DESIGN AND EVALUATION OF ERGONOMIC GRIP HANDLE FOR MANUAL CARRYING OF LONG METAL BAR

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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2021

DECLARATION

I hereby, declared this report entitled "Design and Evaluation of Ergonomic Grip Handle for Manual Carrying of Long Metal Bar" is the result of my own research except as cited in references.

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Date : 15 July 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Aktiviti pengendalian bahan secara manual biasanya dilakukan oleh pekerja di pelbagai industri seperti pembinaan, pembuatan, pertanian, dan automotif. Biasanya, pengendalian bahan manual seperti pemindahan logam panjang akan dilakukan secara manual oleh dua pekerja kerana kos buruh yang rendah. Sekiranya permintaan logam panjang tinggi, pekerja mungkin mengalami 'gangguan otot-berangka disebabkan kerja' kerana proses pemindahan yang berulang-ulang. Dalam keadaan terburuk, logam panjang bergoyang dan berayun semasa proses permindahan. Oleh itu, ini akan menyebabkan pergerakan tidak stabil pada logam pajang semasa proses pemindahan dan mempengaruhi kekuatan genggaman tangan pekerja. Objektif kajian ini bertujuan menentukan keperluan reka bentuk dan kehendak pengguna bagi pemegang cengkaman ergonomik untuk membawa bar logam panjang secara manual, merancang pemegang cengkaman ergonomik berdasarkan keperluan reka bentuk dan kehendak pengguna serta membuat dan menilai prestasi prototaip ketika membawa bar logam panjang secara manual. Terdapat 50 peserta terlibat dalam pengukuran data antropometrik untuk merancang pemegang cengkaman ergonomik. Tinjauan soal selidik dilakukan untuk menentukan keperluan pengguna. Setelah itu, "*Quality Function Deployment*" diaplikasikan untuk menganalisis hubungan antara keperluan pengguna dan spesifikasi kejuruteraan pemegang cengkaman. Beberapa lakaran dilukis berdasarkan hasil yang diperoleh dari QFD. "*Pugh Conceptual Selection*" digunakan untuk memilih konsep yang terbaik bagi menghasilkan lukisan kejuruteraan dan prototaip. "*System Usability Scale*" digunakan untuk menilai kebolehgunaan prototaip. Hasil pengujian kebolehgunaan adalah 77.08 dari 100 telah ditakrifkan prototaip sebagai "baik". Tambahan pula, "*Carry Analysis*" disimulasikan dengan megggunakan perisian "*CATIA*" dan hasil membawa bar logam panjang menggunakan tangan berbanding menggunakan prototaip ialah 231.831 N dan 283.718 N. Oleh itu, membawa logam panjang dengan pemegang cengkaman ergonomik tidak melebihi jarak menegak tangan dan disimpulkan prototaip dapat membantu pengguna atau pekerja semasa proses pemindahan logam panjang secara manual serta memenuhi keperluan ergonomik.

ABSTRACT

Manual materials handling (MMH) activities are typically performed by workers in various industries such as construction, manufacturing, agricultural, and automotive. Usually, MMH associated with transferring of long metal bar will be carried out manually by two workers due to relative low labour cost. If the demand for metal bar is high, worker might be suffered from the Work-Related Musculoskeletal Disorder due to repetitive transferring process. In worst case scenario, long metal bar may be wobble and swing during the carrying process. Hence, it may lead to unstable motion on the metal bar while transferring process and affect the hand grip strength of workers. The objectives of this study were to identify the design requirements and user's requirements of an ergonomic grip handle for manual carrying long metal bar, design an ergonomic grip handle based on the design requirements and user's requirements as well as to fabricate and evaluate the performance of the grip handle prototype in manual carrying of long metal bar. There were 50 participants involved in anthropometric data measurement for designing the grip handle. A questionnaire survey was performed to determine users' requirements. Subsequently, Quality Function Deployment (QFD) was applied to analyze the correlation between users' requirements and engineering specification of the grip handle. Few sketches were created based on the result obtained from the QFD. Pugh Conceptual Selection was developed to choose the best design. The best selected conceptual design was converted into engineering drawing and a prototype was fabricated. The System Usability Scale was applied to evaluate the usability of the prototype. The result on usability testing is 77.08 out of 100 which defined the prototype as "Good". Additionally, carrying analysis was simulated by using CATIA software, the results of carrying a long metal bar using bare hand versus using the prototype are 231.831 N and 283.718 N, respectively. Hence, carrying long metal bar with the ergonomic grip handle will not exceed the standard of hand vertical distance. Therefore, this study concluded that the grip handle prototype was able to assist users or workers to perform manual carrying of long metal bar that fulfil to ergonomics requirements.

DEDICATION

Special dedication to my beloved family and friends
for giving me support, encouragement, and understandings
Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

CAD	-	Computer-Aided Design
EMG	-	Electromyography
FEA	-	Finite Element Analysis
FKP	-	Faculty of Manufacturing Engineering
MMH	-	Manual Material Handling
MSD	-	Musculoskeletal Disorder
QFD	-	Quality Functional Deployment
SOCSO	-	Society Security Organisation Malaysia
SUS	-	System Usability Scale
UTeM	-	Universiti Teknikal Malaysia Melaka
WRMSD	-	Work-Related Musculoskeletal Disorder

LIST OF SYMBOLS

mm	-	millimetre
cm	-	centimetre
kg	-	kilogram
m	-	meter
MPa	-	Megapascal
GPa	-	Gigapascal
N	-	Newton
MPa.m$_{0.5}$	-	Megapascal square root meter

CHAPTER 1

INTRODUCTION

This chapter introduces the background of the study which is related to manual materials handling such as transferring the long metal bar. It has been recognized as one of the common tasks in manufacturing industries and construction sites. Besides, the problem statements of the study are the safety and ergonomic issues during the process of transferring the long metal bar. The objective of the study is to design and evaluate an ergonomic grip handle for manual transferring the long metal bar. The scope and significance of the study will be shown followed by a summary that summarizes the whole chapter.

1.1 Background of Study

Material handling is an invariable part of any manufacturing or service operation' (Rajesh, 2016). For instance, material handling tasks take place in almost all the field including manufacturing, construction, agriculture, workshop, hardware store, etc. Among the example above, material handling tasks is the most frequently occurred at manufacturing industries and construction sites such as transferring the long metal bar, steel plate, etc.

Manual material handling (MMH) can be defined as transfers an object or material either by lifting, lowering, carrying, pushing, or pulling. According to (Rajesh, 2016), Two out of every five workplace injuries reported to the Health and Safety Executive are due to manual handling. Hence, the manual handling handbook is very important to training the workers to follow the standard operating procedure while manual handling an object or material. Even though the safe manual handling method would not make people stronger or able to life a greater load, but it can provide the safe and standard procedure for manual handling an object or material instead to prevent accidents and injuries happen. Figure 1.1 shows the manual handling object.

Figure 1.1: Manual handling object

The metal bar also knows as blank, slug, or billet which is a common material used for manufacturing industries and construction sites. There are several sizes of metal bars which are round, square, hexagon, etc. In manufacturing industries, the metal bars can be fabricated to become a part of the product while in construction sites it is used to develop good bond strengths with concrete on the building. In manufacturing industries, the long metal bar will be manufacture by the traditional manufacturing process to become a part of the product. The traditional manufacturing process involves cutting, milling, drilling, turning, etc. Normally, the long metal bar is stored at the warehouse before sending it to the traditional manufacturing process. If the requirement of the long metal bar to fabricate the product, not a huge portion, generally the long metal bar will be transferred to the machine for the process manually. Hence, the workers manually carrying the long metal bar with a bare hand. Without the dedicated tool support when carrying, can result in strain and fatigue in the hand and arm muscle.

At the construction site, the unloading of the long metal bar from the lorry will be done manually by workers. Due to the huge capacity of the long metal used at the construction site, so the worker must repeat the transferring process of the long metal bar until fully unload. When workers transferring the long metal bar by hand without supportive tools which have the probability to occur safety issues such as the long metal slip and fall from the hand. Besides, the prolonged manual carrying the long metal bar without dedicated tools to risk the factor related to Work-Related Musculoskeletal Disorder (WRMSD).

Work-related musculoskeletal disorders (WRMSDs), defined as a subset of musculoskeletal disorders (MSDs) that arise out of occupational exposures, may lead to work restriction, work-time loss, or consequently cause work leave (Kathy Cheng et al., 2013). 'WRMSD pain is related to the muscles, nerves, tendons, joints, cartilages, and spinal discs associated with exposure to risk factors in the workplace' (Irurhe et al., 2013). Hence, ergonomics play an important role in the workplace to prevent injuries to occur. According to the workplace safety and health report 2019 from the Ministry of Manpower Singapore, the total cases of MSDs are 326 and 293 in the year 2018 and 2019, respectively. The major cause is due to the forceful exertions by manual handling activities. The cases of MSDs mostly took place in industries of manufacturing and construction. Also, according to the report at Great Britain showed the average prevalence rate of WRMSD across all industries was 1,130 cases per 100,000 workers and construction with a rate of 2,020 cases per 100,000 workers averaged over the period 2017/18-2019/20. The main cause of MSDs due to manual handling activities such as lifting a heavy load and improper manual handling method.

Nowadays, there are many types of equipment and hand tools have been designed and fabricated in the market instead to assist industrial practitioners to minimize occupational health risk and work efficiency in lifting and transferring the long metal bar. However, the equipment and hand tools designed which lack ergonomic cause the users' risk to MSDs while manual material handling activities. Hence, ergonomic studies must be conducted to design the grip handle based on Malaysia anthropometric data and strength. This study aims to design and fabricate a high-fidelity prototype of a grip handle for lifting and carrying a long metal bar to improve grip performance, usability, and work efficiency.

1.2 Problem Statement

The long metal bar is a common material used at construction site and manufacturing industries. Normally, all the carrying and transferring of the long metal bar process conduct manually by the workers. Hence, there are many problems and issues that occur if manual carrying and transferring the long metal bar without a proper assist device. Figure 1.2 shows the workers manually carrying the long metal bar.

Figure 1.2: Manual handling long metal bar

From the annual report of the Social Security Organization (SOCSO) in Malaysia, the accident of over-exertion in lifting objects had been analysed in figure 1.3. From the trend, the accident occurs in the gender of male involved more than female because handling the long metal bar is heavy duty. From year 2014 to year 2017, the number of accidents increase steadily and decrease slightly from year 2017 to year 2018.

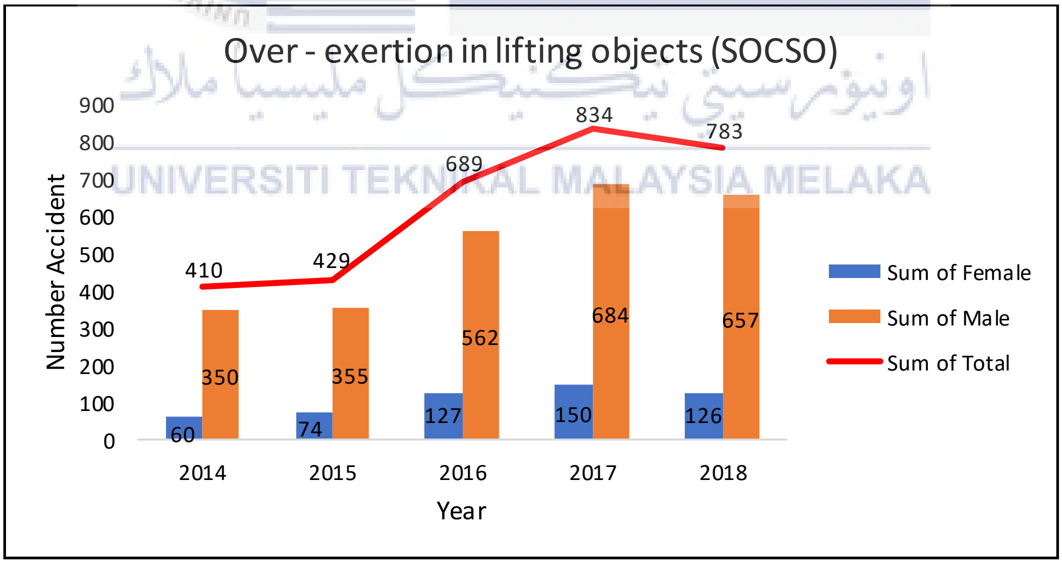


Figure 1.3: Trend of over – exertion in lifting object

1.2.1 Safety and ergonomic issues on manual transferring the long metal bar

Manual handling activities such as lifting and transferring the long metal bar without an assisted tool may occurring poor safety and ergonomic practices. Commonly, the workers are wearing gloves to grasp the load for manual handling activities. However, grasping the long metal bar with a glove becomes more difficult compared to bare hand. Thus, the object can be slipped easily due to the poor and difficult grasping. The workers are hard to grasp the centre of gravity of the load during the transferring process which may be causing the load unstable and unbalanced condition even though it has been gripped by workers. Due to the dimensional of the metal bar is big, workers cannot fully grip the long metal bar surface. As a result, the workers may lose their balance and fall due to the existence of the problem of fatigue and uneven loading of muscles. Figure 1.4 shows the worker unable to enclose the load fully and firmly.

Figure 1.4: Worker is unable to grip the metal bar firmly without a proper grip handle

The metal slip and fall from the hand will have a probability knock on the leg which causes bruised muscles. Bruised muscle is explained as an injury on muscle fibre and connective tissue when the blunt force on the body part. Hence, the blood leaks into the area under the skin resulting in pain, swelling, and skin discoloration. For example, the object falls impact the body part. Figure 1.6 shows the bruised muscles condition on body part.

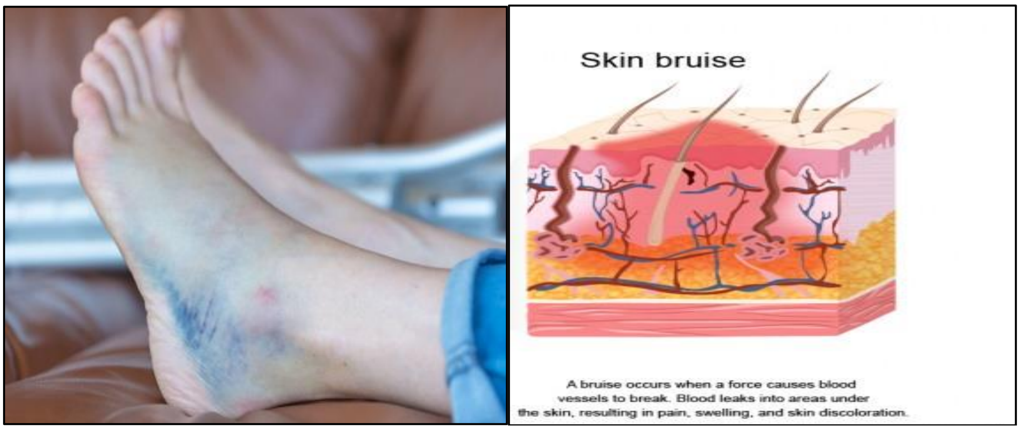


Figure 1.5: Bruised muscles

Besides, ergonomics issue is awkward posture when manual handling the long metal bar. As Figure 1.2 shows one of the postures when handling the long metal bar by two workers, the handling process repeating if the lot size of the metal bar is big. Therefore, the chronic injuries occur due to the prolonged manual handling of the long metal bar by using the method above. For example, it is causing WRMSD as shown in Figure 1.6.

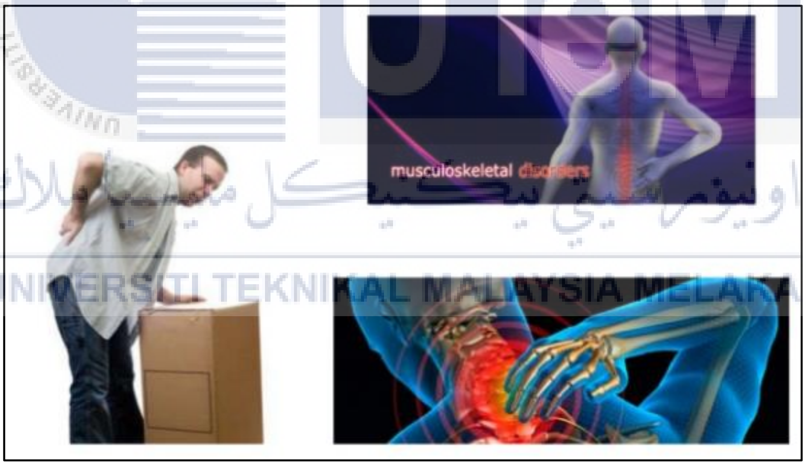


Figure 1.6: Work-related musculoskeletal disorder

To summarize, handling an object or material with a dedicated device is very important to avoid the problems above occur.

1.2.2 Load is wobbling or swinging

When carrying a long metal bar, two or more workers are needed to complete the task. The load may wobble or swing during the manual transferring process. This is because the long length of the long metal bar causes the distance between the workers when they are holding on to the metal bar. Therefore, it will lead to a wave motion on the metal bar while transferring process and affect the hand grip strength of workers. Besides, the effect of wave motion may cause the workers unbalancing during the transferring and thus may occur probability of problem workers fall lead to injuries and fatigue on muscle. Figure 1.7 shows the existence of object wobbling due to the long gripping distance between the workers.

Figure 1.7: Object wobbling due to the long gripping distance between the workers

1.3 Objectives

(a) To identify the design requirements and user's requirements of an ergonomic grip handle for manual carrying long metal bar.

(b) To design an ergonomic grip handle based on the design requirements and user's requirements.

(c) To fabricate and evaluate the performance of the grip handle prototype in manual carrying of long metal bar.

1.4 Scope of Study

This study aims to design a grip handle that allows the worker to work in an ergonomics practice condition when manual handling the long metal bar. This study is mainly cover on the grip handle for use at manufacturing industries, construction site workplace and FKP workshop when manual handling the long metal bar. Due to the pandemic COVID-19, this study will only conduct at the FKP workshop.

The new design grip handle will evaluate the effect of the grip handle on its usability. The usability of the new design grip handle compares with the bare hand condition when manual handling the long metal bar will be conduct in this study. Carry analysis will also involve in this study to determine the maximum acceptable weight can be carried by users with an ergonomic grip handle and bare handle condition. In this study, the participants involved are only Malaysian young adults who are studying under the undergraduate programs of Faculty of Manufacturing Engineering (FKP) and are free from disabilities and injuries on hand.

The new design of the grip handle is mainly needed to solve the issues mentioned in the problem statement. The concepts of design should be based on the feedbacks of members of the Faculty of Manufacturing Engineering Universiti Teknikal Malaysia Melaka (UTeM) including the lecturers, assistant engineers, and students. The fabrication of the prototype basically has to meet the criteria of low cost, safety, and ergonomic use on the tool.

1.5 Significance of Study

There are some benefits that can be gained after the completion of this study. First, by designing and creating a new grip handle for manual transferring the long metal bar that meets the requirement of the users, working conditions, and environment, improvement can be achieved in the aspects of safety, hand tool functionality, and ergonomics factor. Besides, it will be easy to use safely and comfortably for a user when manually transferring the long metal bar. Hence, low the risk of WRMD as well as allow users to work in an ergonomic friendly condition. Lastly, the improvement of productivity of transferring the long metal bar by reducing the time consuming on the gripping process.

1.6 Organization of The Report

To summarize the content of the project, the organization of the study is shown in Figure 1.8.

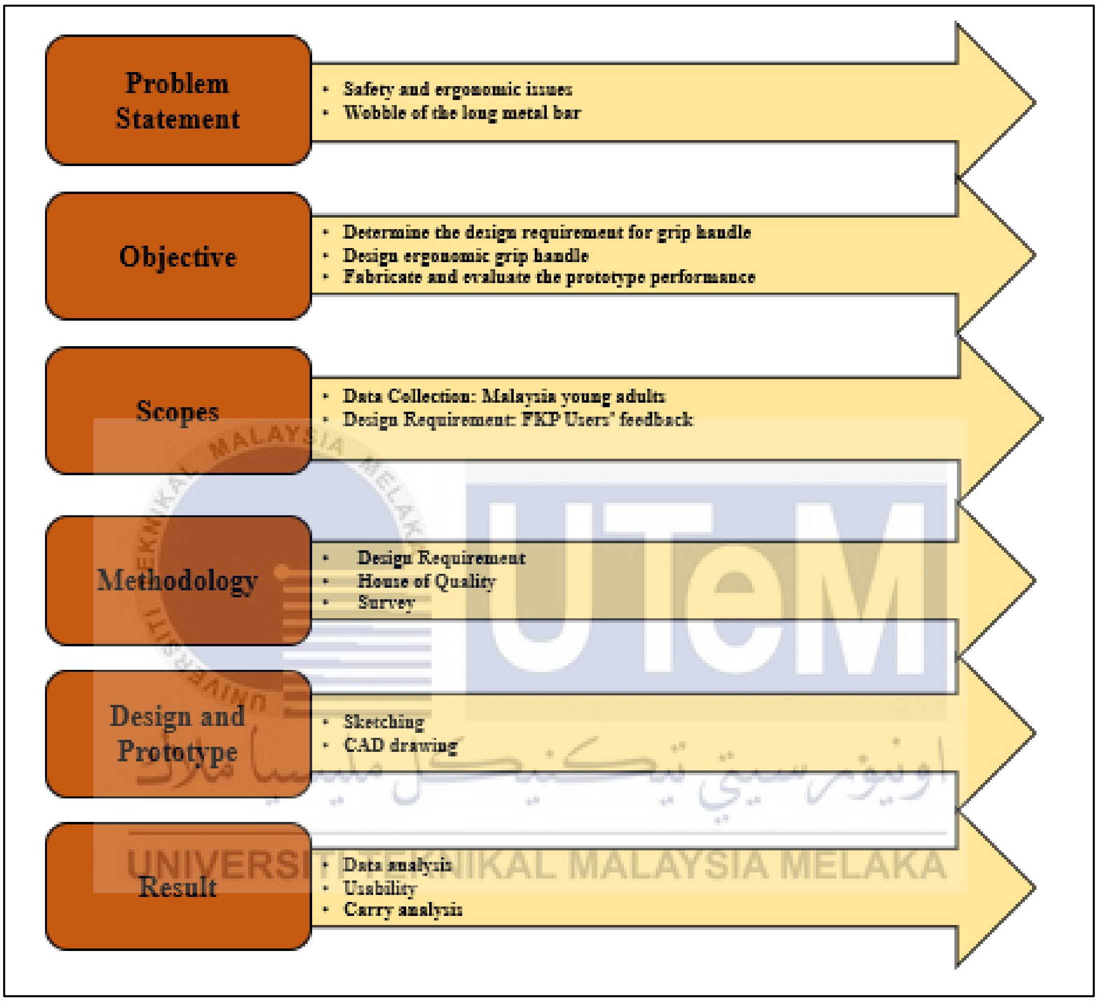


Figure 1.8: Organization of study

1.7 SUMMARY

To conclude, this chapter involved the background of study on design and evaluation of ergonomics grip handle for the manual carrying of the long metal bars in campus workshop, construction site, manufacturing industries, etc. Also, the problem statements are associated with safety and ergonomic issues such as manual carrying long metal bars device easy slip and fall from hand without a dedicated tool. The objectives will conduct on design requirements on the grip handle, design the ergonomic grip handle and fabricate and evaluate the performance of the grip handle. Besides, the scope of the study will conduct on the participants involved are only Malaysian young adults who are studying under the undergraduate programs of Faculty of Manufacturing Engineering (FKP) and are free from disabilities and injuries on arm and wrist. Last but not least, the significance of the study will be summarized.

