ASSESSMENT AND MITIGATION OF ERGONOMICS RISK: AN INDUSTRIAL PRACTITIONER CASE STUDY OF AN ELECTRONIC MANUFACTURING PRODUCTION LINE

LIM LI YIN

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

ASSESSMENT AND MITIGATION OF ERGONOMICS RISK: AN INDUSTRIAL PRACTITIONER CASE STUDY OF AN ELECTRONIC MANUFACTURING PRODUCTION LINE

LIM LI YIN

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE MASTER OF SAFETY, HEALTH AND ENVIRONMENT ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Lim Li Yin

Matric No: 17218513

Name of Degree: Safety, Health And Environment Engineering

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Assessment And Mitigation Of Ergonomics Risk: An Industrial Practitioner Case Study Of An Electronic Manufacturing Production Line

Field of Study: Industrial Ergonomic and Workplace Management

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date: 25/9/2021

Subscribed and solemnly declared before,

Witness's Signature Date: 25/9/2021

Name: Ir Dr Jegalakshimi Jewaratnam

Designation: Senior Lecturer

ASSESSMENT AND MITIGATION OF ERGONOMICS RISK: AN INDUSTRIAL PRACTITIONER CASE STUDY OF AN ELECTRONIC MANUFACTURING PRODUCTION LINE

ABSTRACT

Electronic manufacturing industry, especially in the final assembly area, involves a lot of repetitive movement, prolonged standing and awkward posture problems. Thus, this research has been carried out to determine the risk factors present in the existing workplace and to propose mitigation method to prevent or reduce the risk of Musculoskeletal Disorders (MSDs). The focus of this study is on the operators who working at the sound bar final assembly section. There are total of 15 operators being assessed. The operators are being observed and photos of their postures were taken. Rapid Upper Limb Assessment (RULA) was then carried out based on the photos taken. Those workstation where postures identified as high risk and medium risk were being redesigned using human simulation software (Siemens PLM Software, Jack 9.0). The redesigned workstation was being assessed using RULA and the risk score obtained was compared against the existing risk score to justify the effectiveness of the proposed mitigation method. Two stages of working posture assessment at an existing workstation and redesigned workstation have been carried out. At the existing workstation, out of the 19 postures, four are high risk (21%), five medium risks (26%), and ten are low risks (53%). Among the high risk, three are from the assembly area (75%), whereas the remaining one is from the packaging area (15%). Modifications of the workstation have been proposed to the existing workstation. Moreover, the comparison result of RULA analysis revealed that the redesigned workstation had promoted an effective solution to improve working posture. Based on the RULA analysis, those who were identified as medium and high risk were all reduced to low risk at the redesigned workstation.

Keywords: Ergonomics, Final Assembly, RULA, MSDs.

PENILAIAN DAN MITIGASI RISIKO ERGONOMIK: KAJIAN KES AMALAN PERINDUSTRIAN BARISAN PENGELUARAN PEMBUATAN ELEKTRONIK

ABSTRAK

Industri pembuatan elektronik, terutama di kawasan pemasangan akhir, melibatkan banyak pergerakan berulang, waktu berdiri yang panjang dan postur yang canggung serta tidak selesa. Oleh itu, penyelidikan ini dilaksanakan untuk menentukan faktor risiko yang wujud di tempat kerja tersebut dan mencadangkan kaedah perancangan untuk mencegah atau mengurangkan risiko penyakit muskuloskeletal (MSDs). Kajian ini memberi tumpuan kepada para operator pengeluaran yang bekerja di bahagian pemasangan akhir untuk bar bunyi (soundbar). Terdapat sejumlah 15 operator yang dinilai. Corak pergerakan mereka akan diperhatikan, dan gambar postur tubuh mereka diambil. Rapid Upper Limb Assessment (RULA) kemudian dilakukan berdasarkan gambar yang diambil. Stesen-stesen kerja yang mengakibatkan postur yang kurang ergonomik dikenal pasti sebagai berisiko tinggi dan sederhana. Ianya akan direka semula menggunakan perisian simulasi manusia (Siemens PLM Software, Jack 9.0). Stesen kerja yang direka bentuk semula dinilai menggunakan RULA, dan skor risiko baharu yang diperoleh dibandingkan dengan skor risiko yang sedia ada untuk menunjukkan keberkesanan kaedah yang dicadangkan. Dua peringkat penilaian postur bekerja di stesen kerja sedia ada dan stesen kerja yang direka bentuk semula telah dilakukan. Di stesen kerja sedia ada, dari 19 postur, terdapat empat yang berisiko tinggi (21%), lima berisiko sederhana (26%), dan sepuluh adalah berisiko rendah (53%). Untuk yang berisiko tinggi, tiga daripadanya ialah dari kawasan pemasangan (75%), sementara selebihnya dari kawasan pembungkusan (15%). Pengubahsuaian stesen kerja telah dicadangkan kepada stesen kerja sedia ada. Selain itu, hasil perbandingan analisis RULA menunjukkan bahawa stesen kerja yang direka semula telah menghasilkan penyelesaian yang berkesan untuk memperbaiki postur semasa bekerja. Berdasarkan analisis RULA, postur yang dikenal pasti sebagai berisiko sederhana dan tinggi semuanya telah dikurangkan menjadi risiko rendah di stesen kerja yang direka semula.

Kata Kunci: Ergonomik, Pemasangan Terakhir, RULA, MSDs.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude and appreciation to my supervisor, Associate Professor Dr. Wan Nor Liza Binti Wan Mahadi and co-supervisor, Dr Raja Ariffin Bin Raja Ghazilla for being the backbone on this project and thanks for the guidance, attention, knowledge, supervision and precious time that had been spent throughout the completion of the thesis. Besides, I am thankful to all the lecturers UM who taught me for the whole course of Master in Safety, Health and Environment Engineering. I also wish to thank my friends, special friends and people who had kindly helped me in this project. Finally, I would never finish this project without the encouragement from my beloved family members. Special thanks for their moral support throughout my studies. All the hard works and perseverance that I put in this project was not easy without their motivations and endless supports.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

For examples:

CTD	:	Cumulative Trauma Disorder
ERF	:	Ergonomic Risk Factors
FA	:	Final Assembly
HFE	:	Human Factors Engineering
MSDs	:	Musculoskeletal Disorders
ODM	:	Original Design Manufacturer
REBA	:	Rapid Entire Body Assessment
RULA	:	Rapid Upper Limb Assessment
SOSCO	:	Social Security Organization

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Introduction

Manufacturing is one of the world's most significant sectors today. It is extremely important to the country's development. In order to make a profit and compete with other businesses, the factory's performance must be at a high level. Productivity is used to assess the factory's performance. Furthermore, safety and health are influencing factors on factory productivity. Employees could not do their jobs properly if they did not practice good safety and health. Employees are the most valuable asset in the manufacturing industry. Even if an automatic machine is used, employees are still required to operate the machine.

Ergonomics are vital for the design, safe, comfortable and effective use of human resources in workplaces, equipment, machinery, systems, jobs and surroundings, as well as keeping the environment safe and systematic. The practice of ergonomics necessitates the application of theoretical knowledge regarding anatomy, physiology, and psychology to workplace design. Human Factors Engineering (HFE), Human Engineering, Occupational Psychology, Engineering Psychology, and Applied Experimental Psychology are all terms used to describe ergonomics.

