# DESIGN OF SAFETY RFID WATCHES USING QFD STUDY CASE AT MOUNT GEDE WEST JAVA

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**Abstract.** The accident and death occur at mountain has increasing each year until 2019, and one of the problems is because the climbers are not equipped by a proper tool to mountain climbing, especially for beginner climbers. Mount Gede is a mountain that located in West Java, and has relatively easy track for beginners, many beginners choose this mountain to start their climbing activities. Therefore, this mountain has to prepare a tool that can loaned to the climbers. This research is developing RFid based watch to support mountain climbers activity using quality function deployment method, so the product could meet the customer need statement with the first rank on planning matrix is integrated with mountain base with normalize raw weight is 0,13 and technical response to the researcher with the first rank of normalize raw weight is 0,149 related to product durability, the result is a RFid based watch that equipped with watch, compass, emergency alarm, and integrated with mountain base using RFid technology and also it is already comply with standard of diver's watch from ISO to ensure that the product durability and could survive in extreme activity like mountain climbing.
**Keywords**: RFid, Watch, Mountain Climbing, Quality Function Deployment, Mount Gede

Introduction
Indonesia is a country that has a ring of fire which means this country is surrounded by many active and non-active volcanoes, Indonesia has 127 volcanoes, and this is the country with the highest number of mountains, of 127 volcanoes there are 64 active volcanoes [1]. The large number of mountains in Indonesia leads many mountain climbers who want to explore mountains in Indonesia.
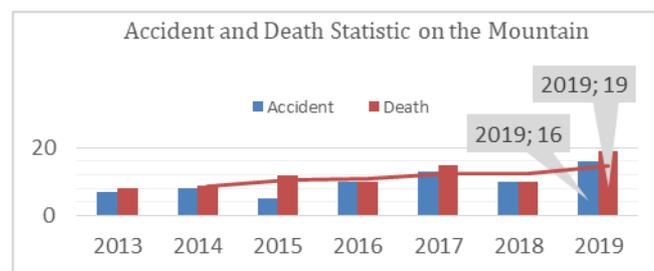


**Figure 1.** Accident and death statistic on the mountain

Based on data obtained from the Indonesian Mountain Guide Association (APGI), from the data on figure I.1 it can be seen that cases of climbers death on mountain are increasing year by year, and the

peak is in 2019 with 19 climbers dying from 16 cases of climber accidents, the number of climbers death is more than cases of accidents that occur because in one case an accident can cause 1 or more climbers death. The total number of climbers who died from this data was 83 people.
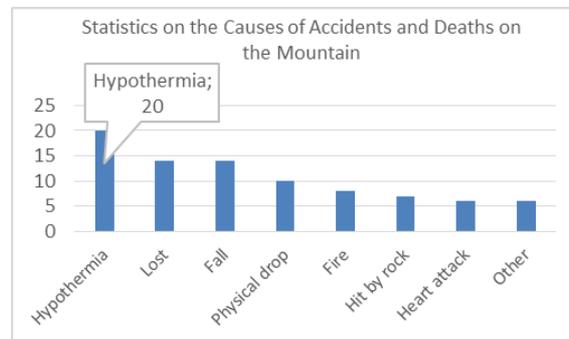


**Figure 2.** Statistic causes of accident and death on the mountain

It can be seen from the figure I.2 that the causes of accidents and deaths of climbers on the mountain, the highest cause is hypothermia, hypothermia is a condition where the body experiences a drastic decrease in temperature, the intended temperature is below 35 degrees, where the normal human temperature is 37 degrees Celsius. The coldest temperature at the peak of Indonesia's mountains can be up to 5 degrees Celsius, plus strong winds will exacerbates hypothermia [2].

In addition to hypothermia, the second largest cause of accidents and deaths based on figure I.2 is getting lost, climbers are often not on the proper climbing route and cause the climber to get lost and disappear from the group. The search for missing climbers was carried out by the SAR team, the search took a long time, even days depending on the information and traces of the victims. One of the mountain that has history of lost climbers is Mount Gede.

Mount Gede is a tourist attraction with a high number of climbers due to its location in the Greater Jakarta area, and the relatively safe track is the reason many beginners start this hobby by climbing Mount Gede [3]. Due to the large number of visitors to Mount Gede, and the absence of tools that can support climbing provided by Mount Gede Pangrango National Park, this is the cause of many cases of climbers who are lost due to getting lost and some have died from hypothermia. In 2009 six students from the city of Sukabumi got lost since (30/06/09), until (03/07/09) they were lost for 3 days, and the Gunung Gede search and rescue (SAR) team conducted a search for the victims on July 3, the sixth. The students can be found because the search and rescue team sounding the whistle and the victims responding by shouting to tell them their position.

However, the conditions at Mount Gede is vary, many locations in Gunung Gede do not have internet signal, therefore it is necessary to have a tracking device for climbers who do not use the internet and provided by the manager of tourist attractions so that the climbers can be safer. There needs to be a tool that can be used by climbers and has RFid technology with tracking feature that can locate the climber's position in order to speed up the evacuation process. RFid (Radio Frequency Identification) is a system that uses radio signals that can be used for various things, one of which is to track an object. internet for tracking and the number of climbers that are difficult to identify, RFid has a unique serial number among other identical objects [4].

There are smart watches that exist in the market with a lot of supporting features of mountain climbing activities such as watches, compasses, altimeters, barometers, health monitoring sensors, navigation systems. The watches with all the features that has been mentioned is having a expensive price starting from Rp. 4,800,000 to Rp. 11,599,000 depending on the brand and quality of the watch [5]. The price

of the watches is relatively expensive and not become priority specially for the beginner, and another product that is similar and become the reference in this research is RFid smart band in Mount Merbabu where the technology already implements and could work as its function in mount area, this product could help beginner climber.

In this final project, researcher will focus on reducing accident and death in mountain by improving mountain safety trough the development of RFid-based watches with additional features by adjusting to the important needs of mountain climbers in Mount Gede to become a suggestion for Gunung Gede Pangrango National Park in providing watches to support the climbers and minimize the victim of accident and death happen in Mount Gede, the additional features are features that can support the mountain climbing activities, the RFid technology already developed in Mount Merbabu with their smart band, and it already proof that it could be used in the Mountain to locate climbers position, this technology will also be used in the proposed tool. Watches and compasses are important for climbers in order to know the time and orientation of their position in order to find a climbing route again when lost.

Method
*2.1 Identification and Introduction*
Identification and introduction stage is the stage carried out to understand the background, and the purpose of carrying out this research, an explanation of this stage in research is as follows. Determine the research object, The object of this research is developing a watch that has features to support mountain climbing activities. In developing the watch, researcher using quality function deployment method, and this phase is done for researchers to understand and get references on how to develop products using these two methods, researchers also conducted a literature study to find out the features that can be applied in watches to support mountain climbing activity. The background of this research is the number of accidents that cause the death of mountain climbers from year to year, this background is obtained by conducting a literature study on the problems and solutions that have been applied to develop the product later. Alternative solutions are carried out with the help of fishbone diagrams so that the roots of the main problem can be described clearly, from the root of the problem the researcher writes alternative possible solutions, then the author chooses an alternative solution that is in accordance with the field and department of the researcher's lecture so that it can overcome these problems. Problem definition has a purpose to describe the problem by point and determine its limitation. The research objective aims to determine the result from this research.

*2.2 Description of Collecting Data Mechanism*
Data that is needed in this research is divided into two types, namely primary data and secondary data Primary Data, primary data is data that is new and directly obtained from this research, primary data is taken directly to the object of research, and can be done in various ways, for example direct observation, interviews or surveys, primary data in this study are Need statement and Technical response. Secondary Data, Secondary data is used to complete the research, in contrast to primary data, this data is taken from other sources by the researcher, this data can be in the form of graphs and important information about the research. Secondary data in this study are feature specification. In this study, we will develop watches with features that will support mountain climbing activities, the features that will be used have special specifications related to energy use and others. The mechanism of data collecting in this research is survey technique; survey is a quantitative research technique, in this research it can be done in several ways, one of which is by using a questionnaire, the researcher asks several people about an existing problem. (Neuman, 2003). The questionnaire used in this study was a satisfaction and importance questionnaire. Study of literature; This mechanism is an activity to find and study books, theses, journals related to Quality function deployments (Andry, 2015). Interview: in this research to collect the need statement from the target of product directly will use interview technique, because with interview

developer can directly contact with the target of the product, with hope that the need statement is more valid.

*2.3 Data Processing*

The data that has been obtained will then be processed by data processing, in this study the data is processed using Quality function deployment, which will be carried out in the following stages, Determine need statement; need statement are comes from the customer based on Voice of Customer (VOC), to define the need statement developer conduct the interview with target user of the product, which are the visitor of Mount Gede, after VOC is collected and it will be translated into several points of need statement or customer attributes. Determine importance and satisfaction of attributes; After the need statements are already collected, the questionnaire about importance and satisfaction of each attribute in need statement will be collected with Likert scale between 1 for very not important and 4 for very important, also for satisfaction with scale 1 for very not satisfied and 4 for very satisfied with the attribute. Validity and reliability test; The results of the importance and satisfaction questionnaire will later be validated to see whether the results of the questionnaire are valid, and reliability tests are used on the data of importance level to determine whether the questionnaire that has been created and distributed is reliable using the Alpha Cronbach formula. Determine technical response; This section will contain the translation between market needs in VOC into developer language or Voice of Developer, which will be carried out by researchers. House of quality calculation; After the customer needs and technical response data has been collected, then the data is entered into the house of quality matrix to be calculated and produces a rank on the product quality attribute. Concept selection: at this stage, the 3D design process is carried out based on the selected attributes and proceeds to the next process. Final specification: the final specification stage contains a description of the product design that has been made, the description is about the elements that exist in the product. In the analysis stage researcher will analyze the result of designing a product using QFD and the HOQ result with attribute that is chosen and the implementation on the product. Conclusion is the stage to summarize the entire research process carried out and provide conclusions related to research results, there are also suggestions for further research. Description of verification mechanism in this study, the object of the product being developed is a watch with RFID technology that has not been implemented by the Mount Gede. The method used in this research is quality function deployments, to produce quality products according to the user's need statement and a technical response from the developer, the quality function deployment method is also used, with this method the product produced will have quality according to the needs of its users with technical input from the developer. The verification will use simulation in Autodesk Inventor Studio to simulate the watch performance using ISO diver's watch standard. Description of design validation mechanism, Validation of the design is needed so the product could be product can be confirmed to fulfill the customer need statement, in this project researcher is developing an existing RFID bracelet for climber to become a wristwatch that has more function to support mountain climbing activity, to validate the design researcher will compare the need statement and the fulfillment to the product design.

Result & Discussion
*1.1 Need Statement*
In this study, the product design will be based on the need statement of the target users, the need statement will be obtained based on interviews conducted with the target user, namely the Mount Gede climber. The number of climbers who will be interview is 11 people based on the specific people who already have experience use the reference product. The method to get the need statement is interview

which has more effort, more time and directly talk to the target user also it is complied with the standard on the Product Design and Development book which states that less than 10 people who were interviewed were too few and 50 interviewed too many people, interviews can be completed when there is no need for a new statement [5].

**Table 1.** Need statement

| No | Need Statement | R |
|----|----------------|---|
| 1 | light weight watch | 1, 7, 11 |
| 2 | Simple watch design | 1, 10 |
| 3 | Clock feature | 1, 10 |
| 4 | Compass feature | 1 |
| 5 | Integrated information system with mountain base | 3,1 |
| 6 | Emergency alarm | 5 |
| 7 | Durable battery | 6 |
| 8 | Durable material | 1, 5, 9, 11 |
| 9 | Strong lock system | 7 |
| 10 | easy to operate in any condition | 2, 4, 8 |

After conducting interviews to get Voice of Customer, then the answers of the target users that is represent by R (number) will be translated into items of attribute need statement which will be used in product development as shown in table above. There are 10 need statements from 11 Mountain Gede climbers that already use the reference product with interview method.

*1.2 Importance and satisfaction level*
After obtaining the attribute need statement, then the importance and satisfaction of the target users regarding each attribute of the need statement need to be determined, there are 10 need statements which will later become 10 questions of importance to customer (ItC) and 10 questions customer satisfaction (CuSP) using Likert scale, the tables below is the code for each question to make it easier to record the results of the questionnaire

**Table 2.** Weight average performance

| Question | Importance | Satisfaction |
|----------|-----------|--------------|
| Q1 | 2,94 | 3,22 |
| Q2 | 2,63 | 3,06 |
| Q3 | 2,94 | 3,19 |
| Q4 | 3,09 | 3,06 |
| Q5 | 3,06 | 3,13 |
| Q6 | 3,09 | 3,28 |
| Q7 | 3,06 | 3,44 |
| Q8 | 3,09 | 3,38 |
| Q9 | 2,91 | 3,34 |
| Q10 | 3,09 | 3,56 |

*1.3 Planning Matrix result*

**Table 3.** Planning matrix result

| Need Statement | Normalized raw weight |
|----------------|----------------------|
| light weight watch | 0,08 |
| Simple watch design | 0,07 |
| Clock feature | 0,09 |
| Compass feature | 0,12 |
| Integrated information system with mountain base | 0,13 |
| Emergency alarm | 0,10 |
| Durable battery | 0,11 |
| Durable material | 0,11 |
| Strong lock system | 0,08 |
| easy to operate in any condition | 0,11 |
| Total | 1,00 |

In the table above, the attribute with the highest normalized raw weight value is an integrated information system with mountain base with a value of 0.13.

*1.4 Technical Response*

Based on the technical response that has been made previously, the researcher determines the target for detailed specifications on the product later, the target is determined based on the study literature.

**Table 4.** Technical response

| Technical Response | Unit | Target | Reference |
|---|---|---|---|
| Total product mass | gr | 41 | (GSM Arena, 2021) |
| Watch dimension | mm³ | 40x40x10 | (GSM Arena, 2021) |
| Digital clock feature | Binary | yes | Product Reference |
| Digital compass feature | Binary | yes | Product Reference |
| Integrated information system | Binary | yes | Product Reference |
| Emergency feature | db | 90 | (Gudang Listrik, 2021) |
| Battery capacity | mAh | 300 | (GSM Arena, 2021) |
| Battery endurance | Hour | 48 | (GSM Arena, 2021) |
| Watch durability | Year | 5 | (Wisesa, 2018) |
| Lock system pulling strength | N | 200 | (ISO 6425, 2018) |
| physical button | Unit | 3 | Observation |
| Water and dust resistant | IP Rating | IP68 | (Fajar, 2020) |

*1.1. HOQ*

After obtaining all the calculation data needed to make the HOQ matrix, then all the data will be combined and calculated for the contribution value of each existing technical response and see the rank for priority importance.