CHAPTER 2

LITERATURE REVIEW

This chapter will cover the literature review of the study. Literature review is substantive findings of academic knowledge in terms of theory and methodologies of previous studies and experiments will be discussed. This chapter is built according to the objectives of the study and all the information presented is supported with relevant and related journals, books, articles, and other resources.

2.1 Ergonomics

According to the International Ergonomics Association Executive Council (2000), ergonomic can be explained as the scientific discipline related to the studying of the relationship between humans and other elements of a system. An ergonomic used to help human well-being and overall machine or tool performance based on theory, principles data, and methods to design (*Ergonomics Origin and Overview*, 2020).

Nowadays, ergonomic has become an important implementation by many employers to ensure the safety and health factors for the working environment to increase workers working performances. Hence, ergonomic consists enormous advantages instead of cumulative efficiency of the institutes. The advantages included reducing discomforts, increasing productivity, cost, and time saving and increasing morale (Valinejadshoubi & Shakibabarough, 2013).

In fact, few organizations consider ergonomics as an important element of risk management according to the rapid change in technology. Therefore, a lack of ergonomic has been given to cumulative on WRMSD such as injuries from repetitive motions or activity. For instance, MSDs mean injuries to the parts of the body such as muscles, nerves, tendons, ligaments, joints, cartilage, and spinal discs due to prolonged repetitive tasks. Meanwhile, the safety and health of all employees should be considered to prevent compensation claims, losing staff, and late progress on activities or programs (Valinejadshoubi & Shakibabarough, 2013).

2.1.1 Manual material handling

Manual material handling (MMH) can be defined as activities or tasks involved manual lifting, lowering, carrying, pushing, and pulling the load. Nowadays, human contribution as a manual labour resource is still prevalent in current manufacturing activities. MMH is the proper term used to describe the activities. The use of MMH was favoured over machines due to its high versatility and relatively low cost. MMH has an advantage in its versatility if manoeuvring during a quick and light transfer of material as opposed to conducting the same task using mechanical aids. However, repetitive MMH tasks, incorrect transfer position, and process as well as heavy loads, could endanger workers with a risk of WRMSD. This will escalate if it happens continuously and for a long period of time. Incorrect MMH practices are potential threats to Low Back Pain and other MSDs (Deros et al., 2015).

Repetitive MMH is one of the categories of ergonomic risk factors and can be explained doing the same action or movement over and over. The time take for repetition tasks can be short which less than 30 seconds or more than one hour. Hence, using the same muscles and soft tissues continuously makes muscle strain and fatigue. For example, manual material handling activities more than 4 hours on a working day causes the possibility of recurrence a human risk factor that may irritate tendons and increase nerve strain (Valinejadshoubi & Shakibabarough, 2013).

2.1.2 Hand tool

In comparison to the developed countries, workers in developing countries are subject to extreme ergonomic stressors and are also at higher risk for health risks. Hand tools are a major part of work practice in many fields such as agriculture, metal industries, vehicle repair shops, construction site manufacturing assembly industries, and others. An ergonomic hand tool consists of characteristics such as size and weight, shape, and handle influence on the human system. Tools affect the physiological parameter of the user, such as muscle activity, biomechanical parameters such as force exertion, torque, and touch pressure, and subjective perception such as discomfort. After prolonged use of inappropriately designed tools, workers suffer fatigue, accumulated trauma pain, and discomfort in the upper extremities, workplace accident, and stress (Vyas et al., 2016).

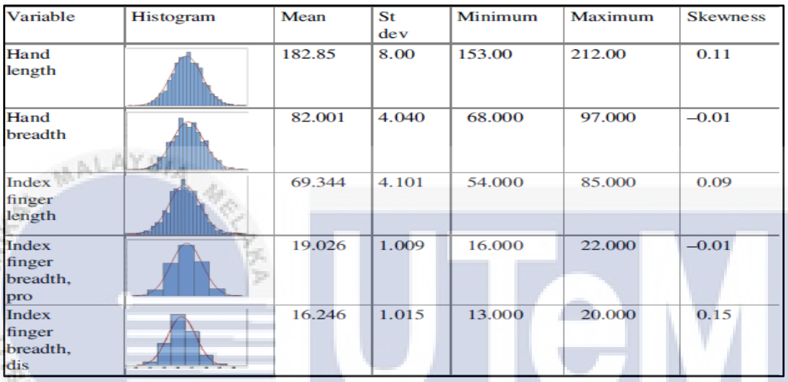
2.2 Hand Tool Design Requirement

A correct tool design is critical for the prevention of musculoskeletal disorders in the upper extremity. Considering the ergonomics of the hand-tool, in addition to its main purpose, the tool handle is the most important component. Tool handle design study has traditionally been limited to the determination of cylindrical handle diameters to increase efficiency and comfort to minimize the chances of Cumulative Trauma Disorder. For instance, blisters, swollen skin, cramped muscles, etc (Wang & Cai, 2017). However, the association of factors such as demographic and anthropometric factors was considered in previous studies (Mohammadian et al., 2016). Handle design of the hand tool is direct influence the task performance, usability, and contact area between the hand and the handle and thus decrease the contact pressure instead to decreased discomfort (Dianat et al., 2015).

2.2.1 Ergonomic design of hand tool

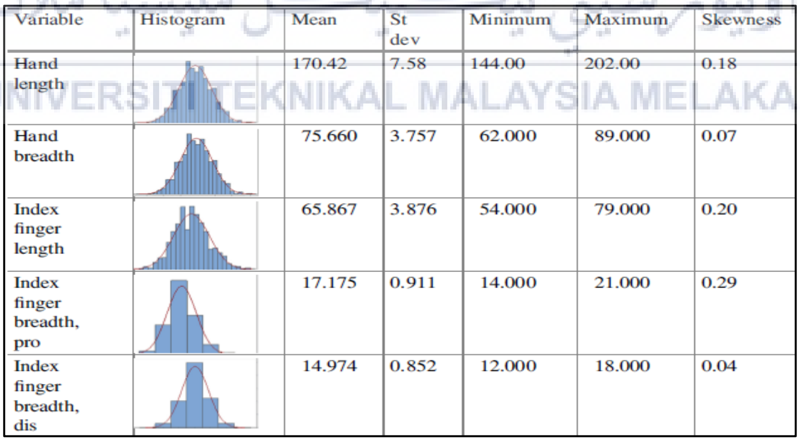
Different demographics such as gender and anthropometric such as height and weight showing different hand shape characteristics. Therefore, these factors are very important for design the proper dimensional grip handle for the user. According to the study of (Zhao et al., 2019), it is important to contribute new knowledge on structuring a size system for men's and women's devices such as hand tools in this modern era. The length of hand, breadth of hand and index finger breadth is totally different between men and women according to the age growing. From the hand shape characterises above, men first increasing and then decreasing between 20-year-old and 50-year-old while women have minor changes on their hand shape characteristic according to their age growing.

In the study had shown the result of the hand shape based on the 4,000 human samples which are 50% male and female respectively between the age of 18-year-old to 50-year-old in china. The analysis had been evaluated based on 5 factors which are hand length, hand breadth, index finger length, index finger breadth; proximal, index finger breadth; distal. The result of men according to the 5 factors are higher than women. For instance, the men's mean of hand length is 182.85 mm while the women's mean of hand length is 170.42 mm. The hand length for men maximum is 212 mm and the maximum hand length for women is 202 mm. Figures 2.1 till Figure 2.4 show the descriptive statics and total mean value of men and women, respectively.



Variable	Histogram	Mean	St dev	Minimum	Maximum	Skewness
Hand length		182.85	8.00	153.00	212.00	0.11
Hand breadth		82.001	4.040	68.000	97.000	–0.01
Index finger length		69.344	4.101	54.000	85.000	0.09
Index finger breadth, pro		19.026	1.009	16.000	22.000	–0.01
Index finger breadth, dis		16.246	1.015	13.000	20.000	0.15

Figure 2.1: Descriptive statistics for men' hands (Zhao et al., 2019)



Variable	Histogram	Mean	St dev	Minimum	Maximum	Skewness
Hand length		170.42	7.58	144.00	202.00	0.18
Hand breadth		75.660	3.757	62.000	89.000	0.07
Index finger length		65.867	3.876	54.000	79.000	0.20
Index finger breadth, pro		17.175	0.911	14.000	21.000	0.29
Index finger breadth, dis		14.974	0.852	12.000	18.000	0.04

Figure 2.2: Descriptive statistics for women' hands (Zhao et al., 2019)

Item	Means by age category (male)					
	≤ 20	≥ 20, ≤ 30	≥ 30, ≤ 40	≥ 40, ≤ 50	>50	Total mean
Hand length	181.66	183.94	182.62	181.96	182.08	182.85
Hand breadth	81.39	82.11	82.24	81.8	81.94	82.001
Index finger length	68.87	69.84	69.13	69.08	68.94	69.344
Index finger breadth, pro	18.82	18.93	19.04	19.2	19.39	19.026
Index finger breadth, dis	15.99	16.16	16.28	16.41	16.58	16.246

Figure 2.3: Total mean value table for men' hand shape (Zhao et al., 2019)

Item	Means by age category (female)					
	≤ 20	≥ 20, ≤ 30	≥ 30, ≤ 40	≥ 40, ≤ 50	>50	Total mean
Hand length	169.93	170.18	170.9	169.87	171.61	170.42
Hand breadth	75	75.24	76.22	76	76.44	75.660
Index finger length	65.82	65.8	65.93	65.77	66.94	65.867
Index finger breadth, pro	16.92	16.96	17.34	17.52	17.56	17.175
Index finger breadth, dis	14.71	14.8	15.11	15.28	15.44	14.974

Figure 2.4: Total mean value table for women' hand shape (Zhao et al., 2019)

2.2.2 Handle diamter

One of the important parts to manufacture a hand tool is the handle. The handle is used as an interconnect between the user's hand and the hand tool in either power or non-powered hand tool. Hand tool which designed ergonomically can enhance grip performance, comfort, and work productivity (Halim et al., 2019). According to the study of (McDowell et al., 2012), the hand length and handle diameter are the elements to improve grip strength. (Dianat et al., 2015) stated that the handle shape diameter between 18 mm to 37mm to obtain the highest hand grip strength while the lowest hand grip strength obtains when the handle shape diameter between 22 mm to 29 mm.

2.2.3 Handle length

Handle length design directly affects the required muscle effort for manual material handling. Longer handle benefits to user transferring the material in a certain distance with a minimum of force applied while short handle length of hand tool cannot meet the breadth of the palm and will experience compression on the muscle nerves and tissues (Halim et al., 2019). From the study of (Veisi et al., 2019), the handle length of the hand tool must more than 100 mm to eliminate the problems of the force exerted when doing the tasks.

2.2.4 Handle shape

Handle shape acts to improve usability and work performance. The handle shape is depending on the method of gripping and pinching the handle by the users (Halim et al., 2019). A proper designed handle shape can eliminate the unconformity of the user during the tasks (Kong et al., 2012). (Dianat et al., 2015) pointed out that the shape of the handle will directly influence the disconformity of the user and the contact pressure when user using the hand tool. Handle shapes designed in round, tapered round, hexagonal, and tapered hexagonal can reduce the muscle load and pinch force during the tasks (Dong et al., 2007).

2.2.5 Tool weight

Tool weight of the hand tool directly affects the grip strength while manual material handling activities. More force exposes by a user to complete manual material handling tasks with a heavy tool as well as decrease the grip strength. Repetitive or continuous activities such as manual material handling with a heavy tool can suffering from muscle strain and pain (Halim et al., 2019). According to the study of the Canadian Centre for Occupational Health and Safety, for designing a precision tools the best weight tool is about 0.4 kg which easier to control and approximately 2.3 kg is an ideal weight for a hand tool that is used above the shoulder height and away from the body.

2.3 Design on Ergonomic Grip Handle

It is not easy work to design a hand tool without proper steps. As the hand tool is not only designed for its functionality but is designed to satisfy the user's comfort as well as ergonomic practice. Develop a new product that meets the user requirement is a key to achieve the goal of product design and development so that customers will desire and buy them (Häggman et al., 2015). This part of the study will be discussing the designing steps and methods carried out by past researchers.

2.3.1 Survey

A questionnaire survey is one of the well-known methods which is used to collect data for academic or marketing research in several of fields. With the improvement of technology, an online questionnaire survey has become a common method to obtain data in recent years because of the cost effectiveness. For example, the price of components used to collect data via online which are hardware and software continuing to decrease. Collect the data which need for a research study via online can obtain usable, reliable, and a vast amount of relevant information within a short period time (Regmi et al., 2017). According to the study of (Taherdoost, 2018) questionnaire survey aimed to collect necessary information with the most accuracy. For instance, the questions aimed to analyse information about product requirements, usability, and ergonomics. From the parameter obtained thought the questionnaire above, it is used to identify two kinds of information which are received information from the sources include target customer, competitor product and general knowledge of product and processed information like product engineering specification such as production, usability and ergonomic (Diban & Gontijo, 2015).

2.3.2 Quality function deployment (QFD)

Quality function deployment (QFD) is an effective technique for identifying and implementing the customer’s requirements and connecting them to a product’s engineering specification requirement. In other words, it is used to translate the customer’s requirement to design and develop a new product (Erdil & Arani, 2019).

In one of the past studies (Zubaidi et al., 2019), indicated how a particular design method, QFD, can be a medium for integrating ergonomics into hand tool design and prevention of occupational risk into work tool design. Figure 2.5 illustrated the house of quality (HOQ) constructed for identifying the engineering specifications of cutting board sets.

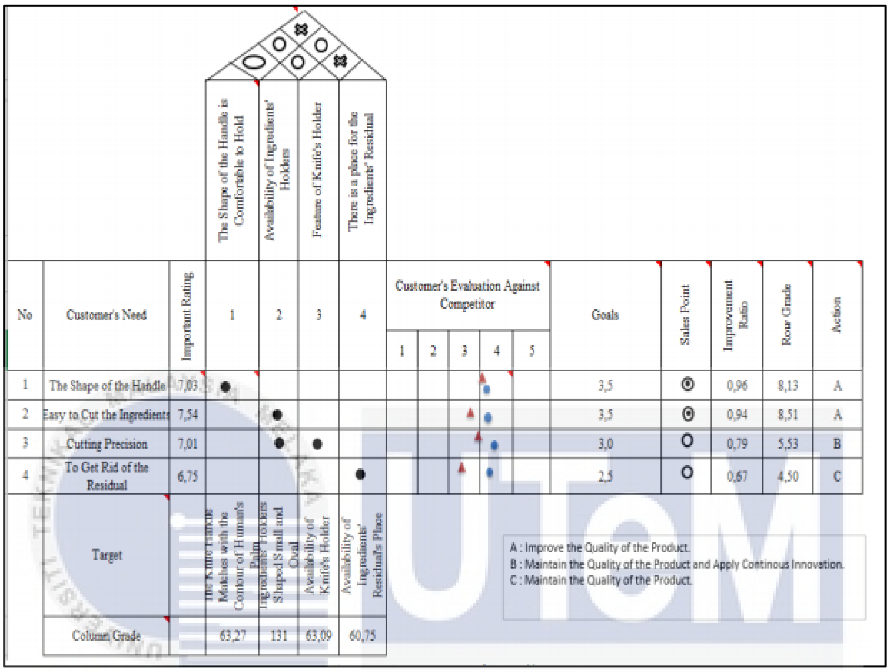


Figure 2.5: HOQ of cutting board sets (Zubaidi et al., 2019)

Based on the percentage of importance of the design specification, the easy to cut ingredient (7.54%) was the most important criteria needed to be developed in the cutting board sets. There are three actions needed to be taken to meet the customer's need: A, improve the quality of the product for the handle shape and easy to cut the ingredient, B, maintain the quality of the product and apply continuous innovation for cutting precision criteria and C, maintain the quality of the product for to get rid of the residual. To conclude, the knife handle must be made adapts to the shape of the human hand and must have a supporter to the blade, so the user does not have to hold the knife with dominant strength.

2.3.3 Sketching

Sketching plays a vital role as well as it is a first step approach in every design process for every designer. Meanwhile, sketching helps to describe or explain the design concepts of a new product. Why stretching is very important for the early stage of the design process before translating the design by using Computer Aided Design (CAD)? This is because sketching drawing can bring an idea, first visualize conceptual of product, contribute the product function and specification (Tufts Kevin, 2020).

2.2.4 Pugh concept selection

Pugh concept selection is one of concurrent method which is used to evaluate the conceptual designs of a new product based on customer's requirement and the other criteria. For instance, choosing one or more conceptual designs of a new product for further study or development by comparing the strength and weakness of the conceptual designs of a new product. Conceptual designs will generate by sketching according to customer's and market's requirements and all the designs will evaluate through the Pugh Concept Selection method. The scoring of this method is according to the symbols of (+) meaning better than, (0) meaning the same as, and (-) meaning worse. Thus, the symbol will be used to score the conceptual designs in each cell of the matrix based on the selection criteria of a product on the left side of the screening matrix. All the conceptual designs will be evaluating and compare with the reference concept designs. Lastly, calculate and rank the best conceptual designs at the bottom which is allowing the designer to select the best designs for further testing and fabrication. Table 2.1 shows the example of the Pugh concept selection method used in the configuration selection of coconut dehusking machine (Roopashree, 2017).

Table 2.1: Pugh concept evaluation on coconut dehusking machine (Roopashree, 2017)

SL NO	SELECTION CRITERIA	CONCEPTS		
		1	2	3
1	Easy to Operate	0	0	+
2	Easy to carry	+	0	0
3	Easy to manufacture	0	0	0
4	Time consumption	0	0	+
5	Durability	0	0	+
6	Initial Cost	0	0	+
7	Portability	-	0	0
8	Safety	0	0	+
9	Power consumption	-	0	0
10	Assembly time	0	0	+
11	Capacity	-	0	+
12	Speed	-	0	+
13	Quality of dehusked nuts	0	0	+
	Sum of +"s Sum of 0"s Sum of –"s	1 8 4	0 13 0	10 3 0
	Net score Rank Continue?	-3 3 No	0 2 No	10 1 yes

2.2.5 Engineering drawing

Engineering drawing is a technical graphic that provides a practical approach for the engineers to draft, test, and evaluate the practicality and attainability of the design concept. It commonly involves Computer-Aided Design (CAD) drawing and maths application. CAD is translating conceptual designs by using computer technology. AutoCAD, Inventor, SOLIDWORKS, CATIA, etc are the drawing software which proper and capable to illustrate the design model with proper specification approximate to the actual design (Manzoor Hussain et al., 2019).

2.2.6 Finite element analysis (FEA)

Finite Element Analysis is an engineering analysis by using a mathematical method to evaluate material or prototype will being to failure or not when the load applied. The evaluation such as von misses stress, deflection, shear stress, safety factor and so on. According to the study of (Ssomad et al., 2013), FEA is used to analysis the best material to be chosen to fabricate the hand tool harvester. The material chose for FEA are Aluminium

Alloy, Cast Carbon Steel, and Plain Carbon Steel. Figure 2.6 till Figure 2.8 show the FEA of these 3 materials, respectively.