The primary objective of an ergonomist is to characterize the human at all levels relevant to the particular system. The aim of ergonomics is to improve productivity, improve workplace safety and health, and enhance work enjoyment. When assessing system productivity, several elements must be addressed, including the design of system components, the state of the system leading to the incident, employees' mental and physical workload, work structure, and external variables. Human errors are frequently an element that contributes to the performance of the workplace system. The ergonomics principle should be incorporated as early as practicable in the product design and system in order to maximize the benefits of the end product, rather than as a final evaluation after product design. Functional efficiency, ease of use, comfort, health, safety, and working life quality are all indicators of a successful design match. The ergonomic method takes into account all relevant criteria rather than merely designing for one criterion at the expense of others.

Employee injuries will occur if ergonomics principles are not included in workplace design. Musculoskeletal Disorders (MSDs) and Cumulative Trauma Disorder (CTD) are the most common ergonomics hazards. All potential indications and symptoms include aching joints and muscles, back discomfort, tingling or numbness, whitening of finger or toes, pain that is similar to being pierced or stabbed, swelling or inflammation, stiffness or movement difficulties, burning feelings and pain at night.

This project is carried out to identify the potential risk of ergonomics issues that could lead to MSD in a real industrial setting. Rapid Upper Limb Assessment (RULA) and Human Factor Design Guidelines will be used to assess and propose mitigation measures. The company of this case study is an Original Design Manufacturer (ODM) that provides services for Information and communication technology products. The workstation design of this company is of the same standard design from the main branch in China. In general, the set up in the most company are pretty similar which this study might be applicable to other companies or industries.

1.2 Problem Statement

The electronic manufacturing industry, especially in the final assembly area, involves a lot of repetitive movement, prolonged standing and awkward posture problems. This leads to an increase in errors, affects operator well-being such as MSD and, is a precursor to injuries and accidents. The lack of human factors consideration to the design of the workstation and task could possibly be the cause of MSDs. Thus, this study attempts to assess and propose a mitigation method by considering the lack of human factors in an electronic manufacturing production line. Such findings can well be extended to other organizations or industries of a similar setup.

1.3 Objectives

The objectives of this project are:

i. To assess and analyze the ergonomic risks of the workstation and task design of an active electronic manufacturing line.

ii. To propose mitigation measures to reduce the risk of ergonomic risks.

iii. To design mitigation measures for workstation to reduce the ergonomic risk.

1.4 Scope

The focus of this research is on the operators who operate in the sound bar's final assembly section. The evaluation should be able to provide the assessor with a meaningful indicator of the ergonomic risk faced by operators. Then, the most effective alternative methods/tools for reducing the risk of MSDs can be recommended.

1.5 Project Significance

Although the study focuses on a specific active production line of an electronic manufacturing company, due to similarities in setup to other electronic manufacturing industries, the finding of possible ergonomics risk and mitigation measures will be helpful in understanding industrial practices. This will allow the relevant department to develop an appropriate mitigation method to reduce the risk of MSDs among the operators.

1.6 Project Schedule

Week / Planning	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Proposal	■	■	■	■										
Introduction				■	■									
Objectives, Problem Statement and scope				■	■	■								
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Methodology									■	■	■	■	■	■
Presentation													■	■

Figure 1.1 Project Gannt Chart For Semester 1

Week / Planning	1	2	3	4	5	6	7	8	9
Methodology	■	■	■						
Result Taking				■	■				
Result Analysis					■	■	■		
Discussion						■	■		
Conclusion							■	■	■
Final Presentation									■

Figure 1.2 Project Gannt Chart for Semester 2

CHAPTER 2: LITERATURE REVIEW

2.1 Ergonomics

Typically, ergonomics is related to people and their occupations. Ergonomics examines the components and limitations of human behavior, psychology and physiology. Ergonomic specialists usually construct new working environments or adjust existing working environments based on human capabilities and limitations.

The basic premise of ergonomics is to avoid employees from being subjected to pressures that might adversely affect their health and safety and the company's production by exceeding employee capacity and limits. Ergonomically implemented measures should seek to remove impediments to quality, efficiency and safety of human performance instead of requesting individuals to adapt products, tasks and surroundings. Ergonomists take a worker, location of work and design into consideration when determining the compatibility between a person and their task.

Ergonomical sciences include a wide range of work circumstances, including illumination, noise, temperature, vibration, heavy lifts, repeated movement, workstation design, tool design, machine design, layout, chair design, and footwear. Furthermore, work design influences shift work, breaks and meal times considerably. These factors can cause tendons, muscles, or nerve injuries or diseases, the majority of which lead to MSDs (Jaffar et al., 2011).

2.1.1 Definition of Ergonomics

Numerous researchers have presented a range of definitions to describe the notion of ergonomics. According to Te-Hsein and Kleiner (2001), ergonomics is a blend of the terms ergo, which means "work," and nomics, which translated to "study," and it refers to the study of work. Tayyari and Smith (1997), on the other hand, defined ergonomics as a discipline of the study of the implementation of optimal interactions between people and their working environments are being addressed, whereas Lee (2005) has said that compatibility of employees and systems should be promoted.

In addition, Fernandez (1995) identified ergonomics, taking into consideration human physical, physiological, biomechanical and psychological abilities and optimizing the effectiveness and productivity of work systems while ensuring the safety, health and well-being of workers, as the design of the workplace, equipment, machining and tools. Generally speaking, the aim of ergonomics is to suit the work with the person rather than a single individual.

Finally, Brooks (1998) argues that ergonomics is an interacting system that comprises employees, the working environment, the workplace and the job. We may conclude that the most frequently highlighted form of the concept of ergonomics is concerned mainly with the connection between humans, machinery and workplace design.

2.2 Ergonomic Risk Factors (ERF)

Humans have always seemed adaptive; yet, how they integrate into the workplace has received less consideration. As a result, workspaces are being structured to move things or support machines rather than assisting humans effectively. Ergonomics has evolved into a vital component of workplace safety. This is seen in the growing number of recurring injuries, unpleasant postures and excessive strength. Ergonomics and human factors are often interchangeable in the workplace. Both describe the relationship between the worker and the work requirements. The difference is that ergonomics focuses on how labor affects employees, whereas human factors highlight designs that reduce the risk of human mistakes (Kourinkaetal et al., 1995). Other studies, on the other hand, have found that tackling conventional and environmental risk factors can help keep employees free from injury (Bonger et al., 2002).

The main ideas utilized in security and ergonomic literature are risk and risk factors. The possibility that an event will occur and the severity of the consequences are referred to as risk. The amount of injuries or accidents that occur as a result of a specific exposure is used to define risk. At the extreme risk level, the risk of damage could be low, but the consequences are severe, such as fatalities, or the probability is higher, but the severity of the effects is lower (e.g., slip, trip and fall).

Risk factors are conduct or situations that increase the likelihood of musculoskeletal injury. Ergonomics research has revealed a small set of common physical risk factors for a variety of professions and working circumstances (Elements of Ergonomics Programs: A Primer Based on Workplace Evaluations of Musculoskeletal Disorders, 1997). The connections of risk factor exposure to the amount of MSD risk are difficult to quantify. Although physical risk factors are important risk factors in the very first line, other factors, such as organizational and psychosocial variables, may also lead to disease or indirectly affect physical risk factors (Kourinkaetal et al., 1995).

