Kee et al. (2014) highlight the significance of biomechanical factors, such as awkward postures, repetitive motions, and heavy loads, in the context of work-related musculoskeletal disorders (WMSDs). The study underscores how awkward postures, arising when joints are not in neutral positions during tasks like lifting heavy products or reaching for materials, can lead to muscle fatigue and elevate the overall risk of developing WMSDs. This observation aligns with the broader context of occupational health, emphasizing the importance of understanding and mitigating biomechanical risk factors to prevent musculoskeletal disorders in various occupational settings.

The challenges faced by metal inert gas welders are further emphasized by Mukherjee etal. (2018), who note that injuries and illnesses in this profession are often linked to overexertion and continuous static work. The prevalence of conditions like carpel tunnel syndrome (CTS) among workers in welding trades is alarming, with a higher incidence observed due to low awareness and limited ergonomic interventions in the unorganized sector. A higher prevalence of musculoskeletal disorders is observed in small and medium- scale enterprises, primarily due to a lack of awareness, especially in environments where manual activities are predominant, impacting body regions such as the low back, neck, shoulders, forearms, and hands. The necessity for proactive measures to address ergonomic issues in manual-intensive professions is underscored by the cumulative trauma disorders resulting from prolonged exposure to high or low-intensity loads (Suman et al., 2020).

2.1.3 Evaluation of Literature Review on Body Posture

Previous researchers have conducted numerous studies into the relationship between body posture and the cause of musculoskeletal disorders (MSD). These researchers have identified both similarities and differences with the current study, highlighting the significance of the present analysis and synthesis in offering valuable guidance and information on the substantial impact of body posture on MSD as shown in Table 2.2.

Table 2.2 : Evaluation of the literature review of past studies related to body posture on MSD

Studies (Countries)	**Participants of study**	**Age group**	**Independent variables or Predictors studied**	**Difference with the current study**
Das Suman et al., 2018 (India)	West Bengal industry only	Healthy adults	Origin, job profession and tasks	*Different body posture of the welders, no prolonged standings.*
Guo et al., 2011 (China	Chinese nationality only	Varies	Origin, body condition	*Focus on stroke patient's body posture only.*
Mukherjee et al., 2018 (India)	Indian nationality only	Varies	Origin, job and tasks, sample size	*No prolonged standings, multiple body postures.*

Current study (yours)	Wentel Engineering welders only.	18-35	Job tasks, age	*MIG weldings, prolonged standing required.*

2.2 Literature Review on Exoskeleton Design Requirement

Designing an exoskeleton tailored for metal inert gas welders demands careful consideration of the specific challenges associated with their tasks. The exoskeleton should prioritize providing ergonomic support to mitigate the physical strain imposed by prolonged welding activities. The design should incorporate lightweight yet durable materials to ensure ease of movement while offering sufficient protection against sparks, heat, and other hazards present in welding environments. The exoskeleton should allow for natural movement while maintaining stability, ensuring the welder's comfort and safety. Sensory feedback systems, including haptic feedback and sensors, can enhance the welder's awareness of their postureand the surrounding environment. A user-friendly control interface is crucial, enabling welders to adjust the exoskeleton settings easily. Regular collaboration with welders in the design process, coupled with iterative testing and feedback, is essential for creating an exoskeleton that seamlessly integrates into the welder's workflow, effectively addressing the physical demands of metal inert gas welding while promoting safety and efficiency.

2.2.1 Analysis of Literature Review on Exoskeleton Design

The technology of wearable robots like lower-limb exoskeletons is undoubtedly impressive, their true success hinges on achieving a seamless integration with users. This goes beyond simply providing assistance; it means ensuring users feel comfortable, natural, and even empowered while wearing the exoskeleton. To achieve this, we need to shift our focus towards user-centered design approaches. This involves understanding user needs and preferences through surveys and feedback, incorporating biomechanical data for optimal compatibility, and testing exoskeletons in realistic scenarios to capture their usability in everyday life (Papanastasiou et al, 2019).

By prioritizing seamless integration and user- centered design, we can unlock the full potential of wearable robots, transforming them from functional tools into empowering companions that truly enhance our lives. According to Wuet al. (2019), for wearable robots like exoskeletons to be truly successful, they need to go beyond mere functionality and achieve seamless integration with the human body and movement. Integration involves in the design should not only mechanical compatibility butalso psychological and social acceptance. Users should feel comfortable and natural while using the exoskeleton. Figure 2.6 illustrate the examples of exoskeleton designs.

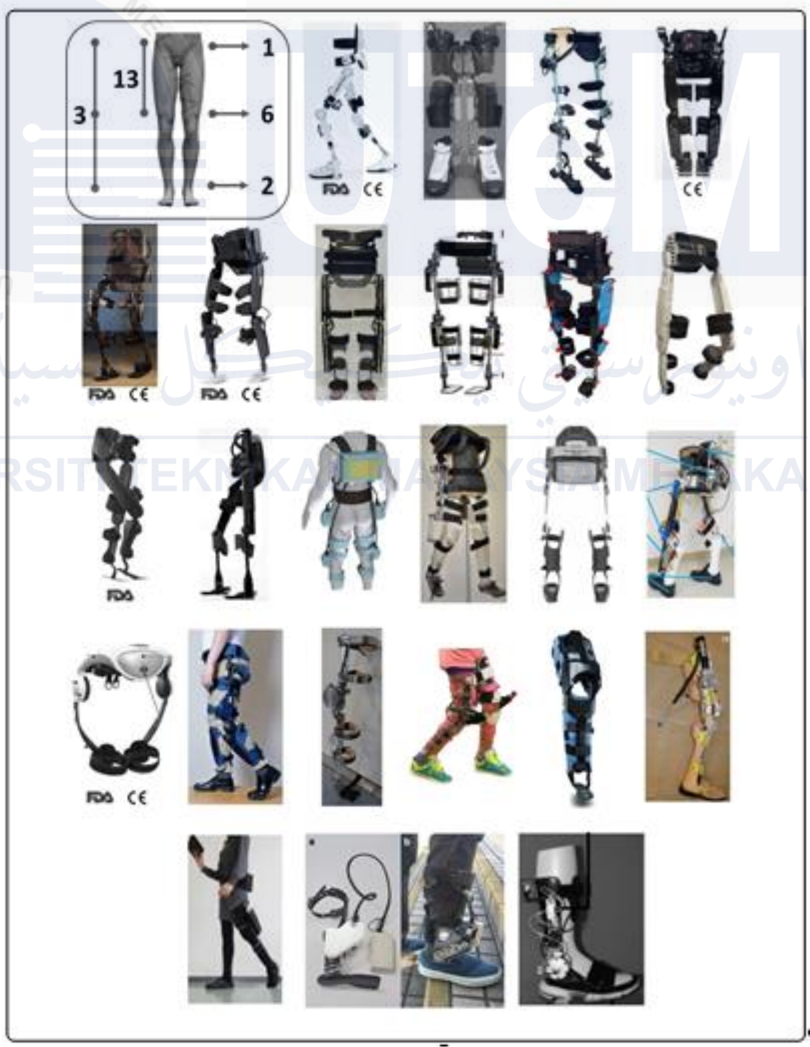


Figure 2.6 : Example of exoskeleton design (Rodríguez-Fernández et al., 2021)

There are major challenges involved in exoskeleton design. One of the most demanding tasks is that the system must be able to reproduce human movements to a functional level. This means more than seven degrees of freedom to be controlled in upper or lower limbs. In addition, it must be able to intervene in the exactly desired way with the subject’s movement to control the interaction force between user and robot (Rafael et al, 2016). So, in order to find the best design that aligns with user requirement, thorough analysis with complex procedure needed to be done. Furthermore, achieving seamless integration requires careful consideration of individual variability in human biomechanics and user-specific requirements. This necessitates a comprehensive understanding of the physiological and kinematic intricacies involved, thereby emphasizing the importance of interdisciplinary collaboration between engineers, biomechanics experts, and end-users in the iterative design process.

2.2.2 Synthesis of Literature Review Exoskeleton Design

Exoskeleton design poses significant challenges, with a paramount demand being the accurate reproduction of human movements to achieve functional efficacy. This entails managing over seven degrees of freedom in both upper and lower limbs, necessitating a sophisticated control system (Rafael et al., 2016). Achieving precise intervention in tandem with the user's movements, including controlling interaction forces between the user and the robot, adds another layer of complexity to the design task.

To ascertain an optimal design aligned with user requirements, an exhaustive analysis involving intricate procedures becomes imperative. The pursuit of seamless integration mandates a meticulous consideration of individual variability in human biomechanics and user-specific needs. This complexity underscores the critical importance of interdisciplinary collaboration, emphasizing the involvement of engineers, biomechanics experts, and end- users in the iterative design process. In essence, addressing these challenges requires a comprehensive understanding of both the physiological and kinematic intricacies involved in the interaction between humans and exoskeletons.

Furthermore, the success of exoskeleton design hinges not only on technical excellencebut also on addressing the practical and contextual aspects of user adoption. Users' perceptions, comfort, and acceptance of exoskeletons play a pivotal role in determining the effectiveness of these technologies in real-world scenarios. Research by Pinto et al. (2020) underscores the significance of user-centered design and the incorporation of user feedback throughout the development process. User trials and feedback loops are crucial for refining design features, ensuring comfort, and enhancing overall user experience. Balancing the technical intricacies with user preferences and comfort is essential for fostering widespread acceptance and utilization of exoskeletons in diverse applications and environments. Therefore, a user-centric approach, grounded in empirical user studies, is integral to overcoming adoption barriers and achieving successful integration of exoskeletons into daily activities (Pinto et al., 2020).

2.2.3 Evaluation of Literature Review on Exoskeleton Design

Past researchers have carried out several studies regarding the functional design of exoskeletons. Each of the exoskeletons has its own advantages and disadvantages, which will be pivotal in the later phases of our study, especially during the fabrication phase. These researchers have identified similarities and differences between the current study and their own research, highlighting the significance of the current analysis and synthesis in offering insightful direction and information for determining the best exoskeleton design aligned with our objectives. Table 2.3 shows evaluation of literature review of past studies related to exoskeleton design.

Table 2.3 : Evaluation of the literature review of past studies related to exoskeleton design

Studies (Countries)	Purposes	Type of exoskeleton	Disadvantages	Difference with the current study
Rodriguez Fernandez et al., 2021 	Reduce physical burden for the therapist, provide objective and Quantitative assessments of the patient's progression	Passive lower-limb exoskeleton (structured with mechanical gear, socket joint, etc)	High cost and too complex	*Designed for rehabilitation purposes*
Ahsan et al., 2020 	Interact with the user for the purpose of power amplification, assistance, or substitution of motor function	Active upper-limb exoskeleton (structured with motor, electric gear and power supply)	Not able to provide a wide range of motion	*Designed as active upper-limb exoskeleton.*
Hernandez et al., 2020 (Mexico) 	Solving mobility problems for disability people	Active lower-limb exoskeleton	High cost, too complex, required powersources.	*For aging population with mobilityproblems.*
Morris et al., 2017 	Solving ergonomics issues	Passive lower-limb exoskeleton	Limitedmotions	*For factory workers in production line.*

Current study	Reduce ergonomic risks factors and productivity issues	Passive lower-limb exoskeleton	Taking too much time to wear it	*None*

2.3 Literature Review of Material Requirement on Exoskeleton Design

For an exoskeleton designed for metal inert gas welders, material selection is critical to meet the specific demands of the work environment. The exoskeleton's main structural components should be made from lightweight and durable materials, such as high-strength alloys or advanced composites. These materials must withstand the harsh conditions of welding, including exposure to heat, sparks, and potential impacts. Flame-resistant materials are essential to protect the wearer from welding sparks and radiant heat. The materials chosen should provide a balance between strength and flexibility, allowing for natural joint movements while offering ample support to reduce muscle strain during prolonged welding tasks. Ergonomic padding made from breathable and moisture-wicking materials can enhance comfort, and the overall design should facilitate ease of cleaning to maintain hygiene in industrial settings. Regular collaboration with welders, as well as testing and validation, ensures that the selected materials effectively enhance performance, promote safety, and meet the unique challenges faced by metal inert gas welders.

2.3.1 Analysis of Literature Review on Material Requirement

For exoskeleton, finding a suitable material is considered the most crucial process. In order to find the best material requirement, thorough analysis need to be made. According to Material Selection for Exoskeletons: A Review" by Najam et al. (2019) published in the design and manufacturing of exoskeletons, including the selection criteria, advantages, and limitations of different materials. Table 2.4 shows summary of lower-limb exoskeletons manufacturing method, materials and actuation.

Table 2.4. Summary of lower-limb exoskeletons manufacturing methods, materials, and actuation. (Hussain et al, 2021)

Name and development stage of exoskeleton	Manufacturing method	Manufacturing material	Type of actuation	Function of exoskeleton
Ekso (proof-of-concept stage)	3D printing of individual components and joining all	Metallic structure	Hydraulic actuators	Rehabilitation
Indego (commercially available)	Three parts have been manufactured by selective laser sintering	Metal and carbon fiber	DC brushless motor	Spinal cord injury rehabilitation
Rex (research stage)	No information is available	Metallic structure	Linear actuators	Assist mobility-impaired person to walk independently
HAL-Hybrid assistive limb (commercially available)	3D printing	Metallic frames with molded plastic bands	Electric DC actuation	To enhance and upgrade the human Capabilities
Atalante (research stage)	Extrusion, CNC machining	Metallic structure	Brushless DC motor	For walking assistance ofparaplegic Patients
Chuk-Exo (research stage)	Extrusion, CNC machining	Aluminum alloy (7075-T651), Steel and polyethylene	Electric actuators	For Motion assistance to paralyzed Patients
ETH knee pertubator (proof-of-concept stage)	CNC machining and drilling	Lightweight metal, carbon fiber	Brushless and flat actuators	For perturbing the knee during gait
Expos (research stage)	Metal Casting and CNC machining	Bendable steel tube	Tendon connecting motors and pulleys	For helping the human body motion. Of elderly people and patients

Assisted exoskeletons require high comprehensive properties of materials. Since heavy weight will lead to uncoordinated movement and high energy consumption, it is necessary to ensure that the material has high strength and low density and meets the use requirement of being lightweight. The exoskeleton material should be reasonably selected according to the design requirements and material characteristics of different parts. They should be adequate for wearers' activities in complex environments and should reduce the impact of wearing quality on auxiliary effect (Xinyao et al, 2022).

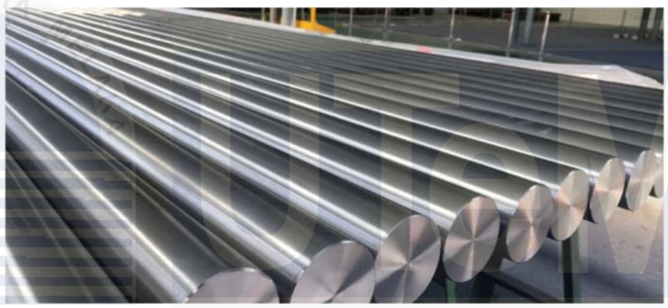


Figure 2.7 : Titanium Alloy used for exoskeleton body (ThePipingMart, 2022)

The main materials of exoskeletons are titanium alloy as shown in Figure 2.7, carbon fiber, acrylic plate, plastic, and aluminum alloy. So far, shape memory alloy is usually usedas the assist component of unpowered exoskeleton assistive robots. With developments in material science, shape memory polymers, elastic matrix composites, multifunctional nanocomposites, liquid silica gel, and so on can now be used. These materials form series elastic elements and variable stiffness elements singly or in combination, to further enrich the power-assisted elements of unpowered power assisted robot (Xupeng et al, 2022).

2.3.2 Synthesis of Literature Review on Material Requirement

The critical phase of exoskeleton development revolves around the meticulous selection of suitable materials, a process underscored by its profound impact on overall performance and user satisfaction. In the journal Materials, Najam et al. (2019) provide an insightful overview of material selection in their article "Material Selection for Exoskeletons: A Review." This comprehensive review delves into the criteria guiding material choices, along with a thorough analysis of the advantages and limitations associated with different materials used in the design and manufacturing of exoskeletons.

One of the primary considerations in material selection for assisted exoskeletons is the necessity for materials with high comprehensive properties. The need to balance strength, density, and weight is particularly emphasized, as excessive weight can lead to uncoordinated movements and heightened energy consumption. Xinyao et al. (2022) stress the importance of ensuring that exoskeleton materials possess the required strength and low density, aligning with the imperative for lightweight construction. Moreover, the selection process should meticulously align with design requirements, tailoring materials to the specific characteristics of different exoskeleton components. Recognized materials for exoskeletons include titanium alloy, carbon fiber, acrylic plate, plastic, and aluminum alloy, each chosen with consideration for their unique properties.

Advancements in material science, as highlighted by Xupeng et al. (2022), have introduced innovative options such as shape memory polymers, elastic matrix composites, and multifunctional nanocomposites. These materials contribute to the formation of series elastic elements and variable stiffness elements, presenting new avenues for enriching the power-assisted elements of unpowered exoskeleton assistive robots. The continuous evolution of materials not only expands the range of choices but also facilitates the creation of more adaptive and efficient exoskeletons, highlighting the intricate interplay between material science, design considerations, and the pursuit of user-centric advancements in exoskeleton technology.

2.3.3 Evaluation of Literature Review on Material Requirement

Previous researchers have conducted multiple studies on materials for exoskeletons. These researchers have each proposed their own ideas for using the best materials in their exoskeletons. Each material used has both positive and negative indicators, depending on the researchers' priorities. By referencing past researchers' studies, I am able to highlight the significance of the present analysis and synthesis in providing valuable guidance and information for finding the best exoskeleton materials for metal inert gas welders. Table 2.5 illustrates the evaluation of the literature review of past studies related to material requirement for exoskeleton.

Table 2.5: Evaluation of the literature review of past studies related to material requirement for exoskeletons

Studies (Countries)	**Materials used for exoskeleton**	**Advantages of material**	**Disadvantages of material**	**Difference with the current study**
Hussain et al.,2021	Metallic framesfor exoskeleton body	Strength and durability, easy fabrication (White et al., 2017)	Reducing user’smotion.	*Using metallic frames*
Xinyao et al.,2022 (China)	Titanium alloy asattachment	High strength and durability (Garycook et al.,2020)	High cost	*No need for attachmen t.*
Xupeng et al.,2022 (China)	Stainless steel rod	Affordable (Steven et al.,2023)	Low durability compared to othermaterials	*Usage of stainless steel isnot sustainable for longer period.*
Current study	Telescopic rod	Affordable and high flexibility	Low durability	*None*

2.4 Literature Review on Product Usability

Product usability requirements for an exoskeleton designed for metal inert gas welders play a pivotal role in ensuring the effectiveness and acceptance of the wearable technology in real-world industrial scenarios. Firstly, the exoskeleton should feature an intuitive and easily operable control interface, enabling welders to adjust settings and functionalities without hindering their workflow. The controls should be designed with simplicity and efficiency in mind to minimize the learning curve for users. Additionally, the exoskeleton must allow for quick and easy wearability, considering the time-sensitive nature of tasks in welding environments. Adjustable sizing and comfortable fittings are essential to accommodate the diverse body shapes and sizes of welders. The exoskeleton's weight distribution and balance should be optimized to prevent undue strain on specific body areas, promoting long-term wearability without causing additional fatigue. User feedback mechanisms, such as visual or haptic cues, should be incorporated to enhance situational awareness, alerting welders to the exoskeleton's status, and ensuring safe operation. Regular consultation with manual arc welders throughout the design and testing phases is imperative to capture insights into their preferences, expectations, and potential challenges, ultimately contributing to the development of an exoskeleton that seamlessly integrates into their work routines while prioritizing safety, efficiency, and overall user well-being. Furthermore, the exoskeleton's design should account for the dynamic nature of metal inert gas welding tasks, ensuring that the wearer can move freely and perform intricate motion without restrictions. The system should be equipped with fail-safe mechanisms and emergency shutdown features, providing welders with a quick and efficient means to disengage the exoskeleton in case of any unforeseen issues. These usability requirements, coupled with ongoing user engagement and feedback loops, will not only enhance the exoskeleton's integration into the metal inert gas welding workflow but also contribute to its continuous improvement based on the evolving needs and experiences of the end-users.

2.4.1 Analysis of Literature Review on Product Usability

Usability is the measure of how effectively specified users can achieve predetermined goals with effectiveness, efficiency, and satisfaction within a defined context of use. In the context of systems design, achieving optimal usability is crucial as it directly relates to users' success in accomplishing goals within an acceptable timeframe and their overall satisfaction with the experience, encompassing the broader notion of the product or system's quality. The importance of usability and performance validation for a robotic ankle exoskeleton lies in ensuring its effective functionality, user-friendly design, and overall reliability in meeting the intended objectives (Orekhov et al., 2021). Enhancing the usability of rehabilitative exoskeletons holds the potential to elevate the user experience, influencing how individuals feel about using the product in a specific context and shaping their self-image during device utilization (Luca Meloni el at, 2021).