**Table 5.** Final specification

| Technical Response | Contribution | Normalize Contribution | Rank |
|---|---|---|---|
| Total product mass | 0,730 | 0,030 | 12 |
| Watch dimension | 1,376 | 0,056 | 9 |
| Digital clock feature | 2,018 | 0,082 | 7 |
| Digital compass feature | 2,288 | 0,093 | 5 |
| Integrated information system | 1,128 | 0,046 | 10 |
| Emergency feature | 2,043 | 0,083 | 6 |
| Battery capacity | 2,955 | 0,120 | 2 |
| Battery endurance | 2,893 | 0,117 | 4 |
| Watch durability | 3,666 | 0,149 | 1 |
| Lock system pulling strength | 0,731 | 0,030 | 11 |
| physical button | 1,892 | 0,077 | 8 |
| Water and dust resistant | 2,935 | 0,119 | 3 |

Based on the normalize contribution calculation, the technical response is obtained which occupies the first place, namely battery capacity, and the last rank is the total product mass, from this ranking obtained from the HOQ matrix, it can be determined which technical response should be prioritized.

*1.2. Design Result*

After the concept already chosen and the HOQ already built, the next step is to summarize the final specification of the proposed watch at table 7

**Table 5.** Final specification

| Final Specification | | |
|---|---|---|
| **Technical Response** | **Unit** | **Target** |
| Total product mass | gr | 28 |
| Watch dimension | mm³ | 40x40x10 |
| Digital clock feature | Binary | yes |
| Digital compass feature | Binary | yes |
| Integrated information system | Binary | yes |
| Emergency sound feature | db | 90 |
| Battery capacity | mAh | 300 |
| Battery endurance | Hour | 48 |
| Watch durability | Year | 5 |
| Lock system pulling strength | N | 200 |
| physical button | Unit | 3 |
| Water and dust resistant | IP Rating | IP68 |



**(a)** Watch face design    (b)Emergency laser light design

**Figure 3.** Design Result

The watch designed using technical response as above, the specification for the watch also match with final specification, the tracking technology in this proposed watch is using RFid, because it is cheaper than GPS satellite, also it has small dimension and it is suitable to make compact watch design, with the small dimension and the chosen material the watch has 41 gr weight as the target, it also has laser light and buzzer with 90 db for emergency feature. The battery for this proposed watch is 300 mAh battery that is located under the watch face, the battery is rechargeable so it will save the cost to buy a new battery, but if there is problem with the battery it is also replaceable with many options in the market that has the same specification.

*1.3. Design Verification*
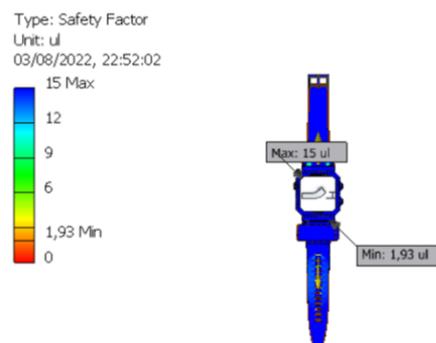


**Figure 4.** Design Verification

To verify the design researcher, use simulation in Autodesk Inventor 2019, the simulation uses to calculate the safety factor in the product. In this simulation there are fixed area that located under the watch face and 3 load with detail 2 load on each strap with 200 N load in opposite direction and on the upper watch face with 30N based on standard divers' watch on ISO 6425 [6]. from the data the minimum safety factor in the product with the load as above is 1,93 ul in the pin area that connect strap and watch face, since the result is 1,93 ul > 1 ul it means that this product is safe enough of the load that applies.

Conclusion

The background of this research is to reduce accident and death in mountain, specifically in Mount Gede where it is become the favorite spot for beginners in around West Java to start mountain climbing activities, the objective of this research is to make a RFid based watch for beginners to have a device that can help them to inform the mountain base if there is any emergency situation and they can be located so they will get help faster. This research using quality function deployment (QFD) to gain the customer needs and develop the product based on the customer needs, this methods also have HOQ matrix where it can develop a product to meets voice of customer also the voice of developer. The proposed tool improves customer satisfaction by fulfil customer need statements, design a lightweight watch with overall mass 41 grams, and it has simple yet functional design with 3 physical buttons to operate easily. Design a tool that has watch also compass feature to prepare the proper watch for climbers. Design a tool that has location tracking technology using RFid tag and reader and it is integrated with mountain base, also complete with emergency alarm feature. Design a watch that has durable battery using 300 mAh battery and variative types of resin to become material for strap and housing that suitable with-it usage and durable, also stainless steel at buckle area to have a strong lock system that capable to comply 200 N force as the standard of diver's watch from ISO.

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# Minimizing Human Error on Activities PC Hollow Girder Using SHERPA and HEART Method

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**Abstract.** PT. PP Urban Precast is a construction company that produces PC Hollow Girder. In the PC Hollow Girder casting process, a human error occurred which resulted in the production process being delayed. Human error that often occurs is miscommunication between the gantry machine operator and the flagman, so that the operator presses the remote-control button more than 2 times. This study aims to minimize human error in the PC Hollow Girder casting process. The method used is Hierarchical Task Analysis (HTA) to break down the work process, the SHERPA method to identify the possibility of human error occurring and the HEART method to determine the probability of human error. The results of identification using the SHERPA method are known that from a total of 12 activities there are 6 error activities with 3 activities having a high probability. Meanwhile, with the HEART method, the highest Human Error Probability was obtained in subtask 2.2, namely pressing the remote to control the passage of the gantry machine to the top of the mold caused by an error in pressing the remote controller for the direction of the gantry machine, which was 1.968. At the end of the study, improvements were proposed in the form of Standard Operating Procedures (SOP) and checklists for vibrator machines.
**Keywords**: Human Error, SHERPA, HEART, Casting

## 2. Introduction

PT. PP Urban Precast is a manufacturing company that produces and develops precast concrete and ready-mix concrete products to meet the needs of the residential construction industry and other construction. Some of its products are CSP, CCSP, PC I Girder, Squirrel Pile, Flat Sheet Pile, Facade, T Girder, Half Slab and PC Hollow Girder. PC Hollow Girder is a product with the highest number of requests and serves to support toll roads and bridges. PC Hollow Girder production process is divided into 9 stages including preparation, setting iron, setting mold walls, mixing raw materials in the batching plant, testing the compressive strength of concrete (slum test), casting, opening of precast molds, labelling and demoulding, and delivery and shipping. Based on interviews with the production floor supervisor, it is known that human errors are often found in the casting process because this process is still done manually. Human error is a failure to complete a specific activity or work that can cause disruption to the operating schedule or cause damage to objects and equipment [1]. Human error is also an unwanted action that can occur, causing an undesirable event, such as an accident and can hamper production [2].

Human error occurs in the gantry engine and vibrator engine. Human error occurred in the gantry machine due to miscommunication between the gantry machine operator and the gantry machine flagman, so that the operator presses the remote-control button more than 2 buttons. This causes the machine to shut down while reading commands. The gantry machine is a machine that is operated using a remote control by the operator with directions from the flagman to lift the cast bucket. Human error occurred on the vibrator machine due to lack of inspection on the vibrator machine, causing the machine to experienced damage during the production process such as an electrical short in the engine, burned or malfunctioned. The vibrator machine is divided into 2, namely external and internal vibrators which are useful for levelling fresh concrete when it is poured into the mold and for compacting and lifting air

in the concrete. This vibrator machine cannot run continuously for 2 hours and causes the vibrator to heat up quickly and be easily damaged in parts. Therefore, this study aims to identify human errors using the SHERPA method followed by calculating the probability of human error using HEART on the operator of the PC Hollow Girder casting stage. Figure 1 is an example of a Hollow Girder PC product that has a defect in the form of porous due to unevenness.



**Figure 1.** Defect Product

SHERPA was developed by Embrey [3] as a method for identifying human errors using HTA [4] in conjunction with an error taxonomy to identify human activity errors. The SHERPA method is more structured and comprehensive to implement, less time-consuming than the observation method, and has an acceptable reliability value [5]. In addition, Human Error Assessment and Reduction Technique (HEART) is a human reliability assessment method developed to help risk analysts identify the main effects on human performance and the likelihood of errors, in a systematic and iterative manner [6].

3. Methods
In this study, data collection was obtained by 3 methods, namely observation, questionnaires and interviews. The method of observation is done through direct observation on the production floor at the Sadang plant. While the questionnaire was given to operators who are directly related to the production process. While the interviews were conducted with field guidance. Questionnaires and interviews were used to determine whether there was a human error in the production process.
The initial stage of data processing is carried out by analyzing activities in the relationship between tasks and subtasks presented in the Hierarchy Task Analysis (HTA) diagram. HTA is a method that presents detailed work steps in a process. HTA is in the form of a breakdown tree with several levels, in this study there are up to level 2 where level 0 contains the names of the stages studied, then at level 1 contains the task or production process at that stage, and for level 2 contains the details carried out by the operator in each process. production at the stage under study. The HTA breakdown stage is useful for identifying the task in which human error occurs.
The next step is to measure and analyze the level of human error using the Systematic Human Error Reduction and Prediction Approach (SHERPA) method. The SHERPA method is divided into 7 stages, namely making HTA, job/task classification, human error identification, consequences analysis, ordinal error probability assessment, critical analysis, and remedy analysis strategy.Then perform calculations and analyze the probability of human error using the HEART (Human Error Probability Assessment and Reduction Technique) method. The HEART method is divided into 4 stages, namely general task type, error producing condition, assessed proportion error, and human error probability. At the end of the study, suggestions for improvements related to human error problems will be given.

4. Results and Discussions

*4.1. Hierarchy Task Analysis (HTA)*

HTA is useful for identifying every step in the manufacture of Hollow Girder PC products in the casting process and has been presented in Table 1. The results from HTA level 2 will be used to analyze the SHERPA and HEART methods which will be placed in the subtask column along with the number of each subtask.

**Table 1.** Hierarchy Task Analysis (HTA)

| Task | Subtask | The casting process |
|---|---|---|
| **1** | | The process of pouring fresh concrete into the cast bucket [1>2] |
| | 1.1 | Recording the PC Hollow Girder code in production |
| | 1.2 | Records critical data errors during Hollow Girder PC production |
| **2** | | The process of lifting the cast bucket onto the PC Hollow Girder mold using a gantry machine [1] |
| | 2.1 | Running the gantry machine in the correct direction according to the Hollow Girder PC mold |
| **3** | | The process of Pouring fresh concrete from the cast bucket into the Hollow Girder PC mold [1>2/3] |
| | 3.1 | Fresh concrete should be poured in layers and sequentially |
| | 3.2 | Record the number of layers that have been poured with fresh concrete |
| | 3.3 | Record the percentage that has been poured with fresh concrete |
| **4** | | Vibration process on PC Hollow Girder mold with external vibrator [1>2>3] |
| | 4.1 | Checking the condition of the external vibrator engine |
| | 4.2 | Setting the position of the vibrator machine (within 1 m from the internal vibrator) |
| | 4.3 | Recording the external vibrator machine during the Hollow Girder PC production process |
| **5** | | Vibration process on PC Hollow Girder mold with internal vibrator [1>2>3] |
| | 5.1 | Checking the condition of the internal vibrator engine |
| | 5.2 | Setting the position of the vibrator machine (within 1 m from the external vibrator) |
| | 5.3 | Recording the internal vibrator machine during the Hollow Girder PC production process |
| **6** | | Inspection [1] |
| | 6.1 | Hollow Girder PC mold inspection |
| | 6.2 | Position size inspection for external vibrator machines |
| | 6.3 | Position size inspection for internal vibrator machine |
| | 6.4 | QC Assurance |

*4.2. Identification and Analysis of Human Errors Using the SHERPA Method*

The SHERPA method is divided into 7 steps [7], first, making HTA which has been presented in Table 1. Second is task classification where each job list that has been described in HTA is further classified into 5 types of errors according to the taxonomy table, namely action errors, checking errors, retrieval errors, communication errors and selection errors. In this study, there are 2 errors, namely action errors, which are errors in actions that occur in the operator during the production process and checking errors, which are errors in inspections carried out by operators during the production process. Thirdly, human error identification is carried out by compiling a list of jobs that have been classified into several types of errors.

Then, identify the consequences analysis to find out the most likely consequences for each error if the operator commits the error. Consequences themselves can be in various forms such as the consequences that occur on machines, humans, the environment or the whole work system if there is a human error. The next stage is the ordinal error probability assessment by assessing the ordinal probability which is divided into 3 types, namely low, medium, and high. Low (L) is an error that has never happened before

as in E32 because the error frequency occurs in 1-2 times/year, medium (M) is an error that occurs 1 or 2 times the previous error as in E11 because the error frequency occurs in 1-2 times/month and high (H) are errors that often occur before as in E21 because the frequency of errors occurs in 4-6 times/month.

The next stage is the identification of critical analysis, where if the consequences of the resulting error are very important, such as causing losses that occur cannot be tolerated, then the consequences of each subtask must be analyzed with a critical level. Critical level has two types of signs that are used to indicate each error, namely (!) which means there is an intolerable error or critical error and (-) which means that it is classified as a non-critical or tolerable error is marked. Finally, after identification by measuring and analyzing the level of human error using SHERPA, a summary of the results of the overall SHERPA analysis is presented in Table 2.