Ergonomics Risk Factors (ERFs) are scenarios that exist or are intentionally or unintentionally created which may or may be able to contribute to outcomes that contradict or conflict with the principles or the ergonomic philosophy and which may harm workers or employees at work or after work (Rani, 2003). Comprehension and awareness about the adverse characteristics of ERF are crucial and required for the implementation of countermeasures prior to remedies to problems.

The ERF's basics include repeatability, strength, an unpleasant posture, vibration, contact stress, static charge, and high temperature. Risk exposure is an early warning of more serious problems – indications of the body and symptoms that can lead to catastrophic harm. Long-term risk exposure diminishes the quality of one's life. Each job involves a certain hazard. Relative risk is the essential issue. Finally, the ERFs discussed in this study include uncomfortable posture, extended standing, and repetition.

2.2.1 Awkward Posture

The position of different parts of the body is called posture. Your muscles, tendons and ligaments must work harder and more stressed when you have an abnormal posture. Awkward posture occurs when a joint of the body bends excessively or twists outside its usual sphere of movement.

Awkward postures can be resulted in many types of work activities, such as:

i. Leaning sideways

ii. Bending down to work at a low level

iii. Reaching overhead

iv. "flaring" the elbows out to the side

v. Bending the wrist when moving objects

vi. Bending the neck down to look at small components

vii. Twisting part of the body

Static posture is when a stance is kept for an extended period of time. You will have muscular aches and pains. Posture is one of the most commonly mentioned occupational risk factors (Armstrong and Lifshita, 1987).

A high risk of damage is associated with an awkward stance. The more a joint differs from its neutral (normal) position, the more likely the injury is to be experienced. Working behaviors (bending to collect a parcel; bending the wrist to assemble a part) or size of the work area may generate postural issues (extended reach to obtain a part from a bin at a high location; kneeling in the storage bay of an aeroplane because of confined space while handling luggage). Injuries in the wrist, shoulder, neck and low back are all connected with specific positions.

2.2.2 Prolonged Standing

Prolonged standing is characterized as standing for more than an hour without moving from the workplace and standing for more than four hours daily (OSH WIKI, 2020). A recent study suggests that workers' exposure to extended-standing is more than 50% of total working hours spent over a complete work shift (Tomei et al., 1999). Long-term standing can produce discomfort and muscle stress, especially in the lower extremities of the employees, before the end of the workday.

Insufficient rest times during standing periods, together with incorrectly constructed footwear and workstations, not only lead to discomfort and muscle tiredness but can also create long-term occupational injuries. In the worst-case scenario, the effects of longer service life might lead to lower output and efficiency, higher medical expenses and demoralized personnel. For example, if a person suffers from long term injuries or discomfort, it might be difficult to do the task successfully under these conditions. In addition, health specialists must be recommended to those suffering from workplace accidents, which will undoubtedly incur significant consulting and prescription expenditures (Halim, 2012).

2.2.3 Repetition

The repetition rate is the average number of movements or exercises made through joint or body connection within a unit of time or doing identical motions with the same body part with minimum rest or restoration. Repetition is defined by excessive repetition of the same motion or set of movements. The same muscles are used repeatedly to perform a job with little chance of rest or recuperation. This is used for large as well as for tiny muscles. Where extra risk factors exist, employees are more susceptible to recurring injuries (such as an awkward posture or heavy force). The re-extension and overuse of certain muscle groups that are repeating the same or comparable movements over time might contribute to muscular fatigue. The symptoms are often connected to stabilizing or antagonistic tendons and muscles used for positioning and supporting the extremities of the space and not to repeated motions of the tendons and muscle groups. By rotating jobs, muscle groups can be alternated with rest intervals, which can be beneficial to minimize tiredness.

The time measurement of the same exercise during an activity is also repetition. A warehouse worker can lift and put three boxes on the floor every minute; a worker can produce 20 items per hour. Repeating motions were associated with injury and employee discomfort (Armstrong and Lifshita, 1987). The larger the number of repetitions, the higher the risk. However, the relationship of repetition and injury risks is influenced by additional risk variables, such as force, posture, length and recovery period. There is no connection between the injury and a specific threshold value (cycles/unit of time, movements/unit of time).

2.3 Musculoskeletal Disorders (MSDs)

"Musculoskeletal Disorders (MSDs)" refer to a group of inflammatory and degenerative disorders that affect a small number of body parts, including muscles, tendons, ligaments, joints, peripheral nerves, and blood vessels. These include clinical syndromes such as tendon inflammations and associated diseases (bursitis, epicondylitis), nerve compression (carpal tunnel syndrome), osteoarthritis, and clearly characterized diseases such as lower back pain or other unrecognized body part pain syndromes. The underside, neck, shoulder, forearm and hand are the most commonly affected areas of the body. Recently, greater emphasis has been placed on the lower extremities.

MSDs take place in various countries, leading to substantial costs and severe consequences for the quality of life. Although not caused in particular by employment, in many countries, they contribute to a substantial proportion of all registered and/or compensable occupational illnesses. The incidence and prevalence of MSDs are difficult to obtain accurately, and the official data are difficult to compare. However, MSDs represent one-third or more of all recognized employment diseases in the USA, Nordic countries and Japan. They are the most prevalent form of working-related sickness (Bernard, 1997; National Research Council, 2001; Pope et al., 1991 & Sjogaard, 1993). MSDs cause work absenteeism or disability issues in the US, Canada, Finland, Sweden and England, compared to any other illness category (Badley et al., 1994; Feeney et al., 1998; Lejion et al., 1998; Rempel, 1997).

In some industries and occupations, MSDs occur at a rate three to four times higher than the total frequency. All of these sectors are high risk: care homes, air transport, mining, food processing, leather tanning and heavy and light manufacturing (electrical and electronic devices, automobiles, furniture) are all high-risk industries (Bernard, 1997). Based on both experimental and epidemiological studies, the physical functions frequently cited as risk factors for MSDs include rapid work pace and repetitive movement patterns: inadequate time for recovery; heavy lifting and manual effort; non-neutral postures of the body - be it dynamic or static; mechanical pressures; segmental or whole-body vibration; local or whole-body cold exposure; and any of these in conjunction with each other or with negative psychosocial work environment elements such as excessive demands and a lack of control over one's own job.

2.3.1 MSDs Trend in Malaysia

In Malaysia, according to Social Security Organization (SOSCO), the total number of cases reported increased from 2013 to 2018 (refer to Figure 2.1). This leads to an increase in MSDs compensation to employees (refer to Figure 2.2). Based on the figures, it is clear that the number of MSDs have been increasing over the years.