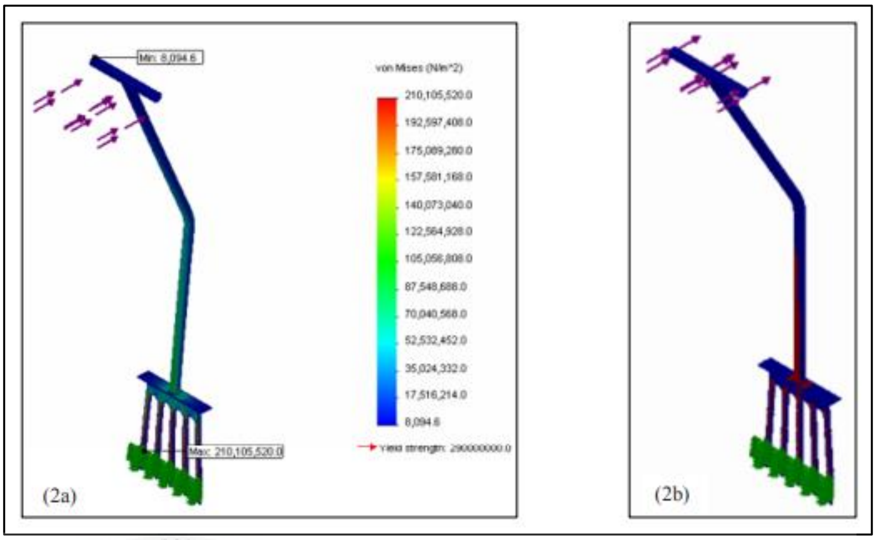


Figure 2.6: FEA on Aluminium Alloy (Ssomad et al., 2013)

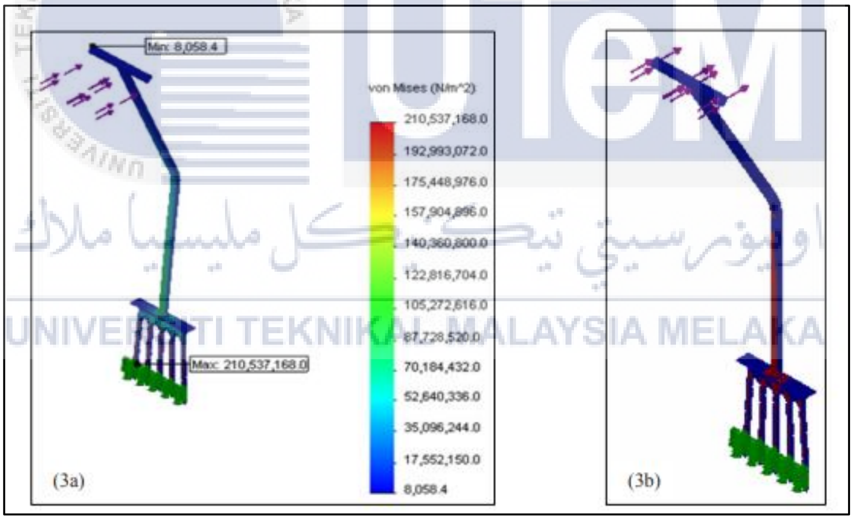


Figure 2.7: FEA on Cast Carbon Steel (Ssomad et al., 2013)

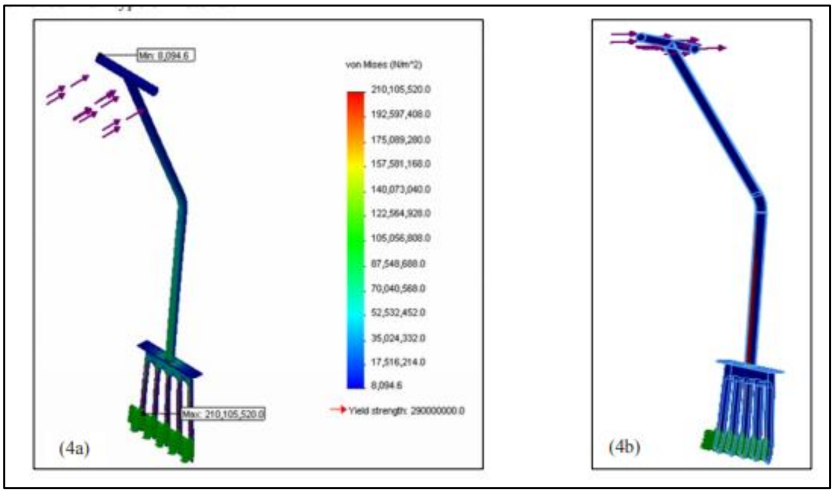


Figure 2.8: FEA on Plain Iron (Ssomad et al., 2013)

From the result above obtained, aluminium alloy will be choosing because it has lighter weight than other materials. Other than that, it has the lowest stress that occur on the hand tool during the harvesting process.

2.4 Evaluation of Effectiveness Prototype

Previous studies showed a few methods used for the evaluation of prototypes to confirm their functionality and test for failures. From journal found that it is very important to evaluate a new prototype because to make sure that the new product developed is in an acceptable quality (Garces et al., 2016).

2.4.1 Usability of prototype

According to the study of (Dianat et al., 2015), a method used for evaluating the usability of the prototype handle tool is the system usability scale (SUS). SUS developed by John Brook in 1986 and it is common and widely used for evaluating the usability of products and services. It is contributing by 10 questions by using psychometric scale method which is rank in 1 to 5 from agreeing to disagree condition to rank the statements for evaluating the usability of a product. For example, the psychometric scale used for this study is 5 ranking condition which are 1 = very low discomfort, 2 = low discomfort, 3 = moderate discomfort, 4 = high discomfort and 5 = extreme discomfort. For the calculation, subtract 1 on the ranking score of the odd number questions and subtract the value score from 5 on the even number questions. Then, sum up all the new values obtained and multiple by 2.5. The range of score will be 0 – 100. The highest score obtained will be evaluated as good usability on product. Figure 2.9 shows the example of the system usability scale.

	Strongly Disagree				Strongly Agree
1. I think that I would like to use this product frequently.	1	2	3	4	5
2. I found the product unnecessarily complex.	1	2	3	4	5
3. I thought the product was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this product.	1	2	3	4	5
5. I found the various functions in the product were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this product.	1	2	3	4	5
7. I imagine that most people would learn to use this product very quickly.	1	2	3	4	5
8. I found the product very awkward to use.	1	2	3	4	5
9. I felt very confident using the product.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this product.	1	2	3	4	5

Figure 2.9: System usability scale (Kortum & Bangor, 2013)

2.4.2 Measurement muscle activity on prototype

Muscle activity is an important measurement of Manual Material Handling activity which provided perception result on the load and function of muscle control on the body part. Surface electromyograms (sEMG) is a common analysis used in previous studies to obtain the electrical potential when muscles are electrically or neurologically activated. The sEMG signal is changed according to the extent of muscle involvement when the MMH activity. sEMG analysis can therefore serve as a non-invasive method for predicting muscle activity and fatigue growth. Root Mean Square (RMS), Average Rectified Value (ARV), Mean Frequency (MNF), and Media Frequency (MDF) are the parameter that requires to study muscle fatigue growth by using sEMG. sEMG is limited to measurement of superficial muscles and its only offers useful information about the muscle activity. Therefore, it cannot use for measuring the load distribution throughout the part of the body when manual handling activity (Li et al., 2017).

2.4.3 Contact force on palm

According to the study of (Welcome et al., 2004), the difference in contact force between the palm hand and tool handle influences the nature of vibration transmitted to the human-arm system and the stresses exerted on the anatomical structure of the system. Many previous studies proved that the magnitude of the hand force transmitted on a tool handle influence serious effect to the hand-transmitted vibration and hand- wrist which may occur problem trauma disorders. Thus, a measurement method is required for evaluating the contact force between the palm hand and tool handle. Grip force or push force when the palm hand contact with the tool handle must be considered. Grip force is like a clamping force when the palm hand enclosing to the handle of the tool while push force is the force that imparted the hand always the human shoulder towards the work surface. Figure 2.10 below shows the relationship of the contact force between the grip force and push force.

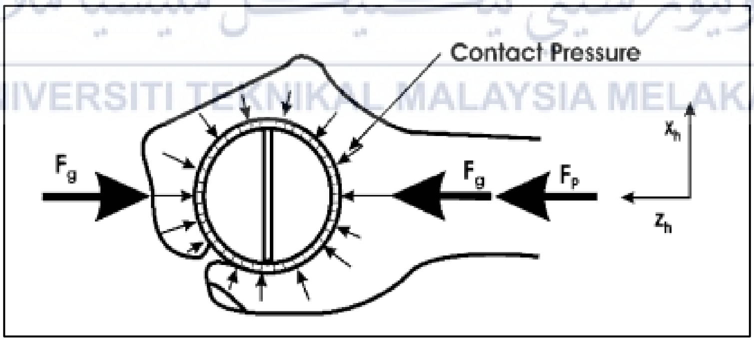


Figure 2.10: Contact force between grip force and push force(Welcome et al., 2004)

2.4.4 Time study

Time study coined by Frederick W. Taylor in the 1880s and it is defined as a method used for measuring the cycle time, performance efficiency, and productivity of a task done by human activity such as manual material handling activity (Chauhan & Shah, 2019). In many of the past studies, time study is a various method used to increase work productivity.

According to the study, the stopwatch method is one of the time study methods used to measure the cycle time for a job which can be done in a short duration and repetitive activity such as manual material handling activities. In the study, a repetitive timing method was used to measure the job. The repetitive timing method also known as snapback method is a technique where the stopwatch is read and simultaneously returned to zero after each job is done completely.

2.4.5 Carry analysis

Carry analysis is an ergonomic study that is very suitable for evaluation of manual handling activities with a dedicated tool. According to the study of (Gonen et al., 2016), carry analysis can be evaluated based on weight, carrying distance, frequency, and duration by referring Snook and Ciriello tables.

In one of the past studies, CATIA software is used to module the carrying analysis on manual handling activity. In the studies, the carrying analysis evaluates carrying a cylinder tube with bare hand. Figure 2.11 and Figure 2.12 show the posture of carrying the cylinder and result of the carry analysis from a study.

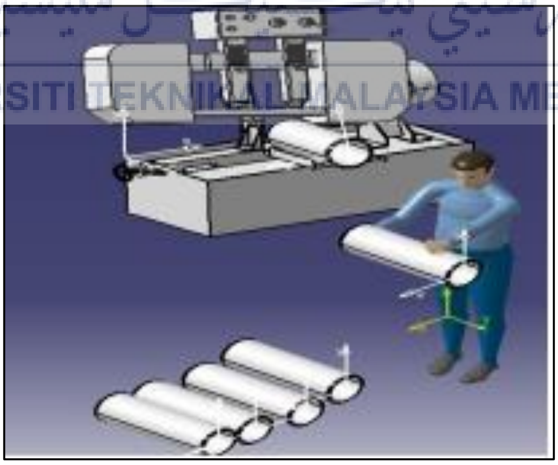


Figure 2.11: Posture Carrying a Cylinder (Liang et al., 2016)

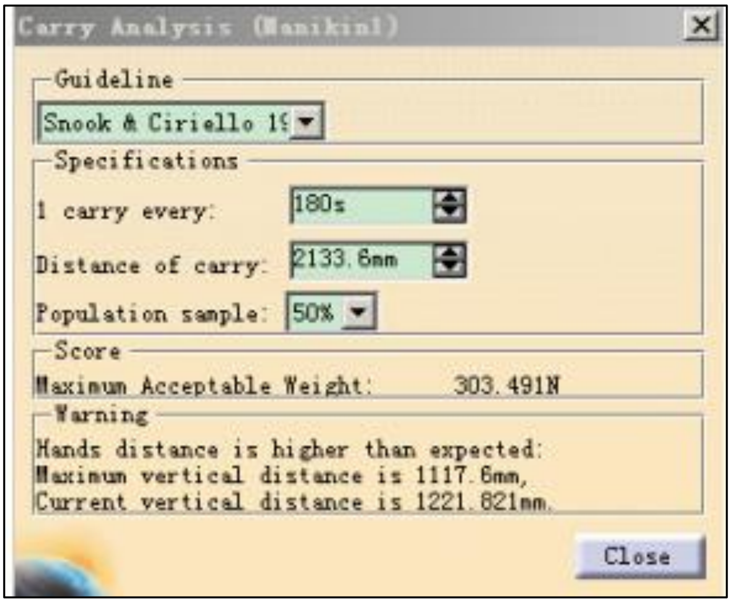


Figure 2.12: Carry analysis result by Men (Liang et al., 2016)

From the result above, we can conclude that the maximum weight is 303.491N can be carrying the cylinder by a man based on the cycle time, 180 second, distance of carry. 2133.6mm and 50%of population sample. The current vertical distance is 1221.821 mm exist the standard maximum vertical distance which is 1117.6mm. Hence, the proper improvement must be made to reduce the injuries. For example, design an ergonomic tool for support while during the handling process. (Liang et al., 2016).

2.5 Differences Between Previous Studies and Current Study

There is a lot of the study between the hand and tool handle during the manual handling material activity. These researchers have similar or different evaluate on tool handle for manual handling material that can be referred to offer good idea and relevant information about the methodologies and result for conducting on the present study. Table 2.3 shows the difference between the previous study and the current study in terms of subject and variables study.

Table 2.2: Differences between the previous studies and the current study

Studies	Subject of study	Variables of study
Welcome et al., 2004	10 male subjects were employed in the study.	Grip and push force, Contact force.
Dianat et al., 2015	18 males were involved in the study.	Tool handle shape on the grip effort, usability and hand and finger discomfort assessments.
Izwan Hamidi Mohd Hairani et al., 2018	14 respondents working at production area participated in this study.	Evaluate ergonomic risk factor during manual handling activity.
Current Study	30 volunteers of Malaysian young adults aged 18 to 25 years old	Evaluate the usability of tool handle. Evaluate the carry analysis to determine the maximum acceptable weight can be carry.

2.7 Summary

This chapter reviews on the theoretical study in ergonomic on tool handle design. According to the different journal, article, and research, design tool handle based on the design requirement and specification were referred. Other than that, the method using for the design and evaluation of the prototype tool handle were discovered and explored. The references and information obtained in this chapter illustrated the idea of the development of the methodology for this study.

CHAPTER 3

METHODOLOGY

This chapter presents the study methodology. The procedures, equipment, and software used to perform the study will be mentioned and elaborated to attain the objectives stated in Chapter 1. First, the operational procedures used to achieve objective 1 which is to determine the design requirement of an ergonomic grip handle for manual carrying long metal bar. For designing the ergonomic grip handle for manual carrying the long metal bar, methods used to obtain the user requirements and select the best design was explained. Lastly, the Inventor drawing software was used to illustrate the design and the fabrication processes is discussed in detail in this chapter.

3.1 Demographic and Anthropometric Data Collection

The purpose of measure and collect data on demographic and anthropometric is to design and determine the dimensional of grip handle tool based on the anthropometric data of the participants such as thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height. In this context, these data are valuable to aid the design and fabrication of an ergonomics hand tools which is ergonomics grip handle for manual carrying the long metal bar.

3.1.1 Participants

50 participants were involved in the data collection for anthropometry data and design requirements surveys. They were student of Faculty of Manufacturing from Universiti Teknikal Malaysia Melaka of both genders between the ages of 20 to 25.

Participants were qualified to participate in this study with criteria of free from disabilities on hand shape that will affect the average analysis. All the participants were well informed about the aim of the study before collecting the data.

3.1.2 Equipment

The equipment used to measure human anthropometry is a measuring tape. The measuring tape is also known as a flexible line gauge for easy measure human anthropometry such as hand length. The measuring tape has two metric scales which are inches and centimetre. Measuring tape will be used to measure the human anthropometric.

Figure 3.1: Measuring tape

The measurement unit used for measuring the human anthropometric is in centimetre and thus convert to millimetre. Millimetre unit is used in the data collection because for easy to do the analysis. Thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height of the participates were measured and collected for use to determine the hand tool’s size. Figure 3.2 shows the human anthropometric parameters that need to measure and collect data to determine the handle size.

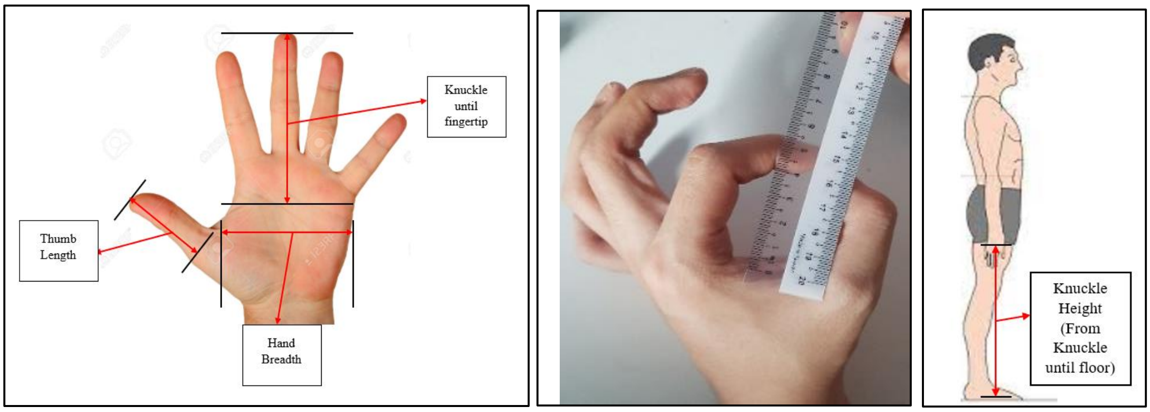


Figure 3.2: Human anthropometric parameters

3.1.3 Confirmation of sample size

The sample size of the data collection was calculated from the sample size calculator available online. Based on the FKP academic website, the enrolment of undergraduate students of FKP is 932 students. Using 932 as the population with a confidence level of 90% and an error margin of 10%, the sample size generated is 64 participants. Since the data collection was conducted through online survey form, and thus some of the data are invalid which was eliminated. So, the sample size for the data collection of this study was 50 participants who are healthy and free from disabilities and injuries. Figure 3.3 shows the sample size calculator by using the online calculator.

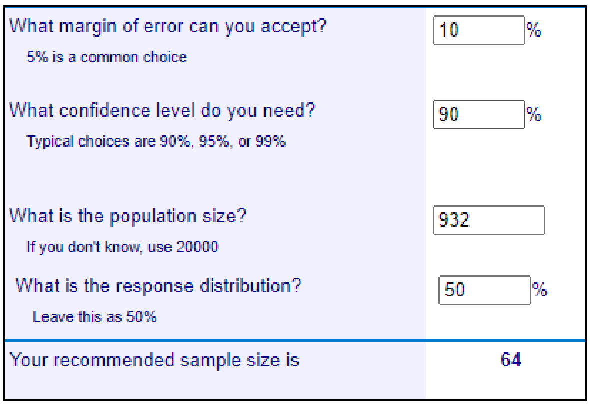


Figure 3.3: Sample size calculation

3.1.4 Data collection via online survey form

According to the previous study, online survey form can obtain usable, reliable, and a vast amount of relevant information within a short period of time. The questionnaire of the survey was divided into two sections which are section A and section B. In section A, it included the questions about the demographic such as gender and age and anthropometry such as height and weight data of the participants while section B is the questions about the human anthropometric parameters as shown in Figure 3.2.

3.1.5 Data collection procedure

Data collection is the action of measuring and collecting statistical information of variables of interest in a standard and systematic way to enable the researcher to answer research questions or test hypothesises. In this study, the data collected are the human anthropometric parameters which are thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter, and knuckle height of the participants.

Procedures:

1. In section A, the participants need to fill in the information of the demographic and anthropometries such as gender, age, height, and weight.
2. In section B, the participants need to prepare a flexible measuring tape for the measurement of the hand size parameter.
3. After the measurement, record the value on the answer blank prepared.
4. All the data units must in millimetre.

Figure 3.4 till Figure 3.8 show the human anthropometries parameter that requires the participants to measure.

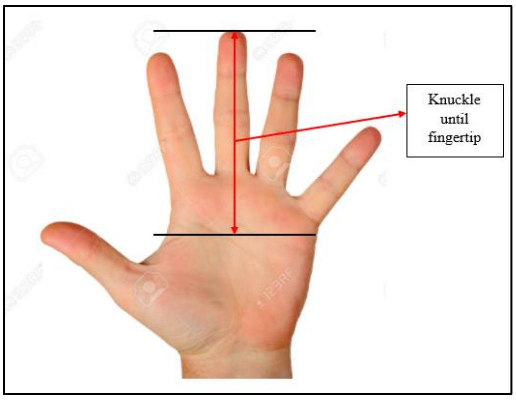


Figure 3.4: Knuckle until middle finger

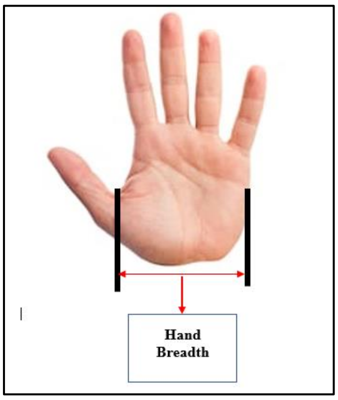


Figure 3.5: Hand breadth

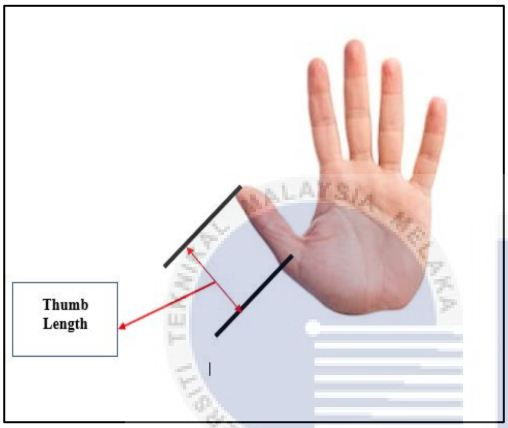


Figure 3.6: Thumb length

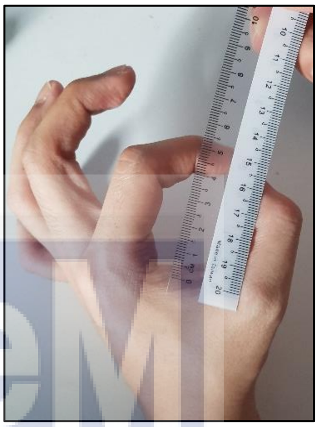


Figure 3.7: Grip breadth inside diameter

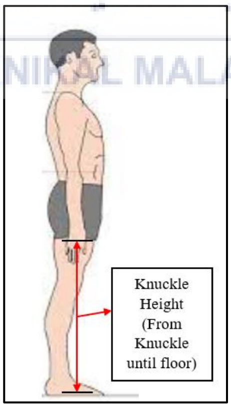


Figure 3.8: Knuckle height (Knuckle to floor)

3.1.6 Statistical analysis of data

Statistical data analysis is a technique for conducting various statistical operations. It is a type of quantitative research that attempted to study the data and is usually used in some sort of statistical analysis. In this study, the collected parameters measurement data will be analysed by using Microsoft Excel.