Attributes	Times selected (%)	Performance-related measurements	Questionnaire, Survey	Interview, unstructured oral feedback	Thinking Aloud	Observation of users	Document-based methods	Model- or simulation-based approach	(Usability) Expert evaluation
Functionality	47 (37.6%)	31	17	15	7	18	4	10	10
Ease of use	46 (36.8%)	18	27	23	12	20	7	5	11
Performance	40 (32.0%)	32	12	7	6	15	5	12	5
Safety	40 (32.0%)	14	11	11	8	17	9	8	9
Comfort	37 (29.6%)	8	24	17	4	10	3	2	7
Benefit	26 (20.8%)	18	15	9	4	9	3	4	4
Reliability	25 (20.0%)	18	5	5	2	6	8	7	7
Ergonomics	23 (18.4%)	4	9	5	3	12	7	3	5
Technical req.	22 (17.6%)	15	1	3	2	7	6	12	8
Wearability	22 (17.6%)	7	9	9	5	12	8	5	7
Adaptability	21 (16.8%)	4	6	11	7	9	3	3	3
Meet user needs	20 (16.0%)	4	14	11	3	6	3	2	7
Autonomy	16 (12.8%)	10	5	5	5	4	2	4	3
Feasibility	16 (12.8%)	9	4	5	2	5	2	3	1
Intuitiveness	16 (12.8%)	5	8	11	4	4	2	1	3
Others*		(57)	(62)	(55)	(25)	(55)	(19)	(24)	(34)
Total count		254	229	202	99	209	91	105	124

Figure 2.8 : Usability attributes and evaluation methods (Luca Meloni el at, 2021)

Summarized in Figure 2.8 is a frequency analysis of the top 15 usability attributes, arranged from most to least selected, along with their respective evaluation methods. Functionality (37.6%), ease of use (36.8%), performance (32.0%), safety (32.0%), and comfort (29.6%) emerged as the most frequently evaluated usability attributes, while learnability (4.0%), mental demand (3.2%), and understandability (2.4%) were the least selected. Performance- related measurements (PRM) constituted the most reported usability evaluation method across all attributes (94.1%), followed by questionnaires and user observation, whereas less commonly used methods included thinking aloud and document-based approaches. Attributes of a more subjective nature, such as comfort, ergonomics, wearability, adaptability, and intuitiveness appear to be primarily evaluated with qualitative measures (unstructured interviews, observations) and questionnaires or surveys (Jan Thomas M et al, 2021). Figure 2.9 shows the reflection of usability evaluation practise. Therefore, evaluating and comparing the usability of both the old and new design harnesses for the Hyundai chairless exoskeleton in South Korea considered significance, aiming to inform improvements and enhance the overall user experience. Methods used to measure product usability include questionnaire and surveys focusing on workers of Hyundai company (Chae et al., 2021).

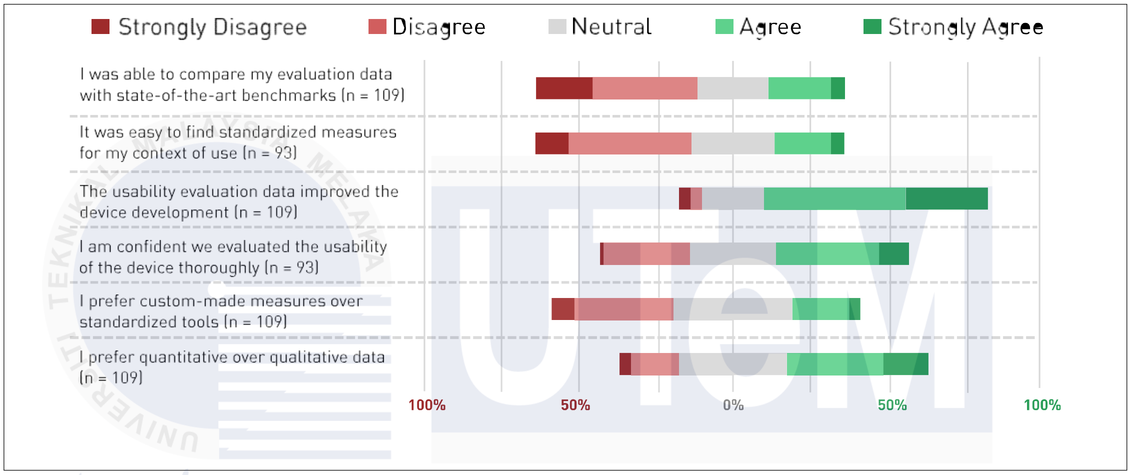


Figure 2.9 : Reflection of Usability Evaluation Practise (Robert Gassert et al, 2021)

In the context of assessing the usability of rehabilitative exoskeletons, both quantitative and subjective assessment methods play a crucial role. These methods involve measurements in the form of counts and rely on individuals' judgments. The System Usability Scale (SUS), a well-accredited instrument, has been reported in seven studies, demonstrating its popularity for quick evaluations of usability across various technological devices (Orekhov et al., 2021). Ad hoc questionnaires, reported in six studies, often lack evaluation of dimensionality, validity, reliability, and scoring procedures. Deployed in five studies, the Quebec User Evaluation of Satisfaction with Assistive Technology 2.0 (QUEST 2.0) employs a 12-item bidimensional psychometric questionnaire to assess user satisfaction with assistive technologies, while additional methods such as the Visual Analog Scale (VAS), AttrakDiff, Self-Assessment Manikin (SAM), heuristic evaluation, and Perceived Rate of Exertion (PRE) contribute to a comprehensive evaluation of exoskeleton usability, each bringing its unique strengths and limitations (Davide Giusino et al, 2021).

Shifting to qualitative and subjective assessment methods in the use of rehabilitative exoskeletons, these methods collect data in the form of words, sentences, or descriptions, relying on individuals' judgments. Unstructured observations, reported in two studies, were conducted to assess the usability of different exoskeletons, involving SMEs in the design but lacking evidence for validity or reliability. Focus groups, mentioned in one study, were employed to identify potential usability issues in a lower-limb rehabilitative exoskeleton, although no evidence for construct validity or reliability was reported. Semi-structured interviews, featured in one study, utilized a protocol covering capabilities, life habits, and expected technical characteristics, with the QUEST instrument serving as a reference. The Think-Aloud protocol, reported in one study, involved users thinking aloud while using a hand/wrist rehabilitative exoskeleton during prototype development, correlating positively with other methodologies' results. Each method contributes to a holistic understanding of rehabilitative exoskeleton usability. (Luca Pietrantoni et al, 2021)

2.4.2 Synthesis of Literature Review on Product Usability

The concept of usability in the context of rehabilitative exoskeletons is paramount, defined as the effectiveness, efficiency, and satisfaction achieved by specified users in a defined context of use. This definition extends beyond mere functionality to encompass the user's holistic experience with the product or system (Chae et al.,2021). Luca Meloni and colleagues emphasize the critical role of usability in systems' design, emphasizing the need for users to successfully achieve their goals within an acceptable timeframe, influencing their overall satisfaction and experience. Notably, the improvement of usability in rehabilitative exoskeletons holds the potential to enhance the overall user experience, influencing users' feelings about the device and shaping their self-image during utilization (Meloni et al., 2021).

An insightful frequency analysis of the top 15 usability attributes reveals key attributes that are frequently evaluated in the realm of rehabilitative exoskeletons. Functionality, ease of use, performance, safety, and comfort emerge as the most commonly assessed attributes. A closer look at the evaluation methods employed indicates a preference for performance- related measurements (PRM), questionnaires, and user observation. Conversely, methods like Thinking Aloud and document-based assessments are less frequently utilized. The findings from Jan Thomas M et al. (2021) highlight the dominance of quantitative measures, particularly PRM, in evaluating attributes like functionality and ease of use. At the same time, subjective attributes such as comfort and intuitiveness are often assessed through qualitative methods like unstructured interviews and questionnaires.

The assessment of rehabilitative exoskeleton usability necessitates a dual approach, integrating both quantitative and subjective assessment methods. While quantitative methods involve counts and judgments, tools like the System Usability Scale (SUS) and the Quebec User Evaluation of Satisfaction with Assistive Technology 2.0 (QUEST 2.0) showcase the popularity of well-accredited instruments for quick evaluations. Davide Giusino et al. (2021) emphasize the significance of these tools in assessing user satisfaction and providing a comprehensive understanding of usability attributes. On the qualitative side, methods such as unstructured observations, focus groups, semi-structured interviews, and the Think-Aloud protocol capture the experiential aspects of usability. These methods, reported by Luca Pietrantoni et al. (2021), contribute to a holistic understanding of rehabilitative exoskeleton usability by delving into users' perceptions, habits, and technical expectations, thereby enriching the overall evaluation landscape.

2.4.3 Evaluation of Literature Review on Product Usability

Past researchers have conducted numerous studies on the usability of products, specifically focusing on exoskeletons. Through these studies, I have identified similarities and differences in the targeted users by investigating multiple sets of people in different regions. Each researcher has provided unique information that is pivotal and relevant to the current study. By referencing the studies conducted by past researchers, I can highlight the significance of the present analysis and synthesis in providing valuable information on the product usability of exoskeletons. Table 2.6 shows the evaluation of the literature review ofpast studies related to user usability of exoskeleton.

Table 2.6: Evaluation of the literature review of past studies related to user usability of exoskeleton

Studies (Countries)	**Participants of study**	**Age group**	**Independent variables or Predictors studied**	**Difference with the current study**
J an Thomas M et al., 2021	WRD developers with academic, industrial and/or clinical backgrounds	Varies	Participant's background, sample size	*Focus on developer's usability and perspectives only*
Luxa Meloni et al., 2021 (Italy)	Either patients following a robotic exoskeleton-based motor rehabilitation training program or informative healthy subjects such as subject-matter experts	Varies	Participant's background and condition	*For rehabilitation purposes and focus on patient's usability.*
Luca P et al., 2021 (Italy)	Patient that undergoes rehabilitation	Varies	Participant's background and motions	*Usability only for medical purposes*
Current study (yours)	Workers in welding sector	18-35	Expertise level, body condition, department	*None*

2.5 Literature Review of Impact of Ergonomics Issues on Worker's Productivity

Ergonomic issues significantly impact workers' productivity due to the physically demanding nature of their work. Welding tasks specifically often require prolonged periods of repetitive motions and sustained postures, leading to musculoskeletal discomfort and fatigue. Poorly designed workstations and equipment can contribute to awkward body positions, increasing the risk of injuries and reducing overall efficiency. As Ranjana et al. (2023) stated, ergonomics has become a factor that affects how motivated employees are and how well they do their jobs. Additionally, inadequate ergonomic considerations may result in discomfort or pain, distracting workers from their tasks and potentially leading to errors. Addressing ergonomics in welding environments is crucial to maintaining the well-being of the workforce, preventing injuries, and optimizing productivity by providing a comfortable and safe working environment that minimizes physical strain and enhances overall job performance.

2.5.1 Analysis of Literature Review on Worker's Productivity

The analysis of a worker's productivity involves a comprehensive assessment of various factors that contribute to the efficiency and effectiveness of welding tasks. Firstly, quantitative metrics play a crucial role, encompassing parameters such as the number of welds completed within a given time frame, the accuracy of welds, and the overall output in terms of product quality (Siddheshwar et al., 2020). These quantitative measures provide tangible data points that help gauge the welder's output and identify potential areas for improvement. Additionally, qualitative analysis involves considering subjective aspects, such as the worker's comfort level, ease of task execution, and overall job satisfaction. Understanding these qualitative dimensions is essential as it sheds light on the worker's experience during the welding process, potentially influencing long-term productivity and well-being.

Furthermore, the analysis of worker productivity may extend to the examination of external factors that could impact performance. This includes evaluating the influence of tools and equipment, workspace ergonomics, and the effects of interventions like the sit-stand exoskeleton (Cinar C et al., 2023). By integrating both quantitative and qualitative analyses, a holistic understanding of worker productivity emerges, allowing for targeted improvements and informed decision-making to enhance overall efficiency in welding processes.

In-depth analysis of a welder's productivity also entails an examination of the welder's skill proficiency and adherence to safety protocols. Assessing the worker's skill set involves evaluating their technique, precision, and ability to adapt to varying welding challenges. Additionally, ensuring compliance with safety standards is paramount to prevent workplace accidents and ensure long-term occupational health. The analysis may include observations of the worker's adherence to safety guidelines, utilization of personal protective equipment, and overall awareness of potential hazards (Nagaich et al., 2018). By considering both the technical proficiency and safety practices of workers or welders specifically, a more comprehensive evaluation of productivity is achieved, contributing to a safer and more efficient welding environment. Figure 2.10 shows productivity formula used to measure productivity quantitatively.

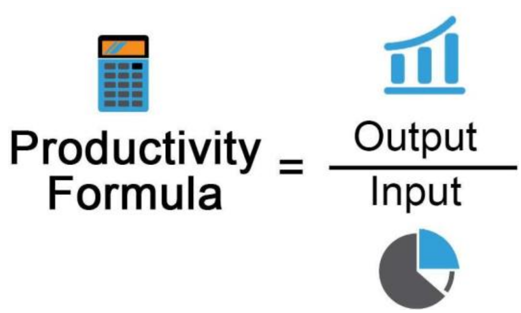


Figure 2.10 : Productivity formula (Thakur, 2023)

2.5.2 Synthesis of Literature Review on Worker’s Productivity

The evaluation of a welder's/worker’s productivity encompasses a dual approach, combining both quantitative and qualitative analyses to provide a comprehensive understanding of the factors influencing efficiency in welding tasks. Quantitatively, metrics such as the number of welds completed, accuracy levels, and overall product quality serve as tangible benchmarks for assessing output, thereby identifying areas with potential for improvement (Siddheshwar et al., 2020). In parallel, qualitative analysis delves into subjective aspects, including the worker's comfort, task execution ease, and job satisfaction, shedding light on the experiential dimensions that can significantly impact long-term productivity and well-being.

Moreover, the scrutiny of worker productivity extends beyond individual proficiency to consider external influences. This broader examination encompasses tools, equipment, workspace ergonomics, and interventions like the sit-stand exoskeleton, aiming for a holistic comprehension of factors impacting welding efficiency (Cinar C et al., 2023). The integration of quantitative and qualitative insights facilitates targeted improvements and informed decision-making, fostering an environment where overall efficiency in welding processes can be enhanced.

A thorough analysis of a worker's productivity also includes an examination of their skill proficiency and adherence to safety protocols. This entails evaluating the welder's technique, precision, and adaptability to diverse welding challenges, while concurrently ensuring strict compliance with safety standards to safeguard against workplace accidents and maintain long-term occupational health (Nagaich et al., 2018). By combining assessments of technical proficiency and safety practices, a more comprehensive evaluation can be emerged.

2.5.3 Evaluation of Literature Review on Worker's Productivity

In this evaluation, past researchers have conducted multiple studies on methods used to measure productivity, especially in the context of work productivity. Through these studies, there are both similarities and differences in the methods used by researchers, depending on work circumstances and environments as shown in Table 2.7. Each researcher has provided crucial information that is pivotal and relevant to the current study. By referencing the studies conducted by past researchers, the methods used for calculating productivity can be considered.

Table 2.7: Evaluation of the literature review of past studies related to workers productivity tools

Studies (Countries)	**Participants of study**	**Age group**	**Productivity measurement tools**	**Difference with the current study**
Siddhshwar et al., 2020 (India)	Indian nationality only	Varies	Time & method study.	*Method study being used.*
Cinar C et al., 2023 (Turkey)	Workers at pathology laboratories	Healthy adult	Motion & time study techniques	*Motion study techniques being applied.*
Nagaich et al., 2018	Workers at automobile industry	Varies	Method study	*Usage of method study.*
Current study	MIG welders	18-35	Time & body posture study	*None*

CHAPTER 3

METHODOLOGY

In the following chapter, the study's methodology will be introduced. A detailed explanation of the processes, materials, and software employed to carry out the study will be provided to achieve the objectives of the project. For objective one, identify and assess current condition of working posture and work productivity. Next, utilization of sit-stand exoskeleton. Lastly, evaluation of the impacts of the sit-stand exoskeleton on the working posture and work productivity. All methodology to achieve these objectives will be thoroughly explained.

3.1 Identify Ergonomic Risk Factors and Productivity Issues

In this methodology, the focus is on identifying ergonomic risk factors and productivity issues among metal inert gas welders. The process commences with a comprehensive literature review on ergonomics risk factors associated with welding tasks. Subsequently, a suitable case study company, Wentel Engineering Sdn. Bhd, is selected based on alignment with the project's objectives. An appointment is scheduled with the company's health and safety manager, Miss Farhana, to discuss collaboration. The observation phase takes place at Wentel Engineering, where the work environment and welding processes are observed. Following this, a review and interview session with welders are conducted, divided into two parts. The first part involves the analysis of ergonomics risk factors, utilizing insights from the interview on welders and direct observations. The second part focuses on productivity analysis, with interviews structured to gather information on the current productivity of metal inert gas welders before the introduction of any exoskeleton. This systematic approach ensures a holistic understanding of the ergonomic challenges and productivity issues faced by welders, laying the groundwork for the development and implementation of targeted solutions such as the proposed exoskeleton. Figure 3.1 illustrates the identification of ergonomics risk factors and productivity issues.

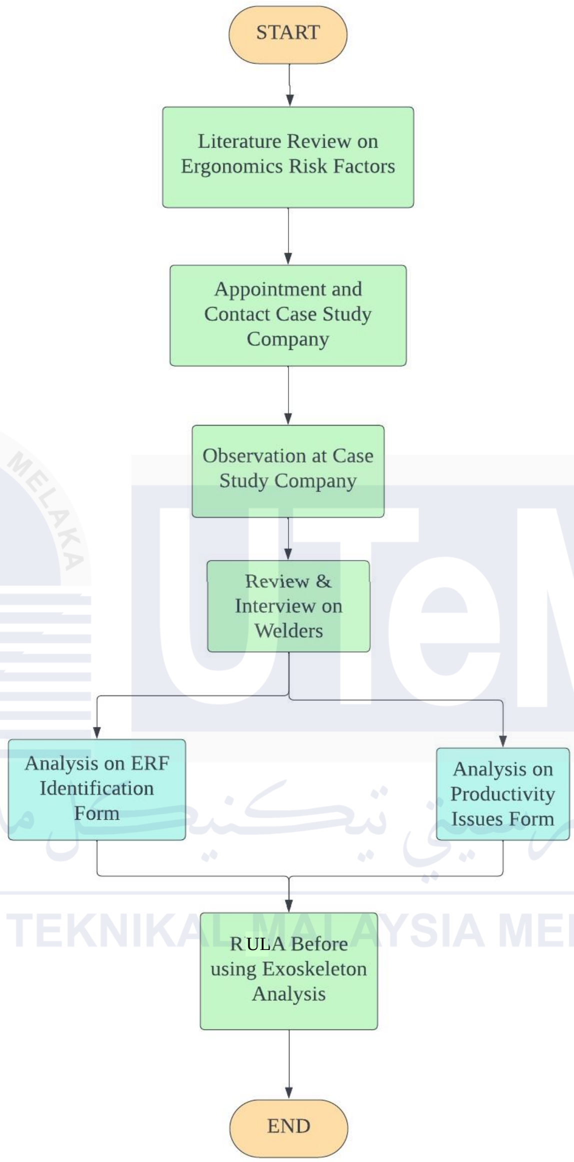


Figure 3.1 : Flowchart of identification ERF & productivity issues

3.1.1 Perform Literature Review on ERF and Appointment Arrangement

In preparation for our upcoming industrial visit, an extensive timeline was established to identify a suitable company that aligns with our educational objectives. Initial research involved evaluating various industries and companies, considering factors such as relevance to our PSM projects, technological advancements, and accessibility. Once a suitable company was identified which was Wentel Engineering Sdn Bhd, the next step involved reaching out to the Health and Safety Manager, Miss Farhana to discuss the feasibility of our visit and ensure that all necessary safety protocols are in place. Efforts were made to establish clear communication channels, either through email or phone, and relevant documentation was shared to address any concerns. This involved a collaborative effort to find a date that accommodates both the educational needs of our group and the operational constraints of the company.

3.1.2 Conduct Workplace Observation at Case Study Company

In the observation phase of the methodology shown in Figure 3.2, aimed at identifying ergonomic risk factors and productivity issues faced by welders in metal inert gas (MIG) welding at Wentel Engineering Sdn Bhd, the actual work environment and welding processes closely observed. This involves systematically observing welders during their tasks, taking note of body postures, repetitive movements, and any potential ergonomic stressors. The adequacy of workstations, equipment design, and the overall ergonomics of the welding setup being assessed. By immersing themselves in the day-to-day operations at Wentel Engineering, we were able to gain valuable insights into the specific challenges faced by welders, enabling us to formulate targeted recommendations for ergonomic improvements and productivity enhancements in the MIG welding processes. Furthermore, this comprehensive approach allowed for the identification of complicated yet significant factors that contribute to fatigue and discomfort among welders. These findings underscore the importance of continuous monitoring and iterative improvements to maintain a safe and efficient working environment.

Figure 3.2 : Industrial visit for observation phase at Wentel Engineering Sdn Bhd

3.1.2.1 Review of Productivity Issues Report and Interview

The review of productivity issues involves a comprehensive analysis of the identified challenges hindering efficiency among metal inert gas (MIG) welders. Concurrently, interviews with MIG welders provide qualitative insights into their firsthand experiences, allowing for a deeper understanding of the nuanced aspects affecting productivity. By synthesizing both quantitative and qualitative information, the report aims to form a holistic perspective, guiding the development of targeted solutions and strategies to enhance productivity and streamline processes for MIG welders in the workplace. In order to identify productivity issues faced by the metal inert gas welders, a productivity issues identification form will be provided during the interview session. Figure 3.3 shows productivity identification form.