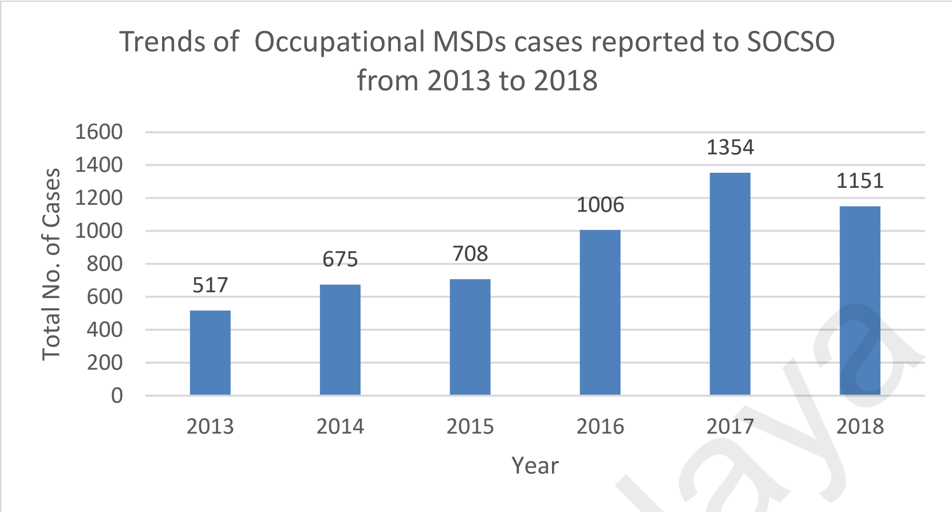

Figure 2.1 Trends of Occupational MSDs cases reported to SOCSO from 2013 to 2018

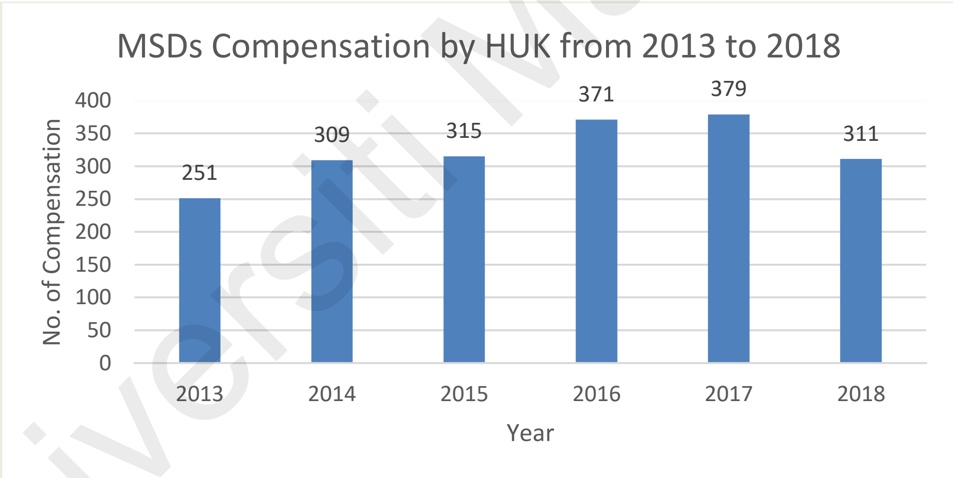

Figure 2.2 Trends of MSD compensation from SOSCO from 2013 to 2018 (by HUK)

Source: SOCSO Annual Report 2013-2018

Furthermore, some researchers conducted a study on occupational risk factors to female workers in the maquiladora industry, including over 100 workers from the electronic industry. They discovered that the probability of reporting lower back, upper back, neck, shoulder and leg discomfort was increasing by 20 to 35% compared to non-assembly employees (Harlow et al. 1999). Tan (1997) found similar findings from two electronic assembly factories in Malaysia producing electronic components and audio equipment. More than 40% of employees experienced neck and back musculoskeletal issues.

There are few studies that have been conducted at semiconductor factories in Malaysia. A cross-sectional study of Malaysian workers (N=200) in several processes of a semiconductor manufacturing industry were evaluated for whole-body postural risk using the Rapid Entire Body Assessment (REBA) was carried out by Abdullah et al. (2009). The result of the study was that over 60% of the workers were found to be at very high risk, while over 30% were considered high risk. Besides that, there is similar research done by Chandrasakaran et al. (2003). Similar ergonomic issues with over 80% of workers having MSDs symptoms in the past year with the back (57.8%), lower leg (48.8%) and shoulder (44.8%) being the most common areas. Both of these studies demonstrated a clear relationship between musculoskeletal pain and the semiconductor industry.

2.4 Summary

In conclusion, the prevalence of ergonomic risk in the electronics industry is very high as they are human-based production systems, especially in the assembly area. Thus, to reduce the risk of a worker developing MSDs in this factory, this project is carried out to analyze, assessed and identified the possible risk factors of MSDs. Assessment will be carried out based on the operators' daily tasks, and the risk level will be analyzed. This will allow the relevant department to come up with an appropriate mitigation method in order to reduce the risk of MSDs among the operators.

CHAPTER 3: METHODOLOGY

3.1 Methodology

The study was conducted in electronic manufacturing situated in Port Klang, Selangor. The company's main activities are printed circuit board assembly, cable assembly, electromechanical assembly, and testing. In general, the company consists of several workstations such as SMT line, DIP, and Final Assembly (FA). The end products of the company are innovative audio, speakers and handheld devices. One of the lines in FA has been chosen for this case study. There is a total of 15 operators being assessed. Eight operators are from the assembly, five operators from the inspection and two from the packaging process.

The ergonomic assessment technique being used in this study was Rapid Upper Limb Assessment (RULA) to identify the most critical ERFs present at the workplaces. Once the critical ERFs were identified, it was modelled, and control measure was proposed to minimize the risk of occupational hazards.

Firstly, in order to assess the ergonomic risks of the workstation and task design of an active electronic manufacturing line, a workstation in the final assembly that involved much manual handling has been chosen. Operators are being observed from a 1-metre distance, and photos of their postures for each task has been taken. Based on the images taken for each task, a RULA assessment was carried out. The risk score was obtained, and the task/ area that falls under medium and high risks are being identified.

Next, to achieve the second objective, to propose mitigation measures to reduce the risk of the ergonomic risk, human simulation (Siemens PLM Software, Jack 9.0) was used. The workstation was redesigned using human simulation. Then in order to justify the possibility of improvement on the ergonomics risk of the proposed mitigation measure, RULA assessment was carried out again to assess the risk of the redesigned workstation. Comparison between the existing workstation and redesigned workstation was carried out to identify the effectiveness.