**Table 2.** Hierarchy Task Analysis (HTA)

| Error | Task | Clasi-fication | Code Error | Mode Error | Description of Error | Consequence | Ordinal Probability | Critical Level |
|---|---|---|---|---|---|---|---|---|
| E11 | Recording the PC Hollow Girder code in production | Checking errors | C2 | Check incomplete | Operators often miscode and out of sync with production mapping | QC has difficulty inspecting the product | Medium | (-) |
| E21 | Running the gantry machine in the correct direction according to the Hollow Girder PC mold | Action errors | A3 | Operation in wrong direction | Operator fatigue causes miss communication | The gantry engine has an error or the engine shuts down | High | (!) |
| E32 | Record the number of layers that have been poured with fresh concrete | Checking errors | C2 | Check incomplete | Operators sometimes miss or miss the process when pouring | The number of layers increases and is uneven which results in defective products (porous) | Low | (!) |
| E33 | Recording the percentage that has been poured with fresh concrete | Checking errors | C3 | Right check on wrong object | The operator does not record the segment that is in production | Layers in the previous and subsequent segments are not in sync with each other so that the product quality has decreased (striped) | Low | (-) |
| E41 | Check the condition of the external vibrator engine | Checking errors | C5 | Check mistimed | Operators often skip the machine checking process and use the internal vibrator for too long | The vibrator engine has an error (short, burned, or does not work) or the engine shuts down | High | (!) |
| E42 | Setting the position of the vibrator machine (within 1 m from the internal vibrator) | Action errors | A6 | Right operation on wrong object | Operator doesn't measure distance first | Vibration is not optimal causing uneven concrete | Low | (!) |
| E51 | Checking the condition of the internal vibrator engine | Checking errors | C5 | Check mistimed | Operators often skip the machine checking process and take too long to use an external vibrator | The vibrator engine has an error (short, burned, or does not work) or the engine shuts down | High | (!) |
| E52 | Setting the position of the vibrator machine (within 1 m from the external vibrator) | Action errors | A6 | Right operation on wrong object | Operator doesn't measure distance first | Vibration is not optimal causing uneven concrete | Low | (!) |

The summary table of the error identification results is useful to make it easier to see the results of the analysis that has been carried out, and it can be seen that there are 8 subtasks that are included in errors or have experienced errors in the operator during the casting stage for Hollow Girder PC products.

*4.3. Analysis and Assessment of Human Error Probability with HEART*

The HEART method is divided into 4 steps [5][8], namely making a task classification based on the generic tasktype (GTT), determining the Error Producing Condition (EPC), determining the Assessed Proportion, and calculating the results of the Human Error Probability (HEP). Task Classification based on Generic Type Task is useful in determining the type of task from possible errors that occur by grouping each task so that nominal human reliability is obtained which will be used in the HEP calculation. Error Producing Condition (EPC) is used to identify conditions because EPC can find out the cause of an error at the casting stage. The Error Producing Condition (EPC) reference table also has a total effect in it so that this can help calculate the probability of the effect caused. Determination of the value of the assessed proportion is also based on the results of the identification of conditions using the EPC. The objective at this stage is to determine or predict the impact of each EPC based on the APOE value that ranges from a minimum value of 0 and the maximum APOE value of each EPCs is 1 and the number of APOE of all EPCs does not have to be equal to 1. larger error occurs.

Human Error Probability (HEP) or probability evaluation, is carried out to assess the reliability of human errors that occur during the casting stage. The HEP calculation requires several data, namely task, generic type task, nominal human unrealibility, error producing conditions, total HEART effect, and assessed proportion that have been obtained in the previous analysis stage and the calculation of Human Error Probability (HEP) produces a probability of failure value that is useful for see the task with the highest score to be given a proposal. The calculation of the probability of failure is carried out using the formula, namely nominal human unrealibility multiplied by the product of the overall assessed effect (AE), and the following formula is used, namely: Assessed Effect (AE) = [pi (fi-1) + 1]. With the information that for pi is the Assessed Proportition obtained from the calculation of the assessed proportion and for fi is the Total HEART Effect obtained from the analysis of Error Producing Condition (EPC). After the Human Error Probability (HEP) for each subtask has been analyzed, all the results of the Human Error Probability (HEP) are summarized in the recapitulation table of operator reliability calculations presented in Table 3.

**Table 3.** Human Error Probability (HEP)

| Error | Task | HEP |
|-------|------|-----|
| E11 | Recording the PC Hollow Girder code in production | 0.043 – Medium – (!) |
| E21 | Running the gantry machine in the correct direction according to the Hollow Girder PC mold | 2.304 – High – (!) |
| E32 | Record the number of layers that have been poured with fresh concrete | 0.043 – Low – (!) |
| E33 | Recording the percentage that has been poured with fresh concrete | 0.043 – Low – (-) |
| E41 | Check the condition of the external vibrator engine | 0.977 – High – (!) |
| E42 | Setting the position of the vibrator machine (within 1 m from the internal vibrator) | 0.006 – Low – (!) |
| E51 | Checking the condition of the internal vibrator engine | 1.062 – High – (!) |
| E52 | Setting the position of the vibrator machine (within 1 m from the external vibrator) | 0.006 – Low – (!) |

The identification results of the recapitulation of operator reliability calculations in Table 3 show that there are 3 ordinal high probability with a probability of failure of 2,304 on E21, 0.977 on E41 and 1,062 on E51. The results of the identification of the two methods, namely the Systematic Human Error Reduction and Prediction (SHERPA) method and the Human Error Assessment and Reduction Technique (HEART) will be combined for analysis which is presented in Table 4. The analysis is carried out on the work process that has the highest potential for human error. based on data processing that has been done.

**Table 4.** Summary of the results of the SHERPA AND HEART method

| Error | Classification | Error code | Mode error | Ordinal probability | Criticality level | HEP | Error description | Recommendation |
|-------|---------------|-----------|-----------|--------------------|-----------------|-----|-------------------|----------------|
| E11 | Checking Error | C2 | Check incomplete | Medium | (-) | 0.043 | Operators often miscode and out of sync with production mapping | Using a Special Ladder for marking / Recording products |
| E21 | Action Error | A3 | Operation in wrong direction | High | (!) | 2.304 | Operator fatigue causes miss communication | Provide 2 shift operators, Making SOP |
| E32 | Checking Error | C2 | Check incomplete | Low | (!) | 0.043 | Operators sometimes miss or miss the process when pouring | Provide checklist |
| E33 | Checking Error | C3 | Right check on wrong object | Low | (-) | 0.043 | The operator does not record the segment that is in production | Provide checklist |
| E41 | Checking Error | C5 | Check mistimed | High | (!) | 0.977 | Operators often skip the machine checking process and use the internal vibrator for too long | Provide checklist |
| E42 | Action Error | A6 | Right operation on wrong object | Low | (!) | 0.006 | Operator doesn't measure distance first | Making SOP |
| E51 | Checking Error | C5 | Check mistimed | High | (!) | 1.062 | Operators often skip the machine checking process and take too long to use an external vibrator | Provide checklist |
| E52 | Action Error | A6 | Right operation on wrong object | Low | (!) | 0.006 | Operator doesn't measure distance first | Making SOP |

Based on the identification recapitulation using the Systematic Human Error Reduction and Prediction (SHERPA) and Human Error Assessment and Reduction Technique (HEART) methods, it was concluded that E21 in the activity had a gantry machine running in the direction appropriate to the PC Hollow Girder print, the highest HEP value was 2,304 with a ordinal high and criticality level (!) are priority activities that need to be improved.

*4.4. Proposed Improvements*

Based on the results of the analysis using the SHERPA and Human HEART methods, it can be seen that in the PC Hollow Girder product casting process there is a high potential for human error in 3 activities, namely subtask 2.1, subtask 4.1 and subtask 5.1. Among the 3 activities that have a high potential for human error, there are activities with a much larger HEP value followed by an intolerable

criticality level and with a high ordinal probability, namely subtask 2.1 with the activity of running a gantry machine in a direction that matches the PC print. Hollow Girders.

Based on the results of the identification that has been carried out on potential human error activities that have been presented in Table 4, suggestions for improvement are given according to the problem or possible cause of human error in subtask 2.1. The proposed improvement is to design a Standard Operating Procedure (SOP) for each process of running the gantry machine in a direction that is in accordance with the Hollow Girder PC mold. Proposed improvements using this method are presented in Table 5 which was made based on the results of interviews and in accordance with the regulation of law no. 1 of 1970 concerning Occupational Safety and several Regulations of the Minister of Manpower.

**Table 5.** Standard Operating Procedure for Gantry Crane Machine Operator

| | PT. PP URBAN PRECAST | |
|---|---|---|
| **(pp) URBAN** PRECAST | **STANDARD OPERATING PROCEDURE FOR GANTRY CRANE MACHINE OPERATOR** | Date : 30 Sept 2021 *Page* : 1 *of* 1 |

**A. Goal:**
1. Work execution guidelines for gantry machine operators
2. To protect workers/operators and those around the work site

**B. Tools and Materials:**
1. PPE (safety shoes, safety helmet, safety gloves and safety glasses)
2. Gantry Crane Machine

**C. Personnel Qualifications:**
Operator in charge of running the gantry machine

**D. PROSEDUR PELAKSANAAN:**
1. Gantry cranes are prohibited from carrying loads that exceed the maximum capacity that has been determined.
2. Information regarding the maximum gantry crane load weight must be attached to the hook or other parts of the gantry crane.
3. Operators and employees are prohibited from crossing the equipment lifting area.
4. Safety helmets and safety shoes are always used.
5. It is forbidden to operate pressing 3 buttons at once (up down, travel, travers)
6. It is forbidden to lift the load suddenly at the beginning of the lift.
7. Check the stability of the load and the balance of the lifting equipment before lifting.
8. The operator must be behind the load or slightly inclined to the side.
9. Make sure the lifting aid is removed from the hook after operation.
10. Make sure the hook is above two meters or more after using the tool so as not to hit the worker.
11. Stopping the Gantry crane at the designated place.
12. The emergency button must be pressed or the button turned off.
13. Checking the operational function of the limit switch, by running the crane without load on the hook gradually until the limit switch limit.
14. Checking mechanical operations such as resetting and checking for mechanical damage.
Operational check of hydraulic and pneumatic components, check the tightness of joints and bolts
16. Checking the deformation of the Hook, checking the Hooks such as cracked or eroded.
17. Gantrying Rope checking, make sure the wires are not broken, aberrated and not coiled according to the grooves on the drum.

| | **PT. PP URBAN PRECAST** | |
|---|---|---|
| (PP logo) **URBAN** PRECAST | **STANDARD OPERATING PROCEDURE FOR GANTRY CRANE MACHINE OPERATOR** | Date : 30 Sept 2021 *Page* : 1 *of* 1 |

18. Check connections such as bolts, nuts, pins and locks, make sure they are not worn and tight.

19. Check rail components, make sure there is no deformation, cracking or corrosion

20. Inspection of mechanical components such as shafts, bearings, pins, gears, rollers, locks and clamps, making sure they are not broken, cracked or distorted by load.

21. Check the components of the pegs, brakes, pins, and lifters, making sure there is no excessive dirt / scale.

22. Checking the components of the drum rope and sheaves, make sure there is no excessive dirt / crust.

23. Checking the motor components, making sure the physical condition is not damaged and is functioning properly.

24. Check the chain components and sprockets, make sure there are no metal crusts and excessive dirt.

25. Check the hooks components such as bolts, locking pins, and safety, make sure there are no cracks in the hook components that can be detected with magnetic particles, immersion in penetrant or other detecting devices.

26. Checking the load safety components and the safety of the tools installed on the crane, make sure they are functioning properly.

27. Checking electrical components such as controls, make sure there is no looseness on the buttons, not dirty and no cables are peeling and the control buttons can function properly.

28. Gantry cranes must be checked at the beginning of each shift by the operator.

29. Gantry cranes must be tested once in a year. At the time of recertification of the tool.

| Compiler | Examiner | Supervisor |
|---|---|---|
| | | |
| Operator | SHE Team | Plant Manager |

5. Conclusion

Based on the results of identification using the SHERPA and HEART methods, it was concluded that E21 running the gantry machine in a direction that corresponds to the Hollow Girder PC mold has the highest HEP value of 2.304 with an ordinal high level and a criticality level of (!) is a priority activity that needs to be improved.

Proposed improvements are given according to problems or possible causes of human error in subtask 2.1, namely designing Standard Operating Procedures (SOP) for each process of running the gantry machine in a direction that is in accordance with the Hollow Girder PC print.

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# Ergonomics and Human Factors in Rice Farm: A Link for Safety and Efficiency

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**Abstract.** This descriptive study focused on the risk evaluation of the three selected farms located at San Jose, Occidental Mindoro, Philippines by using ergonomics principles. The study intended to determine the body parts of the farmers usually experience troubles/pain, assess their work posture while working in the field, and recommend possible solutions that would improve work and/or prevent or lessen the risk in the farm. The data was gathered through observation, temperature measurement, sound level of the environment, the vibration of the machine and the illumination of the direct sunlight, photo documentation while farmers are working, and interview based on the Nordic Questionnaire during the plowing process and harvesting of rice. Results further suggest that farmers have troubles with their body as they work in the fields and were also overexposed that might cause risk such as hearing loss, intrusion with speech communication and with the perception of warning signals, disturbance to job performance, annoyance, eye fatigue, eye strain, spinal health risk, low back pain, dizziness, heat illness and heat stroke. By using RULA and REBA ergonomics tools, it can be concluded that the activity of shoveling the dikes in the farm has the highest risk index of 2.25 and a total score of 9 which is considered high. Further, the use of agricultural rotor can minimize the risk index for the farmers. Lastly, continuous working with this posture can also lead to Work-related Musculoskeletal Disorders (WMSD).

**Keywords**: Rice farming, posture assessment, ergonomics evaluation, risk assessment, Work-related Musculoskeletal Disorders

Introduction

The Philippines is primarily an agricultural country; most Filipinos live in rural areas and support themselves through agriculture [1]. Rice is one of the major agricultural crops in the Philippines. The agricultural sector contributes 14% of the country's gross domestic product and 13 million workers (32 percent) comprise the labour force [2]. Farming, one of the four (4) subs – sectors of agriculture in the country is an important sector for Filipinos especially the rice crops since Filipino meals (breakfast, lunch, and dinner which are all typically big meals) are usually served with a bowl of rice, so rice is/always be present. Agriculture in the Philippine economy is dominating and about 45% of the cultivated area is rice. Rice as one of the main crops of the Philippines agricultural crops is used as a replacement for iced tea refills and Internet connectivity is found in some of the local fast-food restaurants in the country, offering unlimited rice and people are chalking the fact that the Philippines is a rice-producing country. Currently, there are about 10 million rice farmers in the Philippines. They constitute a big portion of the over 100 million Filipinos today [3]. Farming is more on physical labour

and fatigue. It requires a farmer to be always 100% alert while working with machinery and animals. They are working on the farm, making sure their crops are growing and they always overwork and exert their body to the work that sometimes or most of the time they gain fatigue and sometimes a more serious problem.

According to the research of Cornell University, New York, the temperature of the area or room is around 20 degrees; the employees made 44 more errors and were half as productive when they were in nice and warm at 25 degrees temperature. While working in an environment that is too hot can make workers lethargic and unfocused. Too much heat can make them lose electrolytes and water faster, causing low mental performance and decreased motor skills.

Exposure to the sound

Exposure to noise or a high level of sound at work can harm the workers and the best-known effect of noise is the loss of hearing. Too much noise can also cause the workers to lose their focus on their work and may lower the productivity rate of the company. Too much sunlight is harmful to the skin. Sunlight contains ultraviolet (UV) rays that can cause damage to the skin which eventually will become cancer. It may also speed up the aging of the skin, making it lethargic, mottled, and wrinkled [4].