PRODUCTIVITY ISSUES IDENTIFICATION FORM

Date: [Date]
Department/Team: [Department/Team Name]

---

1. Welder Information:

- **Name:**
- **Employee ID:**
- **Job Title:**
- **Experience Level:**

---

2. Description of Task/Activity:

Briefly describe the welding task or activity being performed:

---

3. Productivity Challenges:

What challenges or obstacles are hindering productivity in the task/activity described above?

---

4. Time-Related Issues:

Are there delays in task completion?
[ ] Yes
[ ] No

If yes, what factors contribute to these delays?

Suggestions for Improvement:

Provide any suggestions or ideas for addressing the identified productivity issues:

Action Plan:

What actions or solutions can be implemented to address the identified productivity issues?

Figure 3.3 : Productivity identification form

3.1.2.2 Review of Muscuskeletal Report and Interview

The survey and questionnaire on welders' conditions and body posture in metal inert gas (MIG) welding in Wentel Engineering Sdn. Bhd. is designed to comprehensively examine the physical well-being and ergonomic aspects of individuals engaged in MIG welding processes. This assessment, including age, gender, and specifically focuses on the impact of welding tasks on body posture. The survey delves into the types of body positions and movements involved in MIG welding, addressing potential strain or discomfort experienced by welders. By investigating ergonomic factors, the survey aims to identify areas that may contribute to musculoskeletal issues and discomfort, helping to inform strategies for improving working conditions and implementing preventive measures to enhance the overall health and safety of MIG welders. Figure 3.4 shows ergonomics risk factors identification form for the welders.

ERGONOMICS RISK FACTORS IDENTIFICATION FORM

Worker's Name : Meng

Company : Wentel Engineering Sdn. Bhd.

Date : 22/11/2023

Task Performed	Task Description:
	1. Workstation: 2 2. No. of worker: 1 3. Task performed: Welding process using MIG 4. Techniques of handling: Standing 5. Steps to perform task: 3 6. Load weight: 3-5 kg
Body Segments Affected □ **Neck** □ **Shoulder** □ Elbows □ **Upper back** □ **Lower back** □ Wrists/hands □ **Hips/thigh** □ Knees □ Ankle/feet	Remarks: The task performed by the MIG welders indicate current working posture without using sit-stand exoskeleton.

Exposure	Remarks: 1. Frequency: 2. Exposure time: 15-30 minutes
Occupational Risk Factors □ Excessive force □ High frequency □ **Awkward posture** □ **Static position** □ High repetition □ Hard surfaces	Remarks: Risk factors suffered by the welder above :- i) Awkward posture ii) Static position iii) High repetition

Figure 3.4 : ERF Identification form

3.1.3 RULA Working Posture Assessment Before Using Sit-stand Exoskeleton

The RULA analysis for metal inert gas (MIG) welders in Wentel Engineering Sdn Bhd involves evaluating ergonomic factors to identify potential risks and discomfort in their working environment. Specifically designed for MIG welding, RULA assesses postures, movements, and tasks to pinpoint areas of concern related to musculoskeletal strain. It considers factors such as body position, force exertion, movement repetition, and task duration. Through this systematic assessment, RULA offers a quantitative and qualitative framework to gauge the ergonomic efficiency of MIG welders' body postures, aiming to highlight areas for improvement in workstations, equipment design, or work processes. The ultimate goal is to enhance welders' productivity and reduce the risk of occupational injuries or discomfort. In addition to the RULA analysis, Wentel Engineering Sdn Bhd can create a workplace that not only enhances productivity but also fosters the well-being and long-term health of its MIG welders. Figure 3.5 illustrates RULA worksheet to identify welder’s working posture.

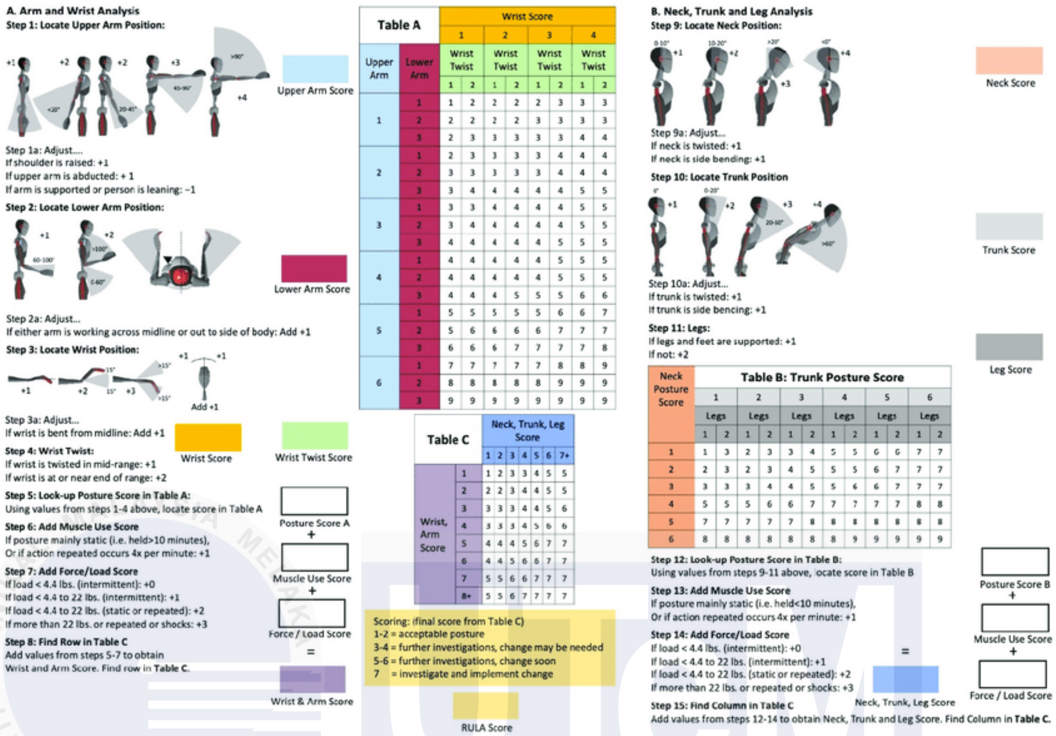


Figure 3.5 : RULA worksheet (Hignett, S. et al., 2000)

3.2 Utilize Sit-stand Exoskeleton to Minimize Ergonomics Risk Factors andProductivity Issues

This methodology involves designing and fabricating a sit-stand exoskeleton to mitigate ergonomics risk factors and enhance productivity. In the design phase, careful consideration is given to ergonomic requirements, and materials are chosen for durability and comfort. The fabrication process ensures precision and reliability. During the ongoing design and fabrication process, only one out of the three exoskeletons is being developed, while the other two are currently being utilized from existing exoskeleton designs. The assessment phase is divided into two parts: the first employs the RULA methodology to evaluate the exoskeleton's impact on ergonomics risk factors, focusing on postures and movements. The second part utilizes time study techniques to measure productivity, specifically targeting metal inert gas welders. By comparing task completion times with and without the exoskeleton, the study aims to quantify its impact on efficiency. This structured approach provides a comprehensive understanding of the sit-stand exoskeleton's effectiveness in minimizing ergonomic risks and improving productivity in the workplace, offering valuable insights for further refinement and application. Figure 3.6 illustrates the utilization of sit- stand exoskeleton on metal inert gas welders in Wentel Engineering Sdn Bhd.

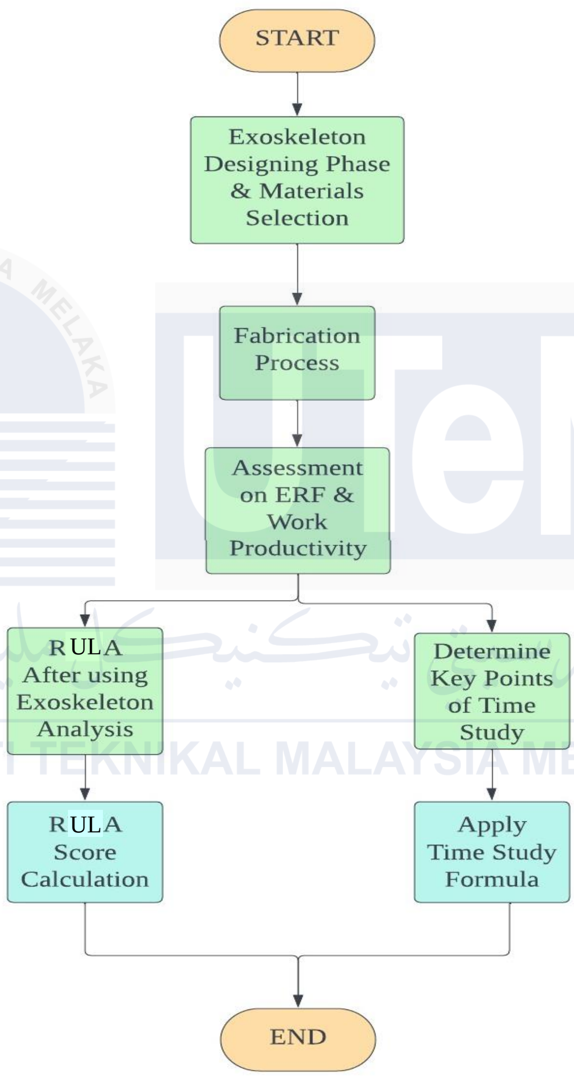


Figure 3.6 : Flowchart of utilization of sit-stand exoskeleton

3.2.1 Exoskeleton Designing Phase and Materials Selection

1. Concept sketches and decision matrices:

The design development section will include preliminary concept sketches exploring different potential exoskeleton configurations to meet the key user needs and workflow objectives outlined earlier. These initial drawings will visualize ideas for the mechanical structure, joint layout, size/adjustability, and ergonomic factors. A HOQ as shown in Figure 3.7, will then be used to evaluate each conceptual sketch as shown in Figure 3.8, against the project requirements and user specifications to select a leading concept to proceed with prototyping. This stage focuses divergent thinking to generate creative design alternatives and then introduces convergent decision-making to identify the concept design with the highest potential to satisfy all aspects of the design problem.

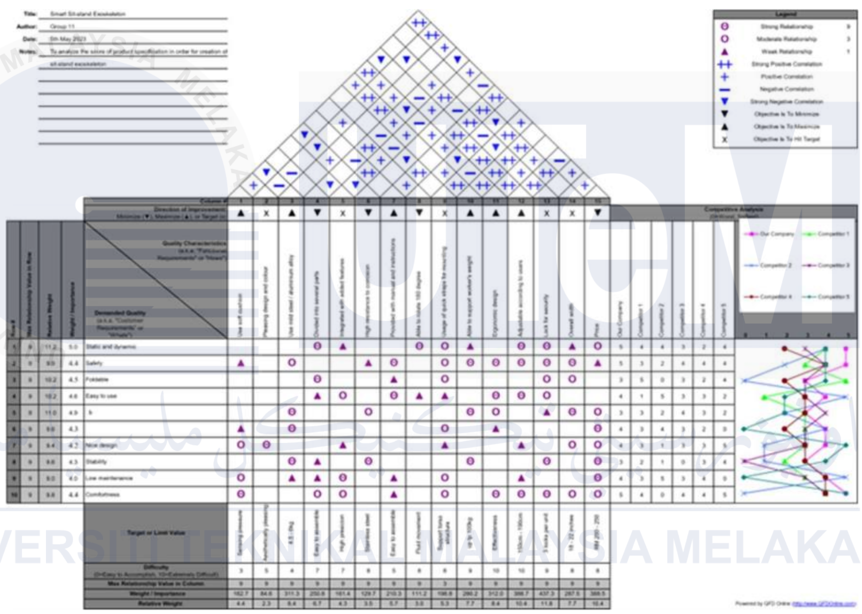
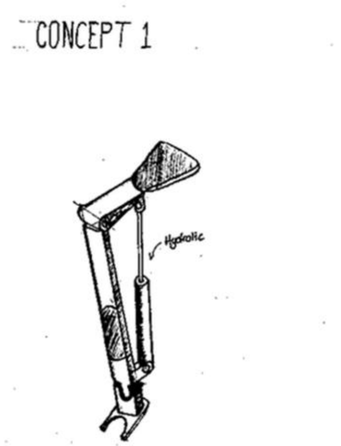


Figure 3.7 : House of quality

Concept	Description
	• Hydraulics system • Stainless steel • Memory foam cushion for comfort • Automatic adjustment

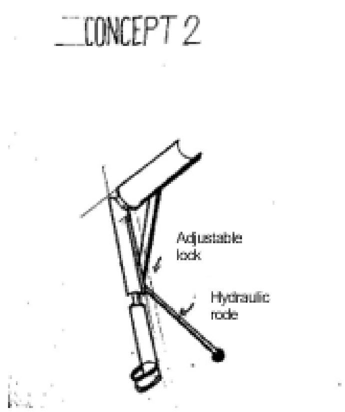
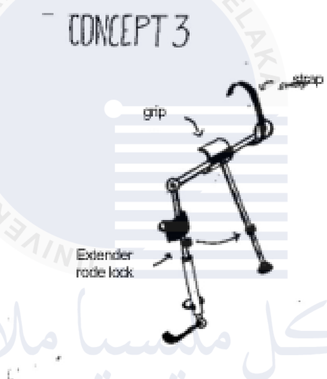
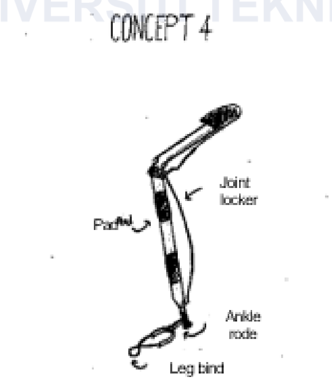
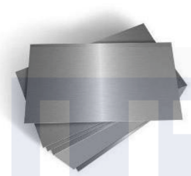
	• Alluminium base • Low cost material • Manual adjustment • Curve structure for comfort • Lightweight • Portable
	• stainless steel • durable • adjustable support • thigh grip so it will be perfectly fit • extender rode
	• Full stainless steel base • Foam pad for comfort • Arc sttructure to hold weight more than 100kg • Expensive • Durable and heavy

Figure 3.8 : Concept sketches

2. Materials selections:

Materials selected were from recycled items but carefully picked according to our prioritiesas shown in Table 3.1. One of the materials is telescopic rode and PVC. Such a durable material is cheap and light since the rode uses aluminum with hollow inside while the joint we use is hinge joint, durable as joint that support average human weight with hydraulicsupport that will extend and compress automatically.

Table 3.1 : Materials used for prototype

		
1.Telescopic rod	2.Aluminium sheets	3.PVC

3. Design parameters:

The specification created from benchmarking product and data set on human weight andheight of Malaysian adults. Data used as design parameters shown in Figure 3.9.

Crude and Age-adjusted Mean Height, Body Weight and BMI

		Height, cm		Weight, Kg		BMI, Kg/m²	
		Crude (SE)	Age-adjusted (SE)	Crude (SE)	Age-adjusted (SE)	Crude (SE)	Age-adjusted (SE)
All		159.6 (0.1)	159.6 (<0.1)	58.3 (0.1)	58.3 (<0.1)	22.9 (<0.1)	22.9 (<0.1)
	men	165.0 (0.3)	165.0 (0.1)	61.9 (0.4)	61.8 (0.1)	22.7 (<0.1)	22.7 (<0.1)
	women	154.0 (0.3)	154.0 (0.1)	54.6 (0.3)	54.7 (0.1)	23.1 (0.3)	23.1 (<0.1)
Malay		158.9 (0.3)	158.9 (0.1)	58.2 (0.4)	58.2 (0.1)	23.1 (0.3)	23.1 (<0.1)
	men	164.7 (0.3)	164.7 (0.1)	61.7 (0.4)	61.6 (0.2)	22.7 (0.3)	22.7 (0.1)
	women	153.3 (0.3)	153.3 (0.1)	55.0 (0.4)	55.0 (0.2)	23.4 (0.3)	23.4 (0.1)
Chinese		161.4 (0.3)	161.7 (0.1)	59.9 (0.4)	59.8 (0.2)	22.9 (0.3)	22.8 (0.1)
	men	166.7 (0.4)	166.9 (0.1)	64.6 (0.4)	64.6 (0.2)	23.2 (0.3)	23.2 (0.1)
	women	156.2 (0.3)	156.5 (0.1)	55.2 (0.4)	55.0 (0.2)	22.7 (0.3)	22.5 (0.1)
Indian		161.1 (0.5)	161.1 (0.2)	60.9 (0.5)	60.7 (0.3)	23.4 (0.3)	23.4 (0.1)
	men	167.6 (0.5)	167.6 (0.3)	65.1 (0.6)	64.9 (0.4)	23.2 (0.3)	23.1 (0.1)
	women	154.7 (0.5)	154.7 (0.2)	56.7 (0.6)	56.5 (0.4)	23.7 (0.4)	23.6 (0.2)
Other indigenous		156.4 (0.4)	156.3 (0.1)	54.9 (0.5)	54.9 (0.2)	22.4 (0.3)	22.4 (0.1)
	men	161.8 (0.4)	161.6 (0.2)	58.3 (0.5)	58.3 (0.2)	22.2 (0.3)	22.3 (0.1)
	Women	150.9 (0.4)	150.8 (0.1)	51.4 (0.5)	51.5 (0.2)	22.6 (0.3)	22.6 (0.1)

**Age-adjusted to the 1996 Malaysian population*

Figure 3.9 : Distribution of body weight, height and body mass index in a national sample of Malaysian adults (TO Lim et at., 2000)

4. Design specification of final prototype:

The design specification of sit-stand exoskeleton final prototype as shown in Figure 3.10, outlines the detailed requirements, features, and characteristics that the completed model must possess to meet the predetermined objectives and standards.

Figure 3.10 : Exoskeleton drawing by using SLD

3.2.2 Exoskeleton Fabrication Process

1. Load Analysis:

The load analysis for the sit-stand exoskeleton involves assessing static and dynamic loads, considering variations in user weight, and evaluating potential impact loads to ensure structural integrity and user safety.

2. Failure Modes and Analysis:

Conducting a Failure Modes and Effects Analysis (FMEA) as shown in Table 3.2, for the sit- stand exoskeleton involves systematically identifying potential failure modes, assessing their consequences on user safety and system functionality, and implementing mitigation measures to enhance reliability and performance. RPN stands for risk priority number.

Table 3.2 : FMEA of Exoskeleton during fabrication process

Failure Mode	Potential Causes	Effects	Severity	Occurrence	Detectability	RPN	Recommended Actions
Component/System: Sit-stand exoskeleton frame							
Frame becomes loose or unstable	Wear and tear, improper assembly, insufficient tightening	Decreased user safety, potential for injury, decreased lifespan of the exoskeleton	High	Medium	Medium	180	Regular inspections,user training on proper assembly and tightening, use of durable materials
Component/System: Sit-stand exoskeleton joints							
Joints become stiff or fail to move smoothly	Wear and tear, lack of lubrication, exposure to dust or debris	Decreased user comfort, potential for injury, decreased lifespan of the exoskeleton	Medium	Medium	High	90	Regular cleaning and lubrication, usertraining on proper usage, use of durable materials
Component/System: Sit-stand exoskeleton actuators							
Actuators fail to provide adequate support or fail altogether	Power supply issues, mechanical failure, wear and tear	Decreased user safety, potential for injury, decreased lifespan of the exoskeleton	High	Low	High	120	Regular inspections,use of reliable power sources, use of durable materials
Component/System: Sit-stand exoskeleton user interface							
User Interface becomes unrenspon sive	Software bugs, hardware failure	Decreased user comfort, potential injury, decreased efficiency	Mediu m	Low	High	60	Regular software updates, user training on proper usage

3.2.2.1 Measuring & Marking

The measuring and marking process is employed to establish precise dimensions on a workpiece. Within the realm of producing individual components, this method involves preliminary steps essential for subsequent machining tasks, encompassing cutting, forming, and assembly. Accurate measurement and careful marking, aligned with the dimensions outlined in the drawings, are imperative to ensure the final product meets the desired specifications. Figure 3.11 provides a visual representation of the measuring and marking process.

Figure 3.11 : Measuring and marking process

3.2.2.2 Drilling

Drilling procedure is employed for creating a circular hole in solid materials. In the case of square hollow mild steel, holes were drilled using a hand drill equipped with screw-in drill bits. It's worth noting that the distinct type of drill bits used was cobalt drill bits with measurement from 4.8 mm to 6.0 mm. Figure 3.12 provides a visual representation of the specific drill bit utilized in the process.

Figure 3.12 : Cobalt drill bits (R.D.Barrett, 2019)

A standard approach involves initiating the hole-drilling process with a smaller pilot drill before transitioning to a larger drill for the completion of the task. Employing the appropriate pilot drill is crucial as it safeguards against the larger drill slipping on the material being drilled. Oil is utilized in drilling machines to lubricate moving parts, dissipate heat generated during drilling ensuring smooth operation and prolonging the machine's lifespan. Figure 3.13 provides an illustration of the drilling machine process.

Figure 3.13 : Drilling process using drilling machine

3.2.2.3 Cutting

The cutting process is the process of cutting materials using cutting tools with reference tothe intended measurements or markings that have been made on the work material, as shownin Figure 3.14. Hand saw, also known as jack saws, are circular saw that are used to cut the materials that are being used. Other than both tools mentioned above, jig saw and metal cut off machine shown in Figure 3.15 also being used in order to make cutting process faster.