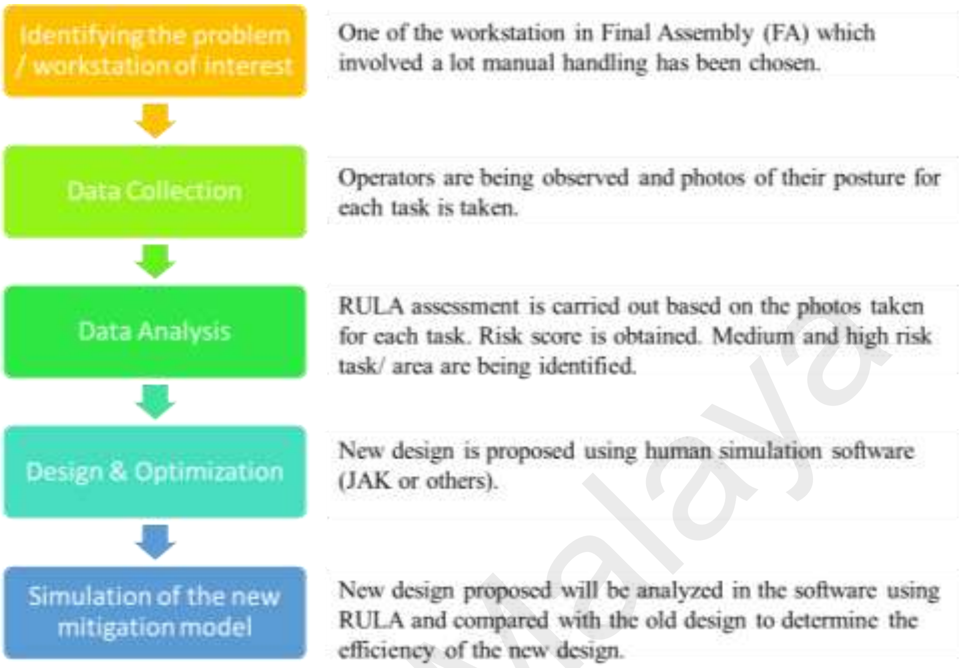

Figure 3.1 Process flow of this study

3.1.1 Working Posture Assessment

The Rapid Upper Limb Assessment (RULA) was applied to assess workers' working posture while performing jobs in their workstations. The outputs of RULA is in the form of scores and action level for the assessed poses. The score obtained from the RULA assessment represented the level of MSD risk present (refer to table 3.1).

Score	Level of MSDs Risk
1-2	Negligible risk
3-4	Low risk
5-6	Medium risk
7	High Risk

Table 3.1 Description of RULA score

"Action level 1" means that the present posture is acceptable if not maintained or repeated for lengthy durations. "Action level 2" implies that more research and modifications may be necessary." Action level 3" implies that an investigation and adjustments are soon necessary. "Action level 4" implies an imminent need for investigation and adjustments. Table 3.2 action levels in RULA method.

Action Level	Description
1	The posture is acceptable if it is not maintained or repeated for long periods
2	The postures needs further investigation and changes may be required
3	The postures needs investigation and changes are required soon
4	The postures needs investigation and changes immediately

Table 3.2 Description of Action Level

To perform RULA analysis, any inputs pertaining to the physical of workers and working environments need to be considered. It comprises the body dimensions (anthropometry) of workers and information on working postures such as angles of the upper arm, wrist, lower arm, neck and trunk, legs condition; mode of posture either static, intermittent or repeated; the shoulders and arms either supported or unsupported; the arms are working across body midline, and the body position whether balanced or unbalanced. All data were observed, evaluated and recorded to determine the postural loads of the assessed worker.

Since the working posture of a worker is directly determined by the relationship of the body parts orientation and the workstation, the study focused on analyzing and proposing a better workstation design to improve working posture. The study comprises two stages of working posture assessment. The first stage of evaluation is carried out at the existing workstation. On the other hand, a second stage assessment is performed when ergonomic intervention has been proposed to the workstation. To reduce cost and time saving, the proposed ergonomic intervention was evaluated through computer simulation. Finally, the effectiveness of the proposed ergonomic intervention was determined by comparing the results from both stages of assessment.

3.1.2 Working Posture Assessment at Existing Workstation

The workstation at the soundbar assembly line, from assembly to inspection to packaging, was selected as a case study. Operators are being observed in the way they perform their daily tasks and assessed using RULA. Each operator is stationed at the workstation permanently from 8 am to 6 pm daily. They only have an hour break in between.

3.1.3 Working Posture Assessment at Redesigned Workstation

The workstation was redesigned using computer simulation after RULA analysis has been performed. The outcomes of RULA analysis will give information on which body orientation need immediate improvement. This information enables the researchers to propose appropriate control measures to improve working postures. Once the existing workstation has been redesigned on computer simulation and/or when administrative control has been presented, the RULA analysis will be performed again to determine the effects of the new design of the workstation on workers' posture. To validate the effectiveness of redesigned workstations, a comparison of the RULA score between existing and redesigned workstations is carried out.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Historical Data and Observations from Workplace

The design of the workstation is of the standard design from the China branch factory. Due to the difference in the diversity of operators working in Malaysia (which consists of Indonesian, Bangladesh, Nepal, Vietnam), it might be one of the causes of the ergonomic risks present at the workplace.

Ergonomic risk factors (ERF) has been identified through RULA assessment. Among them are discussed as follow:

i. Awkward Posture

Awkward posture implies working in a twisted, extended or flexed position instead of a straight or neutral stance with different portions of the body. If an employee is working on a difficult task, he needs to do more than a neutral task, thereby increasing the muscular focus. This condition causes discomfort, such as tired muscles and lower back pain. For instance, Figure 4.1 shows that the worker arranges the products from the table to the pallet. On the other hand, the worker putting the components into the soundbar. These jobs required the worker to perform them in forwarding bending posture. As an effect, this unsafe posture might lead to lower back pain if it is practiced for long periods.

Figure 4.1 Worker perform the job in an awkward working posture.

ii. Prolonged standing

Furthermore, workers are required to perform their job in a standing manner. They are positioned at the workstation from 8 am to 6 pm daily. There is only an hour break in between. Prolonged standing is defined as standing for more than an hour at the workplace and standing for more than 4 hours each day. Long-term standing can produce discomfort and muscle stress, especially in the lower extremities of the workers, before the end of the workday. Figure 4.2 shows that workers are required to work in a standing manner throughout the day. It was clear that there was no stool provided for the operators too.

Figure 4.2 Workers required to work in standing manner

iii. Repetition

Excessive repetition of the same motion or combination of motions is characterized as repetition. It includes repeatedly using the same muscles to do a job with limited opportunity for rest or recovery. One of the examples can be seen in Figure 4.3, where the workers are required to putting the screw into the soundbar repetitively using the electronic screwdriver.

Figure 4.3 Repetitive movement performed by worker

4.2 Working Posture Assessment using RULA Assessment

4.2.1 Existing Workstation

The ergonomic risk level of each posture has been identified by RULA assessment. The RULA assessment is carried out based on the 95th percentiles of the population. Based on the RULA assessment, there are 4 postures with high risk, 5 postures with medium risk and 10 postures in low risk. The score obtained from the RULA assessment are then converted into action levels (refer to Table 4.1). Postures with action level 4 require investigation and immediate changes, whereas postures with action level 3 requires analysis and changes are needed soon. Details of the RULA assessment found that several body parts such as the upper arm, wrists, lower arms, neck, trunk and legs were affected due to the postures. In other words, these body parts experienced postural stress and required immediate improvement.

Area	Task	Posture	Final Score	Risk Level
Assembly	1		5	Medium
	2		6	Medium
	3	1	7	High
		2	7	High
	4	1	7	High
		2	4	Low
		3	4	Low
	5		6	Medium
	6	1	6	Medium
		1	4	Low
Inspection	7		3	Low

	8	1	4	Low
		2	4	Low
	9		4	Low
	10		4	Low
Packaging	11	1	4	Low
		2	6	Medium
		3	4	Low
		4	7	High

Table 4.1 Risk Level Identified at Existing Workstation

Score	Action Level	No. of Postures
1-2	1	0
3-4	2	10
5-6	3	5
7	4	4

Table 4.2 Summary of Action level

Furthermore, based on the pie chart, it is demonstrated that 30% of the posture analyzed at the assembly area possessed high risk, whereas 40% of the postures fall under medium risk, and 30% are low risks. The poses which demonstrated high risk could be seen from Figures 4.5 and 4.6, respectively, whereas those that fall under medium risk can be seen from Figures 4.7, 4.8, 4.9 and 4.10.