Exposure to vibration

Having work that requires to be exposed to high levels of vibration is known to cause injury to workers over time. Hand-arm vibration exposure causes direct injury to the fingers and hands, affecting feeling, dexterity, and grip. Whole-body Vibration (WBV) when dealing with higher than expected levels of low back pain and injury in the workforce causes loss of time and production output.

Work-related musculoskeletal disorders (WMSD) is one of the main occupational health problems. The best strategy to prevent this lies in ergonomic interventions. The variety of industrial processes and environments, however, makes it difficult to define an all-purpose framework to guide these ergonomic interventions. This undefinition is exacerbated by the recurrent introduction of new technologies e.g., collaborative robots [5].

The development of WMSD is mainly attributed to three factors: (i) occupational risk, (ii) individual characteristics, and (iii) social factors [3]. Occupational risk factors include awkward postures, repetitive tasks, frequent and/or excessive tasks involving the handling of heavy loads, and thermal discomfort. The individual characteristics are related to individual limitations or health problems. Finally, social factors such as family and economic problems may interfere with motivation and attention during work.

One of the ergonomics tools that has been used to detect the WMSD are the Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA). It has been utilized in salt farms in the Philippines and provided mitigation to prevent the salt workers in having WMSD [6]. These tools were also used to evaluate the risk in the vehicle's operators and drivers in China and was able to provide recommendation in minimizing the risk to the health of operators and drivers [7].

*1.1 Objectives*

The main objective of this study was to determine the body parts of the farmers who usually experience trouble/pain on the selected farms. Specifically, it aimed to determine the body parts of the farmers usually experience troubles/pain from the selected farms; to evaluate the daily temperatures, vibrations, sound and illuminations, and the range of time that the farmers of the selected farms are exposed; to assess the work posture of the farmers while working in the field using Rapid Entire Body Assessment

(REBA) and Rapid Upper Limb Assessment (RULA); and to recommend possible solutions that will improve work and/or prevent or lessen the risk on the selected farm.

## 1.2    Scope and Delimitation

This study focuses on the risk evaluation of the selected farms located in San Jose, Occidental Mindoro since the province still uses mechanized process, it is labour intensive [8]. There were (3) selected farms and two (2) different machines for plowing the land included in the study. The data gathering was made through observation, measuring the temperature, sound level of the environment, the vibration of the machine, and the illumination of the direct sunlight, photos taken while farmers are working, and interview-based on the Nordic questionnaire. The study was conducted during the plowing process of farming.

Methods
## 2.1 Theoretical Framework
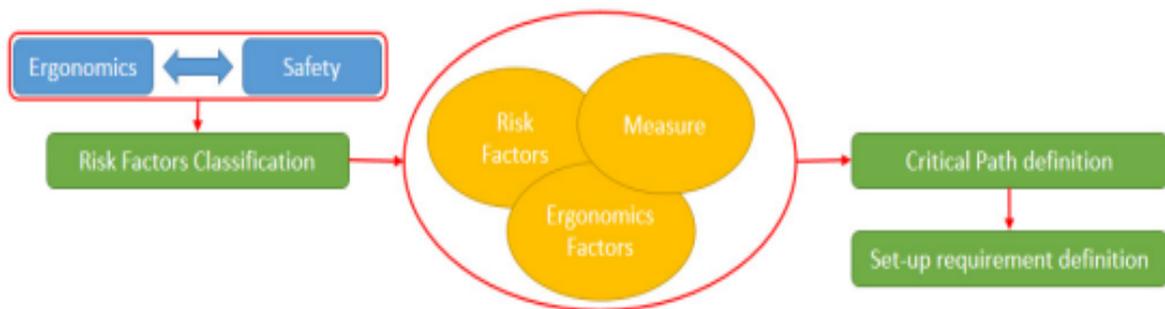


**Figure 1.** Theoretical Framework

Based on the study conducted by [9] in Italy as seen in figure 1, this multipath methodology revealed that ergonomics has a link to safety and efficiency in factories in Italy. With this, the researchers will adopt this framework on rice farms in Occidental Mindoro, Philippines. Risk factors are activities that raise the possibility of musculoskeletal injury; thus this intersect with the ergonomics factors which specifically the physical risk factor which is considered first-line risk factors, since it may provoke a disorder and injury.

## 2.2 Research Design

This study used a descriptive method to learn and investigate the risk in the physical environment on the selected farms located in San Jose, Occidental Mindoro, Philippines as shown in Figure 2. It involves the illumination of the direct sunlight and the sound level on the farm, the vibration of machines used in the selected farms, and measuring the temperature of the area. The data gathered systematically and sequentially followed the descriptive method for better understanding, and to build a significant assumptions and ideas for the improvement of the study. REBA (Rapid Entire Body Assessment), and RULA (Rapid Upper Limb Assessment) with the Nordic questionnaires were used to assess the physical condition of the farmers while working.
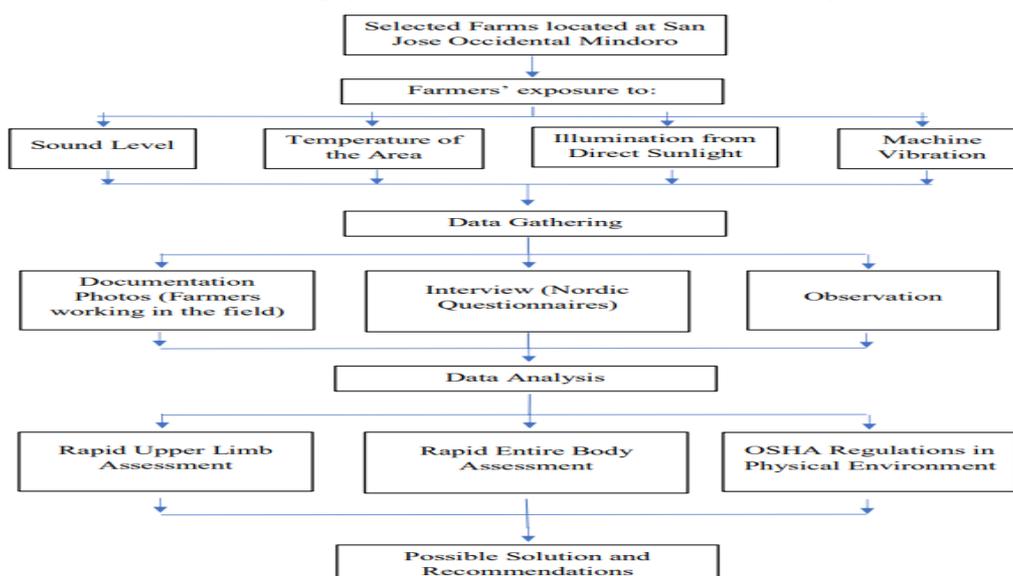
**Figure 2.** Research Design

*2.3 Research instrument*

The researchers asked the permission of the farmers especially the owners of the farms to conduct a study evaluating the possible risks in their work. The researchers observed the farms, and measure the temperatures, illumination of the sunlight, the vibrations of the machines, and the sound level of the area. The data gathered and recorded was kept confidential. The researchers gathered the data through interview and survey questionnaire (Nordic Questionnaire), observation, and documentation (photo-taking for work posture).

Results and Discussion

Based on the data gathered, the following are the Nordic Data Interpretation for farm workers dealing with farm tools and equipment:

Nordic Data Interpretation

**Table 1**. Nordic Questionnaire Result.

| Body Parts | Experienced trouble and pain for the last 12 months (%) | Experience trouble and pain for the last 7 days (%) | Prevented from carrying out normal activities (%) |
|---|---|---|---|
| Neck | 100.00 | 100.00 | 33.33 |
| Shoulders | 83.33 | 66.67 | 100.00 |
| Elbows | 83.33 | 33.37 | 33.33 |
| Wrist/Hands | 100.00 | 66.67 | 100.00 |
| Upper back | 100.00 | 100.00 | 16.67 |
| Lower back | 100.00 | 100.00 | 16.67 |
| Hips/Thigh/Buttocks | 100.00 | 66.67 | 16.67 |
| Knees | 33.33 | 16.67 | 100.00 |
| Ankles/Feet | 33.33 | 33.33 | 100.00 |

Using the Standard Nordic Questionnaire conducted to the six farmers in three farms, the researchers found out they experienced trouble and pain for the last 12 months in the following body parts: neck (100%), shoulders (83.33%), elbows 83.33%), wrist/hands (100%), upper back (100%), lower back (100%), hips/thighs/buttocks (100%), knees (33.33%), and ankles/feet (33.33%). Meanwhile, the trouble and pain experience for the last 7 days before the interview are: neck (100%), shoulders (66.67%), elbows (33.37%), wrist/hands (66.67%), upper back (100%), lower back (100%), hips/thighs/buttocks (66.67%), knees (16.67%), ankles/feet (33.33%); and the corresponding percentage that prevented them from doing the normal activities are: neck (33.33%), shoulders (100%), elbows (33.33%), wrist/hands (100%), upper back(16.67%), lower back (16.67%), hips/thighs/buttocks (16.67%), knees (100%), and ankles/feet (100%), respectively.

To evaluate the daily temperatures, vibrations, sound and illuminations, and range of time that the farmers of the selected farms are exposed, the researchers used equipment and various applications from smartphones namely: Decibel X for sound level meter, Smart Vibration Meter for vibration, Thermometer for the temperature, Stopwatch for the timer and Lux Light Meter Pro for illumination. The researchers gathered the data in three farms within three days and took the measurements in the daytime (9:00-12:00), noontime (1:00-4:00), and afternoon (4:00-6:00).

**Table 2.** Physical Environment Assessment Results.

| Parameters | Farm 1 | | Farm 2 | | Farm 3 | |
|---|---|---|---|---|---|---|
| | Average | Average of total time exposure (hours/day) | Average | Average of total time exposure (hours/day) | Average | Average of total time exposure (hours/day) |
| Daylight Temperature/ Outside Temperature | 29 ◦ C | 7.50 | 29.11◦ C | 8.00 | 29.11◦ C | 7.67 |
| Machine Vibration | 10.7 Hz | 7.50 | 9.79 Hz | 8.00 | 9.40 Hz | 7.67 |
| Sound of The Machine (dBA) | 91.22 dBA | 7.50 | 92.43dBA | 8.00 | 93.78 dBA | 7.67 |
| Illumination Outside/ Direct Sunlight (lx) | 15,444.44 lux | 7.50 | 16,111.11 lux | 8.00 | 16,777.78 lux | 7.67 |

The table above shows the result of the assessment of the physical environment to which the farmers were exposed at. It indicates that the farmers in Farm 1 were exposed to within 7.5 hours a day with an average temperature of 29 ◦C, a vibration of 10.7 Hz, a sound of 91.22 dBA, and 15,444.44 lux of illumination. However, farmers from Farm 2 were exposed for 8 hours a day with an average temperature of 29.11 ◦C, a vibration of 9.79 Hz, a sound of 92.43 dBA, and 16,111.11 lux of illumination. Lastly, farmers from Farm 3 were exposed for 7.67 hours a day with an average temperature of 29.11 ◦ C, a vibration of 9.40 Hz, a sound of 93.78 dBA, and 16,777.77 lux of illumination.

**Table 3.** OSHA Acceptable Level vs Total Exposure of Farmers in Three Farms.

| Parameter | Average for Three Farms | Average of total time exposure hours/day | OSHA Acceptable Level per 8 hour |
|---|---|---|---|
| Daylight Temperature/ Outside Temperature | 29.07 ◦ C | 7.722 | 23-26 ◦ C |

| | | | |
|---|---|---|---|
| Machine Vibration | 9.96 Hz | 7.722 | 5 Hz |
| Sound of The Machine | 92.48 dBA | 7.722 | 85 dBA |
| Illumination Outside/ Direct Sunlight (lx) | 16,111.11 lux | 7.722 | 500-600 lux |

Table 3 presents the comparison of the Occupational Safety and Health Administration (OSHA) acceptable level in four parameters: temperature, vibration, sound, and illumination versus the exposure of the farmers on three different farms. It indicates that the farmers were exposed to more than the acceptable levels that the OSHA set.

The researchers used the tools Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA) to evaluate the postures of the farmers while doing different activities on the farms. Figure 3 shows the first activity which is shoveling the dikes on the farm.



**Figure 3.** Work posture of shoveling the dikes

Figure 3 demonstrates that the working posture of a farmer in shoveling the dikes depends on the shovel's height and how much the shovel scoops/loads. The legs coordinate with the arms in lifting the shovel as well as the neck and trunks. The heavier the load, the lower the position is in scooping the shovel.

**Table 4.** REBA result of shoveling the dikes.

| REBA (Rapid Entire Body Assessment): Shoveling the dikes in the farm | | | |
|---|---|---|---|
| Risk | | Assessment Results | |
| Risk Index | 2.25 | REBA Score | 9 |
| Task Variables | | Task Variables | |
| Neck Position | 20+ degrees | Upper arm Position | |

| Adjustments | Twisted | Adjustments | |
|---|---|---|---|
| Score | 3 | Score | 2 |
| Trunk | | Lower arm | |
| Position | 20-60 degrees | Position | |
| Adjustments | Side bending | Adjustments | 60-100 degrees |
| Score | 4 | Score | 1 |
| Legs | | Wrist | |
| Position | One leg raised | Position | Wrist twisted |
| Adjustments | 30-60 degrees | Adjustments | 15 degrees |
| Score | 3 | Score | 2 |

REBA result shown in Table 4 implies that shoveling the dikes on the farm has a risk index of 2.25 and a total score of 9 which is considered high.



**Figure 4.** Operating a hand tractor machine without a carrier

Figure 4 shows an operator who has no protective equipment and a tractor with no carrier which is more likely prone to any risk he may encounter while tilling the farmland. The upper arm experiences a heavy load during the operation affecting the trunk, while the wrist is twisted for bumpy areas. The legs help in controlling the machine in its direction.