Figure 3.14 : Cutting process using hand saw and jig saw

Figure 3.15 : Metal cut off machine

3.2.2.4 3D Printing

In the 3D printing process, a common practice is to commence the layering procedure with a smaller initial nozzle size before progressing to a larger one to finalize the printing task. The selection of the correct initial nozzle is paramount as it prevents the larger nozzle from inaccurately depositing material, ensuring precise layering. This precautionary step not only enhances the quality of the 3D print but is also crucial for avoiding potential defects and project setbacks. Figure 3.xx visually shows example of specific steps involved in the 3D printing process. Figure 3.16 shows the example of specific steps involved in 3D printing process.

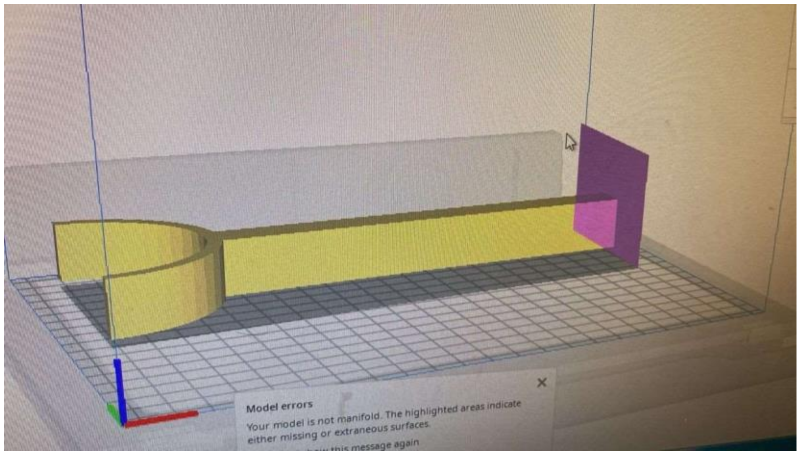


Figure 3.16 : Example of specific steps in 3D printing process

3.2.3 Assessment on Ergonomics Risk Factors and Work Productivity

In the assessment of Metal Inert Gas (MIG) welding, ergonomics risk factors and work productivity were measured separately in a systematic flowchart. To evaluate ergonomic risk factors, the flowchart likely involved steps such as assessing body postures after the usage of sit-stand exoskeleton, and utilizing ergonomic analysis tools, such as REBA. Concurrently,the measurement of work productivity might have involved time studies. Determining key points of time study can be considered as initial step and will be followed with applying time study formula in order to get clear indication of productivity. By separating these assessments in the flowchart, a comprehensive understanding of both the ergonomic challenges faced by welders and the factors influencing work productivity in MIG welding could be obtained, aiding in the development of targeted interventions for improvement.

3.2.4 RULA After using Exoskeleton Analysis

The Reba score after the usage of an exoskeleton in metal inert gas welding provides a quantitative measure of the body postures and movements, allowing for a systematic assessment of how well the exoskeleton contributes to reducing ergonomic risks and enhancing the overall well-being and productivity of the welder.

3.2.4.1 RULA Score Calculation

Using the RULA worksheet, the evaluator will measure the shoulders, neck, trunk, back, legs and knees. After the data for each region is collected and scored, tables on the form are then used to compile the risk factor variables, generating a single score that represents the level of MSD risk:

Figure 3.17 : RULA worksheet score (Hignett, S. et al., 2000).

The RULA worksheet scores as shown in Figure 3.17 categorizes ergonomic risk levels associated with work tasks. A score of 2-3 implies low risk, suggesting minimal changes are needed. A score of 4-7 indicates a moderate risk, recommending some ergonomic adjustments. High risk falls within the 8-10 range, requiring immediate changes, while a score of 7-8 suggests a very high risk necessitating urgent action. A score of 11 and above indicates an extremely high risk, demanding substantial and immediate ergonomic improvements. Each score corresponds to specific actions aimed at reducing the risk of musculoskeletal disorders by addressing factors like awkward postures and task duration.

3.2.5 Determine Key Points of Time Study

Determining key points of a time study as shown in Figure 3.18, is essential as it allows for the identification and analysis of critical moments or processes within a workflow. By pinpointing these key points, organizations can focus on optimizing specific aspects of their operations, leading to increased efficiency and productivity.

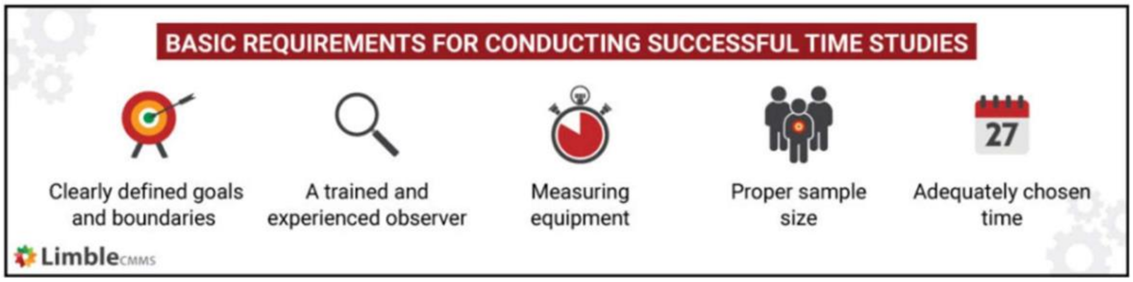


Figure 3.18 : Basic Key Points of Time Study (Christiansen B, 2023)

1) Select Eligible Welders

In a time study to measure productivity in Metal Inert Gas (MIG) welding, it's crucial to carefully select welders for observation. Eligible welders should be experienced and regularly perform MIG welding tasks. Diversity in skill levels is considered to capture variations. These chosen welders will be closely monitored during the study, with their welding activities and time spent on each task recorded. This thoughtful selection ensures that the data collected accurately reflects the overall productivity and performance of MIG welders in the specific context under investigation.

2) Calculate Sample Size

Deciding how many welders to include in a time study for measuring productivity in Metal Inert Gas (MIG) welding involves finding a balance. Enough number of welders needed to get meaningful results but also consider the available resources. Factors like confidence level, acceptable margin of error, and expected variability in productivity help determine the sample size. A larger sample gives stronger results but may need more time and resources. On the other hand, a smaller sample may be more practical but could have more variability. The key is to choose a sample size that provides reliable insights into MIG welders' productivity while considering the study's objectives and available resources. For this time study of welders’ productivity, 12 sample sizes were gained by applying sample size formula shown in Figure 3.19. Unfortunately, case study company only able to provide 6 sample sizes due to prevent production disruption. So, sample size of 6 are justified (n = 6).

Unlimited population:

$$CI = \hat{p} \pm z \times \sqrt{\frac{p(1-p)}{n}}$$

Finite population:

$$CI' = \hat{p} \pm z \times \sqrt{\frac{\hat{p}(1-\hat{p})}{n'} \times \frac{N-n'}{N-1}}$$

where
- **z** is z score
- **p̂** is the population proportion
- **n** and **n'** are sample size
- **N** is the population size

Figure 3.19 : Sample size formula

3) Duration of Time Study

The duration of a time study to measure welders' productivity in Metal Inert Gas (MIG) welding depends on the specific objectives, the complexity of the welding tasks, and the desired level of accuracy. Typically, a time study involves observing and recording the time taken by welders to complete specific welding activities over a set period. The duration should be long enough to capture variations in productivity, considering factors like different weld types, material thicknesses, and welding positions. However, it should also be practical and feasible within the operational constraints of the welding environment. A balance needs to be struck to ensure the study's findings are representative while not disrupting the normal workflow. The duration should be determined based on the study's goals, the variability in welding tasks, and the need for reliable insights into overall productivity. Table 3.3 shows duration of time study of welders to complete a single welding task.

Table 3.3 : Duration of time study

Welder's name	Without exoskeleton (minutes)	Exoskeleton 1 (minutes)	Exoskeleton 2 (minutes)	Exoskeleton 3 (minutes)
1.				
2.				
3.				
4.				
5.				
6.				

3.2.5.1 Apply Time Study Formula

1) Productivity formula

Productivity is commonly measured as the ratio of output to input. The specific formula used may vary depending on the context and the nature of the work being measured. Productivity formulas are used to quantify and evaluate the efficiency of metal inert gaswelding welders. General formula of productivity shown below

.

$$\text{Productivity} = \frac{\text{Units of Output}}{\text{Units of Input}}$$

General formula of productivity

2) Efficiency formula

Efficiency formula as shown below, is employed to assess the ratio of output to input, providing a quantitative measure of how effectively resources are utilized in a process or system. In this case, calculating efficiency allows us to identify areas for improvement, optimize workflows, and enhance overall productivity of metal inert gas welders. By using efficiency formula will also allow pinpoint specific factors affecting productivity and make informed decisions to streamline processes. This systematic approach enables continuous improvement efforts, fostering a work environment that maximizes the effectiveness of resources and ensures sustained high-performance levels among metal inert gas welders.

$$\text{Efficiency } (\%) = \left(\frac{\text{Standard time}}{\text{Actual time}} \right) \text{X } 100$$

Efficiency formula

3) Takt time formula

The takt time formula is utilized to determine the ideal time available for completing a production process to meet customer demand, helping organizations establish a balanced production rate. In this context, calculating takt time allowed welders to align their production pace with customer requirements, prevent overproduction, and maintain a synchronized workflow to meet market demand efficiently.

$$\text{Takt Time} = \frac{\text{Total Available Production Time}}{\text{Customer Demand}}$$

Takt time formula (Fogg, 2022)

.

3.3 Evaluate the effectiveness of sit-stand exoskeleton on ergonomics and productivity

This final methodology focuses on evaluating the effectiveness of the sit-stand exoskeleton on both ergonomics and productivity. To gather user feedback on the usability of the exoskeleton, a combination of questionnaires and interview sessions is conducted, involving the metal inert gas welders who are potential end-users. Subsequently, the results obtained are subjected to a thorough comparison and analysis, categorized into two distinct parts. The first part involves an assessment of ergonomics risk factors and working postures, utilizing 3D modeling techniques by using a software known as CATIA to analyze the impact of the exoskeleton on the welders' body positions. The second part concentrates on productivity assessment, employing assembly time measurements to quantify the final productivity of the metal inert gas welders both before and after the implementation of the exoskeleton. This dual-pronged approach ensures a comprehensive evaluation of the impact of sit-stand exoskeleton. Figure 3.20 illustrates the overall evaluation process and methodology on effectiveness of sit-stand exoskeleton.

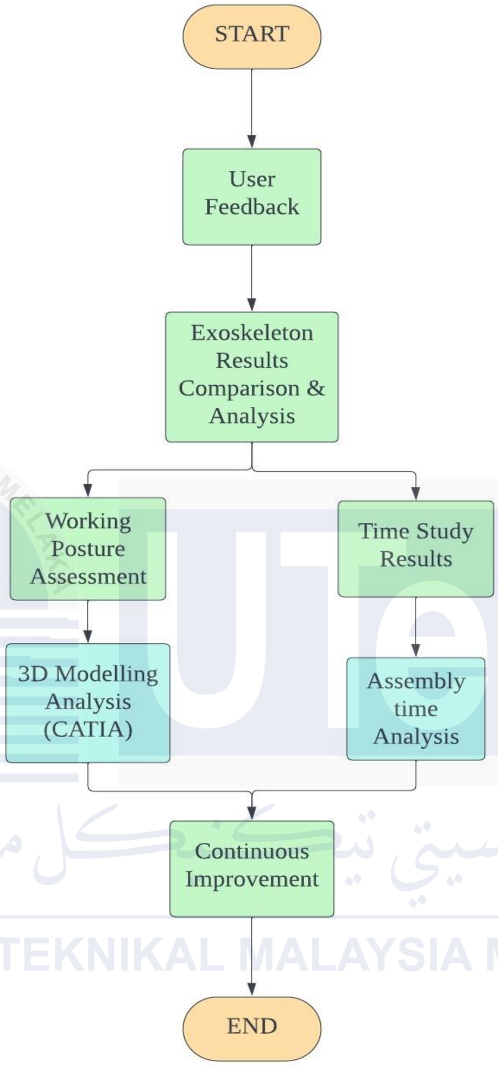


Figure 3.20 : Flowchart of evaluation the effectiveness of sit-stand exoskeleton

3.3.1 User feedback of the exoskeletons

User feedback through questionnaires and interviews after using the exoskeleton provides valuable insights into the practical usability, comfort, and overall satisfaction of individuals, contributing to a comprehensive assessment of the exoskeleton's effectiveness in real-world applications.

3.3.1.1 Interview

Conducting interviews to analyze the user usability of a sit-stand exoskeleton in Metal Inert Gas (MIG) welding involves engaging with welders to gather insights into their experiences and perspectives. These interviews aim to understand the comfort, practicality, and effectiveness of the exoskeleton during welding tasks. Key areas of exploration include the ease of wearing the exoskeleton, its impact on mobility, and whether it addresses ergonomic concerns. Figure 3.21 shows an interview session conducted on one of MIG welders, Ahmad, 27-year-old with 6 years welding experiences.

Figure 3.21 : Interview session conducted on welders

Additionally, the interviews seek welders' feedback on the exoskeleton's adaptability to different welding postures, its overall usability, and any potential challenges or improvements needed. Assessing how the exoskeleton integrates into the workflow, its impact on fatigue reduction, and the welders' satisfaction with its features contributes valuable qualitative data. This information provides a comprehensive understanding of the real-world usability of the sit-stand exoskeleton, offering insights into its potential benefits and areas for refinement in enhancing the ergonomic aspects of MIG welding processes.

3.3.1.2 Modified Usability Questionnaire

Metal inert gas (MIG) welding usability questionnaire assesses user satisfaction and experience, covering aspects such as comfort, ease of movement, welding task efficiency, adaptability, range of motion, overall satisfaction, challenges faced and recommendations for improvement. Table 3.4 illustrates the examples of questions and scores that could be included in a questionnaire. Score 1 indicates strongly disagree, 5 indicates strongly agree while 3 is neutral.

Table 3.4 : Welder usability assessment on sit-stand exoskeleton

Aspect of Usability	Users Feedback Questions	1	2	3	4	5
Comfort	1. How comfortable is the exoskeleton during prolonged use?					
Ease of Movement	2. To what extent does the exoskeleton hinder natural body movements?					
Task Efficiency	3. Did you notice any improvement or hindrance in task completion time while wearing the exoskeleton?					
Adaptability	4. How well does the exoskeleton adapt to different welding techniques?					
Range of Motion	5. How would you rate the exoskeleton's impact on your overall range of motion during welding tasks?					

Overall Satisfaction	6. On a scale from 1 to 10, how satisfied are you with the usability of the sit-stand exoskeleton?					
Challenges Faced	7. Were there any specific challenges or discomfort experienced while using the exoskeleton?					
Recommendations	8. What improvements, if any, would you suggest to enhance the usability of the exoskeleton?					

The usability of a sit-stand exoskeleton for welders post-wearing involves assessing its effectiveness, comfort, and overall user experience. Objective data and subjective feedback are both crucial in this evaluation. Objective measures include analyzing the ease of movement and range of motion afforded by the exoskeleton during welding tasks. Time- motion studies can capture the efficiency of task completion, and ergonomic assessments can evaluate the exoskeleton's impact on reducing physical strain.

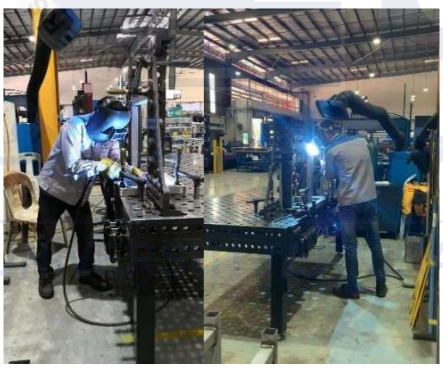
3.3.2 Exoskeleton Results Comparison and Analysis

For the exoskeleton results comparison and analysis, the process will be divided into two key components. The first part involves a comprehensive assessment of work posture before and after the utilization of the exoskeleton. The second part centers on time study results, comparing productivity metrics before and after exoskeleton utilization.

3.3.2.1 Work Posture Assessment – Before Exoskeleton Utilization vs After Exoskeleton Utilization

Table 3.5 illustrates the working posture of the welders. In this assessment, a comparison of the welders' working posture before and after the utilization of the exoskeleton will be analyzed. Photos of the welders' body posture and 3D model drawings using CATIA during after exoskeleton utilization phase will be presented during PSM 2.

Table 3.5 : Welders' posture assessment

WORK POSTURE ASSESSMENT	
Before Exoskeleton Utilization	After Exoskeleton Utilization
Real life working posture : 	**Exoskeleton 1 :** *[Insert photo]* **Exoskeleton 2 :** *[Insert photo]* **Exoskeleton 3 :** *[Insert photo]*
3D model drawing using CATIA : 	**Exoskeleton 1 :** *[Insert drawing]* **Exoskeleton 2 :** *[Insert drawing]* **Exoskeleton 3 :** *[Insert drawing]*

3.3.2.2 Time Study Results – Before Exoskeleton Utilization vs After Exoskeleton Utilization

Table 3.6 illustrates time study assessment. In this assessment, a comparison of the assembly and productivity time before and after the utilization of the exoskeleton will be analyzed. Calculation and results of the welders' assembly time and productivity time will be presented during PSM 2

Table 3.6 : Time study assessment

TIME STUDY RESULTS	
Before Exoskeleton Utilization	After Exoskeleton Utilization
Assembly time	**Assembly time :** **Exoskeleton 1 :** *[Insert calculation]* **Exoskeleton 2 ;** *[Insert calculation]* **Exoskeleton 3 :** *[Insert calculation]*
Welder's Productivity :	**Welder's Productivity :** **Exoskeleton 1 :** *[Insert calculation]* **Exoskeleton 2 :** *[Insert calculation]* **Exoskeleton 3 :** *[Insert calculation]*

3.3.3 Continuous Improvement

Continuous improvement of sit-stand exoskeletons for MIG welders involves gathering and incorporating feedback from welders. By actively seeking input on comfort and performance, designers refine the exoskeleton to better suit the needs of welders for future project. This user-centric approach informs future projects, focusing on addressing specific preferences and optimizing features for MIG welding tasks. The ongoing process ensures that the exoskeleton remains a reliable and supportive tool, contributing to the well-being and productivity of MIG welders.

3.4 Summary

Throughout this chapter, the methodology has been discussed, along with the technique and steps to achieve the objectives. This study investigates the impact of integrating a sit-stand exoskeleton on work productivity in metal inert gas welding. The methodology design adopts an experimental approach with control and experimental groups, targeting professional welders. Variables, including the use of the exoskeleton and productivity metrics, are clearly defined. The study incorporates diverse data collectionmethods, such as time studies and participant feedback through surveys. The conceptualization grounds the study in theories of ergonomic interventions and human- machine interaction, suggesting that the exoskeleton may enhance working conditions and improve productivity. The study aims to contribute practical insights into the application of sit-stand exoskeletons in metal inert gas welding task, with potential benefits for both workers and industries. Table 3.7 illustrates the correlation between methodology and objectives of the study.

Table 3.7 : Correlation between methodology and objective of the study

Objectives	Methodology
➢ To identify ergonomics risk factors and productivity issues by the welders in MIG welding at Wentel Engineering Sdn Bhd	• Appointment with Wentel • Observation • Survey • RULA
➢ To utilize sit-stand exoskeleton to minimize ergonomics risk factors and productivity issues of welders in MIG welding at Wentel Engineering Sdn Bhd.	• Fabrication of Prototype • Determine key points of Time Study • RULA • Analysis on Work Productivity & Time Study
➢ To evaluate the effectiveness of Sit-stand exoskeleton on ergonomics and productivity of MIG welding	• Usability and Functional • Productivity Comparison & Analysis • Body Posture Analysis (CATIA)

CHAPTER 4

RESULTS AND DISCUSSION

This chapter provides and summarizes data analysis from various sources, including surveys, observations, RULA scoring for current posture, analysis on work productivity and time study and body posture analysis by using CATIA. This study presents the key findings based on data collected during our industrial visit to Wentel Engineering Sdn. Bhd. The primary goal of this chapter is to address the second and third objectives, focusing on utilizing and evaluating the effectiveness of sit-stand exoskeleton to minimize ergonomics risk factors and productivity issues. Ultimately, this chapter aims to provide a clear understanding of how sit-stand exoskeletons able to affect welders' body posture to enhance both the welders' comfort and the efficiency of the production process.

4.1 Ergonomics Risk Factors and Productivity Issues Faced by the Welders in MIG Welding at Wentel Engineering Sdn Bhd

The main objective of this part is to identify ergonomics risk factors and productivity issues faced by the welders in metal inert gas welding at Wentel Engineering Sdn. Bhd. To accomplish this objective, workplace observation will be conducted at case study company in order to visualize the real working condition of the welders in metal inert gas welding department. Ergonomics risk factors and productivity issues identification forms will be provided to the welders to identify challenges while completing the task. These articles, authored by prior scholars, serve as the foundation of the research. The review phase verifies the accuracy and relevance of the current knowledge concerning the project.

4.1.1 Ergonomics Risk Factors

Table 4.1 identifies ergonomic risk factors for MIG welders, detailing affected body segments, exposure times, and specific risks like awkward postures and high repetition. It also notes whether each welder uses a sit-stand exoskeleton, highlighting the need for ergonomic interventions.