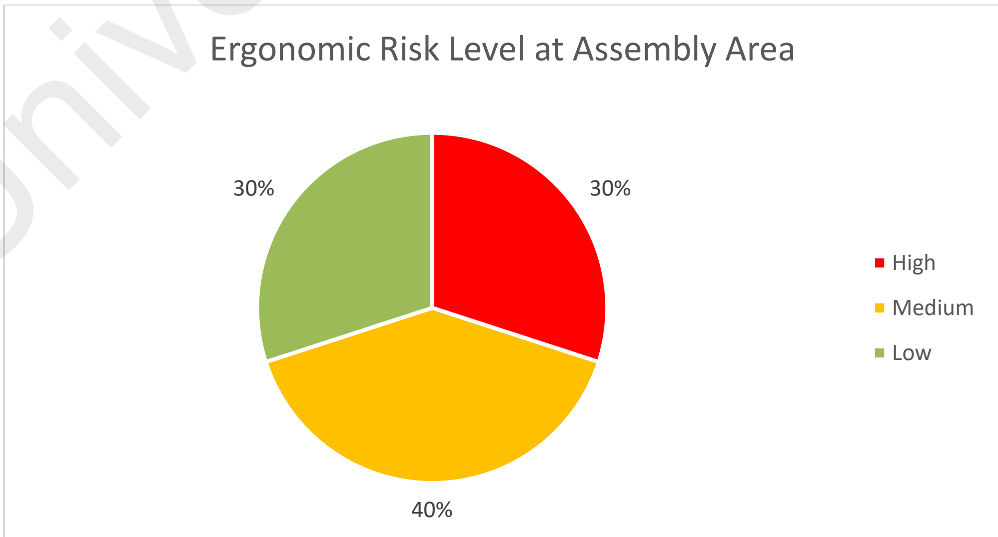

Figure 4.4 Ergonomic risk level at Assembly Area

Figure 4.5 demonstrated the postures of an operator while performing Task 3. The operator is required to screw on the back of the soundbar using the electronic screwdriver. Based on the RULA assessment, the risk score of both postures is 7. On the other hand, Figure 4.6 is one of the postures demonstrated by the operator while performing Task 4. The operator has to fix the wire in the soundbar by using an electronic screwdriver and hot glue gun (if needed). The risk score obtained from the RULA assessment for this posture is also 7.

As we can see, the upper arm position of the operators for both tasks has to be maintained at the level of 20° - 45°, and the upper arm was abducted, whereas the lower arm position is at 100°. Next, the location of the wrist position has to be maintained at the range of 15° throughout the activity. These tasks were repeated four times per minute. The electronic screwdriver weight is around 2 kilograms. The neck position of the operators can be seen at the range of 20°, and the neck is side bending.

Figure 4.5 Postures demonstrated while performing task 3

Figure 4.6 Posture demonstrated while performing task 4

Figures 4.7, 4.8, 4.9 and 4.10 showed the postures that are at medium risk. The risk score obtained for these postures is 5, 6, 6 and 6, respectively. Task 1 and Task 2 are similar activities where the operators are required to put the part into the fixture and paste the components onto the part using a tweezer. From Figures 4.7 and 4.8, we can see that the upper arm of both operators is maintained at 20˚- 45˚, and their shoulders are abducted, whereas the lower arm position is at 100˚. Their neck position is maintained at more than 20˚. These tasks are repeated more than four times in a minute. The difference between Figure 4.7 and 4.8 are the wrist and trunk position due to the operators' height difference.

Postures in Figures 4.9 and 4.10 show that the operators' upper arm and lower arm are at 20˚- 45˚ and 100˚ respectively. Their shoulder is abducted. Both of these tasks are also repeated more than four times in a minute. For Figure 4.9, the neck and trunk positions obtained the second-highest score, three, where the operator is performing the task in a forward bending posture. On the other hand, from Figure 4.10, it is clearly seen that the operator's neck is side bending.

Figure 4.7 Posture demonstrated while performing task 1

Figure 4.8 Posture demonstrated while performing task 2

Figure 4.9 Posture demonstrated while performing task 5

Figure 4.10 Posture demonstrated while performing task 6

Next, tasks performed at the inspection area are all identified as low risk based on the risk score obtained from the RULA assessment. However, in the packaging area, one of the tasks is identified as high risk (25%), one task falls under medium risk (25%), and 2 of the tasks are considered at low risk (50%). This can be seen from Figure 4.11.

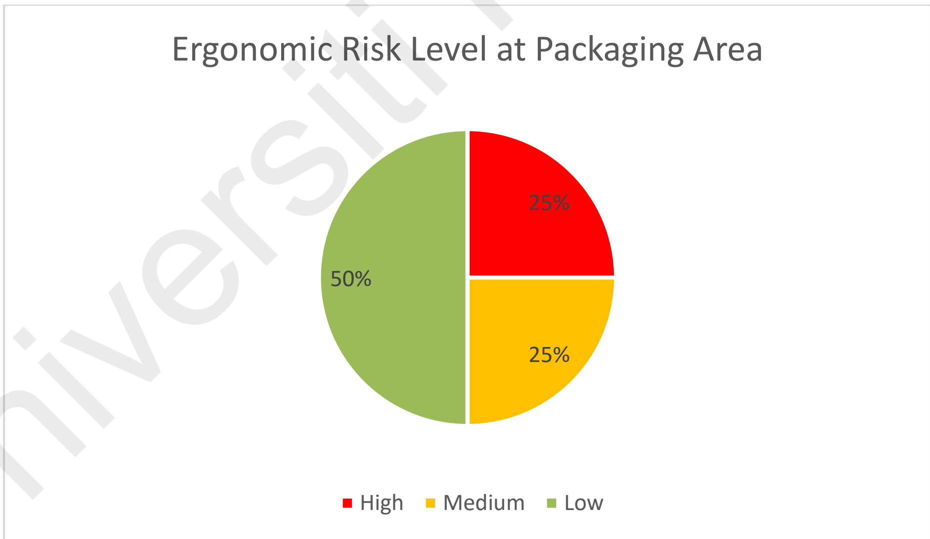

Figure 4.11 Ergonomic risk level at Packaging area

In Figure 4.12, the posture where the operator has to push the box through the sealing machine after pasting the bar code at the side is identified as medium risk. On the other hand, the posture the operator demonstrated while transferring the sealed box from the table to the pallet is identified as high risk.

Figure 4.12 Postures demonstrated while performing task 11

In conclusion, for all these postures identified as medium risk, an investigation shall be carried out to identify possible changes, whereas, for those that are identified as high risk, actions are required immediately to prevent the occurrence of neck pain and lower back pain. After identifying the possible ergonomic risk in existing workstations, these workstations were being redesigned using computer simulation. RULA assessment was performed again for the redesigned workstation. The results show that those who were identified as medium and high risk in existing workstations were all reduced to low risk (refer to Table 4.3).

4.2.2 Redesigned Workstation

The workstation was being redesigned using computer simulation. RULA assessment was performed again for the redesigned workstation. From the results, it is shown that those who were identified as medium and high risk in existing workstations were all reduced to low risk (refer to Table 4.3).