**Table 5.** REBA result of operating hand tractor machine.

| REBA (Rapid Entire Body Assessment): Operating Hand Tractor Machine (without carrier) | | | |
|---|---|---|---|
| Risk | | Assessment Results | |
| Risk Index | 1.5 | REBA Score | 6 |
| Task Variables | | | Task Variables |
| Neck | | Upper arm | |
| Position | 0-20+ degrees | Position | |
| Adjustments | Twisted | Adjustments | |

| | | | |
|---|---|---|---|
| Score | 2 | Score | 3 |
| Trunk | | Lower arm | |
| Position | 0-20+ degrees | Position | |
| Adjustments | Twisted | Adjustments | 60-100 degrees |
| Score | 3 | Score | 1 |
| Legs | | Wrist | |
| Position | Bilateral weight bearing | Position | Wrist twisted |
| Adjustments | 30-60 degrees | Adjustments | 15+ degrees downwards |
| Score | 1 | Score | 3 |

Table 5 shows the REBA result of operating a hand tractor with a REBA score of 6 and risk index of 1.5 means operating the hand tractor without the carrier has a medium risk.



**Figure 5.** Operating agricultural rotor.

Figure 5 describes the posture of a farmer while operating a rotor in the field. It can be gleaned on the image that the operator manifested a static position during the operation which can be attributed to landscape features and machine's design.

**Table 6.** RULA result of operating agricultural rotor.

| RULA (Rapid Upper Limb Assessment): Operating Rotor | | | |
|---|---|---|---|
| Risk | | Assessment Results | |
| Risk Index | 1 | RULA Score | 3 |
| Task Variables | | Task Variables | |
| Upper arm | | Muscle Load A | |
| Position | 45-90 degrees | Posture is mainly static (i.e. held > 1 minute) | FALSE |
| Adjustments | | Adjustments | |
| Score | 3 | Score | 0 |
| Lower arm | | Force Load A | |

| | | | |
|---|---|---|---|
| Position Adjustments | 60-100 degrees | Position Adjustments | 10-20 degrees |
| Score | 2 | Score | 2 |
| Wrist | | Trunks | |
| Position Adjustments | 15 degrees | Position Adjustments | 0 degrees |
| Score | 2 | Score | 1 |
| Wrist Twist | | Legs | |
| Mid-range | FALSE | Position | Bilateral weight bearing |
| End range | FALSE | Adjustments | |
| Score | 0 | Score | 1 |
| Muscle Load B | | Force Load B | |
| Posture is mainly static (i.e. held > 1 minute) | TRUE | Position | |
| | | Score | 0 |
| Neck | | | |
| Position | 20+ degrees | | |
| Adjustments | | | |
| Score | 3 | | |

Operating the rotor has RULA score of 3 with a risk index of 1 means low risk which is shown in Table 6. It has a low risk to the farming who is using or operating it since it is more of driving the said equipment. The Upper limb is active in this activity focus and alertness are necessary to avoid accidents, since this is not just about driving this is riskier than driving an ordinary car, adjustment to the landscape is a necessary skill and the operator must always be active.

Figure 6 shows the farmer operating a hand tractor with a seat carrier for plowing the soil of the farm. It can be noticed that the operator's arms exert more effort in controlling the machine which also affects the trunks. The seat carrier helps to ease the operation than in a standing position. The bumpy the farmland is, the more effort is exerted in operating the machine.



**Figure 6.** Operating a hand tractor machine with a seat carrier.

**Table 7.** RULA result of operating hand tractor machine with seat carrier.

## RULA (Rapid Upper Limb Assessment): Operating Hand Tractor Machine with Seat Carrier

| Risk | | Assessment Results | |
|---|---|---|---|
| Risk Index | 1.33 | RULA Score | 4 |
| Task Variables | | Task Variables | |
| Upper arm | | Muscle Load A | |
| Position | 45-90 degrees | Posture is mainly static (i.e. held > 1 minute) | TRUE |
| Adjustments | | Adjustments | |
| Score | 3 | Score | 0 |
| Lower arm | | Force Load A | |
| **Position** | **60-100 degrees** | **Position** | |
| Adjustments | | Adjustments | |
| Score | 2 | Score | 0 |
| Wrist | | Trunks | |
| Position | 15 degrees | Position | 0-20 degrees |
| Adjustments | | Adjustments | |
| Score | 2 | Score | 3 |
| Wrist Twist | | Legs | |
| Mid-range | FALSE | Position | Bilateral weight bearing |
| End range | FALSE | Adjustments | |
| Score | 0 | Score | 1 |
| Muscle Load B | | Force Load B | |
| Posture is mainly static (i.e. held > 1 minute) | TRUE | Position | |
| | | Score | 0 |
| Neck | | | |
| Position | 20+ degrees | | |
| Adjustments | | | |

| Score | 3 |
|---|---|

Operating the hand tractor with a carrier is better than operating the hand tractor while walking. This demonstrates that plowing the farmland is faster, and the operator may take a rest while in the carrier. Operating a hand tractor with a carrier is better but considering the RULA score of 4 and a risk index of 1.33 which means there still is a low risk in operating the hand tractor and change or improvement is still necessary, observing the operation, researchers found out that the attach carrier to the hand tractor is not based on ergonomics. Thus, this makes the operator uncomfortable sitting on the chair and may cause fatigue or injury if the operator works for a longer time.

Conclusion

Farmers usually have trouble with their bodies as they work in the fields. The six (6) farmers from the selected farms for this study answered one hundred percent (100%) that they all had troubles with their necks, upper back, and lower back for the past twelve (12) months, and seven (7) days before the interview occurred. The farmers also felt a hundred percent (100%) trouble with their wrists/hands during the last twelve (12) months of farming. The body parts where they have troubles are usually the parts that moved and bent the most.

The farmers were exposed to an average of 7.722 hours a day in the field with a temperature of 29.07 ∘ C, vibration of 9.96 Hz, sound of 92.48 dBA, and illumination of 16,111.1. According to OSHA standards for eight-hour heavy work, farmers were overexposed and can have complications such as: hearing loss, intrusion with speech communication and with the perception of warning signals, disturbance to job performance, annoyance, eye fatigue, eye strain, spinal health risk, low back pain, dizziness, heat illness and heat stroke.

Using the RULA and REBA tools in ergonomics, it can be concluded that the activity of shoveling the dikes in the farm has the highest risk index of 2.25 and total score of 9 which is considered high. It can also be added that using agricultural rotor can minimize the risk index for the farmers. Continuous working with this posture can also lead to Work-related Musculoskeletal Disorders (WMSD). This study limits its application within the developing countries wherein the same method of farming is also applied.

Recommendations

In light of the results and findings of this research, the researchers recommend possible solutions that would help the farmers to stay safe and to have a better working process in the farm. The following are the recommendations:  farmers should wear a hat with a brim or any other that covers the ears and the back of the neck to protect them from sunlight. Also, farmers should as well wear long light-coloured clothes to avoid sunburns because light colours help in reflecting sunlight than dark colors. Farmers should stay under shades whenever possible, during breaks and especially lunch time. For instance, inside their houses or under a shady tree where ventilation is good enough for them to rest and reset energy; farmers should take a break in between their working hours, like for instance, a fifteen (15) minutes break. The farmers should as well keep their hands dry and warm and to not touch the vibrating equipment too much in order to avoid muscle cramps or other unavoidable troubles from this; farmers must use ergonomic-based tools on shoveling the dikes in the farm to have a better working capability; farmers should operate the hand tractor with a carrier and make it basely on ergonomics so that farmers can work comfortably. Farmers operating the hand tractor needs to take a break every 1 hour for at least 10 to 15 minutes. Maintenance of the machine should be done often, or have it scheduled for maintenance so that the machine can work better and will lessen the needs in the energy of the farmers; farmers operating the Agricultural Rotors should always observe the proper posture in driving and wear necessary safety equipment; and farmers need to use a carrier based on ergonomics.

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# An Ergonomic-Based Survey of the Computer Workstations of Indonesian Office Workers Both in Offices and Homes

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**Abstract.** The digital transformation, which was driven by the pandemic, increased the level of computer usage among office workers. However, limited studies have been carried out to determine the extent to which ergonomic workstations of Indonesian office workers are being implemented both in their homes and offices. The implementation of ergonomic workstations is very important as it helps to minimize the adverse health effects such as musculoskeletal disorders caused by computer-related work. Therefore, this study aimed to survey the usage frequencies of computer devices, seats, tables, screens, and input devices for both office and home workstations. Furthermore, a total of 128 workers voluntarily participated. The results showed that higher usage frequencies of workstation elements with solid ergonomic guidelines (i.e., office chairs with arms) were observed in offices than homes. Desktop usage was also higher in offices than at homes ($p < 0.05$). In the same vein, the usage of ergonomic furniture for computer-related work was observed more in offices. The results were expected to be evidence for the development of future policies or interventions for workers to establish more ergonomic computer workstations.

**Keywords**: computers, workstations, survey, Indonesian, office workers

## 7. Introduction

The mass adoption of computers has occurred over the last few decades. More than 50% of Americans perform computer-related tasks in their workplace [1]. Also, most households (>70%) in the United States had at least a computer with an internet subscription [2]. Furthermore, the pandemic, which occurred over the past two years induced massive digital transformation that significantly increased the use of digital devices, including computers in various sectors [3]. The increase in computer work frequency and duration, however, is associated with an increase in the prevalence of occupational illness, particularly musculoskeletal disorders and eye problems [4,5]. Office workers who work with a computer for longer periods have a significantly higher prevalence of musculoskeletal symptoms in several body parts, including the neck, lower back, upper back, wrists, and shoulders [6–8]. The pandemic worsened the conditions, which created a remarkably higher prevalence of musculoskeletal disorders in several body parts, such as the neck and lower back [9].

To minimize the adverse health effects caused by computer-related work, workers must employ engineering hazard control measures. This could be done by properly setting up ergonomic workstation, i.e. placing and adjusting chairs, tables, monitors, and input devices following the ergonomic principles [10]. For example, office workers with prolonged use of computers should sit on an adjustable chair with hand and lumbar support to ensure good posture during work [11].

The survey by Gerding et al. [12] reported that workers who were sent back home to perform occupational tasks due to the social restrictions during the beginning of the Covid-19 pandemic worked with their computer systems in ergonomic workstation that were less than adequate for prolonged durations. Working with computers could result in the users working on less neutral spine postures. Docking and external input devices are, therefore, required to ensure they work on more ergonomic posture [13].

However, limited studies have reported the workstation quality of Indonesian office workers who work with a computer on a daily basis. On the other hand, the digital transformation pushed by the pandemic also required some workers to develop their workstations at home. This is very important considering the fact that Indonesians might have different workstation setups. Knowing this would enable ergonomists or occupational health and safety practitioners to develop interventions and educate workers on how to minimize the adverse health effects caused by computer-related work.

This study aims to examine the quality of computer workstations in offices and homes of Indonesian office workers. It was focused on understanding the usage frequencies of several computer workstation components, such as chairs, tables, and input devices. This understanding could lead to the development of correct interventions for workers. Therefore, future adverse health effects caused by computer-related work could be minimized.

## 8. Methods

### 8.1. Participants

The participants in this study were 128 Indonesian office workers who worked using computers for at least four hours daily. Furthermore, the recruitment was conducted through social media such as WhatsApp, Instagram, and Twitter. All the participants provided their consent to participate digitally. This study was approved by the ethical committee of the authors' institution (KE/UGM/032/EC/2022).

### 8.2. Questionnaire

Questionnaires were used to collect data on demographics as well as the usage frequency of six items namely computer devices, seating, tables, screens, and input devices for workstation in both offices and homes. The respondents were asked how often they work using laptops, desktops, tablets, or smartphones. Furthermore, inquiries were made on several seating and table options. This included 'lesehan', a seating position performed by crossing the legs on the floor. Also, questions regarding screens and input devices were asked in order to determine how often the participants utilized various types of screens (e.g., laptops with additional screens) and input devices. The participants' demographic information was also collected by inquiring about gender, age, height/weight, and education level. They were asked to estimate the usage frequency of the investigated items during the last 12 months using the five-point Likert scale (1=never, 5=always). The scales and inquiries were adapted from Gerding et al. [12]. The questionnaires were administered in Bahasa Indonesia, the official language of Indonesia, using an online survey platform (Google Form). Prior to the mass administration, a pilot study, which involved 12 candidates, was performed to ensure the adequate validity and reliability of the questionnaire.

### 8.3. Statistical analysis

Paired t-tests were conducted to determine whether any differences exist between the usage frequencies of the 6 observed items in homes and offices workstations. All statistical analyses were performed using JASP (the University of Amsterdam, the Netherlands) software. In addition, an alpha of 0.05 was used as the cut off for significance in all the statistical analyses.

## 9. Results

### 9.1. Participant characteristics

There were 128 Indonesian office workers (50,7% male; 49,3% female) who met the inclusion criteria voluntarily participated in this study. The majority were older than 25 years (95%) and had a bachelor's degree (57,8%).

*9.2. The usage frequencies of devices, chairs, tables, screens, and input devices*
The usage frequencies of several digital devices are shown in Figure 1. Although desktops were dominantly used in offices (often=42,1%; always =35,1%), it can be seen in the figure that the usage of laptops was higher for those working from their homes (often=60,9%; always=37,5%). Furthermore, the paired t-test results showed significant differences between the usage frequencies of laptops and desktops when utilized as work tools in homes and offices (p<0.05).
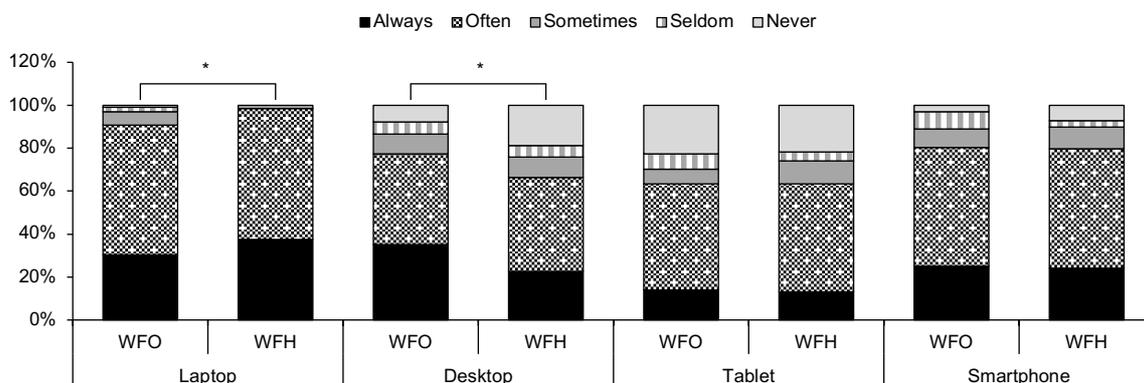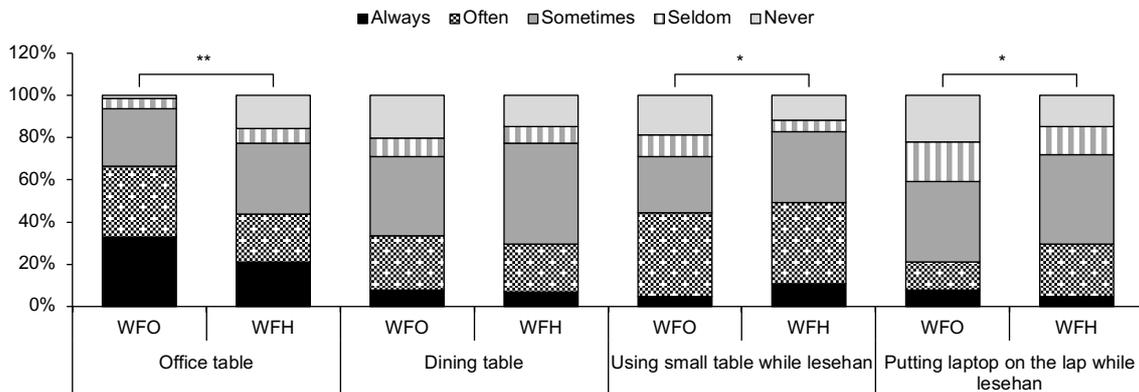


**Figure 1.** The usage frequency of laptops, desktops, tablets, and smartphones for those working from their homes and offices. *p<0.05.