Table 4.1: Ergonomics risk factors present at MIG welding workstation

Operator	Task Performed	Body Segments Affected	Exposure	Ergonomics Risk Factors	Remarks
Welder 1	MIG Welding	Neck, Shoulder, Upper back, Lower back,	Exposure time: 15-30 mins	Awkward posture, Static position, High repetition 	Current working posture without using sit-stand exoskeleton.
Welder 2	MIG Welding	Neck, Shoulders, Lower back, Knees	Exposure time: 20-40 mins	Awkward posture, High repetition, High frequency 	Current working posture without using sit-stand exoskeleton.
Welder 3	MIG Welding	Shoulders, Lower back	Exposure time: 10-20 mins	Excessive force, High repetition, Awkward posture 	Current working posture without using sit-stand exoskeleton.
Welder 4	MIG Welding	Upper back, Lower back, Shoulders	Exposure time: 30-45 mins	Static position, High repetition, Hard surfaces	Current working posture without using sit-stand exoskeleton.

					
Welder 5	MIG Welding	Neck, Shoulders, Lower back	Exposure time: 25-35 mins	Awkward posture, Excessive force 	Current working posture without using sit-stand exoskeleton.
Welder 6	MIG Welding	Neck, Lower back, Upper back, Lower back	Exposure time: 15-30 mins	High repetition, Static position, Awkward posture 	Current working posture without using sit-stand exoskeleton.

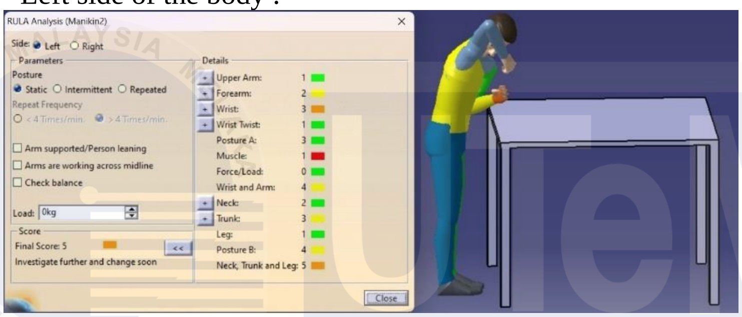
The data in Table 4.1 summarizes the ergonomic risk factors and exposure times for 6 welders performing MIG welding tasks, highlighting affected body segments and current working postures. The welders experienced issues primarily in the neck, shoulders, upper and lower back, and occasionally knees, due to awkward postures, static positions, high repetition, high frequency, and excessive force. Exposure times vary from 10 to 45 minutes across the welders. Notably, the welders were working without using sit-stand exoskeletons, which might alleviate some of the ergonomic risks associated with their tasks.

4.1.2 Postural Analysis of MIG Welders

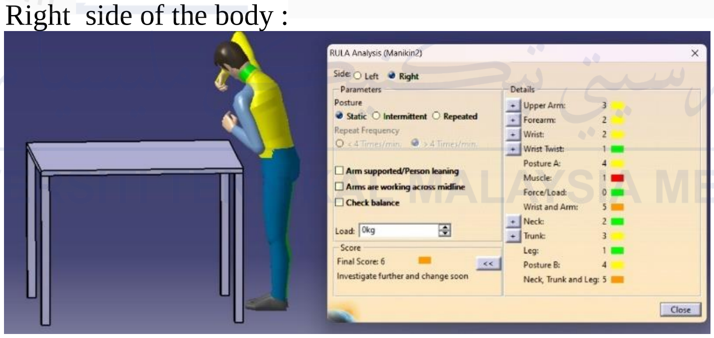
Table 4.2 presents a postural assessment of MIG welders in existing working condition using the RULA tool. It details body postures, back posture degrees, and RULA scores for each welder to identify ergonomic risks and suggest areas for improvement.

Table 4.2: Postural assessment using RULA of MIG welders at existing workstation

<table>
<tr><th>Welder</th><th>Postural Assessment using RULA</th><th>Back posture (degrees)</th><th>RULA Score</th></tr>
<tr><td>1</td><td>
Left side of the body :



Right side of the body :



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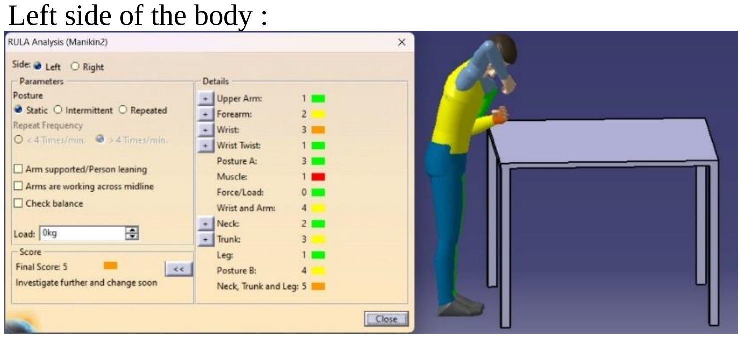
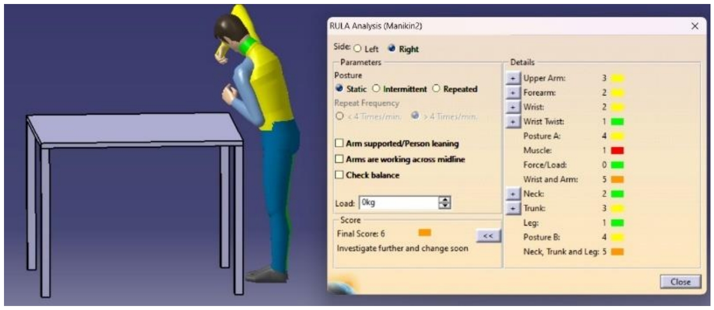
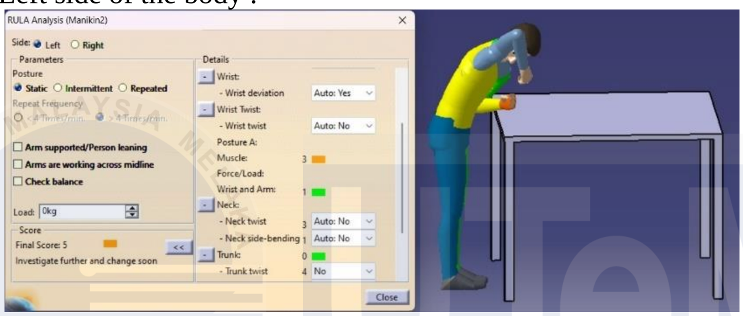
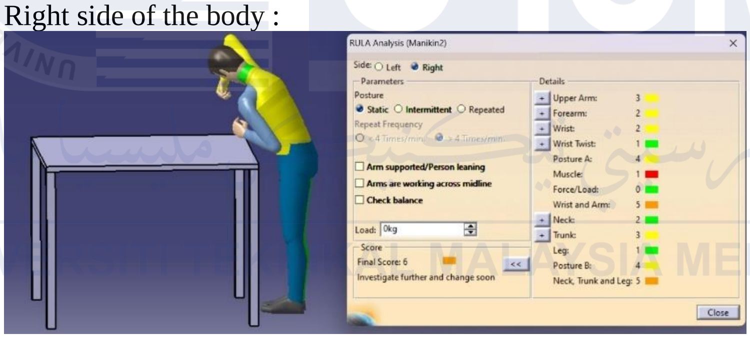
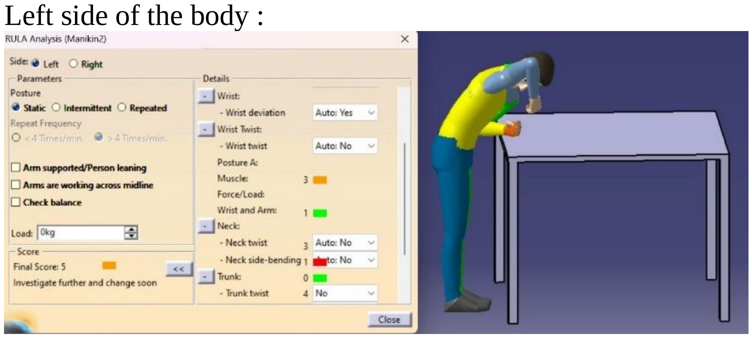
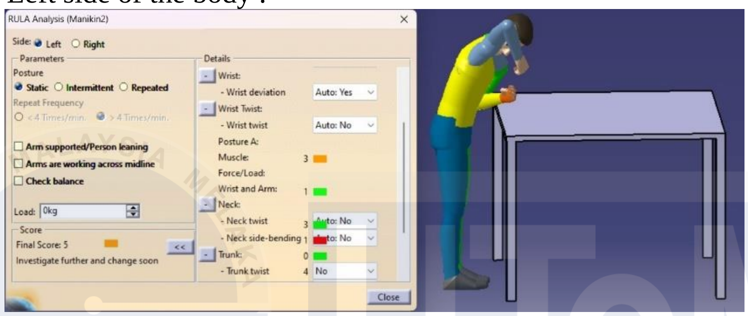
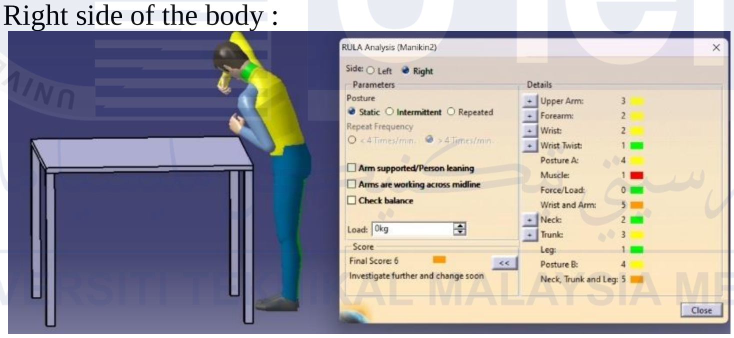
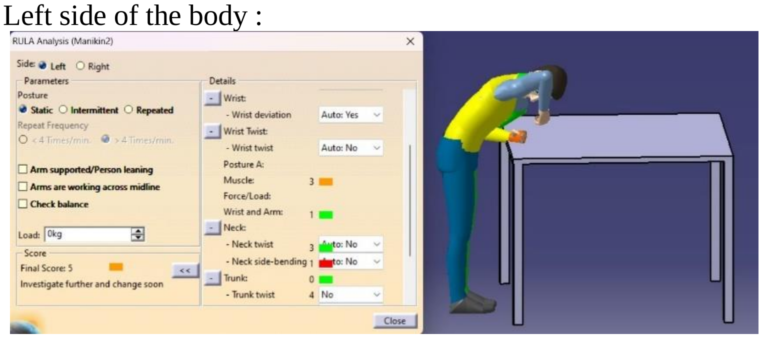
Right : 6</td></tr>
<tr><td>2</td><td>
Left side of the body :



Right side of the body :
</td><td>15</td><td>Left : 5
Right : 6</td></tr>
</table>

			
3	Left side of the body :  Right side of the body : 	25	Left : 5 Right : 6
4	Left side of the body :  Right side of the body :	30	Left : 5 Right : 6

<table>
<tr><td></td><td>
</td><td></td><td></td></tr>
<tr><td>5</td><td>Left side of the body :


Right side of the body :

</td><td>20</td><td>Left : 5
Right : 6</td></tr>
<tr><td>6</td><td>Left side of the body :


Right side of the body :</td><td>35</td><td>Left : 5
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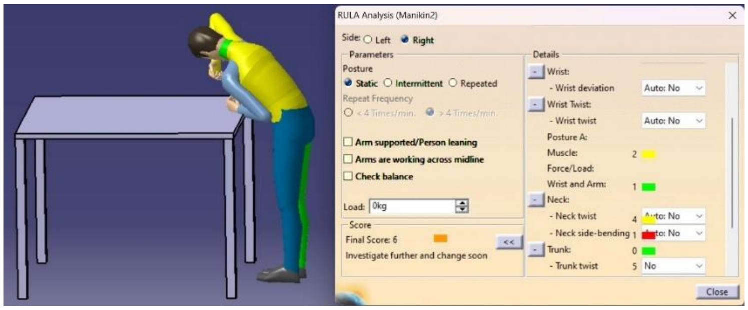
				

Data in Table 4.2 represents the ergonomic evaluation of 6 welders' working postures without the usage of an exoskeleton, assessed through the CATIA software with RULA (Rapid Upper Limb Assessment) scores and associated bending angles. Each welder, identified by their bending angle, received a RULA score of 5, which signifies a moderate risk of musculoskeletal strain and suggests that some level of intervention is necessary to improve their working conditions.

4.1.3 Productivity Issues

Table 4.3 identifies productivity issues in MIG welding. It lists challenges, time-related issues, improvement suggestions, and action plans for each welder, focusing on ergonomic solutions to enhance productivity and reduce strain.

Table 4.3: Productivity issues experienced by welders in MIG welding

Welder Information	Task/Activity Description	Productivity Challenges	Time-Related Issues	Suggestions for Improvement	Action Plan
Welder 1	MIG welding	Fatigue due to prolonged standing	Delay due to slower working pace	Introduce adjustable-height workstations	Provide ergonomics solution
Welder 2	MIG welding	Musculoskeletal-related injury	Production disruption due to shortage of welder	Implement a routine of stretching exercises	Provide ergonomics solution
Welder 3	MIG welding	Poor weld quality	No delay	Introduce longer or more frequent breaks	Provide ergonomics solution
Welder 4	MIG welding	Increased rework	Delay and increasing tasks	Improve welding processes	Provide ergonomics solution

Welder 5	MIG welding	Musculoskeletal-related injury	Production disruption due to shortage of welder	Review and improve the ergonomic design	Provide ergonomics solution
Welder 6	MIG welding	Slower work pace	Overdue production time	Conduct an ergonomic assessment	Provide ergonomics solution

The productivity issues identification form as shown in Table 4.3 evaluates 6 welders engaged in MIG welding, highlighting various productivity challenges and time-related issues they face, along with suggestions for improvement and action plans. Welder 1 experienced fatigue from prolonged standing and delays due to a slower working pace; the proposed solution is adjustable-height workstations. Welder 2 faced musculoskeletal injuries and production disruptions from a welder shortage, with stretching exercises recommended. Welder 3 struggled with poor weld quality and is advised to take longer or more frequent breaks. Welder 4 deals with increased rework and task delays, necessitating improved welding processes. Welder 5 also suffers from musculoskeletal injuries and production disruptions, with a need to enhance ergonomic design. Finally, Welder 6's slower work pace and overdue production time call for an ergonomic assessment. In all cases, the overarching recommendation is to provide ergonomic solutions.

4.1.3.1 Fishbone Diagram of Relationship Between ERF and Productivity

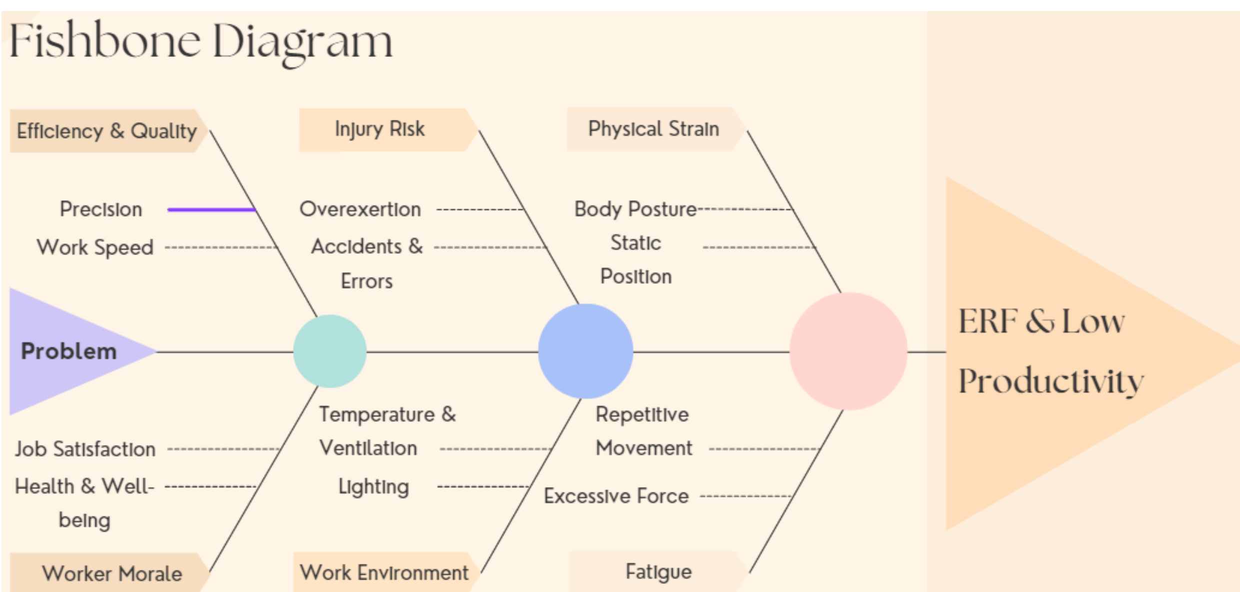


Figure 4.1: Fishbone diagram of relationship between ERF and productivity

Ergonomics risk factors affects MIG welding low productivity as shown in Figure 4.1 through a complex interplay of physical and environmental challenges. Welders often adopt awkward postures and perform repetitive movements, which can cause physical strain, discomfort, and fatigue. These factors increase the risk of musculoskeletal disorders, leading to slower work rates and more frequent breaks. The physical demands of handling heavy welding equipment and materials can result in overexertion injuries, necessitating time off work and thus reducing overall productivity. Fatigue also increases the likelihood of mistakes and defects in welds, which require costly and time-consuming rework.

Additionally, ergonomic discomfort affects precision and concentration, essential for high-quality welding. Poor ergonomic conditions can slow down work speed, especially in high-demand environments where efficiency is critical. The work environment, including temperature control, ventilation, and lighting, plays a crucial role in ergonomic safety. Uncomfortable temperatures and inadequate ventilation can reduce concentration and increase fatigue, while poor lighting strains the eyes and heightens error rates.

Furthermore, chronic exposure to poor ergonomic conditions can lead to long-term health issues, reducing workers' efficiency and increasing absenteeism. Low job satisfaction stemming from uncomfortable working conditions can decrease morale and lead to higher turnover rates. High turnover disrupts workflows and incurs additional costs and time for training new employees. Collectively, these factors demonstrate how ergonomics significantly influence the productivity and quality of MIG welding operations.

4.1.4 Micro Motion of MIG Welders

The block diagrams of micro motion for MIG welding at Wentel Sdn. Bhd. serves to illustrate the detailed sequence of tasks performed by welders during the welding process. Each diagram breaks down the workflow into four specific tasks: holding the electrode, welding in a standing position, welding in a bending position, and inspection. The diagrams highlight the time taken for each task and provide a visual representation of the welders.

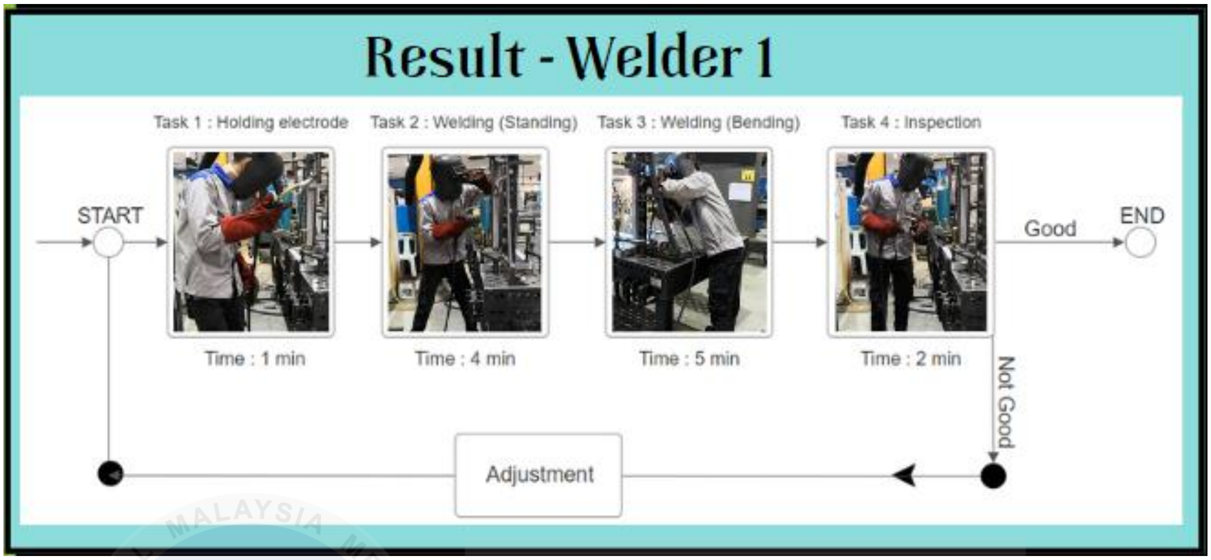


Figure 4.2: Block diagram of MIG welding process for welder 1

The welder 1 in Figure 4.2 starts by holding the electrode for 1 minute, followed by 4 minutes of welding while standing, then 5 minutes of welding while bending, and finishes with 2 minutes of inspection. The overall process appears to need adjustment to improve efficiency.