Area	Task	Posture	Final Score	Risk Level
Assembly	1		3	Low
	2		3	Low
	3	1	3	Low
		2	3	Low
	4	1	3	Low
		2	NA	NA
		3	NA	NA

	5		3	Low
	6	1	3	Low
		1	NA	NA
Inspection	7		NA	NA
	8	1	NA	NA
		2	NA	NA
	9		NA	NA
	10		NA	NA
Packaging	11	1	NA	NA
		2	4	Low
		3	NA	NA
		4	4	Low

Table 4.3 Risk Level Identified at Redesigned Workstation

The following control measures have been proposed in the new design of the workstation to improve working postures. For Task 1 and Task 2, it is suggested to provide an adjustable stool for the operators (refer to Figure 4.13). With the help of an adjustable stool, operators are able to adjust the height of the stool, which are comfortable to them where their arms can be supported on the table instead of what is shown in Figure 4.8, where the operator's arm is not supported.

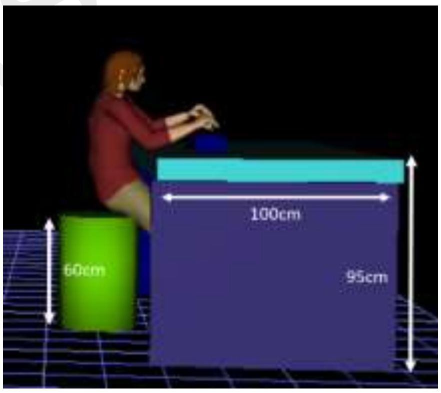

Figure 4.13 Proposed Workstation for Task 1 and 2

Feng et al. (1997) conducted research studying the effects of arm support on the muscular activation of the shoulder and arm during sedentary labor. The findings of the study indicated that the usage of supported activity in both the deltoideus and the upper trapezius exhibited a decreased mean muscle activity. The average muscle activity without arm support for the various occupational activities was over 5% of IMVC, which is indicated for static muscle load. The support of the arm, therefore, plays a key function in minimizing the stress on the shoulder and arm.

For Tasks 3, 4, 5 and 6, the existing workstation is of the same design. Figure 4.14 demonstrated the proposed workstation. The control measure proposed for the workstation is to adjust the table from 95 cm to 105 cm. However, it is best to have an adjustable table so that the operators are able to adjust their workstations according to their height. This modification eliminated extreme flexion of the neck and trunk position. It is also suggested to have a bigger workspace for the operators so that their movements will not be restricted, as we have seen in Figure 4.9.

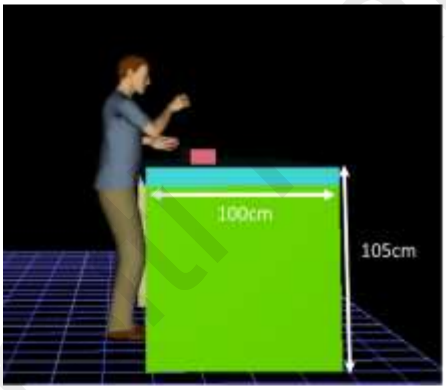

Figure 4.14 Proposed Workstation for Task 3, 4, 5 and 6

In a study by Shikdar and Hadhrami (2007), it has been shown that the performance of the employees may be improved if sufficient table space with height and angle control devices are used. When the workstation is fully adjustable, the operators are allowed to maintain a flexible position during task performance. The ergonomic and method changes made the work more comfortable, less fatigue and more efficient.

Furthermore, ergonomic training is suggested for the operators working in the packaging area so that they are able to carry out their tasks in a correct posture. For instance, in the task where the operator has to push the box through the sealing machine, it is recommended to push the box from the side instead of the middle. On the other hand, it is also suggested to purchase a pallet lifter where the height can be adjusted accordingly (refer to Figure 4.15) so that the operator will not perform his job in a forward bending posture while transferring the box to the pallet. This will eliminate the risk of lower back pain. According to Marras et al. (2000), lift tables have been found to considerably minimize the occupational risk and incident rate for lower back discomfort, probably by lowering peak torso bending as well as the time of external load.

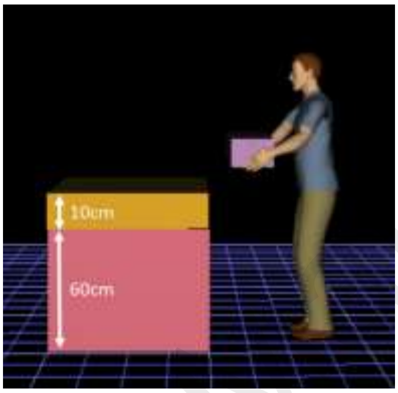

Figure 4.15 Proposed pallet lifter for packaging area

The study also found that the repeat frequency of the posture has influenced the RULA score. It is expected that the posture will be safer if the repeat frequency is controlled to be less than four times per minute. Job rotations are proposed to be one of the control measures. Few researchers have found that job rotation is known as an appropriate administrative control to reduce physical workload (KUIJER et al., 1999, Mossa et al., 2016) in the human based production system (e.g. assembly line), to prevent MSDs, to increase job satisfaction and thus productivity.

Comparison results of the RULA score proved that the effectiveness of the redesigned workstation in improving working posture. The current workstation required employees to work in an uncomfortable way, as indicated by the RULA score of 5-7. In contrast, the redesigned workstation has promoted safe working postures, as shown by the RULA score of 3-4 while performing their task. Interestingly, both unsafe working posture body rotation and extreme flexion have been eliminated.

CHAPTER 5: CONCLUSION

5.1 Conclusion

Identifications of ERFs in the workplaces has been carried out and the ergonomic intervention has been proposed. The findings of the current study are through workplace observation and photo-taking, ERFs associated with awkward posture, repetitive movement and prolonged standing have been identified as potential threats for occupational injuries in the company.

Two stages of working posture assessment at an existing workstation and redesigned workstation have been carried out. The previous workstation was judged to be dangerous since it forced employees to do duties in difficult postures. Out of the 19 postures, four are high risk (21%), five medium risks (26%), and ten are low risks (53%). Among the high risk, three are from the assembly area (75%), whereas the remaining one is from the packaging area (15%). Modifications of the workstation have been proposed to the existing workstation. Moreover, the comparison result of RULA analysis revealed that the redesigned workstation had promoted an effective solution to improve working posture. Based on the RULA analysis, those who were identified as medium and high risk were all reduced to low risk at the redesigned workstation.

Furthermore, administrative control such as job rotation and ergonomic training for the operator has been proposed. This study has found that the repeat frequency of the posture influenced the RULA score. . It is expected that the posture will be safer if the repeat frequency is controlled to be less than four times per minute.

In conclusion, there appears to be an association between the electronic manufacturing industry and ergonomic hazards causing pain/ discomfort to the workers. This association appeared to hold regardless of the factory location and sub-sectors of the industry. The ergonomic risks faced by workers in the electronic industry will continue to be a high focus topic as the industry is projected to grow. Therefore, it is crucial that further research can be done to continue to increase the amount of evidence of this association.

REFERENCES

Abdullah, A.S., Rahman, A. & Nasrull, M. (2009). Ergonomic assessment of working postures in semiconductor manufacturing process. *National Symposium on Advancements in Ergonomics and Safety, 1-2 December*.

Amstrong, J. J., & Lifshita, Y. (1987). *Evaluation and design of jibs for control of cumulative trauma disorders. Ergonomic interventions to prevent musculosketal injuries in industry*. Chelsea, Lewis Publisher, Inc.