3.1.6.1 Descriptive statistical analysis

The basic statistical analysis which is the descriptive statistical study of mean, standard deviation, variance, and other parameters of the data were analysed. In this study, the measurement on the human anthropometric variance which are thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter, and knuckle height (from knuckle until floor) of the participants. Thus, descriptive statistical was used to analyse the mean, standard deviation, minimum, maximum, and percentile value (5th, 50th, and 95th) of male's and female's anthropometric parameters obtained, respectively.

3.2 Design of Ergonomic Grip Handle

Identifying the design concepts and design requirements were to ensure that the final design of a product in order to meet the users' requirement and the study objective. Several methods were used to produce the ergonomic grip handle for manual carrying the long metal bar. An online survey form was used to collect information about the users' requirements. With the information obtained, the Quality Function Deployment (QFD) was performed to identify the correlation between the users' requirements and engineering specification of the ergonomic grip handle.

3.2.1 Survey

A survey was conducted to receive feedback from the users. It is the most practical and economic way to collect information from a large group of people in a short period time.

The questionnaire is divided into 4 sections which are sections A, B, C and D. In section A conducted on the demographic data of the respondents. Section B focused on the question about the general knowledge of manual handling material. Section C regarded the feedback on after manual handling material and the last section which is section D related to the design requirements for the grip handle for manual carrying the long metal bar. The questionnaire survey was developed using google form and thus it has an advantage on the automatic generate the graph analysis after responses receive. Figure 3.9 shows the format of the google survey form used in this study.

DESIGN AND EVALUATION OF ERGONOMIC GRIP HANDLE FOR MANUAL CARRYING of LONG METAL BAR

Information for respondents:

This questionnaire is for the use of student's Bachelor Degree Project. This is a survey sheet which comprises of several questions to analyze the opinions and requirement needed for the ergonomic grip handle design. This questionnaire focuses on (Faculty of Manufacturing Engineering) FKP students of Universiti Teknikal Malaysia Melaka. Please kindly spend five to ten minutes to complete this survey form. Thank you for your attention and cooperation.

The objectives of this questionnaire are:
a) To get feedbacks from FKP students regarding the manual material handling object experience especially manual carrying the long metal bar.
b) To determine the design requirements of the ergonomic grip handle for manual carrying the long metal bar.

Your responses will be kept confidential and used only in aggregated form. Your cooperation is very much appreciated.

Section A: Demographic Data of Respondent
Please tick the appropriate boxes.

Figure 3.9: Google survey form

3.2.2 Quality function deployment (QFD)

Quality function deployment (QFD) is an effective technique for identifying and implementing the user's requirements and connecting them to a product's engineering specification requirement. The responses collected from the questionnaire survey were analysed. The users' feedback of the design requirements on the product was analysed by using QFD to acquire the engineering specifications for designing the ergonomic grip handle. Figure 3.10 shows the template of QFD used in this project.

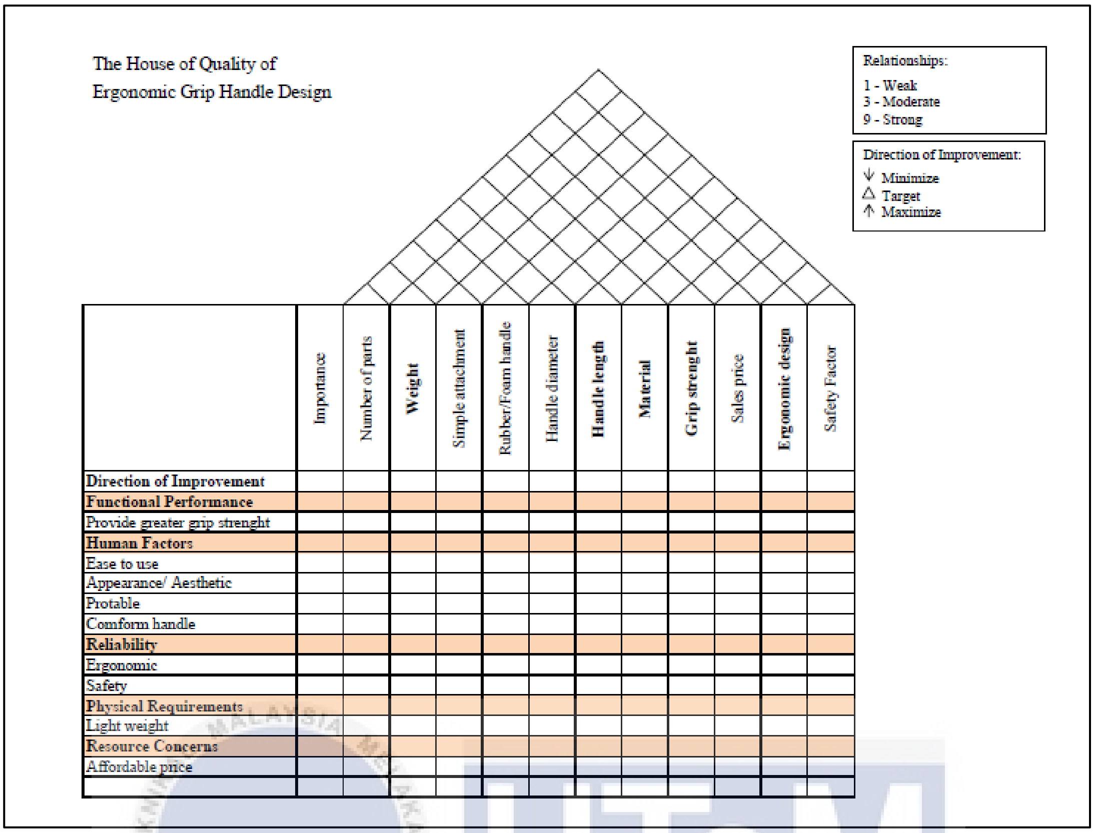


Figure 3.10: Template of Quality Function Deployment

Based on the template above, the row under the triangle in the template is the engineering specifications of the product while the column on the left-hand side is used to list the elements of the users' requirement. The top triangle is also known as the correlation matrix is to evaluate the correlation between the product's engineering specifications. The evaluation is based on the numbers which are 9 = strong; 3 = moderate; 1 = weak; and if left the column empty in the matrix means no correlation between the product's engineering specifications. The second row under the correlation matrix is used to show the engineering specifications that have to be maximized, minimized or targeted. Lastly, the relationship matrix is to rate the users' requirements and the product's engineering specification by using number which are 9 = strong; 3 = moderate; 1 = weak; and 0 = no assignment.

3.2.3 Sketching on conceptual design

Sketching is a technique for easily and quickly illustrating the conceptual design without specifying the detail and dimensional of the product. Based on the feedback from the users, few conceptual designs were sketched freehand. The sketches were proceeding for further concept selection. Figure 3.11 shows the initial conceptual design of the grip handle.

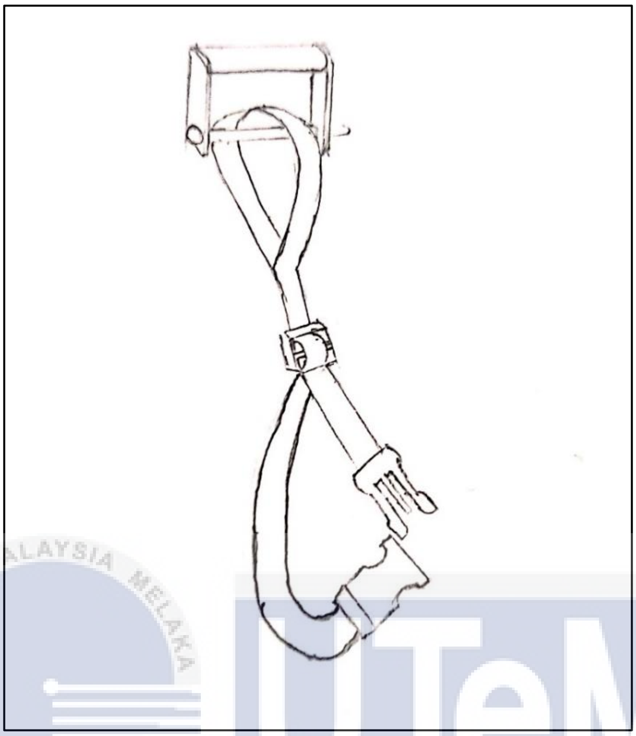


Figure 3.11: Initial Conceptual Design

3.2.4 Pugh concept selection

Pugh concept selection is a technique used to choose the best conceptual design of a product from the conceptual sketches and thus to meet the engineering specifications obtained from the analysed QFD result. Figure 3.12 exhibits the template of Pugh Concept Selection table used in this study.

Engineering Specification	Concept 1	Concept 2	Concept 3	Concept 4
Adjustable Handle Length				
Material				
Grip Strength				
Weight				
Ergonomic Friendly				
Sum of +				
Sum of 0				
Sum of -				
Total				
Rank				
Continue				

Figure 3.12: Template of pugh concept selection

From the template above, the first column is used to list the engineering specifications while the first row is to state the conceptual sketches. Symbols used to rank the conceptual designs with the engineering specification. The symbols are '++' = much better than reference; '+' = Better than reference; '0' = same as reference; '--' = much worse than reference; and '-' = worse than reference. The bottom of the table is used to rank the conceptual design by using the total number symbol of (+) to minus the total number symbol of (–) and thus choose the highest score as the best conceptual design for further evaluation and fabrication.

3.2.5 CAD drawing

The best conceptual design of the product chose from the selection process was illustrated in the drawing software with specified dimensions. In this study, the software used for engineering drawing is Inventor. The engineering drawing was illustrated before the fabrication process which can eliminate the waste of time and cost. Figure 3.13 shows the ergonomic grip handle design by using INVENTOR.

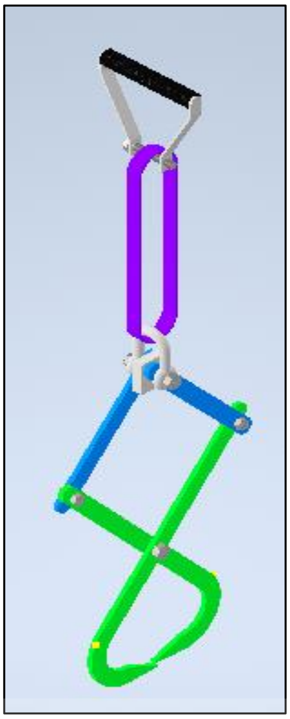


Figure 3.13: Ergonomic Grip Handle Design

3.2.6 Material selection

Material selection is to determine the material used to fabricate the product. In this study, stainless steel, zinc alloy, and aluminium alloy were selected to fabricate the prototype. Thus, the materials used for the fabrication of the grip handle were selected before the analysis of FEA. The parts of the ergonomic grip handle which are handle and linkage were performed in this selection process.

3.2.6.1 Handle

Table 3.1 shows the translating of the handle design which to identify the design requirement as function, constraints, objective, and free variable of the handle. The function of the handle is to grasp by hand. The constraints are light weight, high strength material, and adequate toughness. The objectives are minimizing cost and maximizing strength. The free variable is the choice of material.

Table 3.1: Translating of handle design

Function	Handle – To grasp by hand
Constraints	• Light weight • High strength material • Adequate toughness
Objective	• Minimize cost • Maximize strength
Free variable	Choice of material

Table 3.2 shows the material properties based on stainless steel and aluminium alloy. The properties are density, young modulus, tensile strength, etc which was ranked between 1 to 10 score. After performing the ranking process, stainless steel was selected to fabricate the handle part with the total score of 36 compared with aluminium alloy with the total score of 29 as shown in Table 3.3.

Table 3.2: Material properties (handle design)

Properties \ Material	Stainless Steel	Aluminium Alloy
Density (kg/m^3)	7.85e3	2.7e3
Young modulus (GPa)	199.5	75
Tensile strength (MPa)	1.36e3	304
Fracture toughness ($MPa.m^{0.5}$)	106	28.5
Price (RM)	18.9/kg	7.715/kg

Table 3.3: Material ranking (handle design)

Properties \ Material	Stainless Steel	Aluminium Alloy
Density (kg/m^3)	2	10
Young modulus (GPa)	10	4
Tensile strength (MPa)	10	2
Fracture toughness ($MPa.m^{0.5}$)	10	3
Price (RM)	4	10
Total Score	36	29
Rank	1	2

3.2.6.2 Linkage

From table 3.4, the function of the linkage is to grip and hold the object. The constraints are light weight, high strength material, and adequate toughness. The objectives are minimizing cost and weight. The free variable is the choice of material.

Table 3.4: Translating of linkage design

Function	Upper Linkage and Jaw Linkage - To grip and hold the object
Constraints	• Light weight • High strength material • Adequate toughness
Objective	• Minimize cost • Minimize weight
Free variable	Choice of material

Table 3.5 shows the material properties based on zinc alloy and aluminium alloy. The properties are density, young modulus, tensile strength, etc which was ranked between 1 to 10 score. After performing the ranking process, aluminium alloy was selected to fabricate the linkage part with the total score of 38 compared with aluminium alloy with the total score of 33 as shown in Table 3.6.

Table 3.5: Material properties (linkage design)

Properties \ Material	Zinc Alloy	Aluminium Alloy
Density (kg/m^3)	5.975e3	2.7e3
Young modulus (GPa)	81.5	75
Tensile strength (MPa)	327.5	304
Price (RM)	7.765/kg	7.715/kg

Table 3.6: Material ranking (linkage design)

Properties \ Material	Zinc Alloy	Aluminium Alloy
Density (kg/m^3)	4	10
Young modulus (GPa)	10	9
Tensile strength (MPa)	10	9
Price (RM)	9	10
Total Score	33	38
Rank	2	1

3.2.7 Finite element analysis (FEA)

Finite Element Analysis evaluated analysis of von misses' stress, deflection, and safety factor on the linkage part. As the theoretical with the load add on the grip handle, the critical occur will be on the linkage part of the grip handle. Therefore, the FEA analysis was done on the linkage part by suppressing the upper part of the grip handle by using the ASNYS software. The force magnitude applied to do the FEA analysis is based on the maximum load of material (long metal bar) that set in the experiment which is 75 mm diameter with 4000 mm length of steel bar. With the calculator online the weight for the long metal bar is 138.72 kg and thus converted to Newtown is 1360.84 N. Figure 3.14 shows the calculation of the weight of the long metal bar.

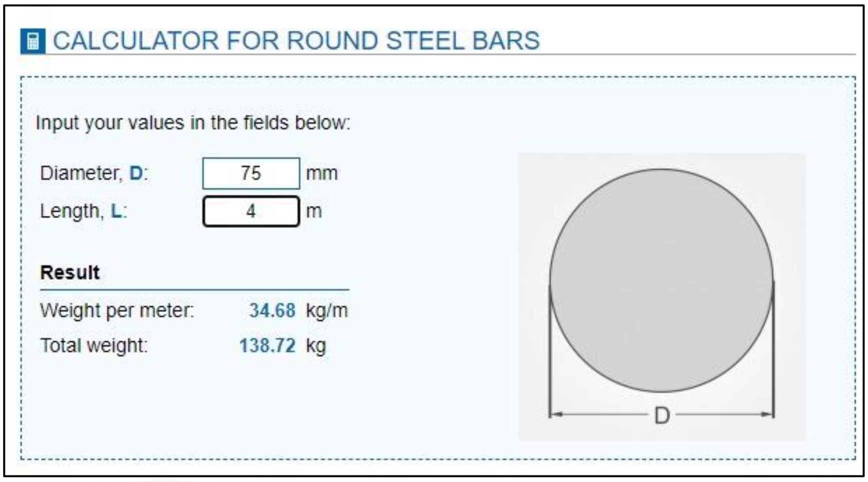


Figure 3.14: The calculation of the weight of the long metal bar

3.2.8 Wobbling measurement

Wobbling on the long metal bar was calculated based on the length of the long metal bar. As the wobbling condition is because the long length of the long metal bar causing the distance between two workers far when they carry the metal bar. To calculate the wobbling by using the displacement of the metal bar from its original axis which caused by the distributed load on the metal bar. The measurement was performed by using ANSYS software to simulate.

3.3 Fabrication of Prototype

Fabrication can be defined as the process of producing a product from raw materials. In this section, the traditional manufacturing and advanced manufacturing process used to fabricate the ergonomic grip handle prototype was discussed. The traditional manufacturing process included cutting, welding, bending, and drilling while the advanced manufacturing process is CNC milling process.

3.3.1 Handle

3.3.1.1 Cutting

The machine used to cut the stainless-steel hollow tube and flat bar is a Bomar STG 230 DG bandsaw machine located at the FKP workshop. Cut the stainless-steel hollow tube and flat bar with the dimensional required based on the CAD drawing. Figure 3.15 and Figure 3.16 show the Bomar STG 230 DG bandsaw and the cutting process.

Figure 3.15: Bomar STG 230 DG Bandsaw

Figure 3.16 : Cutting Process

3.3.1.2 Bending

Bending process is a process to deform the metal part to change the shape with the load added on. For this process, the bending process used bend on the stainless-steel flat bar according to the shape of CAD drawing before weld with the hollow stainless-steel tube by using the welding process.

3.3.1.3 Welding

Welding process is a process to join two materials by applying heat to melt the parts together and thus allowing them to cool. In the fabrication, welding process was used to join the hollow stainless-steel tube and the stainless-steel flat bar to form a handle of the prototype. Figure 3.17 below shows the part join by using welding process.

Figure 3.17: The welding between the stainless-steel hollow and flat bar

3.3.1.4 Drilling

Drilling process is the process to drill a hole on the part. In the process, gate vertical milling machine located at the FKP workshop was used to drill holes on the handle. The purpose of the holes is to insert the handle screw bracket. Figure 3.18 shows the gate vertical milling machine.

Figure 3.18: Gate vertical milling machine

3.3.2 Linkage

Milling process is used to fabricate the linkage of the grip handle. The material used to produce the linkage is an aluminium plate with 6 mm thickness times 150 mm width times

400 mm length. The machine used to mill the linkage is Haas VOP-B CNC milling machine which located at the FKP workshop. Figure 3.19 and Figure 3.20 below show the Haas VOP-B CNC milling machine and the CNC milling process.

Figure 3.19: Haas VOP-B CNC milling machine

Figure 3.20: CNC Milling Process

3.3.3 Structure tree

Structure tree of product is to show the materials, components, and part subassemblies to form a product or prototype. First, the upper part of the grip handle included the handle, nylon scrap and hook. All the assemblies were fastening and connected by using bolt and nut. The lower part of the grip handle is the structure of the linkage. The Jaw linkage was fastening and connected to the upper linkage by using bolt and nut. Lastly, join the upper part and lower part of the grip handle by fastening with bolt and nut. Figure 3.21 shows the product structure tree of the grip handle.

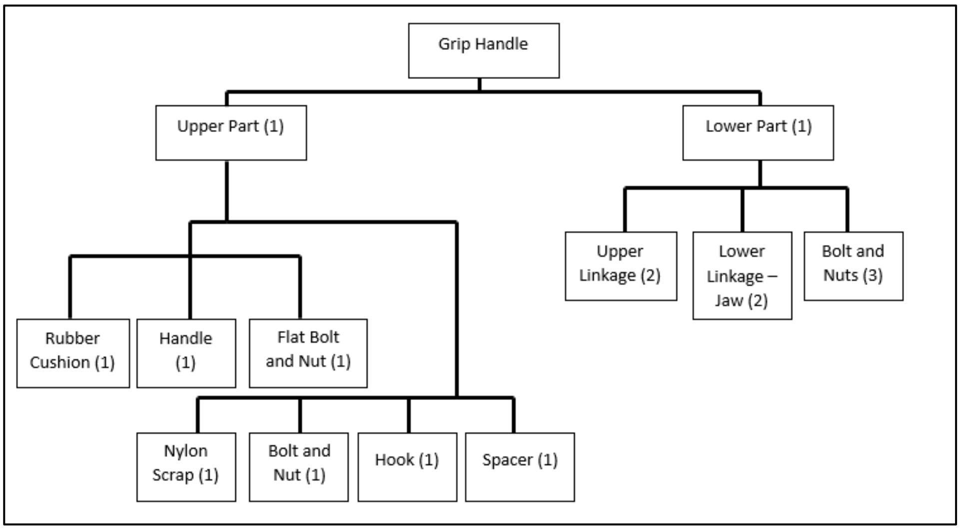
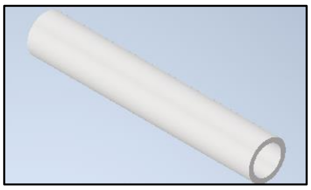


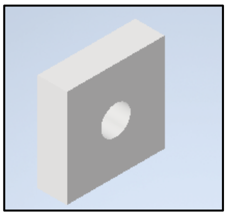
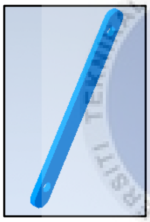
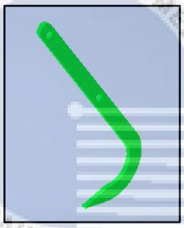
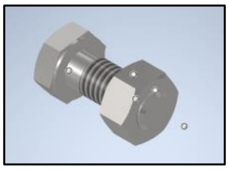
Figure 3.21: Product structure tree of the grip handle

3.3.4 Bill of material

Bill of material illustrated the materials and cost used to fabricate the grip handle prototype. Table 3.7 shows the bill of material of the grip handle.