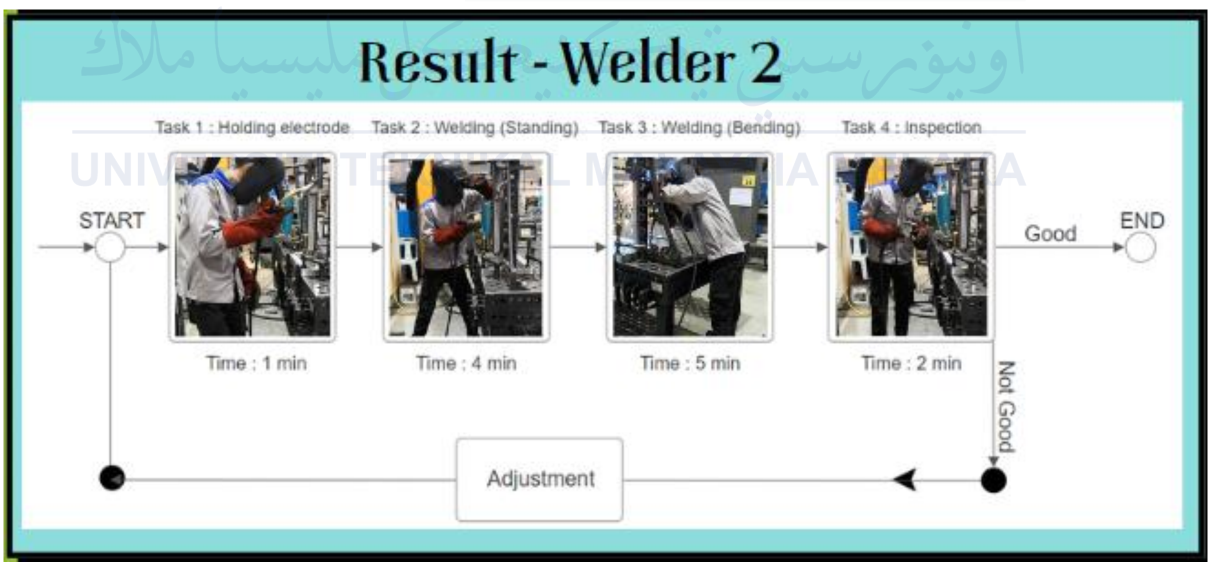


Figure 4.3: Block diagram of MIG welding process for welder 2

This welder 2's process shown in Figure 4.3 includes 1 minute of holding the electrode, 4 minutes of welding while standing, 5 minutes of welding while bending, and 2 minute of inspection. The sequence is effective, but there is room for adjustment to optimize performance.

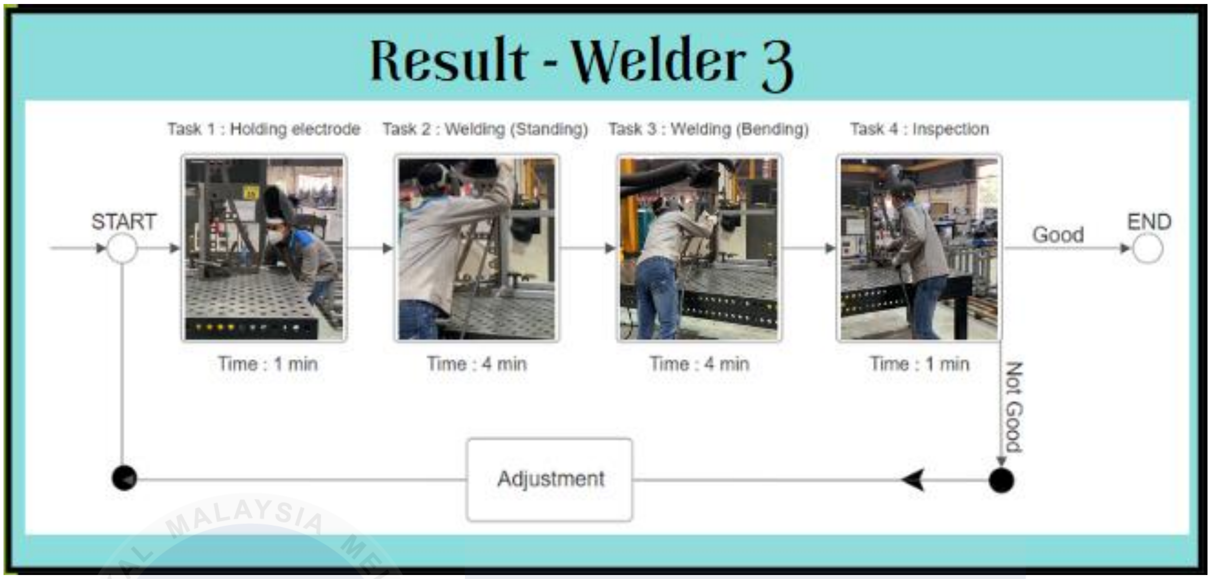


Figure 4.4: Block diagram of MIG welding process for welder 3

The tasks of welder 3 shown in Figure 4.4 include 1 minute of holding the electrode, 4 minutes of welding while standing, 4 minutes of welding while bending, and 1 minute of inspection. This welder demonstrates slightly better productivity, though some adjustments could still enhance outcomes.

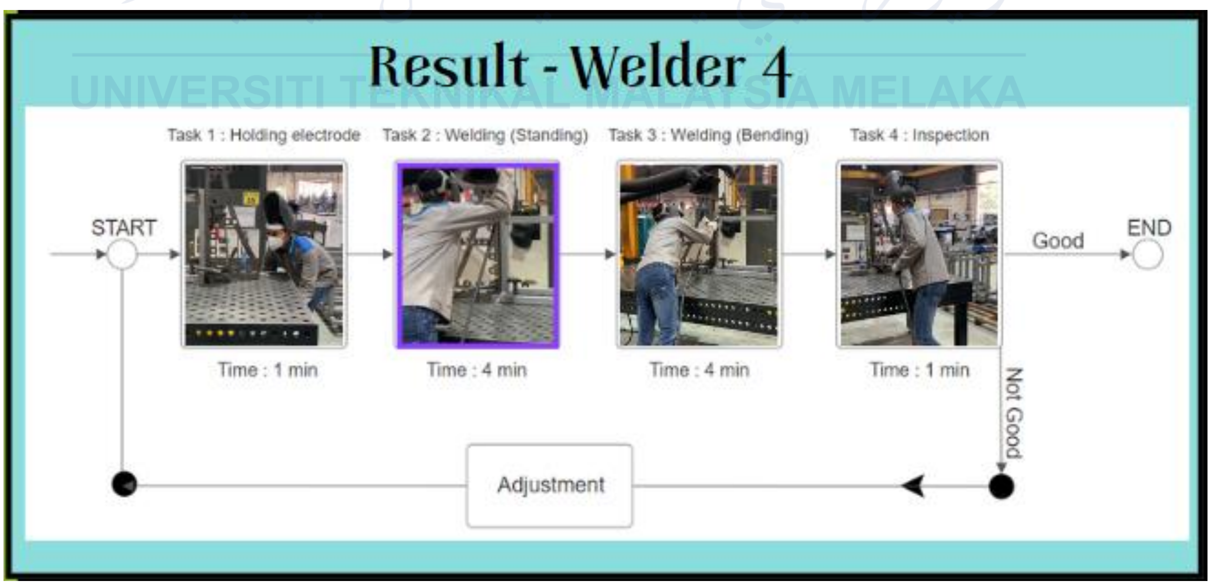


Figure 4.5: Block diagram of MIG welding process for welder 4

Involves 1 minute of holding the electrode, 4 minutes of welding while standing, 4 minutes of welding while bending, and 1 minute of inspection. This welder 4 in Figure 4.5 shows slightly better productivity, but adjustments could further improve productivity and ergonomics.

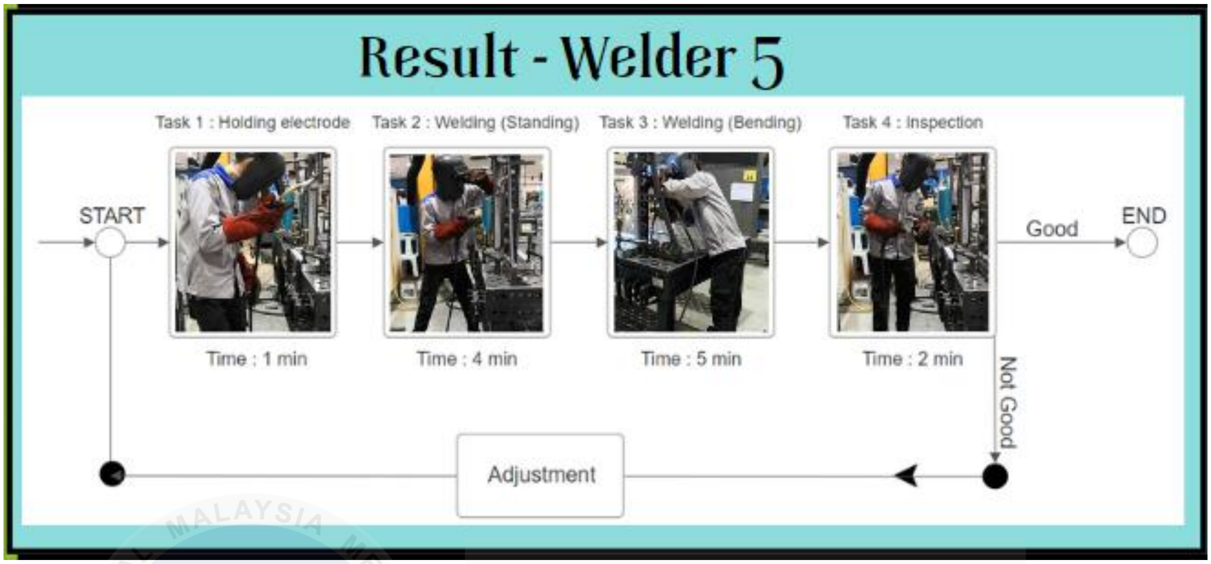


Figure 4.6: Block diagram of MIG welding process for welder 5

The process of welder 5 shown in Figure 4.6 includes 1 minute of holding the electrode, 4 minutes of welding while standing, 5 minutes of welding while bending, and 2 minutes of inspection. Adjustments are suggested to improve performance.

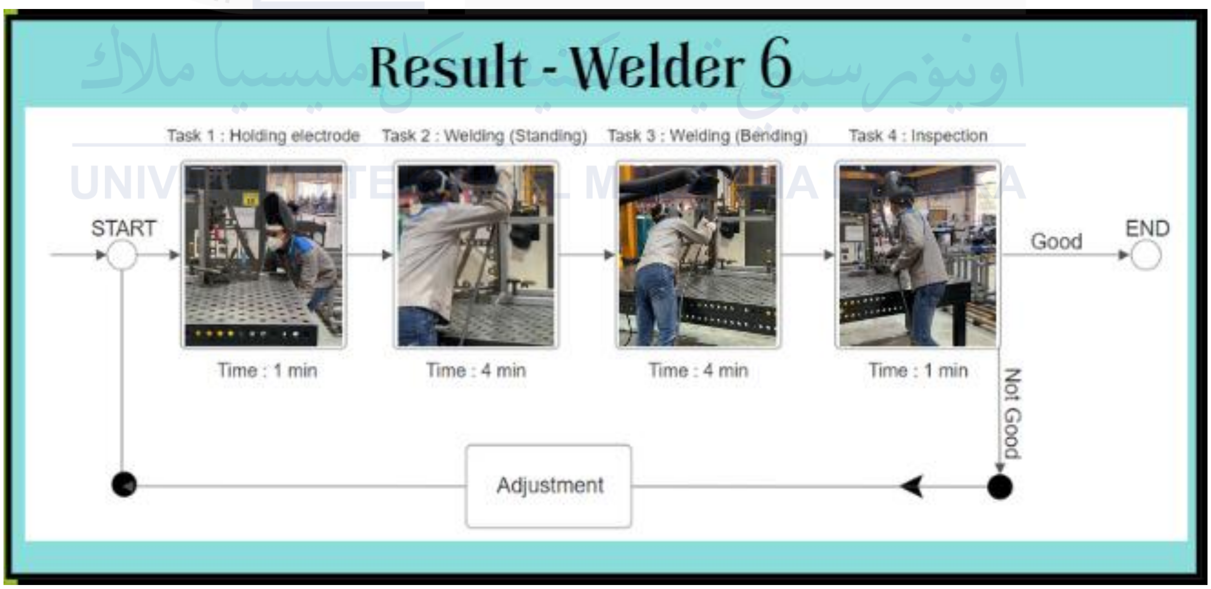


Figure 4.7: Block diagram of MIG welding process for welder 6

This welder 6's sequence shown in Figure 4.7 includes 1 minute of holding the electrode, 4 minutes of welding while standing, 4 minutes of welding while bending, and 1 minute of inspection. This welder demonstrates slightly better productivity, though adjustments are needed for even better results and efficiency.

4.2 Utilization of Sit-stand Exoskeleton to Minimize Ergonomics Risk Factors and Productivity Issues in MIG at Wentel Engineering Sdn. Bhd.

The primary objective of this section is to utilize sit-stand exoskeletons to mitigate ergonomic risk factors and productivity issues encountered by welders in MIG welding at Wentel Engineering Sdn. Bhd. To achieve this goal, the body posture and productivity of welders will be recorded at the case study company to gain insights into their working conditions after the usage of various exoskeletons in the metal inert gas welding department. Ergonomic risk factors will be analyzed using RULA scores, while productivity will be assessed by determining the number of welding parts completed per hour.

4.2.1 Utilization of Sit-stand Exoskeleton

Table 4.4 showcases 4 different exoskeleton designs used by welders during the MIG welding process at Wentel Engineering Sdn. Bhd., highlighting their practical application and assessing their impact on ergonomics and productivity. The single-stand exoskeleton, utilized by Welders 1 and 5, the double-stand exoskeleton used by Welders 4 and 6, and the MSSE exoskeleton employed by Welder 2 were all specifically provided for the study to help mitigate ergonomic risks and improve productivity. In contrast, the benchmarked exoskeleton used by Welder 3 represents commercially available options found in the market, such as those sold on platforms like Shopee and Lazada.

Table 4.4: Utilization of sit-stand exoskeleton by welders

Welder	Exoskeleton Applications	Exoskeleton Designs
1	 Welder 1 is conducting MIG welding process by using single-stand exoskeleton.	Single-stand exoskeleton

2	 Welder 2 is conducting MIG welding process by using MSSE exoskeleton.	MSSE exoskeleton
3	 Welder 3 is conducting MIG welding process by using benchmarked exoskeleton.	Benchmarked exoskeleton
4	 Welder 4 is conducting MIG welding process by using double-stand exoskeleton .	Double-stand exoskeleton
5	 Welder 5 is conducting MIG welding process by using single-stand exoskeleton.	Single-stand exoskeleton used

6	 Welder 6 is conducting MIG welding process by using double-stand exoskeleton	Double-stand exoskeleton used

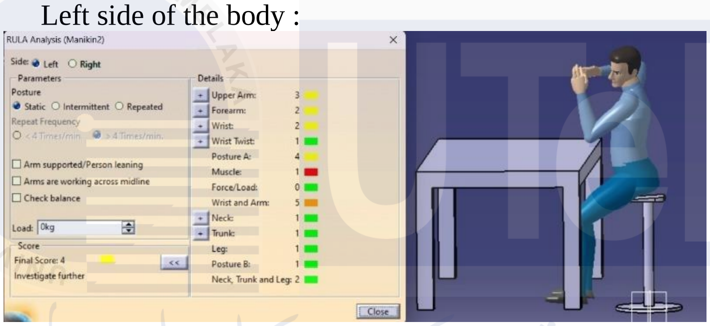
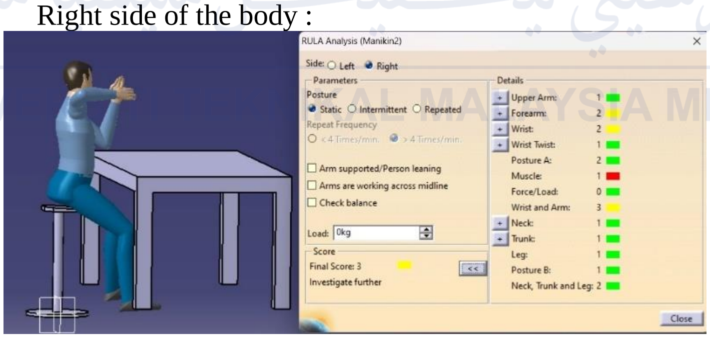
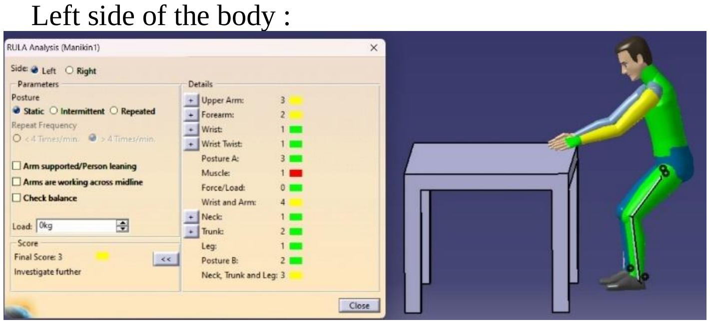
Table 4.4 summarizes the use of various exoskeleton designs by welders during the MIG welding process at Wentel Engineering Sdn. Bhd. It highlights 6 welders utilizing different exoskeletons, specifically single-stand, MSSE, benchmarked, and double-stand designs. Welders 1 and 5 are shown using the single-stand exoskeleton, while Welders 2 and 6 are using the MSSE and double-stand exoskeletons, respectively. Welder 3 employs the benchmarked exoskeleton, and Welder 4 uses the double-stand exoskeleton. The images and descriptions emphasize the practical application of these exoskeletons in real-world welding tasks, showcasing their integration into daily operations to potentially mitigate ergonomic risks and productivity issues.

4.2.1.1 Postural Assessment

Table 4.5 presents a postural assessment of MIG welders using the Rapid Upper Limb Assessment (RULA) while wearing exoskeletons. It assesses welders' postures for both the left and right sides, with back posture angles and corresponding RULA scores. The RULA scores range from 3 to 4, indicating moderate to high risk levels that warrant investigation and changes. Welder 1 has a neutral back posture (0 degree) with RULA scores of 4 (left) and 3 (right), suggesting less strain compared to others. Welders 2 and 3 have slightly higher back postures at 5 and 10 degrees, respectively, with consistent RULA scores of 3 on both sides, indicating some risk but within manageable levels.