Figure 2 shows the frequency of use for various forms of computer seating in offices and homes. Furthermore, it can be seen that more participants utilized adjustable office chairs with hand support in offices than homes (often=28,9%; always=26,5%). While dining chairs were utilized more often by those working from their homes (often = 27,3%; always=4,6%). The statistical analysis also showed that the usage frequencies of office chairs, dining chairs, beds, and *lesehan* were significantly different across different workstation.
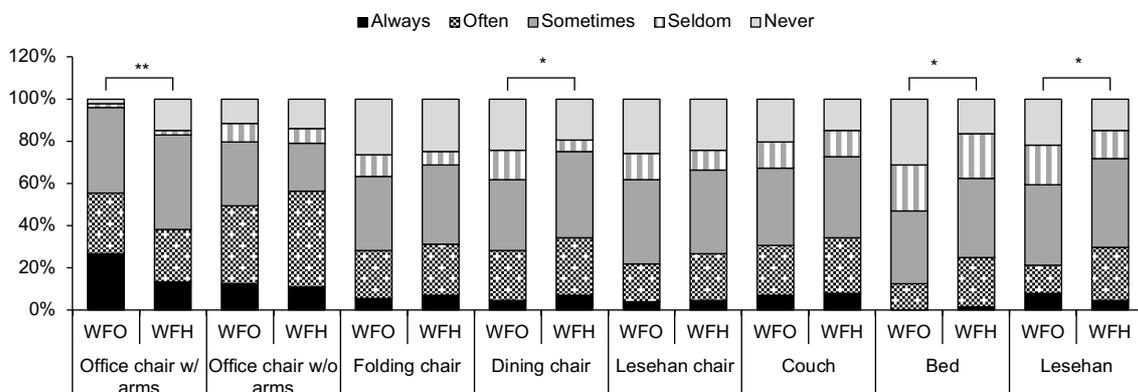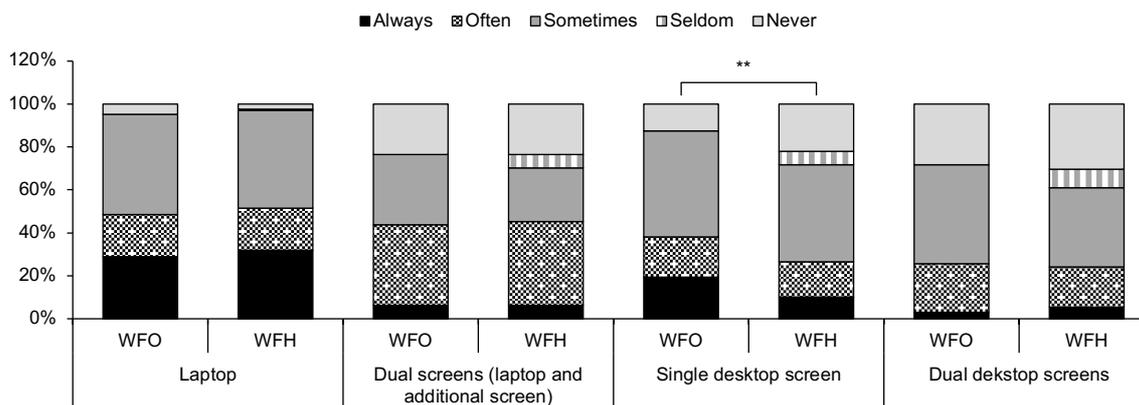


**Figure 2.** The usage frequency of various types of seats for working in offices and homes. *p<0.05; **p<0.001.

Figure 3 shows the usage frequency of various tables for computer-related work both in offices and homes. Obviously, participants use office tables more often in their offices (often=33.5 %; always= 32,8%). However, small tables are dominantly employed in homes (often= 38,2%; always= 10,9%). The statistical analysis showed that the usage frequencies of the office tables, *lesehan* with a small table, and *lesehan* with the laptop on the lap were significantly different (p<0,05 and p<0,001).



**Figure 3.** The usage frequency of various type of tables for working in offices and homes.
*p<0.05; **p<0.001.

Following this, the usage frequencies of the various types of screens, including laptops with or without additional screens, as well as desktops with one or double screens, are presented in Figure 4. The usage frequency across all types of screens had a similar trend. Additionally, a significant usage frequency difference was observed for the desktop with one screen. Participants tend to use the screen more often when doing computer-related work in their offices than homes (p<0.001).



**Figure 4.** The usage frequency of various types of screens for working in offices and homes.
**p<0.001.

Figure 5 shows the usage frequencies of various input devices utilized for computer-related work both in homes and offices. Wireless external keyboards are dominantly used when working in the office (often= 39%; always= 10,9%), while laptop keyboard is mostly used when the work is being carried out from home (often=28,9%; always=23,4%). On the other hand, wired mouse are mostly used both in homes (often=45,3%; always=17,9%) and in the office (often=44,5%; always=17,9%). The statistical

analysis showed that the usage frequencies of input devices such as wired external keyboards and wired mouse were significantly different (p<0,05 and p<0,001).
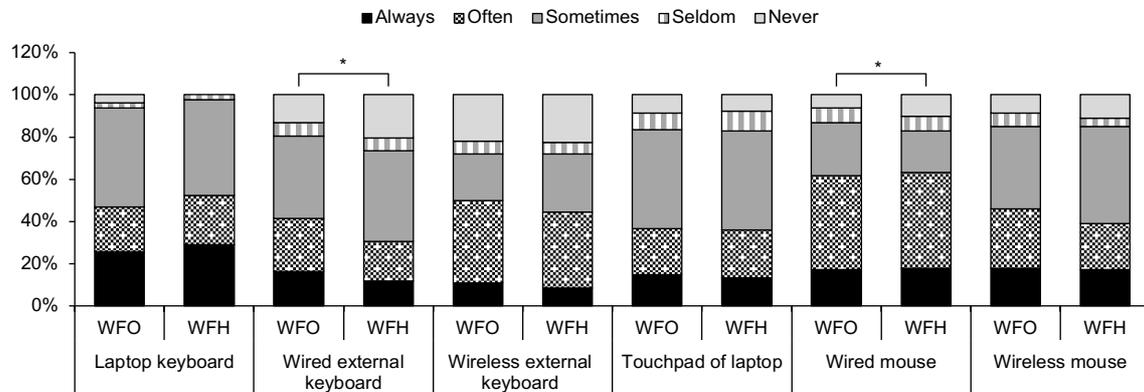


**Figure 5.** The usage frequencies of various input devices for working in offices and homes. *p<0.05.

## 10. Discussion

This study showed that participants have a tendency to use laptops often when working from home, but are more likely to use desktops when doing computer-related work at the office. This finding is similar to Gerding et al. [12], where it was observed that most university employees always utilized laptops for working at home because of the social restrictions caused by the Covid-19 pandemic. Furthermore, when working at the office, the high usage frequency of desktops may be pushed to a company policy where most data are placed in the internal network to minimize data breaches [14]. The improved data security may, however, allow workers to access the data anywhere using laptops which could increase laptop use in the future. Office workers should be educated on how to adapt to adjust the laptops for prolonged use. Inappropriate laptop placement during prolonged use can impair neck posture, which is associated with increased musculoskeletal symptoms in the region [15].

Following this, office chairs were utilized more commonly in offices than in homes. Hence workers in the office have a chance to create more ergonomic workstation due to the better cushioning and some adjustable features [16]. Meanwhile, dining chairs are the most dominantly used seatings in homes, which means that workers are likely to have less ergonomic workstation in homes. This study also indicated that Indonesian office workers tend to adopt *lesehan* more often as a seating option in their homes. Apart from the differences in office chair usage, the difference in office desk usage frequency was also examined. Office desks are less typically used in homes. Employees who work from home most frequently place the laptop on their laps or use a small table while *lesehan*. Therefore, to minimize musculoskeletal problems, future research should be proposed to create evidence-based guidelines to help them do computer-related work ergonomically while *lesehan*.

The survey results showed that single screens were typically found both in offices and homes. This finding is not in line with Gerding et al. [12], where it was noted that many American office workers use dual screens when using laptops or desktops. Although it does not significantly improve muscle load [17], working with dual screens could increase productivity while performing computer tasks (18,19). Therefore, when computer-related work still play an essential role in some Indonesian offices, workers need to consider the adoption of dual or large screens to ease their work.

This study also showed that a large number of participants still use wired input devices. While wireless devices can provide more freedom in controlling input devices, working with a wired mouse does not significantly affect muscle activity which should correspond to a similar workload (20). Indonesian office workers can, therefore, still use the wired input device. However, when there is no restriction on budget, workers can adopt better ergonomic input devices, including vertical mouse and

split keyboard. These devices should help lessen the awkward wrist posture, which may decrease the musculoskeletal problems in that region [21,22].

The study had a limited number of participants, which could make the results of this study less generalizable to broader communities of office workers in Indonesia. Hence, the future study may involve a considerable number of participants from various industries in Indonesia to ensure generalisability. This study also did not survey the use of ergonomic input devices and adjustable desks, which nowadays have become promising ergonomic interventions to minimize adverse health effects caused by computer work [23,24]. Furthermore, this study only assessed the workstation components without assessing the postures. This could be important since awkward postures may be caused not only by the poor setting of workstations but also by other personal factors such as anthropometry [25]. Therefore, the future study may investigate the usage of widely available ergonomic interventions related to computer work and assess Indonesian office workers' posture.

11. Conclusions

In conclusion, this study revealed notable variations in the usage frequencies of the major computer workstation components both in offices and homes of Indonesian office workers. Desktop computers were a typical computing device used in offices, while laptops were more commonly used in homes (p<0.05). Furthermore, good chairs defined by ergonomic principles are more frequently used by workers while working in offices than homes (p<0.001). While working from home, they tend to use seating options with less ergonomic guidelines, such as a *lesehan* chair, *lesehan*, and sitting on a bed. A similar trend was also observed, where more adoption of tables with solid ergonomic guidelines was higher in offices than in homes (p<0.001). Additionally, understanding that the survey participants had higher usage frequencies of workstation elements with solid ergonomic guidelines, it could be inferred that workers have more ergonomic workstation in their offices than homes. Future guidelines or interventions for workers to adopt ergonomic workstation in their homes should, therefore, be specialized considering the existing preferences.

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# Ergonomic Interventions in a Work Facility Design for Reducing MSDs Complaints at a Cowhide Cracker SME

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**Abstract.** Small and Medium Enterprise (SME) X is a cowhide cracker SME in Padang, West Sumatra, Indonesia, which has six workstations: washing, boiling, cutting, drying, frying, and packaging. Many problems were found here that could reduce its productivity. The results of the initial assessment using the Nordic Body Map (NBM) questionnaire and Rapid Entire Body Assessment (REBA) assessment on workers found that there were complaints of pain in workers after work and the risk of Musculoskeletal Disorders (MSDs) requiring immediate control measures, especially at cutting workstations. This study aims to design work improvement through designing work facilities and work instructions at the SME X cutting workstation to reduce the risk of MSDs in workers. Work facilities are designed in the form of worktables, work chairs, cutting rulers, and connecting channels to containers for cutting cowhide. Prototypes were made for the designs and evaluated with new work methods according to the proposed work instructions. The evaluation results show that the pain complaints in workers' body parts and the MSD risks have decreased by about 52% and 73%, respectively, after improving work facilities.

**Keywords**: work facility, improvement, NBM, REBA, Small and Medium Enterprise (SME)

## 12. Introduction

Small and Medium Enterprises (SMEs) are small-scale people's economic activities, with the business sector being most small business activities and needing to be protected to prevent unfair business competition [1]. SMEs have an essential role in driving Indonesia's economic growth. With the existence of SMEs, unemployment due to the labor force not being absorbed in the world of work is reduced [2-5]. Padang is one of the cities in West Sumatra, Indonesia, with many SMEs. Based on data from the Padang City Industry and Trade Office in 2015, there were 1,213 SMEs in the food sector, 298 SMEs in the clothing and leather sector, 427 SMEs in the chemical and building materials sector, 170 SMEs in the metal and electronics sector, and 93 SMEs in the craft sector [6].

An SME in the food sector developing in Padang is the cowhide cracker (from now on referred to as SME X). SME X produces leather crackers made from cow and buffalo leather. These raw materials are obtained from the region of West Sumatra and outside West Sumatra. SME X can produce approximately three tons of cowhide in a month. This SME has six workstations: washing, boiling, cutting, drying, frying, and packaging. The workforce involved is eight workers, four working in the washing up to frying workstation, while four working in the packaging workstation. Workers work every day from 8 am to 4 pm with the rest time is from 12 pm to 1 pm. Based on the observations, the production process begins with washing the cowhide using a concrete mixer. At this stage, the worker works in a standing position. The worker puts the cowhide into the machine, then waiting for the mixer to work until it is finished while sitting or standing (Figure 1a).

After being washed using a machine, the cowhide is boiled using a vat of oil for about 10-15 minutes. At this boiling workstation, workers put washed cowhide into the drum, then workers can sit while waiting for the boiling to finish. The conditions at the boiling workstation can be seen in Figure 1(b). Next step is cutting the cowhide. In the cutting process, workers work with non-ergonomic work postures (Figure 1c). Workers work while sitting on small chairs and cutting while bending. At this

workstation, workers must work for 8 hours/per day, which is very risky to cause back injuries and accelerate worker fatigue. The following process is drying the in the drying area provided (Figure 1d).