Table 3.7: Bill of material of the grip handle

No	Part	Material	Price	Quantity	Cost
1	Handle 	Stainless Steel	RM 60 per piece	1	RM 60
2	Rubber Cushion 	Rubber	RM 1.60 per piece	1	RM 1.60

3	Hook 	Steel	RM 4.50 per piece	1	RM 4.50
4	Spacer (Washer) 	Stainless Steel	RM 0.55 per piece	7	RM 3.85
5	Upper Linkage and Lower Linkage-Jaw  	Aluminium Alloy	RM 53 per piece	1	RM 53
6	Nylon Scrap 	Nylon	RM 5.00 per piece	1	RM 5
7	Flat Bolt and Nut (AS 1110 - M10 x 60) 	Stainless Steel	RM 4.50 per piece	1	RM 4.50
8	Bolt and Nut (AS 1110 - M10 x 55) 	Black Steel	RM 0.90 per piece	1	RM 0.90
9	Bolt and Nuts (AS 1112 - M8 x 25) 	Black Steel	RM 0.30 per piece	3	RM 0.90

Calculation

Total Material Cost = RM60 + RM 1.60 + RM 4.50 + RM3.85 + RM53 + RM 5 + RM4.50 + RM0.90 + RM0.90 = **RM 134.25**

2 Ergonomic Grip Handle needed = RM 134.25 x 2 = **RM 268.5**

3.4 Evaluation on Prototype

In this context, the methods used to evaluation on prototype was discussed. The evaluation on prototype is the usability on prototype when using the prototype while the carry analysis was performed by using CATIA V5 software based on the weight, height and knuckle height of male obtained from the data collection.

3.4.1 Usability on prototype

The method uses to perform this evaluation is the system usability scale (SUS) (Dianat et al., 2015). The SUS method is using questionnaires to get feedback on usability from the user. This system consists of ten questions for users to answer after using the grip handling for manual carrying the long metal bar. Psychometric scale method which is rank in 1 to 5 from agreeing to disagree condition to rank the ten questions. The psychometric scale is using 5 ranking condition which are 1 = strongly disagree; 2 = somewhat disagree; 3 = neutral discomfort; 4 = somewhat agree; and 5 = strongly agree. To calculate the score for usability, first subtract 1 on the ranking score of the odd number questions and then subtract the value score from 5 on the even number questions. After that, sum up all the new values obtained and multiple by 2.5. The range of score will be 0 – 100. The score of the usability on the prototype with be interpreted based on the indicator table as shown in Figure 3.23. Figure 3.22 shows the template of the system usability scale used in this project.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this handle frequently.					
2. I found the tool unnecessarily complex.					
3. I thought the handle was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this handle were well integrated.					
6. I thought there was too much inconsistency in this handle.					
7. I would imagine that most people would learn to use this tool very quickly.					
8. I found the handle very cumbersome to use.					
9. I felt very confident using the handle.					
10. I needed to learn a lot of things before I could get going with this handle.					

Figure 3.22: Testing of usability using questionnaire feedback, adapted from the SUS

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 3.23: Usability indicator table (Interpreting System Usability Scale, 2021)

3.4.2 Carry analysis

CATIA software was used to perform carry analysis with determine the maximum acceptable weight for carrying based on the posture of carrying the long metal bar. The result generated can determine the maximum load which is safe to carry in order to eliminate the risk of injuries. First, a manikin was created by setting the weight, height, and knuckle height.

The posture of carrying the long metal bar was simulated by using the CATIA software. Inputed the cycle time and distance of transferring to the software. Lastly, the result of maximum acceptable weight load which is safe to carry with the posture position was generated. Figure 3.24 and Figure 3.25 show the posture carrying the long metal bar with bare hand and the posture carrying the long metal bar with grip handle was simulated by the CATIA software.

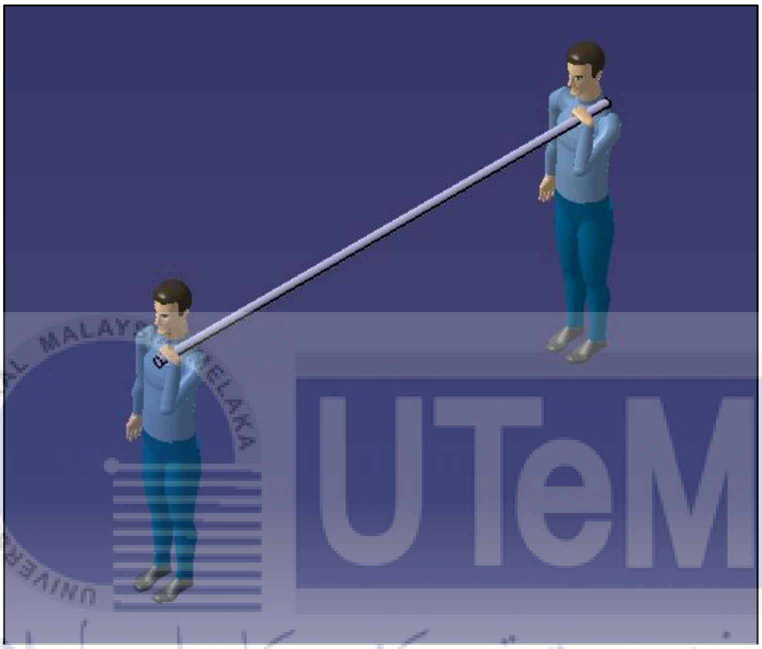


Figure 3.24: The posture carrying the long metal bar with bare hand

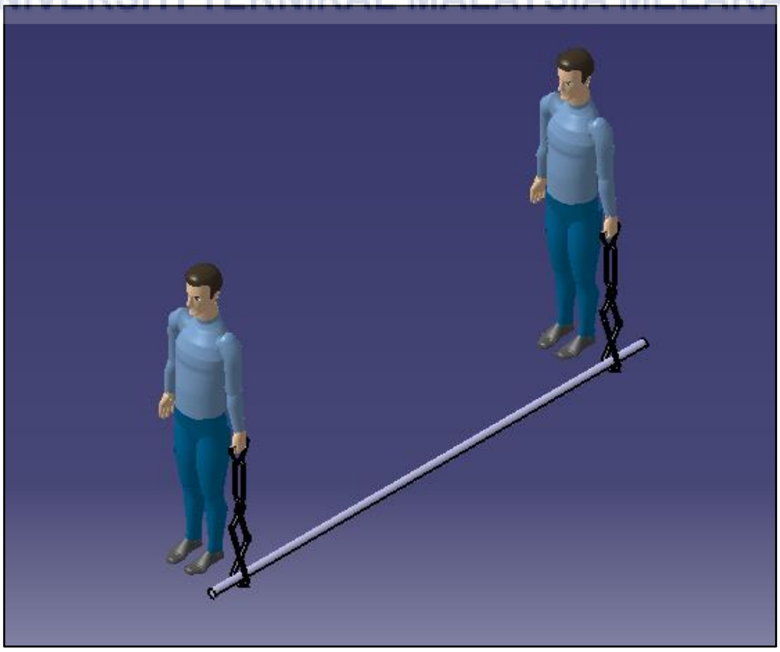


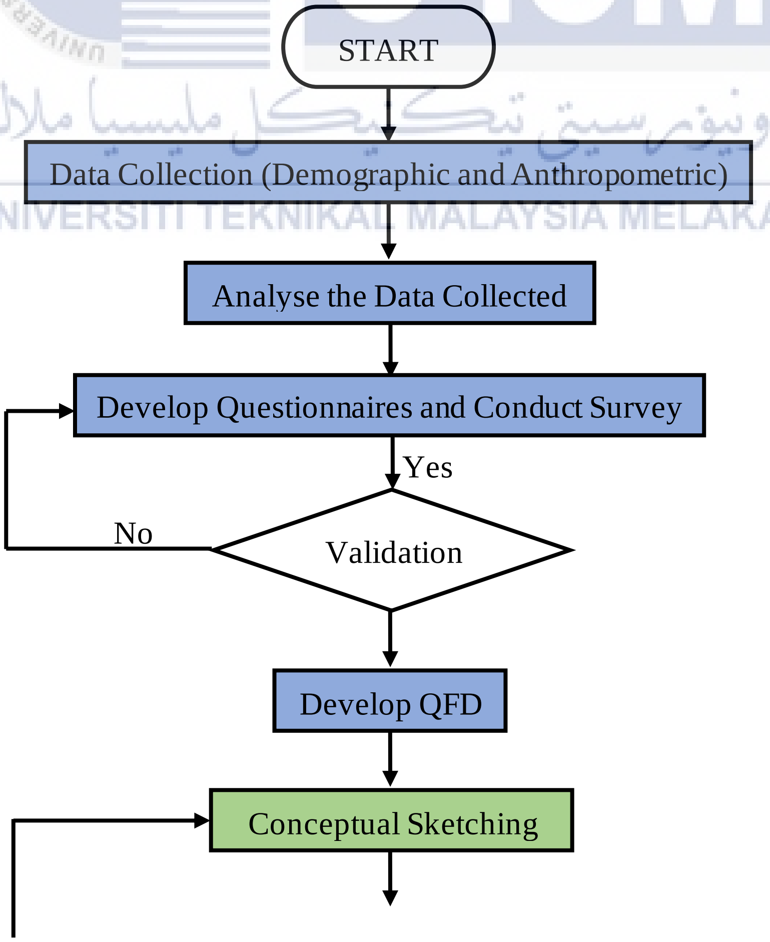
Figure 3.25: The posture carrying the long metal bar with grip handle

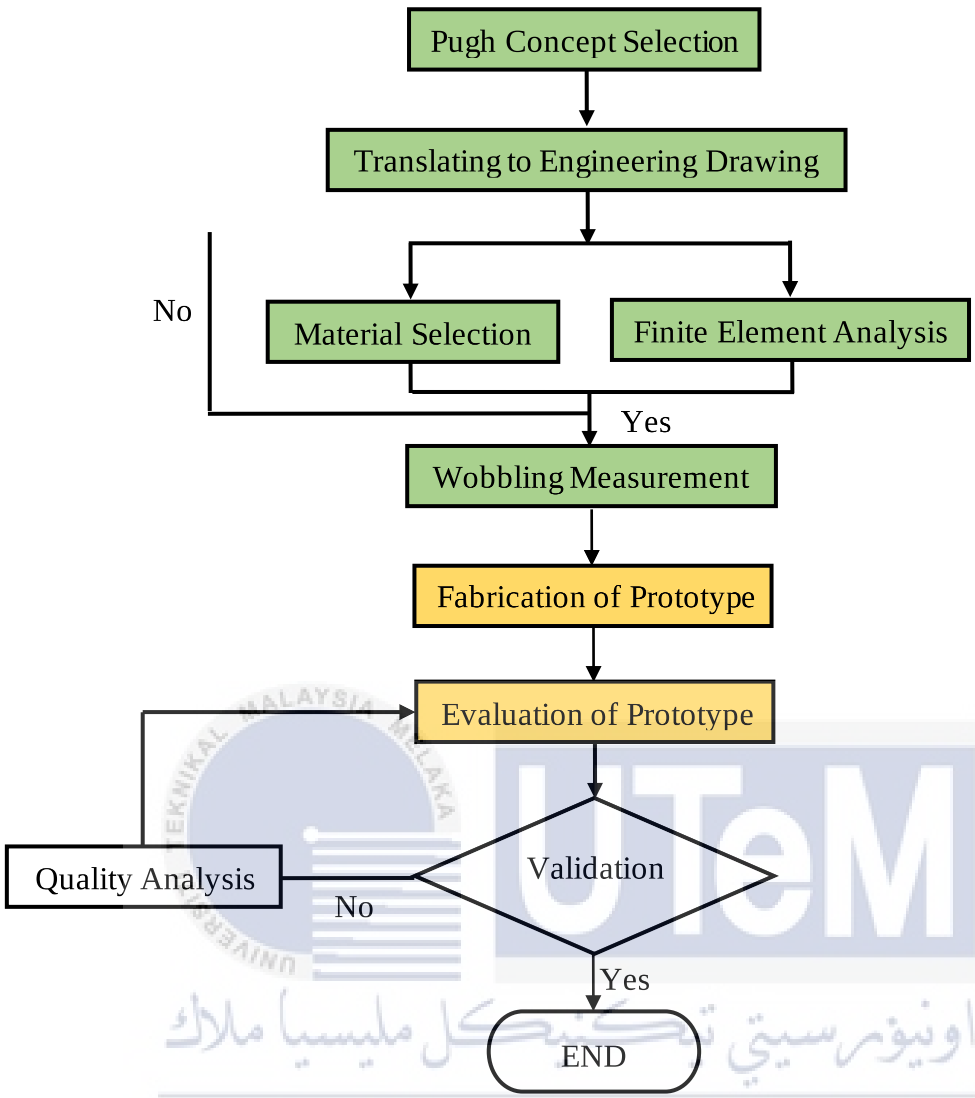
3.5 Quality Analysis

Quality analysis is a method use to ensure the product meet the quality and customers' requirements. For this process if the ergonomic grip handle failure on analysis evaluation, quality analysis on the grip handle is very important to investigate the root causes of the grip handle and thus refabricate the grip handle. Quality tool fish bone diagram will be performed to investigates the root causes of the grip handle based on 4M which are method, man, machine, and material. With the root causes identify by using the fish bone diagram, refabricate the grip handle with solving the root causes on the grip handle.

3.6 Summary

A flowchart is an overview on the methodology of the project and was showed in as below:





Objective 1: To identify the design requirements and user's requirements of an ergonomic grip handle for manual carrying long metal bar.

Objective 2: To design an ergonomic grip handle based on the design requirements and user's requirements.

Objective 3: To fabricate and evaluate the performance of the grip handle prototype in manual carrying of long metal bar.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter discusses the result obtained from the collected data of demographic and anthropometric and user requirements from survey form data collection to design the ergonomic grip handle. Besides, the result on evaluation on the ergonomic grip handle will also be discussed.

4.1 Participants' Demographic and Anthropometric

In this section, participants' demographic, and anthropometric data such as gender, weight, height, thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height for Malaysian young adults is illustrated and discussed.

4.1.1 Demographic data of participants

The analysis of demographic data of gender, height, and weight meanwhile for the anthropometric data included the thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height. These data are collected from FKP students of age 21 to 25 who are free from disabilities and injuries. Figure 4.1 shows the pie chart distribution of gender involved in the study. Out of the 50 participants, male occupied 50% in the pie chart which is 25 males out of 50 participants while the female participants, the number of participants is 25 which occupied 50% of the pie chart.

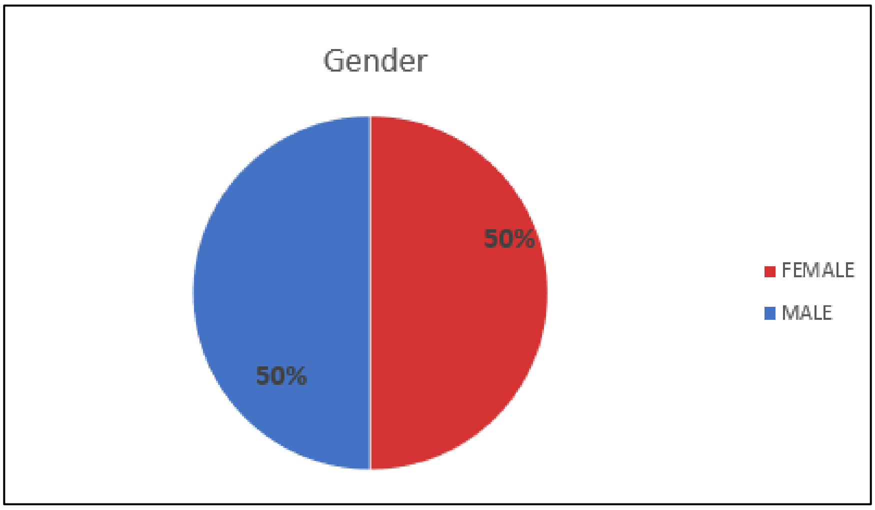


Figure 4.1: Gender of participants

Table 4.1 and Table 4.2 show the quantitative data of weight and height by gender, respectively. Based on the Table 4.1 above, the mean height is 1.71 m with standard deviation 0.053 m while the mean weight is 72 kg with standard deviation 9.82 kg from the 25 participants of male. The maximum male participants' height is 1.83 m, and the minimum height is 1.60 m while the maximum weight is 100 kg, and the minimum weight is 55 kg.

Table 4.1 : Descriptive statistics analysis of height and weight of male

Variable	Mean	Std. Deviation	Maximum	Minimum
Height (m)	1.71	0.053	1.83	1.60
Weight (kg)	72	9.82	100	55

In Table 4.2, the mean height is 1.62 m with standard deviation 0.043m while the mean weight is 72 kg with standard deviation 8.41 kg from the 25 participants of female. The maximum female participants' height is 1.83 m, and the minimum height is 1.60 m while the maximum weight is 100 kg, and the minimum weight is 55 kg.

Table 4.2: Descriptive statistics analysis of height and weight of female

Variable	Mean	Std. Deviation	Maximum	Minimum
Height (m)	1.62	0.043	1.70	1.55
Weight (kg)	55.48	8.41	90	46

4.1.2 Percentile of the anthropometric data with 5th, 50th and 95th

The anthropometric data obtained which are thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height. Three of the percentiles which are 5th, 50th and 95th were calculated by using the Microsoft Excel. With the percentiles generated to determine the dimension to the design the grip handle. Table 4.3 and Table 4.4 show the three of the percentiles' values according to the anthropometric data of male and female, respectively.

4.1.2.1 Percentile of the anthropometric data male participants

Based on the Table 4.3, the first anthropometric data is length from knuckle until the middle fingertip of male and the mean is 95.6mm with standard deviation 5.27mm. The maximum length of the knuckle until the middle fingertip for male is 110mm while the minimum is 90mm. The 5th, 50th and 95th percentile length of knuckle until middle fingertip are 90mm, 95mm and 104mm, respectively. The mean length of hand breadth is 77.8mm with standard deviation 5.96mm. The maximum length of the hand breadth for male is 89mm while the minimum is 65mm. The 5th percentile of hand breadth length is 70mm, 50th percentile of hand breadth length is 78mm and the 95th percentile of hand breadth is 57.6mm for male. Grip breadth inside diameter is the third anthropometric data and the mean value at 48.28mm with standard deviation 5.86mm. The maximum and minimum value of the length of grip breadth inside diameter for male are 58mm and 39mm. 40mm, 50mm and 57.8mm are the percentile of length grip breadth inside diameter at 5th, 50th and 95th respectively. The mean of thumb length is 61.96mm and the standard deviation is 4.32mm. The maximum of value of thumb length for male is 70mm while the minimum is 55mm. For the percentile of the thumb length, 5th is 55mm, 50th is 62mm and 95th is 67.6mm. The mean of knuckle height for male is 68.4mm and the standard deviation is 5.03mm. The maximum and minimum of knuckle height for male are 78mm and 60mm. The percentile of the knuckle height for male are 62.4mm (5th), 67mm (50th) and 78mm (95th).

Table 4.3: The percentiles' values of male according to the anthropometric data

Anthropometric Data	Maximum	Mean	Minimum	Std. Deviation	Percentile		
					5th	50th	95th
Knuckle until middle fingertip (mm)	110	95.6	90	5.27	90	95	104
Hand Breadth (mm)	89	77.8	65	5.96	70	78	87.6
Grip Breadth Inside Diameter (mm)	58	48.28	39	5.86	40	50	57.8
Thumb Length (mm)	70	61.96	55	4.32	55	62	67.6
Knuckle height (mm)	78	68.4	60	5.03	62.4	67	78

4.1.2.2 Percentile of the anthropometric data female participants

From the Table 4.4, the first anthropometric data is length from knuckle until the middle fingertip of female and the mean is 84.4mm with standard deviation 6.18mm. The maximum length of the knuckle until the middle fingertip for female is 100mm while the minimum is 70mm. The 5th, 50th and 95th percentile length of knuckle until middle fingertip are 76mm, 85mm and 90mm, respectively. The mean length of hand breadth is 64.16mm with standard deviation 5.34mm. The maximum length of the hand breadth for female is 80mm while the minimum is 54mm. The 5th percentile of hand breadth length is 56.4mm, 50th percentile of hand breadth length is 64mm and the 95th percentile of hand breadth is 68.8mm for female. Grip breadth inside diameter is the third anthropometric data and the mean value at 49mm with standard deviation 3.16mm. The maximum and minimum value of the length of grip breadth inside diameter for female are 56mm and 44mm. 44.2mm, 50mm and 54.8mm are the percentile of length grip breadth inside diameter at 5th, 50th and 95th respectively. The mean of thumb length is 57.36mm and the standard deviation is 4.47mm. The maximum of value of thumb length for female is 65mm while the minimum is 50mm. For the percentile of the thumb length, 5th is 50.2mm, 50th is 58mm and 95th is 65mm. The mean of knuckle height for female is 65.08mm and the standard deviation is 3.63mm. The maximum and minimum of knuckle height for female are 72mm and 60mm. The percentile of the knuckle height for male are 60mm (5th), 64mm (50th) and 70.8mm (95th).

Table 4.4 The percentiles' values of female according to the anthropometric data

Anthropometric Data	Maximum	Mean	Minimum	Std. Deviation	Percentile		
					5th	50th	95th
Knuckle until middle fingertip (mm)	100	84.4	70	6.18	76	85	90
Hand Breadth (mm)	80	64.16	54	5.34	56.4	64	68.8
Grip Breadth Inside Diameter (mm)	56	49	44	3.16	44.2	50	54.8
Thumb Length (mm)	65	57.36	50	4.47	50.2	58	65
Knuckle height (mm)	72	65.08	60	3.63	60	64	70.8

4.1.3 Grip handle dimensional based on the percentile of anthropometric data

Due to the carrying and transferring of the long metal bar is a heavy duty, so the anthropometric data of male will be considered to determine the grip handle shape and design.