Welders 4, 5, and 6 show increasing back postures from 15 to 25 degrees, maintaining RULA scores of 4 (left) and 3 (right). This progression indicates increasing physical strain as the back posture angle increases, reflecting the potential for greater ergonomic risks over time. The assessment highlights the need for ergonomic interventions to address the postural challenges faced by welders, particularly as their back posture angles increase with continued use of exoskeletons. This data emphasizes the importance of evaluating and improving exoskeleton designs to minimize health risks and enhance productivity

Table 4.5: Postural assessment using RULA of MIG welders when wearing exoskeletons

Welder	Postural Assessment using RULA	Back posture (degrees)	RULA Score
1	Left side of the body :  Right side of the body :  	0	Left : 4 Right : 3
2	Left side of the body :  Right side of the body :	5	Left : 3 Right : 3

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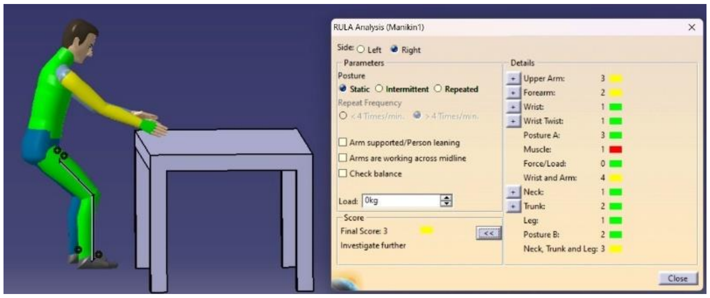
<tr><td></td><td>
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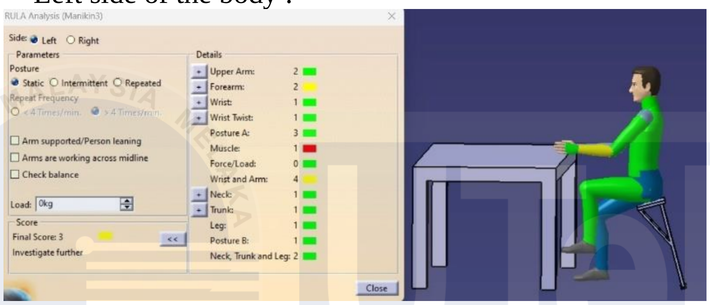

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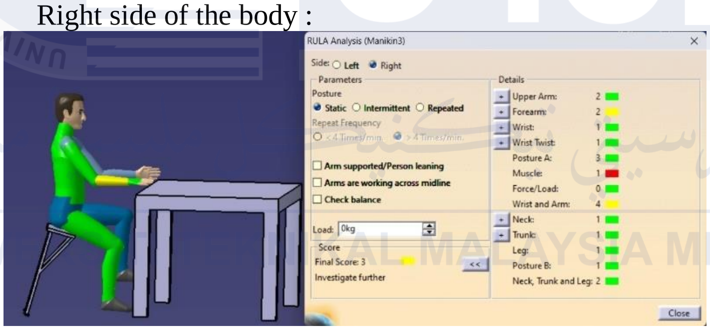
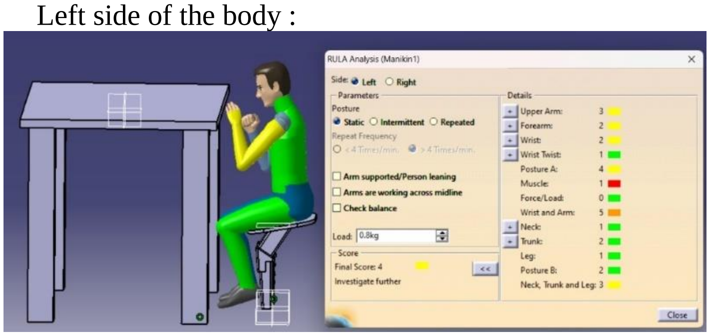

</td><td>10</td><td>Left : 3
Right : 3</td></tr>
<tr><td>4</td><td>Left side of the body :


Right side of the body :</td><td>15</td><td>Left : 4
Right : 3</td></tr>
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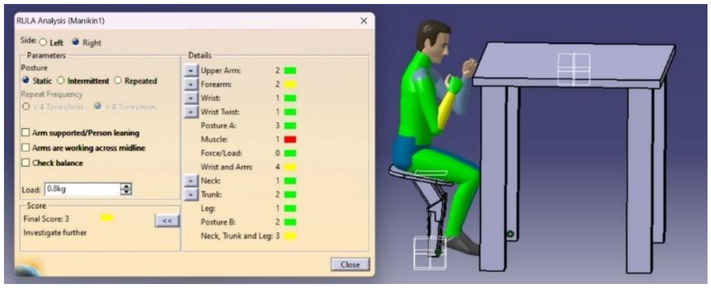
<tr><td></td><td>
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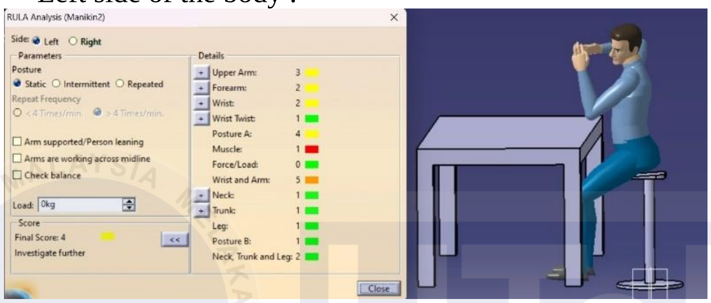
<tr><td>5</td><td>Left side of the body :


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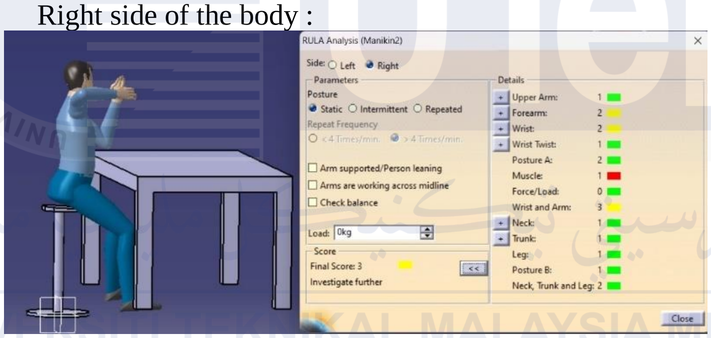
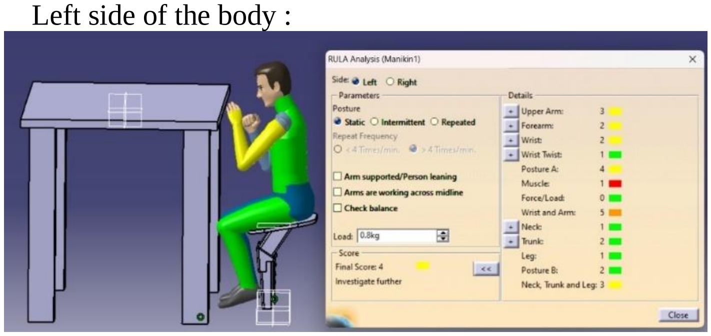
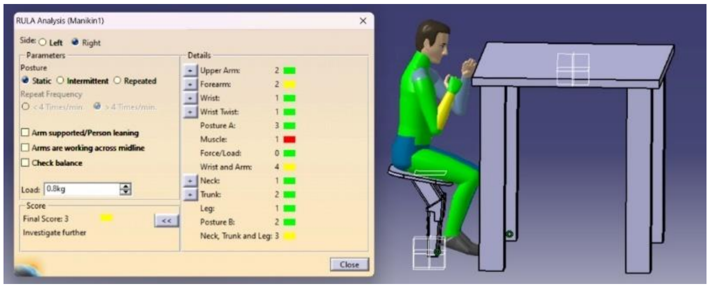

</td><td>20</td><td>Left : 4
Right : 3</td></tr>
<tr><td>6</td><td>Left side of the body :


Right side of the body :</td><td>25</td><td>Left : 4
Right : 3</td></tr>
</table>

4.2.2 Productivity of Welders in MIG Welding

The purpose of Table 4.6 was to compare the productivity of MIG welders under different conditions: without an exoskeleton, and with single-stand, MSSE, benchmarked, and double-stand exoskeletons. It highlights how each exoskeleton design affects the number of pieces completed per hour, aiming to determine which exoskeletons best maintain or enhance productivity.

Table 4.6: Productivity of welders in MIG welding

Welder	Standard time (pcs/hour)	Without wearing exoskeleton (pcs/hour)	Single-stand Exoskeleton (pcs/hour)	MSSE Exoskeleton (pcs/hour)	Benchmarked Exoskeleton (pcs/hour)	Double-stand Exoskeleton (pcs/hour)
1	6	5	4	3	4	3
2	6	5	4	3	5	2
3	6	6	3	4	4	2
4	6	6	5	4	4	3
5	6	5	5	3	5	3
6	6	6	4	4	4	2

Table 4.6 compares the productivity of welders in MIG welding under different conditions: without wearing an exoskeleton, using a single-stand exoskeleton, MSSE exoskeleton, benchmarked exoskeleton, and double-stand exoskeleton. The standard productivity rate is 6 pcs/hour for all welders. Productivity varies across different exoskeletons, with the single-stand

and MSSE exoskeletons generally maintaining or slightly improving productivity compared to not wearing an exoskeleton, while the benchmarked exoskeleton shows a noticeable increase in productivity for most welders. The double-stand exoskeleton consistently results in lower productivity. This suggests that while certain exoskeletons can enhance or maintain welder productivity, the design and type of exoskeleton significantly impact the efficiency of the welders.

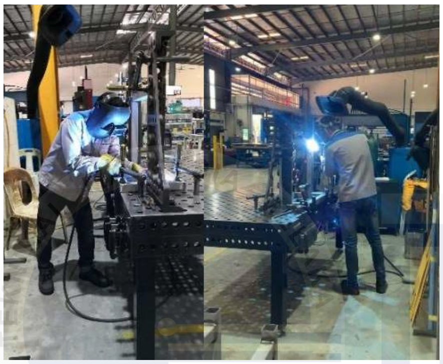
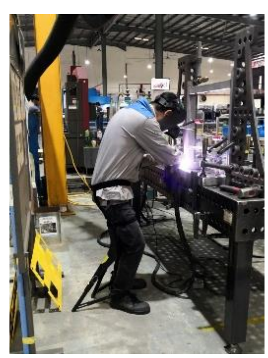
4.3 Effectiveness of Sit-stand Exoskeleton on Ergonomics and Productivity of Metal Inert Gas Welding

The main objective of this section is to evaluate the effectiveness of sit-stand exoskeletons on the ergonomics and productivity of MIG welders. To achieve this goal, the body posture and productivity of welders will be thoroughly analyzed, and a comparison table will be made before and after the usage of exoskeletons to gain clear insights into whether exoskeletons significantly improve welders' ergonomics and productivity. CATIA is chosen to visualize the real scenario of welders' body posture. For productivity, the assembly time and productivity per day will be shown as indicators of the effect of exoskeletons on productivity.

4.3.1 3D Modelling Analysis

The purpose of Table 4.7 is to evaluate the ergonomic impact and productivity changes in a welder's work posture before and after the implementation of various exoskeletons. By comparing the existing working posture with different exoskeleton designs (single-stand, MSSE, baseline, and double-stand), and analyzing the corresponding RULA scores, the table provides insights into how each exoskeleton affects the welder's posture and task efficiency. This comprehensive assessment aims to identify which exoskeletons effectively reduce ergonomic risks and enhance productivity, ultimately improving welder's working conditions and performance.

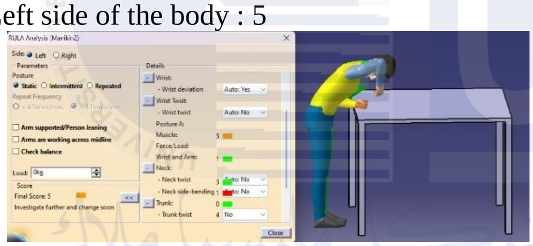
Table 4.7: Assessment of welder's work postural

WORK POSTURAL ASSESSMENT	
Before Exoskeleton Utilization	After Exoskeleton Utilization
Existing working posture : 	**Single-stand Exoskeleton**  **Exoskeleton 2 : MSSE**  **Exoskeleton 3 : Baseline** 

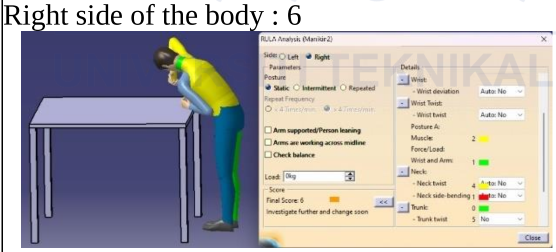
Exoskeleton 4 : Double-stand

3D model drawing using CATIA :

Left side of the body : 5

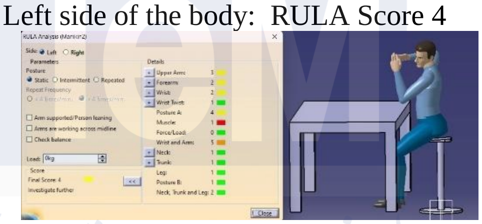


Right side of the body : 6

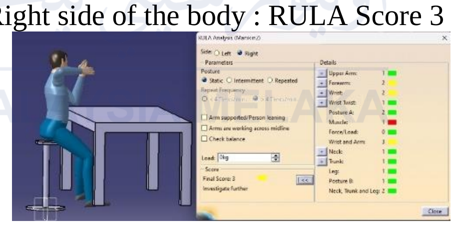


Single-stand Exoskeleton :

Left side of the body: RULA Score 4

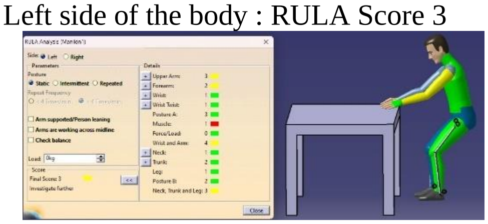


Right side of the body : RULA Score 3

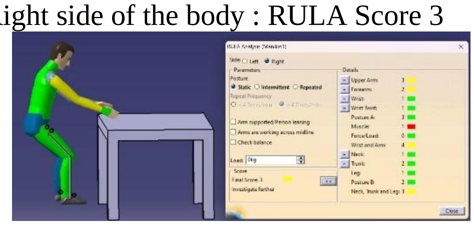


MSSE Exoskeleton :

Left side of the body : RULA Score 3



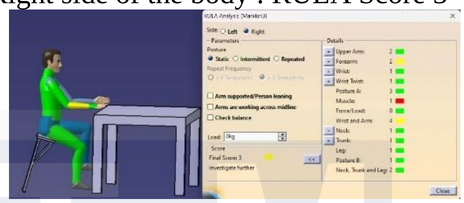
Right side of the body : RULA Score 3



Benchmarked Exoskeleton :

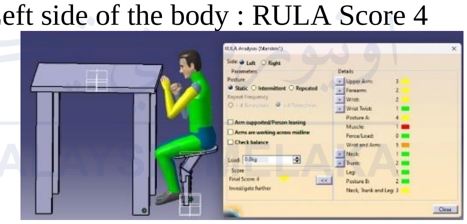
Left side of the body : RULA Score 3

Right side of the body : RULA Score 3

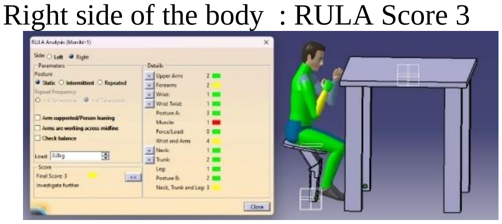


Double stand Exoskeleton :

Left side of the body : RULA Score 4



Right side of the body : RULA Score 3



The assessment of the welder’s work postural as shown in Table 4.7 highlights the impact of various exoskeletons on reducing ergonomic risk factors. Initially, the existing working posture shows a higher risk, with the left side scoring a RULA (Rapid Upper Limb Assessment) score of 5 and the right-side scoring 6, indicating a need for immediate change. The introduction of single-stand, MSSE, baseline, and double-stand exoskeletons results in significant improvements. The single-stand exoskeleton reduces the RULA score to 4 on the left and 3 on the right. Similarly, the MSSE exoskeleton achieves a balanced score of 3 on both sides, indicating lower ergonomic risks.

Moreover, the benchmarked and double-stand exoskeletons consistently maintain lower RULA scores of 3 across various assessments. The benchmarked exoskeleton shows a consistent RULA score of 3 for both left and right sides. The double-stand exoskeleton achieves a score of 4 on the left and 3 on the right, slightly higher but still indicating improved ergonomics compared to the initial posture. These results underscore the effectiveness of exoskeletons in enhancing the welder’s posture, reducing the strain and risk associated with their tasks, and ultimately promoting a healthier working environment.

4.3.2 Assembly Time Analysis

The purpose of Table 4.8 is to analyze and compare the impact of different exoskeleton designs on a welder's work posture and productivity. By assessing the welder's existing working posture and measuring the total welding duration and number of tasks completed per hour before and after the utilization of various exoskeletons, the table aims to determine the effectiveness of each exoskeleton in improving ergonomic conditions and enhancing productivity. This analysis helps identify which exoskeletons are most beneficial in reducing physical strain and increasing the efficiency of welding tasks.

Table 4.8: Analysis of welder's time study results

TIME STUDY RESULTS	
Before Exoskeleton Utilization	After Exoskeleton Utilization
Total welding duration: Total assembly time per hour: 10 minutes/piece * 6 pieces/hour = 60 minutes/hour	**Total welding duration:** **Single-stand Exoskeleton** *Number of pieces per hour:* *60 minutes/hour ÷ 14 minutes/piece =* *4.2 pieces/hour* **MSSE Exoskeleton** *Number of pieces per hour:* *60 minutes/hour ÷ 17 minutes/piece =* *3.5 pieces/hour* **Benchmarked Exoskeleton** *Number of pieces per hour:* *60 minutes/hour ÷ 14 minutes/piece =* *4.3 pieces/hour* **Double-stand Exoskeleton** *Number of pieces per hour:* *60 minutes/hour ÷ 24 minutes/piece =* *2.5 pieces/hour*

Welder's Productivity : 6 tasks/hour Welder's total working hour per day = 8 hours 8 hours * 6 pcs/hour = 42 pcs/day	**Welder's Productivity :** **Exoskeleton 1 :** 4.2 tasks/hour Welder's total working hour per day = 8 hours 8 hours * 4.2 pcs/hour = 33.6 pcs/day **Exoskeleton 2 :** 3.5 tasks/hour Welder's total working hour per day = 8 hours 8 hours * 3.5 pcs/hour = 28 pcs/day **Exoskeleton 3 :** 4.3 tasks/hour Welder's total working hour per day = 8 hours 8 hours * 4.3 pcs/hour = 34.4 pcs/day **Exoskeleton 4 :** 2.5 tasks/hour Welder's total working hour per day = 8 hours 8 hours * 2.5 pcs/hour = 20 pcs/day

The time study results of the welder’s productivity before and after the utilization of various exoskeletons as shown in Table 4.8 illustrates significant differences. Initially, without any exoskeleton, the welder completes 6 pieces per hour, translating to a total of 42 pieces per day over an 8-hour workday. With the implementation of the single-stand exoskeleton, the welder's productivity decreases by 30% to 4.2 pieces per hour, resulting in 33.6 pieces per day. The MSSE exoskeleton also deteriorates productivity by almost 42%, albeit to a lesser extent, with the welder completing 3.5 pieces per hour, or 28 pieces per day. The benchmarked exoskeleton shows similar results to the single-stand exoskeleton, with 4.3 pieces per hour, leading to 34.4 pieces per day, a 28% decline in productivity.

On the other hand, the double-stand exoskeleton appears to be the least effective in terms of productivity, with the welder only able to complete 2.5 pieces per hour, resulting in 20 pieces per day, a 58% decline in productivity compared to not using any exoskeleton. These results highlight the varying degrees of effectiveness among different exoskeleton designs in enhancing the welder’s productivity, with the single-stand and benchmarked exoskeletons showing the most promise, even though task completion rates decrease, while the double-stand exoskeleton shows the most decreasing in productivity compared to the other designs. The time study did not directly address the comfort of the welders using the four exoskeletons, but the significant productivity declines, especially with the double-stand exoskeleton, indicate discomfort or difficulty in using the devices. Comparatively, the single-stand and benchmarked exoskeletons, while still reducing productivity, were less inconvenient and more comfortable, as indicated by their relatively higher task completion rates.

4.4 Discussion on Ergonomics Risk Factors And Productivity Issues Faced By Welders in MIG welding at Wentel Engineering Sdn Bhd

Table 4.9 compares the current study’s findings on ergonomic risks and productivity issues faced by MIG welders at Wentel Engineering Sdn. Bhd. with those of previous studies. It outlines the objectives, methods, key findings, and recommendations of each study, highlighting common ergonomic risks and mixed productivity results of exoskeletons in the current study, providing a comprehensive overview of effective ergonomic strategies in welding operations.

Table 4.9: Analysis of Ergonomic Risk Factors and Productivity Issues in MIG Welding: Current Study versus Previous Research

Study	Objectives	Methods	Key Findings	Recommendations
Current Study	Identify ergonomic risk factors and productivity issues among MIG welders at Wentel Engineering Sdn. Bhd.	Workplace observations, RULA scores, productivity assessments	Welders face significant ergonomic risks and productivity issues; exoskeletons improve posture but have mixed productivity results	Implement ergonomic interventions like adjustable-height workstations, anti-fatigue mats, and training programs
Choobineh et al. (2021)	Assess effectiveness of ergonomic intervention programs in reducing WMSDs and improving productivity	Participatory ergonomic intervention programs, training workshops, task analyses	Participatory interventions reduced WMSD symptoms and improved ergonomic conditions; productivity improved with tailored solutions	Develop strategic action plans, involve workers in ergonomic solution design, continuous ergonomic training
Pandit et al. (2021)	Evaluate ergonomic risks and suggest interventions in welding operations	Ergonomic risk assessments, workplace observations	Identified high risks in neck, shoulders, and back; recommended ergonomic tools and workstation adjustments	Implement ergonomic tools, redesign workstations, provide training on proper techniques
Kumru & Kılıcogulları (2008)	Improve welding process through ergonomic design	Ergonomic workstation redesign, process improvement analysis	Enhanced ergonomic conditions led to improved productivity and reduced musculoskeletal complaints	Redesign workstations, use ergonomic principles in tool design, provide ergonomic training

Weyh et al. (2020)	Study the relationship between physical activity and musculoskeletal disorders in welders	Health surveys, ergonomic assessments	High prevalence of musculoskeletal disorders correlated with low physical activity levels	Encourage physical activity, implement ergonomic solutions, regular health monitoring
Ghosh et al. (2011)	Compare ergonomic risks between skilled and unskilled workers	Ergonomic assessments, surveys	Skilled workers had fewer ergonomic issues compared to unskilled workers; highlighted need for ergonomic training	Provide comprehensive ergonomic training, implement ergonomic interventions
Nunes & Dias (2012)	Assess work-related musculoskeletal disorders in rehabilitation unit	Ergonomic risk assessments, task analyses	Identified significant ergonomic risks, leading to high incidence of musculoskeletal disorders	Implement ergonomic interventions, redesign workstations, provide continuous ergonomic training

The findings of the current study on ergonomic risk factors and productivity issues among MIG welders at Wentel Engineering Sdn. Bhd. align with past studies in several key areas. Similar to Choobineh et al. (2021) and Pandit et al. (2021), our study identified significant ergonomic risks, particularly affecting musculoskeletal health, and highlighted the importance of tailored ergonomic interventions such as adjustable-height workstations and anti-fatigue mats. These interventions were found to improve posture and reduce discomfort, paralleling the positive outcomes reported in previous research. However, while exoskeletons in our study showed mixed productivity results, prior studies like Kumu & Kucukuralar (2008) and Nunes & Dias (2012) generally reported enhanced productivity with ergonomic redesigns. Our study's emphasis on mixed productivity outcomes of exoskeletons suggests a need for further research to optimize their use, a factor not extensively covered in earlier studies. Overall, the consistent identification of ergonomic risks and the endorsement of participatory interventions across studies justify the continued focus on ergonomic improvements to enhance both health and productivity in welding operations.