After being dried in the sun until dry, the cowhide is fried. Figure 1(e) shows the working conditions at the frying workstation. The worker stirs the pieces of cowhide in the cauldron several times, after which it is left for 1 hour, and the worker can sit while resting. The final process is packaging which is the worker's work sitting on the floor in a bent position (Figure 1f). This kind of work position lasts quite a long time (8 hours) of work a day with approximately 1 hour of rest time. If done continuously, this will undoubtedly harm workers because it can cause back injuries and tire them. After all, they work in non-ergonomic conditions.

(a) Washing workstation → (b) Boiling workstation → (c) Cutting workstation

(f) Packaging workstation ← (e) Frying workstation ← (d) Drying workstation
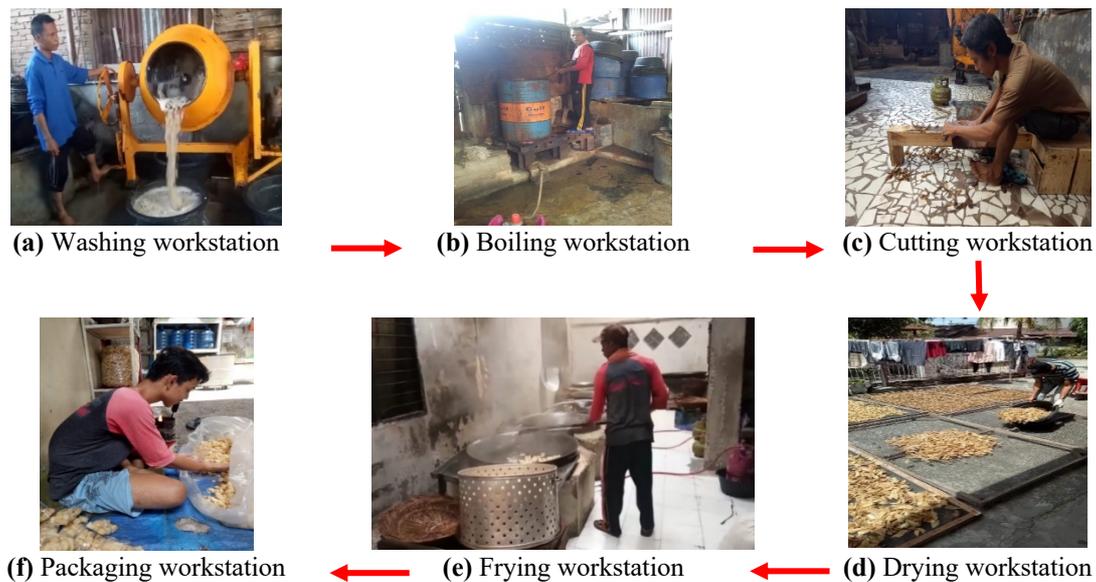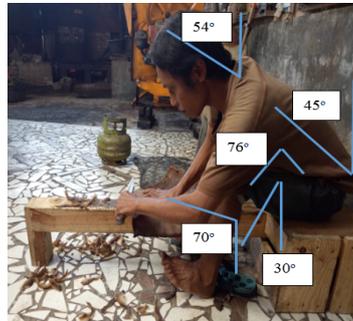
**Figure 1.** Workstations at SME X

Further investigations were carried out using Nordic Body Map (NBM) questionnaire to investigate the physical complaints felt by all workers (6 workers) while working at those workstations (Each work station consists of 1 worker). NBM has been widely applied in assessing pain complaints felt by workers while working [7-9]. It is found that the critical problems that should be overcome immediately were at the cutting workstation. The investigation found that at the cutting workstation, eight body segments were classified as very painful, 16 body segments were classified as painful, four body segments were classified as moderate pain, and zero body segments were classified as no pain. Most of the complaints found were on the back, waist, neck, shoulders, elbows, and legs. The NBM score was 92, which means that immediate action is required for this workstation [10].

Musculoskeletal disorders (MSDs) are complaints in parts of the skeletal muscles that a person feels, ranging from very mild complaints to very extreme complaints [11,12]. If the muscles receive static loads repeatedly and for a long time, it can cause damage to muscles, nerves, tendons, joints, cartilage, and intervertebral discs [13]. The upper body, especially the back and arms, is the most vulnerable part of the risk of getting MSDs [14,15]. Interviews with SME owners and workers found that the work conditions harm the workers, so they often take days off work due to pain, especially in the back and waist. If this is allowed to happen, it can lead to decreased work productivity.

Additional assessment was carried out to assess the current working posture of workers using the Rapid Entire Body Assessment (REBA) method [16,17]. REBA was selected because it is general and applicable to various occupations. Moreover, it considers all body parts as well as all well-known Work Musculoskeletal Disorders (WMSDs) risk factors, i.e., awkward posture, force, and types of activity (repetitive and static) [18]. The analysis of the working posture of workers when cutting cowhide using

REBA can be seen in Figure 2. REBA score for worker cutting the cowhide is 11 (Very high level, means needs improvement right now).



**Figure 2.** Actual working posture when a worker cutting the cowhide

Based on these initial observations and assessments, improvements are urgently needed at the cutting workstation at SME X. Therefore, the study aims to design work facilities and work instructions at the SME X cutting workstation to reduce the risk of musculoskeletal disorders in workers.

13. Methods

This study proposes the design of work facilities to improve work posture in the production process of UKM X. The stages in designing work facilities are:

- Determination of assistive device features to be designed following customer requirements
- Determination of the tool dimensions using anthropometric data and dimensional data of cowhide. The anthropometric data is determined based on an evaluation of the work system at the cutting and packaging workstation.
- Design modelling (Functional requirements) using Solid work software in 2D and 3D forms. The design is based on an ergonomic evaluation and the features of the tools needed with each function to make the work easier.
- Implementation and Testing. Initial prototypes are made using components with the shape and size of actual production but do not require the same manufacturing process as the real thing. After the prototype is finished, work instructions are designed for an ergonomic cutting process. The prototype is tested to determine whether the product will perform as planned. Tests were carried out at cutting workstations using the NBM and REBA questionnaires.
- The next step is to conduct a comparative analysis of NBM and REBA before and after the improvement.

14. Results

*14.1. Product design and implementation*

Product design and implementation consist of several parts: determining the dimensions of work facilities, designing work facilities, and determining materials. The proposed design was carried out based on the recommendations and suggestions obtained from direct observation through the NBM questionnaire and the REBA method. The proposed designs at the cutting workstation are an ergonomic table and chair, cowhide ruler, and connecting channel design to the container.

*14.1.1. Determination of work facilities design dimensions at cutting workstations.* The dimensions of the work facility are adjusted to the anthropometry of the human body with certain limitations. The aim is to provide comfort to workers who use the proposed design. The limitation in determining the dimensions of the cowhide-cutting tool is the length of the cowhide to be produced because it determines the length of the proposed design table.

Work facilities are designed in the form of table and chair. Anthropometric data used for designing chair and table can be seen in Table 1 and Table 2. The cutting boundary ruler is designed according to the size of the cowhide to be fried. The connecting channel to the cut cowhide container is designed with the size of the hole on the table.

**Table 1.** Chair design dimensions

| Body dimensions | Percentile (cm) | | | Dimension for design (cm) | Design part |
|---|---|---|---|---|---|
| | P5 | P50 | P95 | | |
| Popliteal height | 37.45 | 41.97 | 46.49 | 41.97 | Chair leg height |
| Hip width | 24.99 | 34.30 | 43.61 | 43.61 | Seat width |
| Popliteal length | 39.51 | 47.34 | 55.17 | 47.34 | Chair length |
| Sitting shoulder height | 52.51 | 61.56 | 70.62 | 52.51 | Seat back height |

**Table 2.** Table design dimensions

| Body dimensions | Percentile (cm) | | | Maximal dimension (cm) | Allow-ance (cm) | Dimension for design (cm) | Design part |
|---|---|---|---|---|---|---|---|
| | P5 | P50 | P95 | | | | |
| Hand reach forward | 68.11 | 77.07 | 86.02 | - | - | 68.11 | Table width |
| Seat height + sitting elbow height | - | - | - | - | - | 68 | Front table height |
| Finished product length | - | - | - | 61 | 9 | 70 | Table length |
| Front table height + slope $10^0$ | - | - | - | 76 | - | 76 | Back table height |

In addition to the design of work facilities, the design of the cutting ruler is also carried out. The cutting border dimensions are 2 cm long, 68 cm wide, and 2 cm thick. The design of the channel connecting to the reservoir uses dimensions of 68 cm in length and 30 cm in width. The size is obtained directly from measurements in the table hole.

*14.1.2. Work facility design.* The chair is designed as a seat for workers if workers want to rest. The chair has a chair back so workers can relax more in using it. The chair is also equipped with a detachable cushion. The table is designed as a place for workers to cut cowhide. The table is designed in a rectangular shape to make it easier for workers to work. The table is designed to be tilted at an angle of $10^0$. To the right and left of the table is a trapezoidal partition, making it easier for workers to place a dividing line. This dividing ruler is helpful to make it easier for workers to cut products to the desired size. To the right of the table, there is a 5 cm long hole used for the cut product's fall. Then, on the right side of the table, a channel is made to make it easier for the finished product to fall into the holding bucket. The channel's purpose is to make the product's fall easier, so it does not scatter when it goes down. On the edge of the table is designed to place a buffer ruler. Its use is to help workers cut to the desired size. The cutting ruler is designed as a limiting place for cutting, so the results obtained are according to the size of 2 cm. The connecting channel to the container is designed as a place for the final cutting product so that the product dropping into the bucket provided on the lower right can fall neatly and not be scattered.

The determination of the material must be carried out correctly so that the results of the work facility design for the leather cutting workstation can be used optimally. Some things that need to be considered in determining the material forming a product are [19]: (1) Materials are not very expensive; (2) Material is easy to process; (3) Use materials as efficiently as possible; (4) Use leftover materials; (5) Material used follows the standard specifications that are commonly used. Based on these considerations, the material used in making the work facility design for cutting table, chair, and ruler

are from mahogany while for the connecting channel is from stainless steel. The proposed design images in 3D form are presented in Figure 3.



**(a)** Chair  **(b)** Table  **(c)** Cutting ruler  **(d)** Connecting channel to container
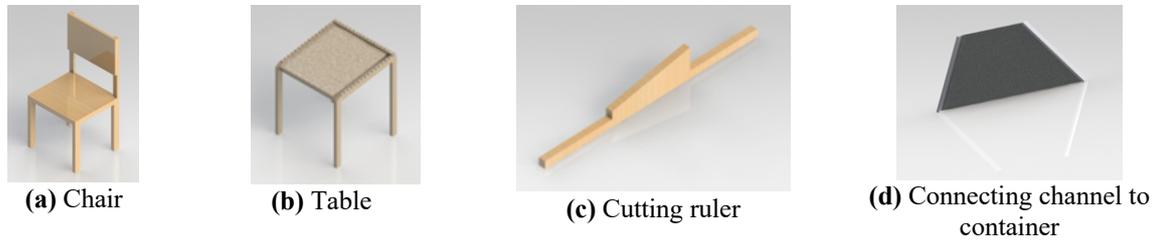
**Figure 3.** Proposed design of work facilities

### 14.2. Work instruction design

Work instructions are orders provided to assist workers in carrying out work. The following work instructions for the cutting workstation can be seen in Figure 4.

| WORK INSTRUCTION Cowhide Cutting | |
|---|---|
| **Location** **Manufacture date** **Revision date** | |
| **Description** | Cowhide cutting activity |
| **Aim** | Produces smaller pieces of cowhide |
| **Equipment** | Table, chair, connecting channel to the container, cutting ruler, container |
| **Procedure** | 1. Make sure the cowhide to be cut has been washed clean<br>2. Cut the cowhide with a maximum size of 1 = 61 cm x 64 cm<br>3. Position the cowhide on the table according to the size of the available table, then the worker sits on the available chair<br>4. Cut the cowhide using a ruler according to the size of the barrier<br>5. Cowhide which has been cut into small pieces, is flowed through the connecting channel to the container which is under the worktable. |
| **Flow diagram** |  |

**Figure 4.** Cutting Workstation Work Instructions

### 14.3. Prototyping

Making a prototype aims to see whether the design results have helped improve the worker's posture. The prototype is a work facility in the form of a worktable, work chair, dividing line, and connecting channel to the container. The prototype of the proposed design is shown in Figure 5.

### 14.4. Workstation Improvement Evaluation

*14.4.1. NBM questionnaire.* The NBM questionnaire was given to workers using a work facility prototype and instructions designed for three days. The NBM score obtained was 44 with a low-risk level, meaning that the workstation was good, and no corrective action was needed.

*14.4.2. REBA score calculation.* The REBA score calculation is also carried out to evaluate the work posture of workers after working using the proposed design of work facilities. The REBA score is calculated after improvement based on Figure 6. The REBA score after improvement is 3, which means that it may need to be repaired [10]. This score is lower than before the workstation improvement is carried out. These results show that there is a better improvement in the working position of workers compared to before using the proposed design.



**Figure 5.** Prototype



**Figure 6**. Worker posture after workstation improvement

15. Discussion

The design of the table at the cutting workstation was carried out because previously the worker worked in a small chair and the cutting was done while bending. Workers employed with uncomfortable postures, over extensions, forceful exertions, and repetitive movements for a long period usually leads to muscle dysfunction, tingling, inflammation, and pain in their musculoskeletal systems causing serious injuries or disabilities [20-23]. Thus, the workbench is designed according to the anthropometric data of the workers and the raw material/dimensional data of cowhide so that workers can work comfortably. The application of anthropometric data has been proved by many previous studies can reduce work-related health problems, especially for designing tools and machinery [24].

Then, the table is designed in a rectangular shape with a tilt angle of $10^0$; this slope can make it easier for workers to work. The table's width is adjusted to the anthropometric data of the forward span of the hand with the 5th percentile so that workers can use it with small body dimensions. The table length is determined based on the dimensions of the raw material. The table is designed with a trapezoidal partition between the right and left sides which helps place a cutting ruler that makes it easier for workers to cut to the desired size. On the table's right side is a hole used to drop the cutting cowhide into the container provided on the right side below the table.