Badley, E. M., Rasooly, I., & Webster, G. K. (1994). Relative importance of musculoskeletal disorders as a cause of chronic health problems, disability, and health care utilization: findings from the 1990 Ontario Health Survey. *The Journal of Rheumatology 21*, *3*, 505–514.

Bernard-BP. (1997). *Musculoskeletal disorders and workplace factors. A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back.* (No. 97–141). NIOSH. https://www.cdc.gov/niosh/docs/97-141/

Bongers, P. M., Kremer, A. M., & Laak, J. T. (2002). Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: A review of the epidemiological literature. *American Journal of Industrial Medicine*, *41*(5), 315–342. https://doi.org/10.1002/ajim.10050

Brooks, A. (1998). Ergonomic approaches to office layout and space planning. *Facilities*, *16*(3/4), 73–78. https://doi.org/10.1108/02632779810205602

Chandrasakaran, A., Chee, H.L., Rampal, K.G. & Tan, G. L. E. (2003), The prevelance of musculoskeletal problems and risk factors among women assembly workers in the semiconductor industry. *Medical Journal of Malaysia*, *58(5), 657-666.*

Elements of Ergonomics Programs: A Primer Based on Workplace Evaluations of Musculoskeletal Disorders (No. 97–117). (1997). https://www.cdc.gov/niosh/docs/97-117/

Feeney, A., North, F., Head, J., Canner, R., & Marmot, M. (1998). Socioeconomic and sex differentials in reason for sickness absence from the Whitehall II study. *Occupational and Environmental Medicine*, *55*(2), 91–98.

Feng, Y., Grooten, W., Wretenberg, P., & Arborelius, U. P. (1997). Effects of arm support on shoulder and arm muscle activity during sedentary work. *Ergonomics*, *40*(8), 834–848. https://doi.org/10.1080/001401397187829

Fernandez, J. E. (1995). Ergonomics in the workplace. *Facilities*, *13*(4), 20–27. https://doi.org/10.1108/02632779510083359

Halim, I., Omar, A. R., Saman, A. M., & Othman, I. (2012). Assessment of Muscle Fatigue Associated with Prolonged Standing in the Workplace. *Safety and Health at Work*, *3*(1), 31–42. https://doi.org/10.5491/shaw.2012.3.1.31

Harlow, S. D., Cedillo Becerril, L. A., Scholten, J. N., Monroy, D. S., & Sénchez, R. A. (1999). The prevalence of musculoskeletal complaints among women in Tijuana, Mexico: sociodemographic and occupational risk factors. *International Journal of Occupational and Environmental Health*, *5*(4), 267–275.

Jaffar, N., Abdul-Tharim, A., Mohd-Kamar, I., & Lop, N. (2011). A Literature Review of Ergonomics Risk Factors in Construction Industry. *Procedia Engineering*, *20*, 89–97. https://doi.org/10.1016/j.proeng.2011.11.142

Kourinkaetal, I., Hagberg, M., & Forcier, L. (1995). *Work-Related Musculoskeletal Disorders Wmsds*. Taylor & Francis.

KUIJER, P. P. F. M., VISSER, B., & KEMPER, H. C. G. (1999). Job rotation as a factor in reducing physical workload at a refuse collecting department. *Ergonomics*, *42*(9), 1167–1178. https://doi.org/10.1080/001401399185054

Lee, K. (2005). Ergonomics in total quality management: How can we sell ergonomics to management? *Ergonomics*, *48*(5), 547–558. https://doi.org/10.1080/00140130400029282

Leijon, M., Hensing, G., & Alexanderson, K. (1998). Gender trends in sicklisting with musculoskeletal symptoms in a Swedish county during a period of rapid increase in sickness absence. *Scandinavian Journal of Social Medicine*, *26*(3), 204–213.

Marras, W. S., Allread, W. G., Burr, D. L., & Fathallah, F. A. (2000). Validation of a Low-Back Disorder Risk Model in a Prospective Study of Ergonomic Interventions into Manual Materials Handling Jobs. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*(29), 5. https://doi.org/10.1177/154193120004402902

Mossa, G., Boenzi, F., Digiesi, S., Mummolo, G., & Romano, V. (2016). Productivity and ergonomic risk in human based production systems: A job-rotation scheduling model. *International Journal of Production Economics*, *171*, 471–477. https://doi.org/10.1016/j.ijpe.2015.06.017

Musculoskeletal disorders and prolonged static standing: OSHwiki. (2020). OSH WIKI. https://oshwiki.eu/wiki/Musculoskeletal_disorders_and_prolonged_static_standing

National Research Council. (2001). *Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities*. National Academies Press.

Pao, T., & Kleiner, B. H. (2001). New developments concerning the occupational safety and health act. *Managerial Law*, *43*(1/2), 138–146. https://doi.org/10.1108/03090550110770462

Pope, M. H., Andersson, G. B. J., Frymoyer, J. W., & Chaffin (Eds.), D. B. (1991). *Mosby-Year Book*. Inc, St Louis, MO.

Rani, M. R. A. (2003). *Managing Ergonomics Risk Factors at Workplace*. NIOSH 6th National Conference and Exhibition on Occupational Safety and Health, Petaling Jaya, Malaysia.

Rempel, D. M., & Punnett, L. (1997). Epidemiology of wrist and hand disorders. *M. Nordin, G.B. Andersson, M.H. Pope (Eds.), Mosby-Year Book, Inc, Philadelphia, PA*, 421–430.

Shikdar, A. A., & Hadhrami, M. A. A. (2007). Smart workstation design: an ergonomics and methods engineering approach. *International Journal of Industrial and Systems Engineering*, *2*(4), 363. https://doi.org/10.1504/ijise.2007.013184

Social Security Organisation. (2014). *ANNUAL REPORT 2013*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Social Security Organisation. (2015). *ANNUAL REPORT 2014*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Social Security Organisation. (2016). *ANNUAL REPORT 2015*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Social Security Organisation. (2017). *ANNUAL REPORT 2016*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Social Security Organisation. (2018). *ANNUAL REPORT 2017*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Social Security Organisation. (2019). *ANNUAL REPORT 2018*. https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html

Sjøgaard, G., Sejersted, O. M., Winkel, J., Smolander, J., Westgaard, K., & Westgaard, R. H. (1993). Exposure assessment and mechanisms of pathogenesis in work-related musculoskeletal disorders: significant aspects in the documentation of risk factors, in: O.Johansen, C. Johansen (Eds.), Work and health: Scientific basis of progress in the working environment. *European Commission, Directorate-General V, Employment, Industrial Relations and Social Affairs, Copenhagen, Denmark*, 75–87.

Tan, G. L. E. (1997). Ergonomics in manufacturing industries in Malaysia. Education and Training, Small Industries, Countries in Transition, Theories and Methodologies. *Miscellaneous Topics*, *7*, 160–162.

Tayyari, F., & Smith, J. L. (1997). *Occupational Ergonomics: Principles and applications (Manufacturing Systems Engineering Series, 3)* (1997th ed.). Springer.

Tomei, F., Baccolo, T. P., Tomao, E., Palmi, S., & Rosati, M. V. (1999). Chronic venous disorders and occupation. *American Journal of Industrial Medicine*, *36*(6), 653–665.