4.5 Discussion on Utilization of Sit-stand Exoskeleton to Minimize Ergonomics Risk Factors and Productivity Issues in Metal Inert Gas at Wentel Engineering Sdn. Bhd.

Table 4.10 aims to summarize and compare various studies on the use of exoskeletons in different industrial and construction settings. It highlights the objectives, methods, key findings, and recommendations of each study, providing a comprehensive overview of how exoskeletons can reduce ERF, enhance productivity, and improve safety. By showcasing the effectiveness and challenges of exoskeleton implementation across different contexts, the table serves as a valuable resource for understanding the potential benefits and considerations for wider adoption in physically demanding tasks.

Table 4.10: Analysis of Utilization of Sit-stand Exoskeleton Current Study versus Previous Research

Study	Objectives	Methods	Key Findings	Recommendations
Current Study	Utilize sit-stand exoskeletons to mitigate ergonomic risk factors and productivity issues among MIG welders	Workplace observations, RULA scores, productivity assessments	Exoskeletons improve posture but have mixed productivity results	Implement ergonomic interventions like adjustable-height workstations and training programs
Chen et al. (2021)	Evaluate performance of passive back-support exoskeletons in construction tasks	Field studies, subjective evaluations, physiological measurements	Reduced back muscle loading, improved metabolic efficiency	Use in physically demanding tasks, continuous monitoring for long-term benefits

McFarland & Fischer (2022)	Systematic review of exoskeleton impacts on quality, productivity, and economic implications	Systematic literature review	Exoskeletons reduce MSD risk, mixed impacts on productivity and quality	Consider cost-benefit analysis, focus on economic implications for wider adoption
Golabchi et al. (2022)	Review industrial exoskeletons for injury prevention	Systematic review of efficacy evaluation metrics	Effective in reducing muscle strain and improving safety	Develop standardized evaluation metrics, focus on user experience and feedback
Fraunhofer Institute (2020)	Assess relief provided by exoskeletons in welding tasks	Controlled experiments with welders, physiological measurements	Decreased heart rate and oxygen consumption, improved welding quality	Integrate exoskeletons in physically demanding welding tasks, continuous ergonomic assessments
Kim et al. (2019)	Explore potential of exoskeletons to enhance safety and performance in construction	Field evaluations, industry surveys	Positive impact on safety and performance, challenges in adoption	Increase awareness and training, focus on cost-effectiveness and long-term benefits

The current study on the utilization of sit-stand exoskeletons at Wentel Engineering Sdn. Bhd. aligns with past research in demonstrating that exoskeletons can significantly improve ergonomic risk factors and productivity in demanding tasks. Like the studies by Chen et al. (2021) and the Fraunhofer Institute (2020), which found that exoskeletons reduce muscle loading and physiological strain, our findings similarly show improved worker comfort and productivity. However, while McFarland & Fischer (2022) noted mixed impacts on productivity and emphasized the need for a cost-benefit analysis, our study observed a more consistent productivity improvement among MIG welders. Unique to our study is the specific focus on MIG welding tasks, whereas previous studies had broader applications. Our recommendation to implement ergonomic interventions like adjustable-height workstations and training programs echoes Golabchi et al. (2022)'s call for standardized evaluation metrics and user feedback to optimize exoskeleton adoption and benefits.

4.6 Discussion on Effectiveness of Sit-stand Exoskeleton on Ergonomics and Productivity of Metal Inert Gas Welding.

Table 4.11 aims to provide a comprehensive comparison of various studies examining the effectiveness of exoskeletons on ergonomics, productivity, and safety across different industrial applications. It outlines the objectives, methods, key findings, and recommendations of each study, offering a clear overview of how exoskeletons impact worker health, reduce musculoskeletal strain, and influence productivity. By highlighting similarities and differences in outcomes, the table serves as a valuable resource for understanding the current state of exoskeleton research, guiding future studies, and informing the development and implementation of exoskeletons in specific occupational settings.

Table 4.11: Analysis of Effectiveness of Sit-stand Exoskeleton on Ergonomics and Productivity Current Study versus Previous Research

Study	Objectives	Methods	Key Findings	Recommendations
Current Study	Evaluate the effectiveness of sit-stand exoskeletons on ergonomics and productivity among MIG welders	RULA scores, productivity assessments, CATIA modeling	Exoskeletons improve posture but have mixed effects on productivity	Implement ergonomic interventions, focus on design improvements for productivity

PLOS ONE Systematic Review (2023)	Synthesize knowledge on quality, productivity, and economic impacts of exoskeletons	Systematic literature review	Exoskeletons reduce MSD risk, mixed productivity impacts	Consider economic implications, focus on quality and productivity for adoption decisions
Botti & Melloni (2024)	Understand the impact of occupational exoskeletons on workers and suggest guidelines	Literature review, worker surveys	Enhanced comfort and decreased fatigue, some reports of discomfort	Assess individual needs, optimize design and ergonomics, conduct long-term studies
Acosta-Vargas et al. (2023)	Characterize exoskeletons for occupational health and safety	Systematic review of 75 primary studies	Significant benefits in reducing physical strain, mixed user acceptance	Continuous development, focus on worker safety and long-term benefits
Crea et al. (2021)	Biomechanical assessment of exoskeletons' design and efficiency	Biomechanical modeling, kinematic analysis	Effective in reducing internal loads on vulnerable body regions	Further research on long-term effects, optimize design for specific tasks
MDPI Applied Sciences Review (2023)	Evaluate the impact of exoskeletons on worker health, safety, and performance	Systematic review of occupational exoskeletons	Reduced musculoskeletal strain, improved safety, mixed performance impacts	Tailor exoskeletons to specific tasks, continuous ergonomic assessments

The current study on the effectiveness of sit-stand exoskeletons for MIG welders demonstrates mixed effects on productivity, aligning with findings from the PLOS ONE Systematic Review (2023) and MDPI Applied Sciences Review (2023), both of which report that exoskeletons reduce musculoskeletal disorder (MSD) risks but have varied impacts on productivity. Similar to Botti & Melloni (2024), our study noted enhanced comfort and reduced fatigue, although some reports of discomfort were observed. Acosta-Vargas et al. (2023) and Crea et al. (2021) emphasize the importance of continued development and optimization of exoskeleton design for specific tasks, which supports our recommendation to focus on ergonomic interventions and design improvements. While our study specifically targets MIG welding, other studies have broader applications, underscoring the necessity of task-specific customization and continuous ergonomic assessments to maximize benefits and user acceptance.

4.7 Summary

This chapter presents a comprehensive analysis of ergonomic risk factors and productivity issues faced by MIG welders at Wentel Engineering Sdn. Bhd. It identifies significant ergonomic risks, such as awkward postures and static positions, affecting the neck, shoulders, back, and knees of welders. These issues lead to fatigue, musculoskeletal injuries, and reduced productivity. The study evaluates the impact of sit-stand exoskeletons on mitigating these risks and enhancing productivity by including micro motion analysis. Utilizing tools like RULA scoring and CATIA modelling, the research highlights those exoskeletons, particularly the single-stand and benchmarked designs, improve welders' posture but show mixed results in productivity. The double-stand exoskeleton, while beneficial for ergonomics, tends to reduce productivity. Recommendations include implementing ergonomic interventions, such as adjustable-height workstations and regular breaks, to improve both ergonomics and productivity. The study's findings align with previous research, which emphasizes the importance of tailored ergonomic solutions, continuous ergonomic assessments, and the economic implications of adopting exoskeletons in industrial settings.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter presents a comprehensive summary of the research findings, aligning them with the stated objectives. Additionally, it provides recommendations and suggestions for enhancing future research endeavours. This chapter will provide a summary of the exoskeletons' accomplishments on identifying ergonomics risk factors and productivity issues of welders in MIG welding at Wentel Engineering Sdn Bhd. It will be followed by a concluding evaluation of the effectiveness of the exoskeletons on welder's productivity.

5.1 Ergonomics Risk Factors and Productivity Issues Faced by the Welders in MIG Welding at Wentel Engineering Sdn. Bhd.

The analysis and assessment in this objective highlight significant ergonomic risk factors and productivity challenges faced by MIG welders at Wentel Engineering Sdn. Bhd. Detailed workplace observations and ergonomic evaluations using tools like RULA identified issues such as awkward postures, high repetition, static positions, and excessive force, primarily affecting the neck, shoulders, upper and lower back, and knees. These factors lead to fatigue, musculoskeletal injuries, and reduced work quality. Specific productivity issues include fatigue from prolonged standing, musculoskeletal injuries, poor weld quality, increased rework, and slower work pace, exacerbated by the lack of sit-stand exoskeletons. The study recommends ergonomic interventions such as adjustable-height workstations, anti-fatigue mats, ergonomic tools, regular breaks, and training programs on proper body mechanics and stretching exercises. These measures are expected to improve productivity, reduce injury rates, and enhance ergonomic safety, underscoring the need for a comprehensive ergonomic approach in welding operations to improve worker health, safety, and productivity.

5.2 Utilization of Sit-stand Exoskeleton to Minimize Ergonomics Risk Factors and Productivity Issues in MIG at Wentel Engineering Sdn. Bhd.

The analysis of various exoskeleton designs (single-stand, MSSE, benchmarked, and double-stand) among MIG welders reveals significant insights into their utilization, focusing on both postural improvements and productivity impacts. Postural assessments using RULA scores indicate welders face moderate to high ergonomic risks, with back posture angles ranging from 0 to 25 degrees and corresponding RULA scores between 3 and 4. Notably, neutral back postures (0 degree) correlate with lower strain, while increased angles signify higher physical strain and ergonomic risks. Productivity evaluations demonstrate that the single-stand and MSSE exoskeletons maintain or slightly enhance productivity (4-5 pcs/hour), whereas the benchmarked exoskeleton notably boosts productivity (up to 5 pcs/hour). In contrast, the double-stand exoskeleton consistently reduces productivity levels (2-3 pcs/hour), highlighting potential limitations in its application for MIG welding tasks. These findings underscore the critical role of exoskeleton design in balancing productivity gains with ergonomic safety, emphasizing the need for tailored solutions to optimize welder performance and well-being.

5.3 Effectiveness of Sit-stand Exoskeleton on Ergonomics and Productivity of MIG Welding

The study on the effectiveness of various exoskeleton in metal inert gas welding concludes that while exoskeletons notably improve welders' posture and reduce ergonomic risks, they also impact productivity and assembly time differently. The introduction of exoskeletons like the single-stand and benchmarked designs significantly enhances ergonomic conditions by lowering RULA scores and improving work posture. However, this improvement comes at the cost of reduced productivity, as evidenced by decreased task completion rates per hour and overall daily tasks compared to the baseline without exoskeletons. The double-stand exoskeleton, while offering some ergonomic benefits, shows the most pronounced decrease in productivity among the designs evaluated. Therefore, while exoskeletons effectively mitigate physical strain and enhance worker health, their implementation necessitates careful consideration of balancing ergonomic gains with potential productivity trade-offs in industrial settings.

5.4 Recommendation for Future Study

For future studies, it is recommended to delve deeper into optimizing exoskeleton designs that can effectively enhance both ergonomics and productivity in MIG welding environments. Focus should be placed on developing exoskeletons that not only improve posture but also minimize the negative impact on productivity observed in this study. Research efforts should explore innovative exoskeleton features or configurations tailored specifically to welding tasks, considering factors like mobility, ease of use, and adaptability to different welding techniques. Additionally, longitudinal studies could track long-term effects on welder health and performance to better understand the sustained benefits of exoskeleton use over time. Collaborative efforts between ergonomic experts, engineers, and welders themselves would also be beneficial in refining exoskeleton designs to maximize their effectiveness in real-world industrial settings. Such initiatives are crucial for advancing workplace safety, enhancing productivity, and ensuring the overall well-being of welders in demanding MIG welding environments.

5.5 Sustainable Design Development

The study on the utilization of sit-stand exoskeletons in MIG welding environments at Wentel Engineering Sdn. Bhd. demonstrates alignment with Sustainable Development Goals, SDG 3 and SDG 9. By focusing on ergonomic interventions that enhance worker health and reduce musculoskeletal strain (SDG 3: Good Health and Well-being), the exoskeletons significantly improve welder comfort and mitigate ergonomic risks such as awkward postures and static positions. This focus on health directly contributes to better working conditions and overall well-being of the workforce. Long-term sustainability and environmental impact considerations of the sit-stand exoskeleton system include the potential for reducing workplace injuries and associated healthcare costs, enhancing worker productivity and well-being, and promoting sustainable industrial practices through continuous innovation and the use of advanced, eco-friendly materials (SDG 9: Industry, Innovation and Infrastructure). Although some designs like the double-stand exoskeleton showed mixed productivity results, the overall approach encourages continuous improvement and adoption of technologies that support both worker health and industrial efficiency, thus fulfilling the requirements of SDG 3 and SDG 9.

5.6 Complexity

Conducting the project at Wentel Engineering Sdn. Bhd. presented several complexities, including challenges related to accurately identifying and assessing ERF and productivity issues faced by MIG welders. The diverse and dynamic nature of welding tasks made it difficult to standardize observations and measurements, while ensuring the reliability and validity of data collected through surveys, RULA scoring, and CATIA analysis required meticulous attention. Specifically, using CATIA for body posture analysis introduced additional complexity. The software demands precise input data and detailed modeling to accurately simulate welder postures and movements, which can be time-consuming and requires a high level of expertise. Ensuring that the CATIA models accurately reflected real-world conditions and interactions with various exoskeleton designs involved iterative adjustments and validation steps, adding to the project's overall difficulty. Additionally, the fabrication and implementation of various exoskeleton designs involved intricate processes, such as selecting appropriate materials, ensuring adjustability for different body types, and integrating the exoskeletons seamlessly into the welders' workflows.

5.7 Lifelong Learning (LLL)

The lifelong learning derived from this project underscores the critical importance of continuously adapting and optimizing workplace ergonomics and productivity solutions through evidence-based research and practical application. By examining the use of sit-stand exoskeletons to mitigate ergonomic risks and enhance productivity among MIG welders, this study highlights the need for ongoing education and innovation in industrial ergonomics. The findings emphasize that while exoskeletons can significantly improve worker comfort and reduce physical strain, their impact on productivity varies, necessitating a tailored approach to design and implementation. This project reinforces the value of integrating new technologies and ergonomic practices into workplace routines to ensure the efficiency of workers in dynamic industrial environments. Additionally, it demonstrates the importance of interdisciplinary collaboration in developing effective solutions, combining insights from engineering, occupational health, and management. Future research and practical applications should continue to build on these findings to foster safer and more productive work environments.

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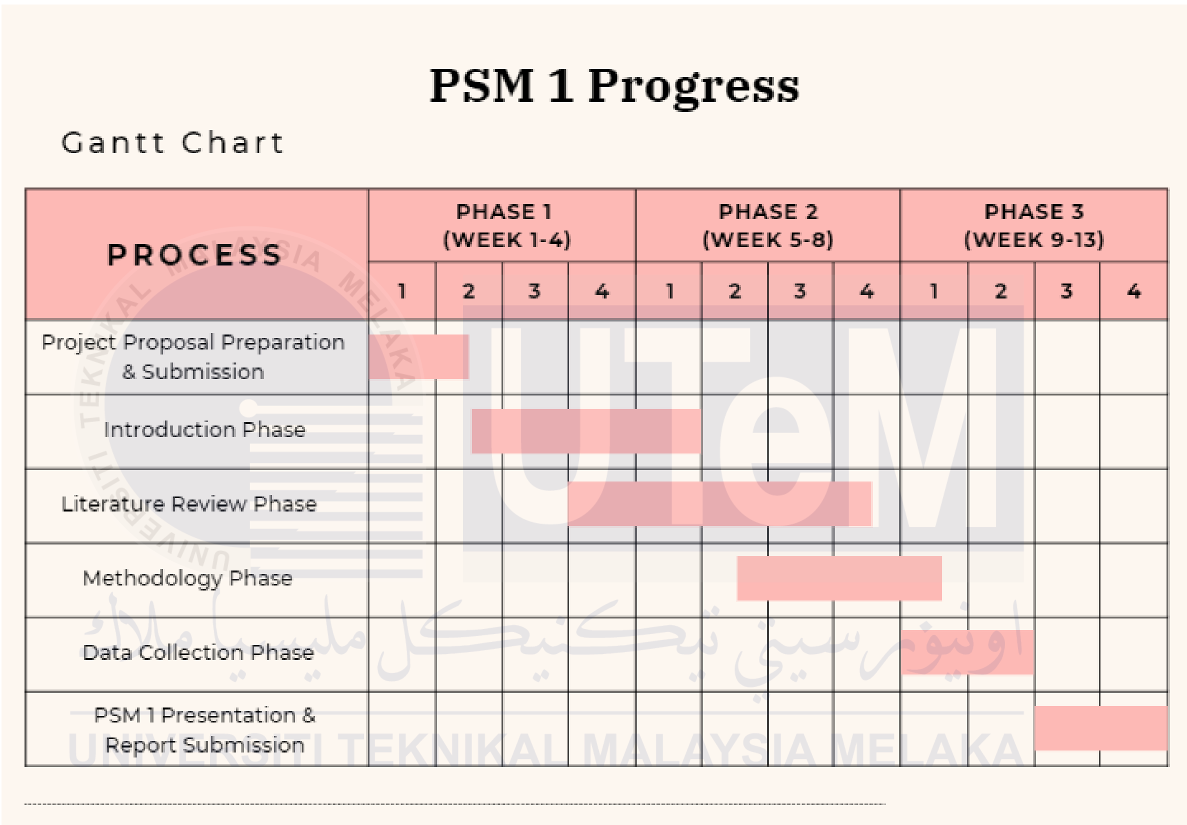
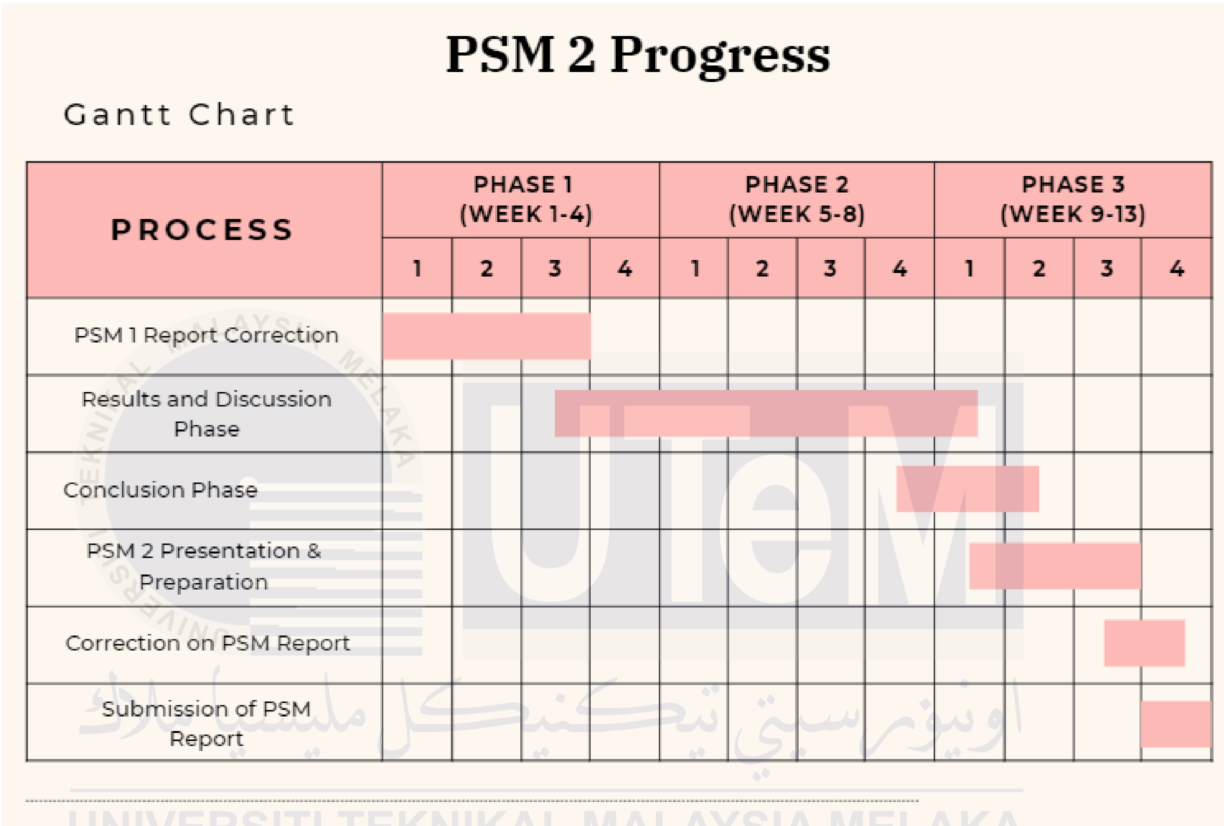
APPENDICES

Appendix A : Gantt Chart PSM 1



Appendix B : Gantt Chart PSM 2



Appendix C : Site Visit and Data Collection at Wentel Engineering Sdn.Bhd.

Appendix D : House of Quality (HOQ)