4.1.3.1 Knuckle height until middle fingertip (handle length)

From the Figure 4.2 above, the 95th percentile of knuckle until middle fingertip is 104mm. Hence, the length of the handle considered on the 95th percentile in order to let the user can be easy to grasp the handle. As the result showed that if the handle design with length at 95th percentile, 24 of male out 25 would be easy to grasp the handle without difficult. Therefore, the dimension of the length of the handle must design at 104 mm and above.

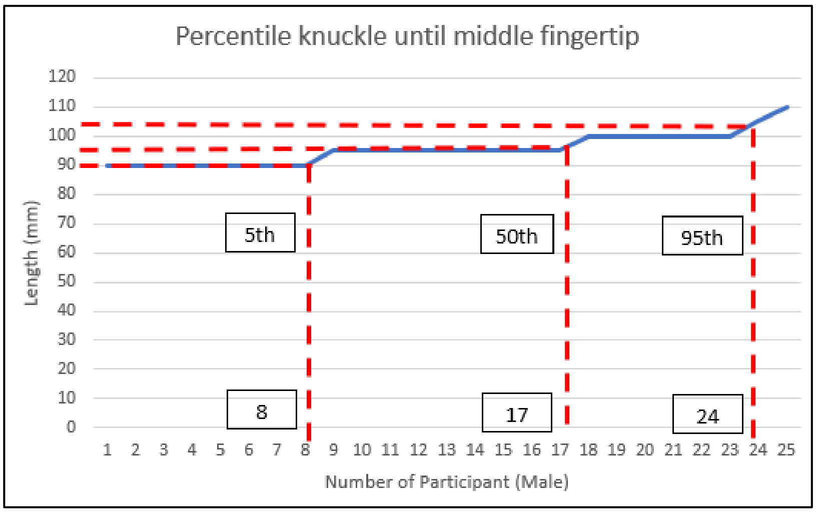


Figure 4.2: Percentile knuckle until middle fingertip

4.1.3.2 Hand breadth (handle width)

The design of the handle breadth is based on the hand breadth data of male. From the figure 4.3, the handle width considered on the 95th percentile value according to the 25 of male data and the value is 87.6mm. The dimension on design the handle width must be at 87.6mm and above, so that the handle will fit to the participants' hand breadth without discomfort when handling the long metal bar. From the Figure 4.3, the result showed if the handle width with 87.6mm and above can meet the requirement of 24 male out of 25.

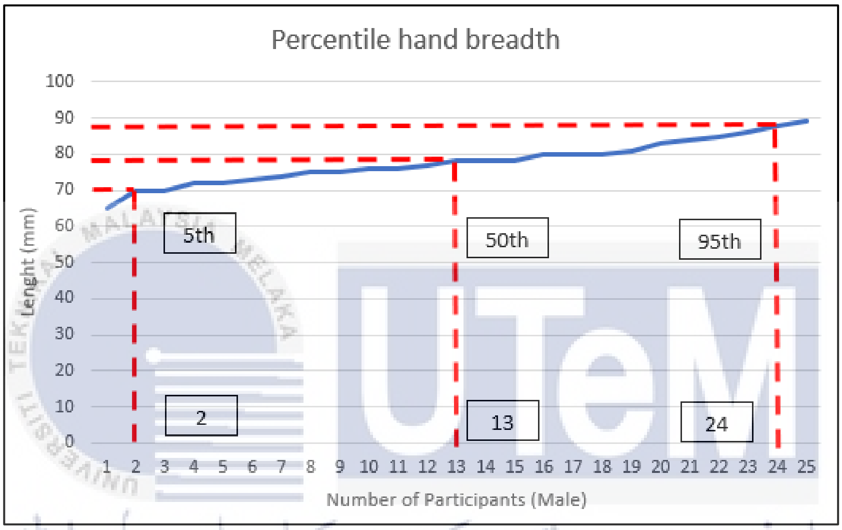


Figure 4.3: Percentile hand breadth

4.1.3.3 Grip breadth inside diameter and thumb length (handle shape and diameter)

Based on the Figure 4.4, if the handle design with the percentile 95th which the value is 57.8mm, there were 23 of male out 25 cannot meet the requirement of the users. The average of the male grip breadth inside diameter are below 57.8mm. Hence, the handle diameter too large and during the transferring they will feel discomfort due to not fit to the participants' grip breadth inside diameter. As the result, the 5th percentile grip breadth inside diameter and the value is 40mm referred to design the diameter of the handle. The handle was designed in round shape to reduce the muscle load and pinch force when the users' transferring the long metal bar with the grip handle.

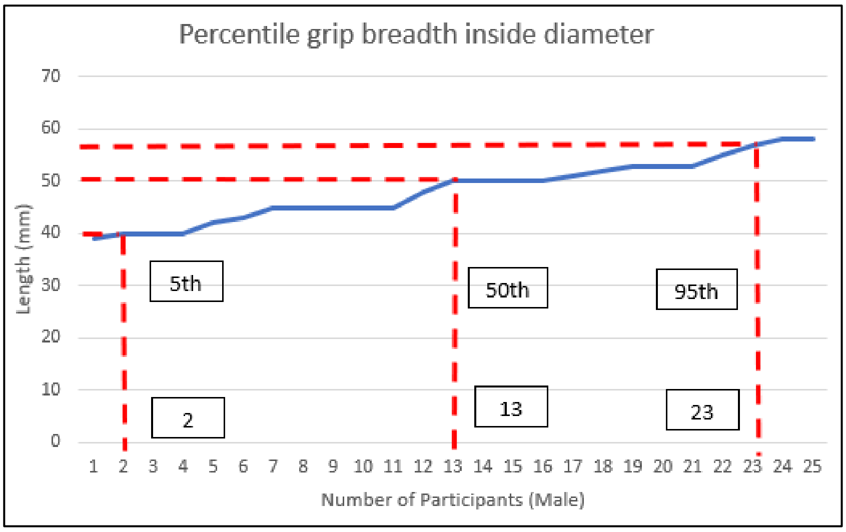


Figure 4.4: Percentile grip breadth inside diameter

Figure 4.5 is the data of thumb length of 25 male. As the result showed that 24 of male had less than the percentile of 95th which is 65mm. The longer the thumb length to provide them greater grip strength. Therefore, when they grasp a small diameter handle, the participants will ensure their thumb and fingers are fully supported by the handle. As a result, the handle diameter referred to the 5th percentile of the grip breadth inside diameter.

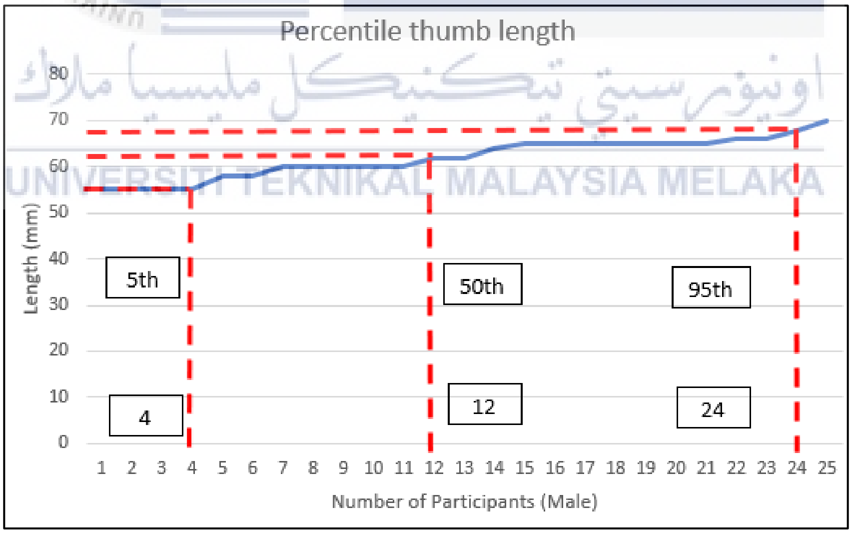


Figure 4.5: Percentile thumb length

4.1.3.4 Knuckle height (grip handle length)

Knuckle height of male was used to design the length of the grip handle. Based on the Figure 4.6, the value of 95th percentile knuckle height is 70.8mm and the value of 5th percentile knuckle height is 60mm. The length of the grip handle must be designed in between these two values. This is because to prevent the grip handle to touch the floor if the handle too long when they are transferring the long metal bar. As a result, adjustable length of the grip handle designed in order to meet the requirement of knuckle height of male.

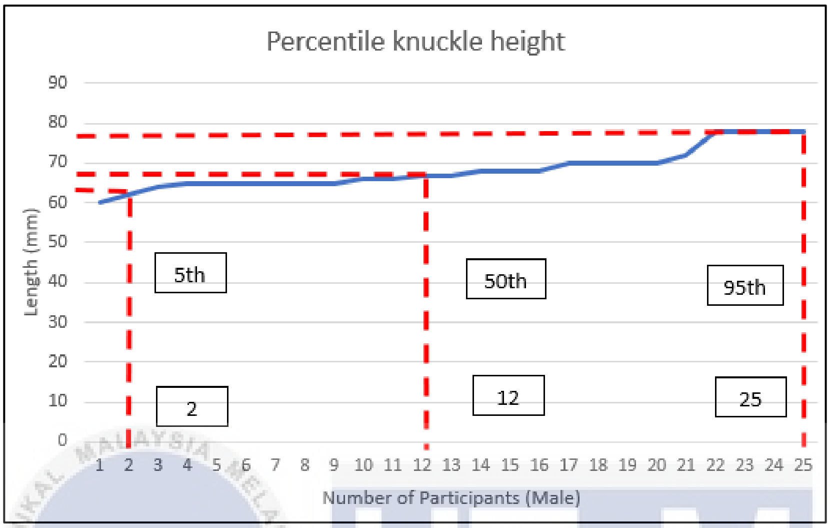


Figure 4.6: Percentile knuckle height

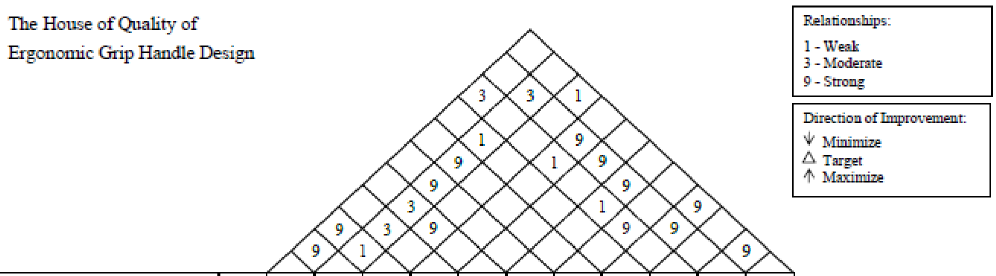
4.2 Grip Handle Design

In this section, the design specifications of the grip handle are obtained, and a few design concepts are proposed. The best design is selected through concept selection and is illustrated in INVENTOR drawing software. A prototype of the designed grip handle is fabricated.

4.2.1 Quality Function deployment

House of Quality created as shown in Figure 4.7. From the figure, the elements in the left column are the design requirements obtained from the survey feedback of the respondents with the highest rating of 5 and the lowest 1 while the elements in the upper row are the engineering specifications of the grip handle design. The direction of improvements shows the technical specifications that have to be maximize, minimize or targeted. The numbers in the QFD show the relationships between the elements with the number of 9 =

strong; 3 = moderate; and 1 = weak. The last row is the summation of the ratings of relationship. The five highest score show the engineering specifications that must be considered the most in designing the new grip handle.



	Importance	Number of parts	**Weight**	Simple attachment	Rubber/Foam handle	Handle diameter	**Handle length**	**Material**	**Grip strength**	Sales price	**Ergonomic design**	Safety Factor
Direction of Improvement		↑	↓	△	↑	△	↑	△	△	↓	△	△
Functional Performance												
Provide greater grip strenght	5						9	9	9		9	9
Human Factors												
Ease to use	4			9		3	9			9	3	3
Appearance/ Aesthetic	3			1	1	1				9		
Protable	4		9					1		3		
Comform handle	4		9		9	9	9	9	9		9	
Reliability												
Ergonomic	4		3		9	9	9		9		9	9
Safety	5		3						9		1	9
Physical Requirements												
Light weight	4	9	9	9	1		3	9		3	3	
Resource Concerns												
Affordable price	4	3			1	1		9		9		
		48	135	75	83	91	**165**	**157**	162	123	146	120

Figure 4.7: QFD for grip handle design

Based on the feedback, the design requirements on the grip handle such as provide greater grip strength, lightweight, ergonomics, safety and so on are rated by the respondents to decide the importance of these requirements for the design of new grip handle for transferring the long metal bar. The requirements are applied in the QFD to assist in finding the engineering specifications for the design. After the summation of all relationships rating, the five higher rated engineering specifications are the “handle length” with score of 165, “grip strength” with score of 162, “material” with score of 157, “ergonomic design” with score of 146 and “weight” with score of 135. For the handle length, it has to be maximized so that the grip handle length can adjustable. Besides, the grip handle must provide better grip strength to prevent the long metal bar slip and fall during the transferring. The grip handle must ergonomic friendly such as added on the rubber cushion on the handle to reduce the contact pressure between the users’ palm and the handle. The material used to fabricate the grip handle must high in strength to prevent fracture and light weight to reduce the load when transferring the long metal bar.

Table 4.5 shows the justification relationship between the user's requirements and engineering specification. To determine the relationship between the user's requirements and engineering specification, user's requirements are translated to engineering specification and thus by using engineering concept thinking to evaluate the importance between each other to design the grip handle. For instance, the relationship between the handle length (engineering specifications) and the provide better grip strength (user's requirement) is evaluated at 9 which is strong relationship due to Handle must fit to anthropometric data of user in order to provide better grip strength. Therefore, if the handle length too long which will touch the floor and during the transferring process may create friction in order to reduce the grip strength. Figure 4.8 shows the comparison between the grip handle which does not fit to the knuckle height; and fit to the knuckle height of user. Figure 4.9 shows the grip handle was used light material to fabricate which are stainless steel and aluminium alloy. Figure 4.10 shows that the handle size is fit to the user's palm hand.

Table 4.5: Relationship between the user's requirements and engineering specification

Relationship		Indicator	Justification
Handle Length	Provide better grip strength	9	Handle must fit to anthropometric of user in order to provide better grip strength. (Strong)
	Ease to use	9	Handle length must ease to adjustable to fit the knuckle height of user. (Strong)
	Comfort handle	9	Handle length must fit user anthropometric to ensure the user to grasp the grip handle comfortably. (Strong)
	Ergonomics	9	Handle length must be ergonomically fit to user's anthropometric for user to use. (Strong)
	Light weight	3	Material use to design handle must not too heavy. (Moderate)
Grip Strength	Provide better grip strength	9	The grip handle must provide better grip strength to handle the long metal bar. (Strong)
	Comfort Handle	9	Comfort handle must be designed in order to provide better grip strength during transferring. (Strong)
	Ergonomics	9	Ergonomic design of grip handle in order to let user can carry the long metal bar with ergonomic posture. (Strong)
	Safety	9	Grip handle must provide power grip strength at the same time it safe for the user to use it. (Strong)
Material	Provide better grip strength	9	Grip handle must design with non-slip, non-conductive and compressible materials. (Strong)
	Portable	1	Material use to fabricate the grip handle weak relationship with portable due to the grip handle is not a huge device. (Weak)
	Comfort handle	9	Material use to design the handle must comfort for the user to grasp the tool. (Strong)

	Light weight	9	Light weight material uses to design the grip handle in order to add external load to the user during the transferring process. (Strong)
	Affordable price	9	Material use to fabricate the grip handle must not expensive especially recyclable material will be used to fabricate it. (Strong)
Ergonomic Design	Provide better grip strength	9	Ergonomic design on the grip handle provides better grip strength. (Strong)
	Ease to use	3	Ergonomic design on the grip handle
	Comfort Handle	9	Ergonomic design on the grip handle to give the user can grasp the grip handle comfortably. (Strong)
	Ergonomics	9	Ergonomic design on the grip handle gives the user to use ergonomic practice on the transferring process. (Strong)
	Safety	1	The relationship between ergonomic design and safety is weak. (Weak)
	Light weight	3	Light weight material uses to design the grip handle in order to add external load to the user during the transferring process. (Moderate)
Weight	Portable	9	Weight of the grip handle must light for the user easy to bring on place to the other place. (Strong)
	Comfort handle	9	A light weight of grip handle can let user grasp the grip handle comfortably. (Strong)
	Ergonomics	3	Material use to fabricate the grip handle moderate relationship with ergonomic due to the grip handle is not a huge device. (Moderate)
	Safety	3	Material use to fabricate the grip handle moderate relationship with safety due to the grip handle is not a huge device. (Moderate)
	Light weight	9	Light weight material used to fabricate the grip handle. (Strong)

Figure 4.8: Grip handle not fit and fit to the knuckle height of user

Figure 4.9: Material used to fabricate the prototype

Figure 4.10: Handle size fit to the user palm hand

4.2.2 Conceptual design

4 design concepts illustrated according to the design specifications obtained from the QFD analysis. Figures 4.8, Figure 4.9, Figure 4.10, and Figure 4.11 show the conceptual design of grip handle for manual carrying the long metal bar.

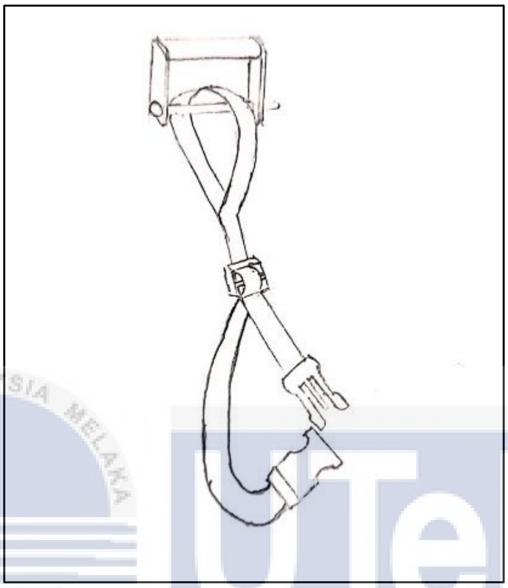


Figure 4.11: Conceptual design 1

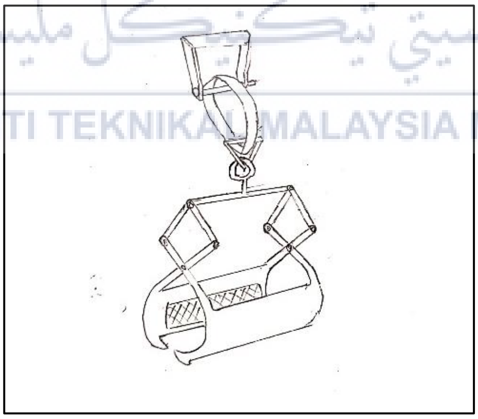


Figure 4.12: Conceptual design 2

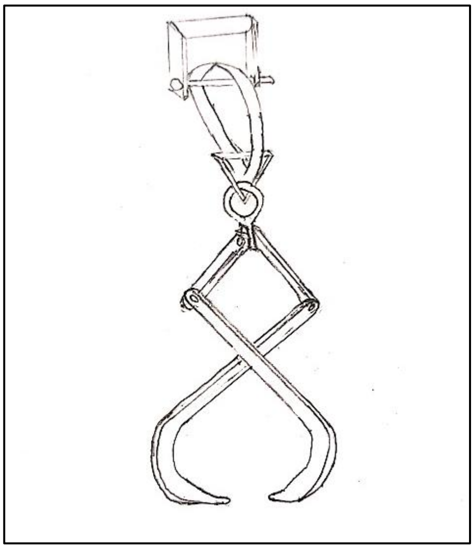


Figure 4.13: Conceptual design *3*

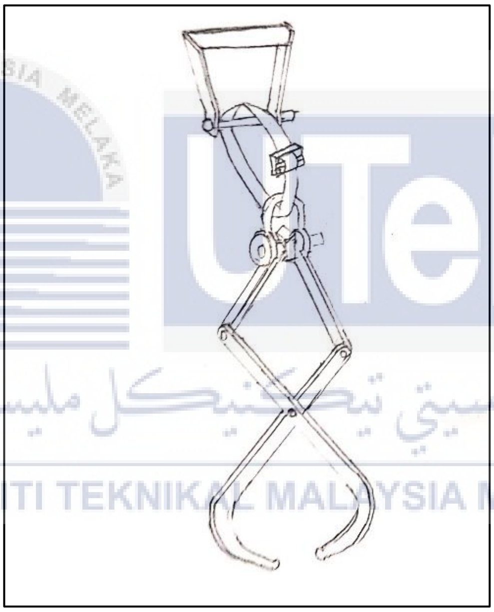


Figure 4.14: Conceptual design 4

4.2.3 Pugh concept selection

Pugh concept selection will be applied to select the best conceptual design which meet the engineering specification. The engineering specifications obtained from QFD which are handle length, grip strength, material, ergonomic friendly and weight. All the conceptual design will compare in a matrix table according to the engineering specifications.

4.2.3.1 Concept screening

Table 4.5 indicates the concept screening process of the concept selection used to determine few designs that are more relevant to the engineering specifications obtained from the QFD. The indicator table is used to rank the conceptual design compare with the engineering specifications by using the symbol which are (--) much worse than reference, (-) worse than reference, (0) same as reference, (+) better than reference, and (++) much better than reference. From the result above, conceptual design 1 is selected as a reference conceptual design. Therefore, the screening process performed by comparing the reference with the other three conceptual design according to the engineering specification. After the ranking in the matrix table, two conceptual designs with higher rank is chose and proceed to the concept scoring process to select the best conceptual design. Hence, conceptual design 3 and conceptual design 4 were ranked at the first and second place after comparing with the reference according to the engineering specifications.

Table 4.6: Concept Screening

Engineering Specification	Concept 1	Concept 2	Concept 3	Concept 4
Adjustable Handle Length	0	--	--	0
Material	0	+	+	+
Grip Strength	0	+	+	+
Weight	0	--	-	-
Ergonomic Design	0	--	++	++
Sum of +	0	2	4	4
Sum of 0	5	1	0	0
Sum of -	0	6	3	1
Total	0	-4	1	3
Rank	3	4	2	1
Continue	No	No	Yes	Yes

Relative Performance	Indicator
Much worse than reference	--
Worse than reference	-
Same as reference	0
Better than reference	+
Much better than reference	++

4.2.3.2 Concept scoring

Table 4.6 shows the result of the best conceptual design after the scoring process. In this process, two conceptual designs compared by rank between each other according to the engineering specifications. The indicator is used to perform in the concept scoring process is by ranking the conceptual design based on the indicating result obtained from the concept screening process. The ranking indicator are (--) rank 1, (-) rank 2, (0) rank 3, (+) rank 4 and (++) rank 5. After ranked the conceptual design, the rank will be multiplying with the weight scale of the engineering specifications. Then, summing up all the weight score and the highest score will be selected as the best conceptual design. After the scoring process, conceptual design 4 is chose as the best conceptual design with score of 4.32 compared to the conceptual design 3 with score 3.60.

Table 4.7: Concept scoring

Engineering Specification	Weight	Concepts Design			
		Concept 3		Concept 4	
		Ranking	Weight Score	Ranking	Weight Score
Adjustable Handle Length	18%	1	0.18	5	0.9
Material	20%	4	0.8	4	0.8
Grip Strength	24%	3	0.72	3	0.72
Weight	19%	5	0.95	5	0.95
Ergonomic Design	19%	5	0.95	5	0.95
Total	100%	3.60		4.32	
Rank		2		1	
Continue		No		Yes	

Relative Performance	Indicator	Rank
Much worse than reference	--	1
Worse than reference	-	2
Same as reference	0	3
Better than reference	+	4
Much better than reference	++	5

4.2.4 Ergonomic grip handle prototype

The ergonomic grip handle of conceptual design 4 is illustrated using INVENTOR drawing software as shown in Figure 4.12 accordingly to the users' requirements and a prototype is fabricated as shown in Figure 4.13. The upper linkage and lower linkage will be fastening together by using bolt and nut. The jaw shape of the lower linkage is to fully grasp the long metal bar and provide better grip strength to prevent the long metal bar fall during the transferring process. The linkage part will connect with the handle by using the nylon strap which can adjust the length of ergonomic grip handle based on the knuckle height of the users. The rubber cushion will be added to the handle to reduce the contact pressure between the users' palm and the handle.

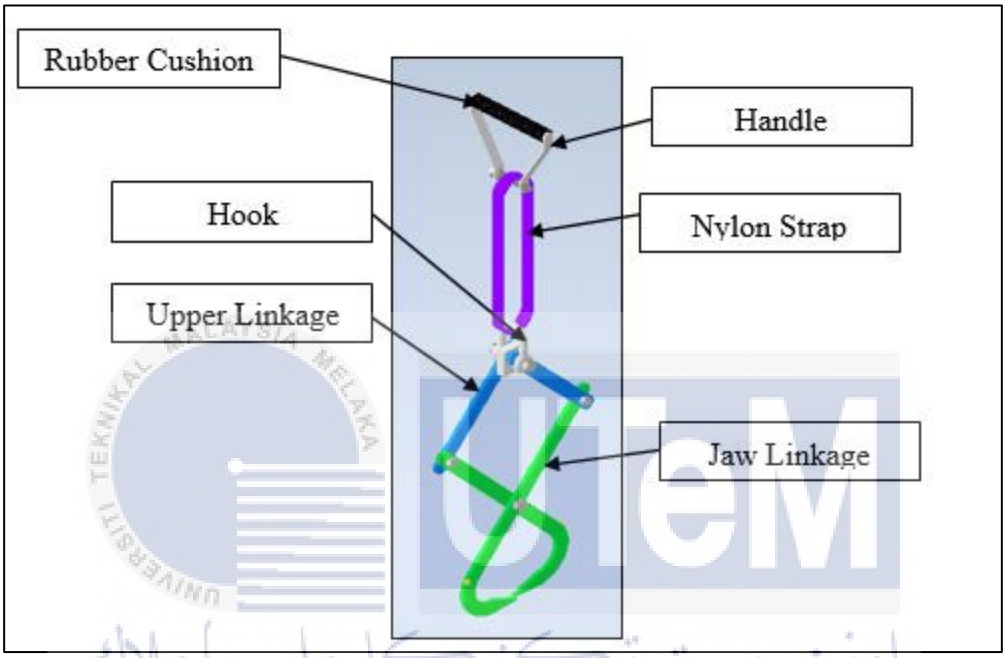


Figure 4.15: Ergonomic grip handle by INVENTOR drawing software

Figure 4.16: Ergonomic grip handle prototype

4.2.5 Finite element analysis (FEA)

Finite Element Analysis evaluated analysis of von misses' stress (Equivalent stress), deflection (Total deformation), and safety factor on the linkage part by using ANSYN software. The FEA is used to analyse fracture risk on the linkage after the load added. The magnitude of load is about 1360.84 N which is the load of the long metal bar with 75 mm diameter and 4000 mm length.

4.2.5.1 Von misses' stress (equivalent stress)

Figure 4.14 shown the result of Von Misses' Stress on the linkage after the load applied. Von Mises Stress is a value used to determine if the used material will yield or fracture after applied the load. To analyse the material will be yielded or fractured, the maximum value of von misses' stress will be compared with the material used yield tensile strength. As the material used for the linkage is aluminium alloy and the yield tensile strength of aluminium alloy is 276MPa. From the result, the maximum value of von misses' stress is 240.19 MPa less than the aluminium alloy yield tensile strength. Hence, the linkage will not yield or fracture when the load is applied. As the result of carry analysis obtained for the maximum acceptable weight for carrying the long metal bar is 283.718N

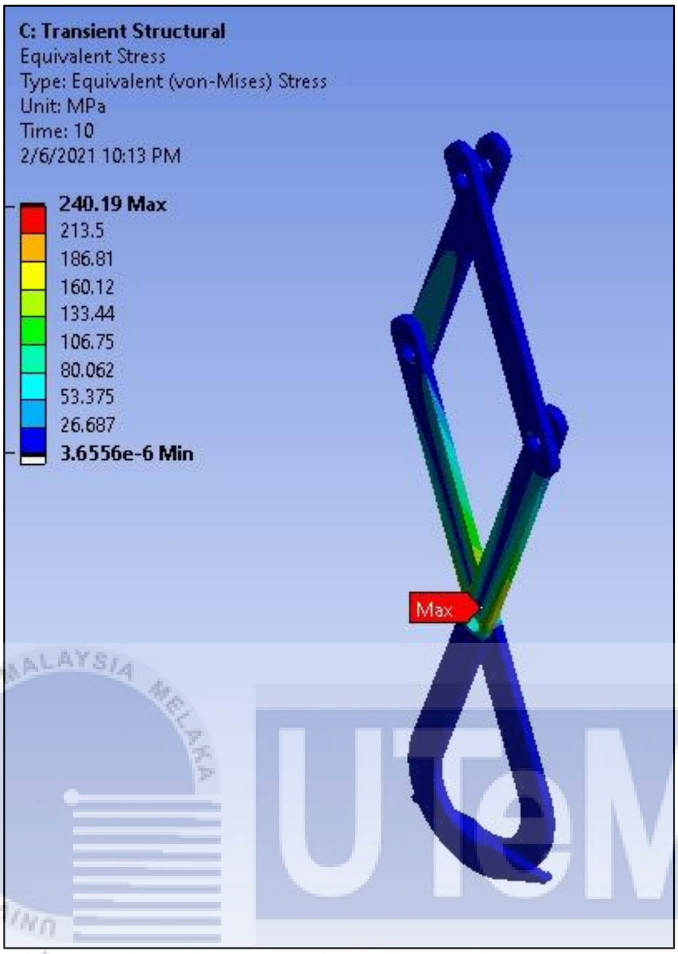


Figure 4.17: Von misses' stress (Equivalent stress)

4.2.5.2 Deflection (total deformation)

Figure 4.15 shows the result of the total deformation on the linkage after the load applied. Total deformation is the displacement of the structure from the original axis. From the result, the maximum total deformation occurred at the left-hand side of the connection of linkage with 2.8616mm and the von misses' stress at 240.19MPa. As mentioned at the result of the von misses' stress, the linkage will not yield or fracture after the load is applied due to the maximum von misses' stress (240.19MPa) is lesser than the yield stress of aluminium alloy (276MPa). As the result of carry analysis obtained for the maximum acceptable weight for carrying the long metal bar is 283.718N which is less than the magnitude force applied and thus it will not dent or occur minor deflect on the jaw linkage during the transferring process.

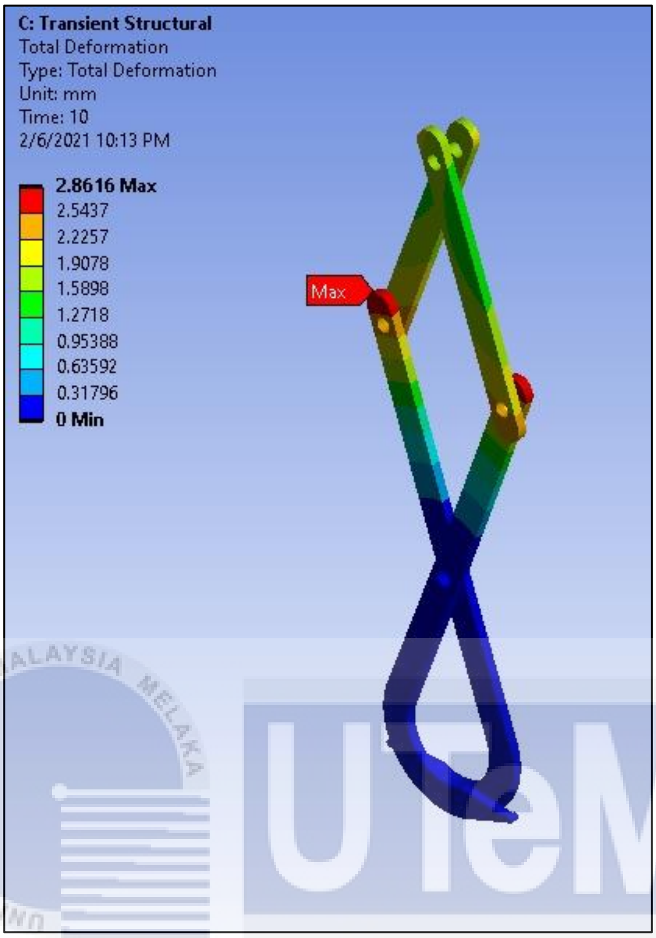


Figure 4.18: Deflection (Total deformation)

4.2.5.3 Safety factor

Figure 4.16 shows the result of the safety factor on the linkage after the load applied. As the theoretical from the Autodesk website (How to Determine the Factor of Safety | Search | Autodesk Knowledge Network, 2021), a safety factor value greater than 1 can be explained as the stress or load applied is within the allowable limit. The load applied is the load of the long metal bar with 75mm diameter and 4000mm. In short, the safety factor result showed is 1.1658 more than the index value 1 and which mean the linkage is able to withstand the load of the size of the long metal bar that set in this study.

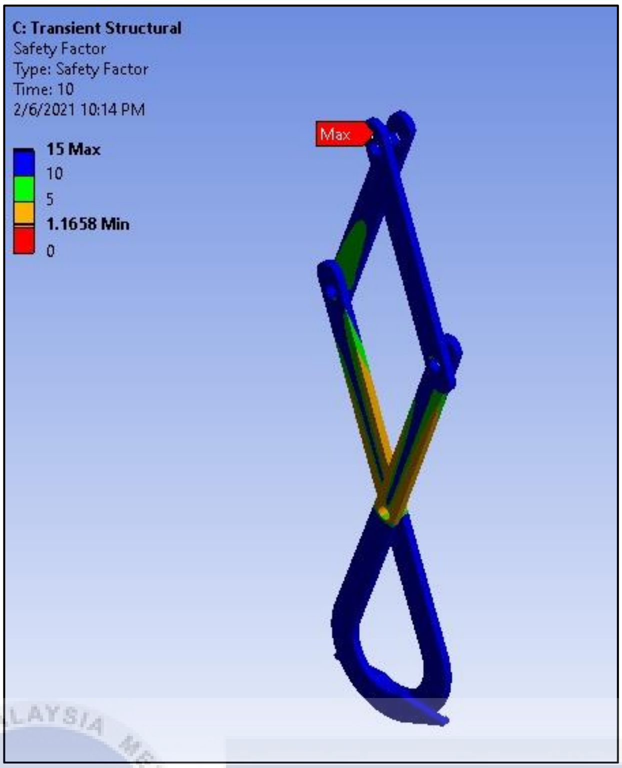


Figure 4.19: Safety factor

4.2.6 Wobbling measurement

Figure 4.17 shows the total deformation of the long metal which performed by using ASYSN software. The total deformation of the long metal bar by its distributed load is 4.2128 mm which mean the wobbling of the metal bar is at 4.2128mm distance from its original axis. Hence, with the designed grip handle used for carrying the long metal bar, workers no need direct contact the long metal bar surface by using their hand. In short, it can reduce the risk of damage on their hand nerves system of hand in order to trigger muscle pain. Also, the wobble will affect the grip strength of the workers during the transferring process. Therefore, the rubber cushion added on the handle to absorb the vibration caused by the wobble of long metal bar.

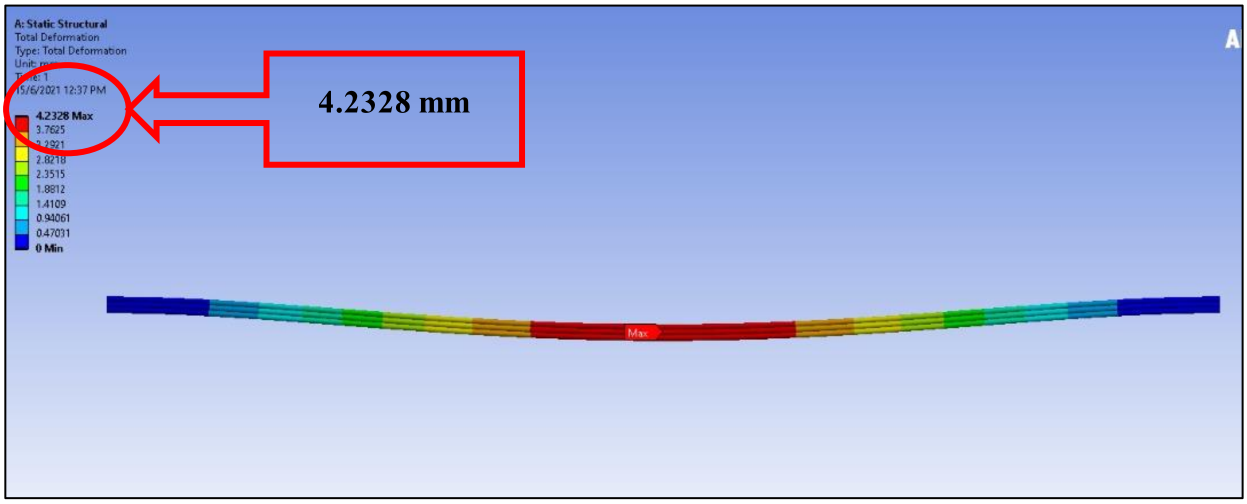


Figure 4.20: Wobbling condition (deflection)

4.3 Evaluation on Prototype

In this context, the methods used to evaluation on prototype will be discussed. The evaluations on prototype are the usability on prototype and carry analysis on prototype.

4.3.1 Usability on prototype

The method uses to perform this evaluation on the prototype ergonomic grip handle is the system usability scale. The SUS method is using questionnaires to get feedback on usability from the user. This system consists of ten questions for users to answer after using the grip handling for manual carrying the long metal bar. Due to pandemic Covid-19, only 6 participants involved in this evaluation.

After the participants used the ergonomic grip handle, they were asked to fill a 10 questionnaires SUS form. Table 4.7 shows the score of SUS questions from the participants.

Table 4.8: Score of SUS questions from participants

Participant \ Questions	1	2	3	4	5	6	7	8	9	10
Participant 1	5	2	5	2	3	2	5	3	4	2
Participant 2	4	3	5	1	4	1	5	3	5	1
Participant 3	4	2	4	2	3	3	5	2	5	1
Participant 4	4	1	4	2	4	2	5	3	4	1
Participant 5	5	3	3	3	4	2	5	4	4	2
Participant 6	5	3	4	3	5	2	5	3	4	2

1	Strongly disagree
2	Somewhat disagree
3	Neutral
4	Somewhat agree
5	Strongly agree

Table 4.8 shows the evaluation usability based on the effectiveness, efficiency, easy to use and satisfaction of the grip handle. For the effectiveness of the grip handle is related to question 1. From the Table 4.7 shows that average of the participants felt somewhat agree and strongly agree and thus can be concluded the grip handle is effectively solve the problem of carrying long metal bar with bare hand condition. The efficiency of the grip handle is linked to question 5 and the score of question 5 shows in the Table 4.7 is 2 out 6 participants felt neutral, and the other participants felt average in somewhat agree and strongly agree. In short, the efficiency of the grip handle is good. For instance, the grip handle can be easy to grasp the long metal bar compared with grasp the long metal by using bare hand condition. Third, the ease to use on the grip handle is correlated to question 3 and 7. From the score shows in the Table 4.7, average of participants felt strongly agree on question 3 and 7. In brief, the participants can be easy to use and quickly learnt of the use of grip handle to grasp and transferring the long metal bar. Lastly, the satisfaction evaluation on the usability is correlated to question 9, as the score in the Table 4.7 shows that average of participants felt somewhat agree and strongly agree with this question. Therefore, the participants felt confident when using the grip handle to transfer the long metal bar.

Table 4.9: Evaluation on the usability of the prototype

Evaluation	Question	Description
Effectiveness	1	• I think I would like to use this handle frequently.
Efficiency	5	• I found the various functions in this handle were well integrated.
Ease to use	3,7	• I thought the handle was easy to use. • I would imagine that most people would learn to use this tool very quickly.
Satisfaction	9	• I felt very confident using the handle.

From table 4.9, X is the total score of the odd number questions and Y is the total score of the even number questions. Then, total of X value obtained will minus with 5 and 25 minus the total value of Y obtained. After that, summing up the value of new X and Y value. Last, the total amount will be multiplying by 2.5 to obtain the score. Average the score of the usability of from each participant. The range of score will be 0 – 100 scale. As the result of usability from the table 4.8 shown is about 77.08 out of 100. The score of 77.08 can be interpreted the ergonomic grip handle on usability at grade B which the adjective rating is “Good”. Hence, the prototype of the grip handle for users to use with high satisfaction. Figure 4.18 shows the indicator to rate the usability of the ergonomic grip handle.

Table 4.10: Score result on SUS from participants

Variable / Participant	X	Y	X-5	25-Y	(X-5) + (25-Y)	(X-5) + (25-Y) * 2.5
1	22	11	17	14	31	77.5
2	23	9	18	16	34	85
3	21	10	16	15	31	77.5
4	21	9	16	16	32	80
5	21	14	16	11	27	67.5
6	23	13	18	12	30	75
					Average	77.08

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 4.21: Indicator of score SUS (*Interpreting System Usability Scale*, 2021)

4.3.2 Carry analysis

Carry analysis was performed by using CATIA software to determine the maximum acceptable weight of the long metal can be carry by male with 2 difference condition which are carrying the long metal bar with bare hand condition and with ergonomic grip handle support tool as shown in Figure 4.19 and Figure 4.20. The anthropometry data of male such as height, knuckle height and weight will refer to the average result obtained from the survey. The height, knuckle height and weight are 1710 mm, 648 mm and 72 kg, respectively.

In Figure 4.17 shows the result of maximum acceptable weight for male to carry the long metal bar with this position and bare hand condition is 231.813 N. The carry time and the distance are 45 s and 5000 mm per cycle, respectively. With this position, the hands distance of male is higher than expected which at 1123.34mm and the standard carry hand height cannot exceed the vertical distance at 1117.6mm. In short, carrying the long metal bar with this position is lack of ergonomic.

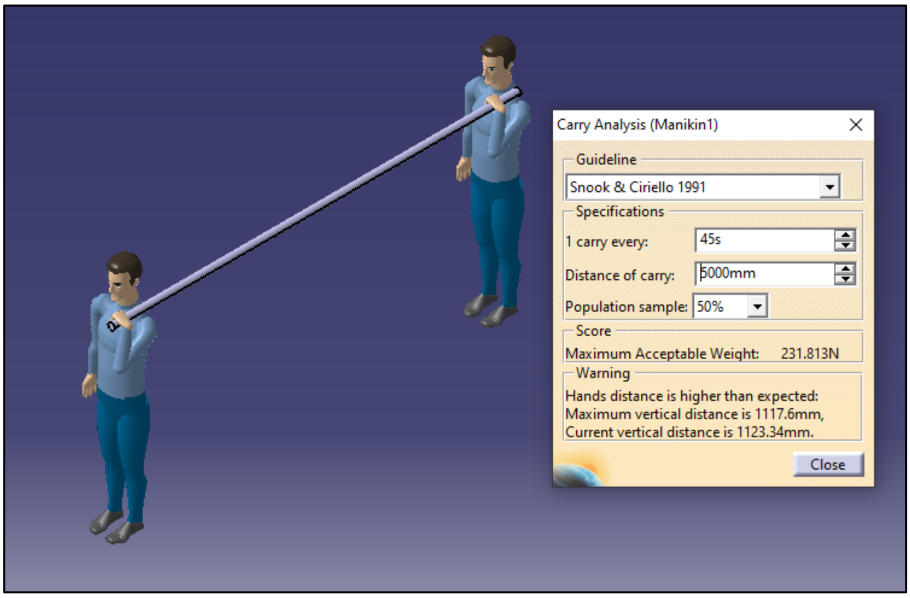


Figure 4.22: Carrying the long metal bar with bare hand and result carry analysis

The position carrying the long metal bar with an ergonomic grip handle was simulated as shown in the Figure 4.20. With the dedicated tool used, the maximum acceptable weight is 283.718 N with is higher than the maximum acceptable weight of carrying the long metal bar with bare hand condition at 231.813 N. Besides, the hand distance for carrying the long metal bar with an ergonomic grip handle will not exceed the standard. Hence, with support of the ergonomic grip handle can adjust the posture of carrying the long metal bar to prevent users use more muscle contraction in order to suffer from muscle pain or fatigue.

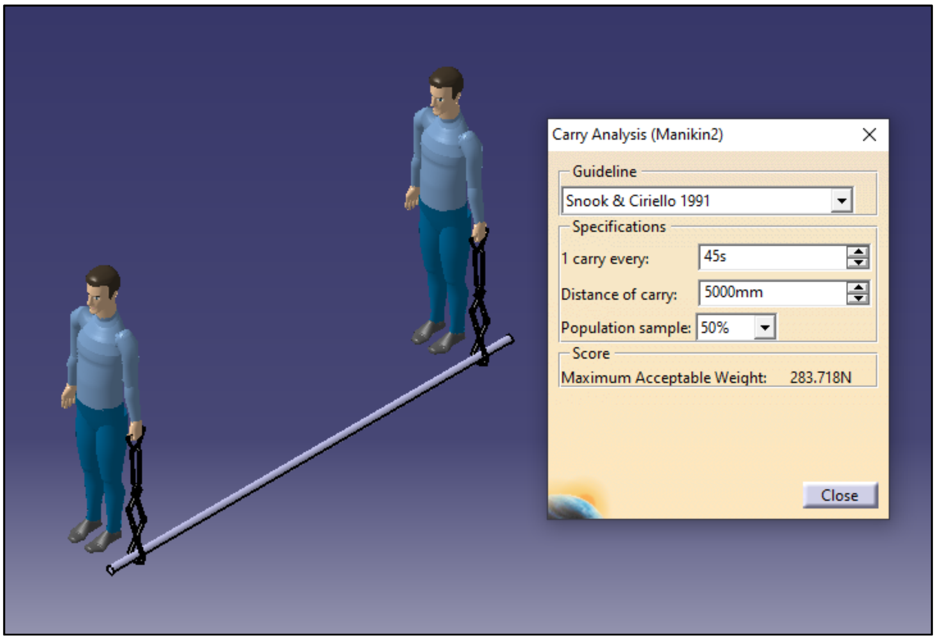


Figure 4.23: Carrying the long metal bar with grip handle and the result carry analysis

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This chapter concludes the findings of the research in line with the objectives and gives recommendations and suggestions for further improvement on the research in the future. The achievement on the design ergonomic grip handle based on the anthropometric data and user requirements obtained will be summarized in this chapter following by the evaluation of usability and carry analysis on the grip handle prototype.

5.1 Design Ergonomic Grip Handle Based on the Anthropometric Data

The participants involved in this study were Malaysian university students aged between 20 to 25 who free from disabilities and injuries. The anthropometric data collected which are thumb length, hand breadth, knuckle until fingertip, grip breadth inside diameter and knuckle height between male and female. The male's anthropometric data was analysed to determine the design of ergonomic grip handle. First, the result showed that the if the handle design with length at 95th percentile (104 mm) of male length from knuckle until the middle fingertip, 24 of male out 25 can be easy to grasp the handle without difficult. Therefore, the dimension of the length of the handle designed at 104 mm and above. Second, the handle width referred on the 95th percentile value (87.6 mm) of male hand breadth. The dimension on design the handle width designed at 87.6 mm and above, so that the handle fit to the users' hand breadth without discomfort when handling the long metal bar. The average of the male grip breadth inside diameter are below 57.8 mm. The handle diameter and shape referred to the 5th percentile value (40 mm) of male grip breadth inside diameter and thus the users with bigger diameter of grip breadth inside diameter can fit to use the handle. The handle designed in round shape to reduce the muscle load and pinch force when the users transferring the long metal bar with the grip handle. Lastly, the length of grip handle was designed between 95th percentile value (70.8 mm) and 5th percentile value (60mm) of male knuckle height. This is because to prevent the grip handle touch to the floor if the grip handle too long when they are transferring the long metal bar. As a result, adjust able length of the grip handle designed in order to meet the requirement of knuckle height of male.

5.2 Ergonomic Design of Grip Handle

Questionnaire survey has been conducted out the received users' opinion on the grip handle design requirements. Requirements such as provide greater grip strength, lightweight, ergonomics, safety and so on are suggested and thus QFD has been constructed. The final engineering specifications obtained are handle length, grip strength, material, ergonomic friendly and weight. Concept 4 is chosen to be the best design after performing the concept selection for the conceptual designs and translated to the CAD drawing by using INVENTOR drawing software. A prototype is fabricated based on the conceptual design selected. Before the fabrication, the material selection strategy performed to select the suitable materials used to fabricate the grip handle which are stainless steel for handle and aluminium for linkage structure. FEA analysis is performed by using ASYNS software to analyse the von misses' stress, total deformation, and safety factor when the load applied on the linkage structure. The handle and the linkage were connected to an adjustable nylon scrap for easy to adjust the length of the grip handle based on the knuckle height of users. Rubber cushion was added on the handle to reduce the contact force between the handle and user's palm.

5.3 Evaluation on the Grip Handle Prototype

The usability of the prototype was evaluated by using the scale usability system. From the result obtained, the average score of the usability on the grip handle is 77.08 out 100. According to the indicator to rate the usability, score at 77.08 can be interpreted the ergonomic grip handle on usability at grade B which the adjective rating is "Good". Hence, the prototype of the grip handle for users to use with high satisfaction. For carry analysis, the position of carrying the long metal with bare hand condition and with the designed ergonomic grip handle were simulated by using CATIA V5 software. The manikin is created based on the anthropometric data such as height, weight and knuckle height which obtained from data collection. The maximum acceptable weight for the position carrying the long metal bar with bare hand condition is 231.813 N. With is position, the hands distance of male is higher than expected which at 1123.34 mm and the standard carry hand height cannot exceed the vertical distance at 1117.6 mm. In short, carrying the long metal bar with this position is lack of ergonomic. While for the position of carrying the long metal bar with the designed ergonomic grip handle, the maximum acceptable weight is 283.718 N with is higher than the maximum acceptable weight of carrying the long metal bar with bare hand condition. Besides, the hand distance for carrying the long metal bar with an ergonomic grip handle will not exceed the standard. Hence, with support of the ergonomic grip handle can adjust the posture of carrying the long metal bar to prevent users use more muscle contraction in order to suffer from muscle pain or fatigue.

5.4 Recommendations and Suggestion

Due to pandemic Covid-19, this project is limited without proceed on actual testing of user carrying and transferring the long metal bar by using the new designed ergonomic grip handle. The electromyography (EMG) testing is recommended to evaluate the muscle activity of the users when they are transferring the long metal bar with the new designed ergonomic grip handle. With EMG result on muscle bicep, deltoid, erector spinae and brachioradialis obtain compare with the maximum voluntary contraction (MVC) whether muscle contraction during the transferring the long metal bar is less than 20% of MVC.

Besides, the evaluation on contact pressure between the handle and users' palm is suggested during the transferring of the long metal bar. As the contact pressure can evaluate force distribution is in normal condition or not when using the grip handle prototype. If continuously high-pressure contacts while transferring, it will affect the blood circulation in order to slow supply oxygen to the muscle. Thus, less oxygen supply will trigger muscle fatigue because lactic acid accumulated in muscle.

Furthermore, a time study is recommended to be used to observe the time taken for transferring the long metal bar. It is to compare the productivity between the bare hand condition and with a support of ergonomic grip handle on transferring the long metal bar.

Lastly, to minimize the wobble on the long metal which can be evaluated by serval method. First, the stabilizer added on the handle such as an aluminium rod to tie the long metal bar to avoid the deflection on the metal bar. Hence, reduce the deflection on the metal bar can minimize the wobble of the metal during the transferring process. Other than that, assign one more in the middle of the long metal and therefore the deflection on the long metal will not touch to the floor in order to prevent the decreasing of the grip strength during the transferring process. Moreover, during the transferring process, set a transferring method to carrying the long bar such as do not grasp the metal bar both side end during the transferring process. Workers can grasp the long metal bar with a gap such as distance 0.3m for both side end of the long metal bar in order to reduce the deflection. Hence, by reducing the deflection can reduce the wobble of the long bar. In short, these several method should be carried out to prove the statement of reduce wobble on the long metal bar in the future.

5.5 Sustainable Design and Development

The grip handle is designed with sustainable element to enable users to work ergonomically. Such as the grip handle is adjustable length to fit the knuckle height of the users. Besides, the rubber cushion on the handle is to reduce the contact pressure between the handle and users' palm. Lastly, the linkage was designed as a jaw to ensure that the long metal is fully grasp, prevent the long metal slip, and provide greater grip strength during the transferring process. Hence, it helps to enhance users' occupational health and safety by allowing them to perform the task in proper working posture by using the new designed grip handle. Moreover, the processes used to fabricate the prototype are of low costs and easily available at the FKP machine shop while the materials used were excessive scraps left from other projects.

5.6 Complexity

There are minimal complications encountered throughout this project's completion. Firstly, to analyse the anthropometric data of the participants to design the grip handle. As the grip handle must be proper and fit to the anthropometric of the participants. Next, the user’s requirements obtained for QFD need to use to design the grip handle in order to meet user satisfaction. Then, the material with high tensile strength must be decided to fabricate the prototype in order to prevent any failure such as yield during the transferring of the long metal bar. After material selected, the FEA analysis is used to evaluate the prototype can withstand the maximum magnitude force applied. Then, the fabrication process needs to be decided for manufacture the prototype. After the protype formed, evolution on the prototype need to be done in order to ensure that the prototype is suitable for use and meet the user’s requirement. Usability on the prototype to evaluate the effectiveness, efficiency, ease to use and satisfaction of the prototype when the users using the prototype to transfer the long metal bar. Additionally, carry analysis must be carried out to determine the maximum acceptable weight for carrying in order to ensure that the weight of the long metal bar is safety for the user to carry and transfer.

5.6 Lifelong Learning

In this project, the designing of the grip handle serve as a sense of lifelong learning. When the prototype grip handle is used during the transferring of the long metal bar which can reduce the risk of occupational safety and health. With a dedicated tool assisted, the workers no need to direct contact with the metal bar surface during the transferring process. Hence, it can reduce the risk of damage nerve of hand in order to trigger muscle fatigue. Using a proper dedicated tool on carrying the long metal bar can reduce the poor ergonomics posture during the transferring process. Therefore, in short to reduce the risk of work-related musculoskeletal disorder. Furthermore, using a grip handle for carrying the long metal bar can reduce the use of muscle contraction of the workers.

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APPENDIXES

Appendix A

FYP 1 GANTT CHART

	Month	Oct-20				Nov-20				Dec-20				Jan-21			
No	Week / Activity	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Submission of FYP Title	■	■														
2	Meeting with FYP supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
3	FYP Title Briefing	■	■														
4	Talk 1: Chapter 1: Introduction				■												
5	Talk 2: Chapter 2: Literature Review					■											
6	Talk 3: Technical English						■										
7	Talk 4: Chapter 3: Methodology							■									
8	Talk 5: Reference and Format											■					
9	Report Progress: Chapter 1	■	■	■	■												
10	Report Progress: Chapter 2					■	■	■	■	■	■	■	■	■	■	■	■
11	Report Progress: Chapter 3											■	■	■	■	■	■
12	Logbook Submission												■				
13	Presentation															■	
14	FYP 1 Submission																■

Appendix B

SURVEY FORM 1

FACULTY OF MANUFACTURING ENGINEERING

BACHELOR'S DEGREE PROJECT

TITLE: DESIGN AND EVALUATION OF ERGONOMIC GRIP HANDLE FOR MANUAL CARRYING THE LONG METAL BAR

Information for respondents:

This questionnaire is for the use of student's Bachelor Degree Project. This is a survey sheet which comprises of several questions to obtain the anthropometric parameter needed for the ergonomic grip handle design. This questionnaire focuses on (Faculty of Manufacturing Engineering)

FKP students of Universiti Teknikal Malaysia Melaka. Please kindly spend five to ten minutes to complete this survey form. Thank you for your attention and cooperation.

The objectives of this questionnaire are:

a) To obtain the data hand size data for determining the parameter, shape and size of ergonomic grip handle for manual carrying the long metal bar.

Your responses will be kept confidential and used only in aggregated form. Your cooperation is very much appreciated.

Instruction

Prepare measuring tape to measure the anthropometric data by following figures given below in section B.

Section A: Demographic Data of Respondent

Please tick the appropriate boxes.

1. Gender

   Male ( )   Female ( )

2. Age

   21 ( )   22 ( )   23 ( )   24 ( )   25 ( )

3. Height (Centimetre)

   ( )

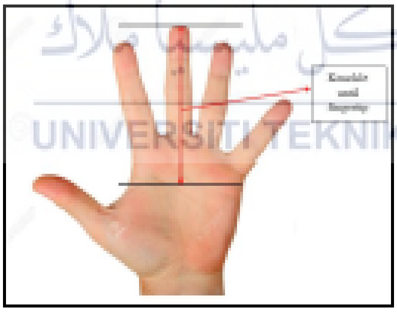
4. Weight (Kilogram)

   ( )

Section B: Hand Size Data of Respondent

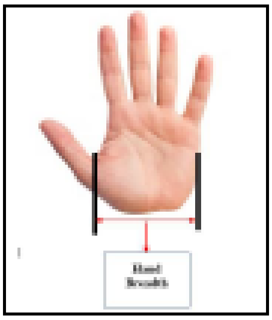
Please fill the blank given below.

1. Knuckle until Middle Finfertip (Millimetre)



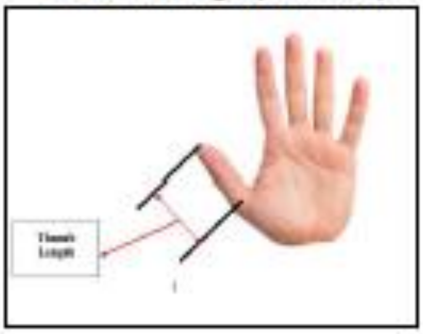
   (   )

2. Hand Breadth (Millimetre)



   (   )

3. Thumb Length (Millimetre)

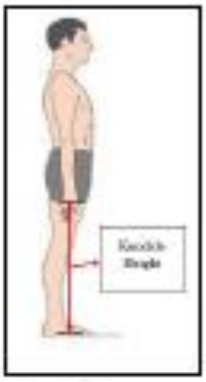


( )

4. Grip Breadth Inside Diameter (Millimetre)

( )

5. Knuckle Height



( )

SURVEY FORM 2

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FACULTY OF MANUFACTURING ENGINEERING

BACHELOR'S DEGREE PROJECT

TITLE: DESIGN AND EVALUATION OF ERGONOMIC GRIP HANDLE FOR MANUAL CARRYING THE LONG METAL BAR

Information for respondents:

This questionnaire is for the use of student's Bachelor Degree Project. This is a survey sheet which comprises of several questions to analyze the opinions and requirement needed for the ergonomic grip handle design. This questionnaire focuses on (Faculty of Manufacturing Engineering) FKP students of Universiti Teknikal Malaysia Melaka. Please kindly spend five to ten minutes to complete this survey form. Thank you for your attention and cooperation.

The objectives of this questionnaire are:

a) To get feedbacks from FKP students regarding the manual material handling object experience especially manual carrying the long metal bar.

b) To determine the design requirements of the ergonomic grip handle for manual carrying the long metal bar.

Your responses will be kept confidential and used only in aggregated form. Your cooperation is very much appreciated.

Section A: Demographic Data of Respondent

Please tick the appropriate boxes.

1. Gender

Male () Female ()

Section B: General Knowledge of Manual Handling Material

Please choose the appropriate answer.

1. Do you have experience on manual carrying an object with bare hand condition?

   Yes ( ) No ( )

2. Which object you did manual carrying before with bare hand condition?
   - Heavy Boxes ( )
   - Furniture ( )
   - Long metal bar ( )
   - All the above ( )
   - Other ( )................
3. Select the following handling technique that you applied during carrying the long metal bar?

( )

(

Section C: Experience and Feeling when manual carrying the long metal bar.

Please rate the following:

1 – Strongly disagree
2 – Disagree
3 – Neutral
4 – Agree
5 – Strongly agree

No	Question	Scale				
1	I can easily manually carry the long metal bar with bare hand.	1	2	3	4	5
2	I feel comfort when manual carrying the long metal bar with bare hand.	1	2	3	4	5
3	I feel muscle pain and fatigue after manual carrying the long metal bar with bare hand.	1	2	3	4	5
4	I feel hard to lifting the long metal bar with a bare hand.	1	2	3	4	5
5	The metal bar swing during the transferring process.	1	2	3	4	5
6	I feel hard to fully grip the metal bar surface during the transferring process.	1	2	3	4	5
7	I prefer using a supportive tool to manual carry the long metal bar.	1	2	3	4	5
8	I think that it is not safe when manual carrying the long metal bar without a supportive tool.	1	2	3	4	5
9	It is hard to maintain body balance when manual transferring the long metal bar with bare hand.	1	2	3	4	5

Section D: Design Specifications

Please choose the options that you agreed.

1. What is the major concern when manual carry the long metal bar?

   Application effectiveness of Supportive tool ( )

   Ergonomics concern ( )

   Safety issues ( )

2. If a new grip handle for manual carrying the long metal bar is to be designed, which features are more important to you?

   Please rate.

Features	Scale				
Affordable Price	1	2	3	4	5
Ease to use	1	2	3	4	5
Light weight	1	2	3	4	5
Provide greater grip strength	1	2	3	4	5
Appearance/Aesthetic	1	2	3	4	5
Safety	1	2	3	4	5
Ergonomics	1	2	3	4	5
Portable	1	2	3	4	5
Comfort handle	1	2	3	4	5

Appendix C

CONSENT FORM AND EVALUATION FORM

INFORMED CONSENT FORM

I am _______________________________, student ID _______________________ and IC no. _______________________ agreed to participate in this experiment. The purpose of this form is to state clearly the terms of my participation in this experiment.

1. I confirmed that I have fully understood the overall procedures of this experiment through the briefing from the researcher.
2. I understand that my participation is voluntary and I am willing to take the risk while doing this experiment.
3. I understand that all information I provide for this experiment will be treated confidentially.
4. I understand that I have the right to withdrawn from this experiment if I feel uncomfortable during the execution of experiment.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Should you have any question about the study or any other matter related to your participation in this experiment, or if you experience a experiment related injury as a result of this study, you may call Liew Jee Seng at 0198480204 or email at B051710100@student.utem.edu.my

____
Signature of subject

Date: _______________

____
Signature of researcher
Liew Jee Seng
Date: _____________

EXPERIMENT Safety Precautions

Subjects should ensure safety before executing the experiment.

1. Subjects should wear shoes and suitable attire during the experiment.
2. Make sure the experiment is under supervision of lecturers or Penolong Jurutera.
3. Subjects should healthy and free from physical injuries.
4. Subjects should read and understand the experimental procedures.
5. Start the experiment until subjects told to do so.
6. Subjects will be explained and demonstrated about the complete procedures of carrying out the experiment.
7. Subjects are required to fill up the consent form before executing the experiment.
8. Subjects will be examined their physical and psychological at before and after performing the experiment to ensure their safety.

PARTICIPANT FORM

A. Screening *(to be excluded from the experimental session if any of these conditions apply)*

1. Sleep duration (i.e. through self-reported)

   □ Sleep duration of the night prior to experimental session is less than 6 hours

2. Current health condition (i.e. through observation or self-reported)

   □ Unhealthy *(e.g. participant shows a sign of fever, cold, migraine, sinus, or etc.)*

3. Medical history or current condition of upper extremity (i.e. through observation or self-reported, may check more than one box)

   □ Injured/broken of upper extremity – e.g. carpal tunnel syndrome
   □ Health problem with upper extremity – e.g. rheumatoid arthritis, osteoporosis
   □ Other condition of limiting strength on upper extremity – e.g. hand hemodialysis

4. Alcohol & drug consumption (i.e. through self-reported, may check more than one box)

   □ Consume alcohol within 24 hours prior to the experimental session
   □ Consume any prescribed and/or drowsiness medication 24 hours prior the session
   □ Taking any kind of illegal drug at any time

B. Demographic

1. Gender: □ Male □ Female
2. Age: _____ years
3. Weight: ____________ kg
4. Height: _____________ meter
5. Hand dominance: Left-handed / Right-handed

Evaluation 1: System Usability Scale

System Usability Scale (SUS)

Please enter your participant number: _____

This is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement after using the handle today.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this handle frequently.					
2. I found the tool unnecessarily complex.					
3. I thought the handle was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this handle were well integrated.					
6. I thought there was too much inconsistency in this handle.					
7. I would imagine that most people would learn to use this tool very quickly.					
8. I found the handle very cumbersome to use.					
9. I felt very confident using the handle.					
10. I needed to learn a lot of things before I could get going with this handle.					