Ergonomically designed chairs aim to assist workers when cutting cowhide. In actual conditions, workers work while sitting on small chairs and cutting while bending their bodies, so workers are at high risk of experiencing back injuries. An ergonomic chair is designed with body dimensions including the popliteal height as the chair leg height with the 50th percentile. This size puts the worker's leg position in an ideal state. The chair's width using the 95th percentile is intended so that workers who use work chairs with extremely high or low data can be comfortable using work chairs. The length

dimension of the chair base uses the popliteal length with the 50th percentile. The 50th percentile was chosen so that the chair can be used by people who have small or large body dimensions.

For chair back height, the dimension of shoulder height in a sitting position is used with the 5th percentile. The 5th percentile is used so that workers with low and tall body sizes can comfortably use a work chair so that the shoulders and upper arms are more flexible to move. Chairs are equipped with chair backs so workers can be more relaxed using them. If the worker wants to add a seat cushion, such as foam, that can be removed, that is also possible, according to the worker's comfort. The cutting ruler is designed as a border for cutting cowhide. This cutting ruler makes it easier for workers to cut cowhide to the desired size. The size of the cutting ruler is adjusted to the size of the partitions. The channel length is adjusted to the width of the hole on the table. At the same time, the width of the channel is made in the form of a trapezoid that tapers downwards, intending to make it easier for the pieces of cowhide to fall right into the bucket. The table, chairs, and cutting ruler material are made of mahogany because mahogany is wood with relatively strong resistance. This study also designed work instructions for cutting workstations that are useful for assisting workers in using the designed work tools or facilities.

Complaints of pain in workers' body parts have decreased about 52% after the improvement of work facilities (NBM score = 92 before improvement to NBM sore = 44 after the improvement). A decrease in pain complaints was found in almost all body segments. The body segments that experienced a decrease in the level of complaints were the back and waist body segments; where before the improvement, the workers felt very sick in the back and waist, while after the improvement, there was a decrease in complaints to no pain. Furthermore, after the improvement, there was a decrease in workers' complaints of pain in the arms and wrists. The same goes for the thighs, knees, ankles, and toes. The addition of these facilities can make it easier for workers to cut cowhide to reduce complaints of back injuries to workers, and workers can work in an ergonomic position. Moreover, the risk of MSD based on REBA assesment also shows a decrease of 73% from the REBA score = 11 before improvement, to 3 after the improvement.

Unfortunately, this study has not yet designed a cutting tool that is really suitable for cutting cowhide which is quite thick and hard. Therefore, in future research, a design of cutting tools for cutting cowhide will be carried out, so that workers can reduce their workload, especially on the hands when cutting cowhide and can provide neater and cleaner cutting results. The final impact of improving working conditions is reduced the MSD's symptoms and increased productivity for the SME. Several similar research results have found that improvements with an ergonomic approach can reduce the MSD's symptoms [25] and increase productivity [26]. The increase in productivity obtained was due to an improvement in physiological response, faster processing time, and increased production [27].

16. Conclusion

This study can conclude that the work system at the SME X cutting workstation still needs improvement to increase worker productivity. Improvements are made by designing work facilities and work instructions. The evaluation of the proposed design implementation in the form of the new work facility design and work methods found a decrease in pain complaints in workers as evidenced by a decrease in NBM score of 52% and a decrease in the risk of MSD of 73% based on REBA scores between before and after improvement.

17. Acknowledgments

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# Improving Boiler Performance With Failure Mode Effect And Criticality Analysis (FMECA)

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**Abstract.** Boilers in the manufacturing industry have an important role in the production process. Boilers can produce steam, which is used in the production process. Steam produced by boilers can also be used as a power plant where the steam flow is used to drive a turbine. Several manufacturing industries that utilize boilers include the food, beverage, petrochemical, and fertilizer industries. Boiler B 03, which operates in one of the subsidiaries of PT Pupuk Indonesia Group, is the focus of this research because of an issue in which this boiler cannot produce steam according to its design capacity. Based on the problem, through this research an investigation will be carried out to improve the reliability of the B 03 boiler system and what components cause the boiler cannot operate according to design capacity. A boiler that cannot produce steam according to its design capacity can be ascertained to have low efficiency in manufacturing. Boiler B 03 is included in the category of water tube boilers. In this type of boiler, the water or steam pipe is in the pipe with the combustion flame being outside. The method used to find the root of the problem to improve the performance of the boiler system is by using the failure mode effect & criticality analysis (FMECA). By using the FMECA method, it is hoped that all problems in the B 03 boiler can be identified and, as a result, the company can determine the priority of repairs to the boiler components and the company can obtain recommendations regarding steps in improving the boiler production system.
**Keywords**: Boiler, water tube boiler, FMEA dan FMECA

## 1. Introduction

Boilers in the manufacturing industry have an important role in the production process. Boilers can produce steam which is used in the production process. Steam produced by boilers can also be used as a power plant where the steam flow is used to drive turbines. Several manufacturing industries that utilize boilers include the food, beverage, petrochemical, and fertilizer industries. This research was conducted at a subsidiary of PT. Pupuk Indonesia Group because there is a problem with one of the boiler equipment where this boiler cannot produce steam according to its capacity design. A boiler that cannot produce steam according to its design capacity will certainly have an impact on the company's losses. In the production process, there are two sources of generators. Internal generating sources are capable of producing around 80% of the total electricity demand for one year, while the remaining 20% is met from external sources of electricity obtained from PLN. One of the internal sources of power generation is obtained from the Steam Turbine Generator in a utility unit with a design capacity of 20 MW. If there is a failure of this boiler operation it can disrupt the production process. This unit has 3 pieces of equipment that produce steam, namely boilers B 01, B 03, and B 04 each with a capacity as shown in Table 1.

Table 1. Steam Boiler Design and Product Data in the Utility Unit

| No. | Boiler | Design Pressure | Operating Pressure | Design Product Steam |
|-----|--------|-----------------|--------------------|--------------------|
| 1. | B 01 | 42 kg / cm$^2$ | 36 kg / cm$^2$ | 42 Ton / Hour |
| 2. | B 03 | 47 kg / cm$^2$ | 36 kg / cm$^2$ | 93 Ton / Hour |
| 3. | B 04 | 42 kg / cm$^2$ | 36 kg / cm$^2$ | 70 Ton / Hour |

Based on Table 1. B 03 has the highest design working pressure but B 01, B 03, and B 04 when operated are at the same actual working pressure. The main difference between the three boilers in table 1.1 is in the resulting design steam product where the B 03 boiler is capable of producing the largest steam up to 93 tons/hour, followed by B 04 as much as 70 tons/hour and B 01 as the smallest steam producer as much as 42 Tons/Hour.

Based on the actual production of steam produced in the last 3 years, the quantum of steam products is always below its capacity. Figure 1. shows a graph of steam production against the capacity of each boiler in the utility unit.
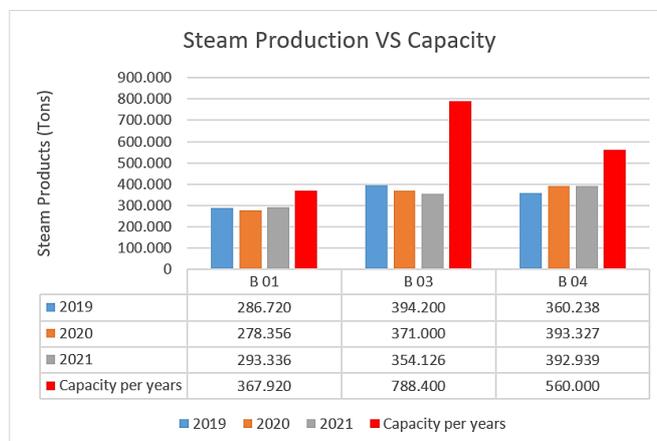


Figure 1. Graph of Steam Production VS Boiler Capacity

The red bar chart shows the capacity of each boiler while the 3 bar charts to the left of the capacity show the actual production quantum between 2019 and 2021. In boiler B 01, the realization of steam production is almost close to the boiler capacity of 367,920 tons, while the realization between 2019 and 2021 is close to 300,000 tons. The realization of B 04 steam production in 2019 to 2021, almost touches the 400,000-ton mark, while the capacity of the 04 boilers is 560,000 tons. In boiler B 03, actual steam production between 2019 and 2021 is below 400,000 tons, while the capacity of boiler 03 is 788,400 tons. When referring to the graph of steam production vs capacity, the performance of the B 03 boiler is far below the design capacity which only reaches 50% of the total capacity. Therefore the B 03 boiler will be the focus of the author's research so that the performance of the B 03 boiler can be increased.

Boiler B 03 is a type of water tube boiler. Boilers of this type are brought in from the manufacturing plant to the location of use and still consist of separate components so that when they arrive at the company's location, the user must do the assembly. In this type of water tube boiler, water or steam is in the pipes with the fire outside. In a water tube boiler, boiler feed water flows through the pipes into the drum. Steam is formed due to the circulation of water heated by the combustion gas that occurs in the steam area in the drum.

## 2. Method

This chapter will explain the steps that will be taken to identify each component in the boiler which causes the boiler unable to reach its design capacity and provide recommendations for improvement plans to increase efficiency in the boiler. This research was conducted through 4 systematic stages, namely:

1. Problem identification
2. Collection and processing of data

3. Results analysis and discussion stage
4. Conclusion and suggestion stage
Data collection in this study is intended to obtain two kinds of data, namely primary data and secondary data. Primary data is data obtained by researchers directly, while secondary data is data obtained by researchers from existing sources. Primary data was obtained by direct observation, interviews, and study questionnaires. The resource persons in the interviews and questionnaires in this study were: Supervisors for groups A, B, C, and D in production units, Assistant Vice Presidents and Junior Assistant Vice Presidents for utility units, mechanical supervisors, electrical supervisors, and instrumentation supervisors. Meanwhile, secondary data is obtained from documentation data/history of the production process and technical data related to processes and equipment in the document.

Based on the results of the data processing above, then the results are analyzed and discussed. In analyzing the results and discussing this, the first step is to analyze the components in the boiler. The next step is to make a failure mode effect & criticality analysis (FMECA) to find out the priority for improvement that can be done by looking at the risk priority number. In making a risk priority number, what must be done is to determine the Severity, Occurrence, and Detection criteria. Rating ratings are carried out by brainstorming companies according to each criterion. Severity or the level of bad influence on the waste that occurs is done by giving a rating from a scale of 1 to 10 according to the level of influence starting from 1 = no effect, 2 = very minor, 3 = minor, 4 = very low, 5 = low, 6 = moderate, 7 = high, 8 = very high, 9 = dangerous, and 10 = very dangerous. Occurrence or the chance of failure occurring during the production process is also carried out by giving a rating from a scale of 1 to 10. The occurrence value is based on the value of the probability or frequency of possible errors. Ratings from 1 to 10 include 1 = never, 2-3 = rarely, 4-5 = sometimes, 6-7 = quite often, 8-9 = often, and 10 = very often. Detection or measurement of the ability to control failures that will occur is also carried out by giving a rating from a scale of 1 to 10. Defining the value of detection involves management, so it can be assumed that the value given is not biased. Ratings from 1 to 10 include: 1 = definitely, 2 = very easy, 3 = easy, 4 = fairly easy, 5 = moderate, 6 = moderately difficult, 7 = difficult, 8 = very difficult, 9 = extreme, and 10 = almost impossible.

Next, a table is compiled containing potential failure modes, potential effects, potential causes, controls, risk priority numbers (RPN), and actions taken. Rows in the table with an RPN value of more than 100 are categorized as high and further analysis is carried out by using a criticality matrix and then compiling recommended actions and actions taken so that it is expected that the new RPN value obtained will be smaller. Based on the recommended actions and actions taken, alternatives for improvement and actions taken will be developed. There can be more than 1 alternative improvement proposed maybe four or five alternatives. The next step is to choose the best repair alternative. This step is done by asking for consideration from the respondents. After that, an analysis of the causes of the problem is carried out. This can be done using a Pareto. The Pareto principle itself is 80/20, meaning that 80% of problems are caused by 20% of the boiler components having problems.

## 3. Result and Discussion

### 3.1 Initial Identification
The boiler has experienced downtime several times due to several problems in the last 3 years. The components that cause the boiler to experience downtime can be seen in Table 2. Based on the data, the water tube boiler component has the most failure frequency of 26 times and causes 130 days of downtime. The components in the boiler are then carried out Pareto diagram to get the 5 biggest problems. The results of the Pareto diagram of boiler components can be seen in Figure 2.

Table 2. Cumulative Percentage of Component Failures

| Components | Failure Frequency | Down Time (Days) | Cumulative Percentage |
|---|---|---|---|

| Drum Shell | 0 | 0 | 0 % |
|---|---|---|---|
| Fire brick | 5 | 15 | 6 % |
| Furnace | 10 | 30 | 18 % |
| Water tube | 26 | 130 | 50 % |
| Superheater | 0 | 0 | 50 % |
| Economizer | 3 | 6 | 54 % |
| Burner | 11 | 1,375 | 67 % |
| Force Draft Fan | 11 | 10 | 80 % |
| Induce Draft Fan | 6 | 2,68 | 88 % |
| BFW pump | 10 | 0,62 | 100 % |

Based on the Pareto diagram, the components that are the dominant causes are the Water tube, Burner, Force Draft Fan, Furnace, and BFW Pump. From the Pareto results, it can be seen that the burner and the forced draft fan have the same failure frequency as well as the furnace and BFW pump components, therefore further analysis is carried out using FMECA and cause and effect diagram analysis so that improvement targets can be obtained optimally.
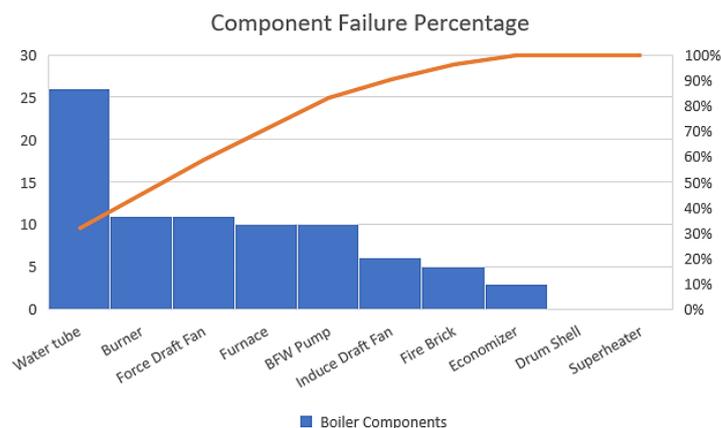


Figure 2. Pareto Diagram of Boiler Components

3.2  FMEA of Each Component

FMEA is carried out to know the level of risk of each root cause obtained from the cause-effect diagram. From FMEA it will be possible to measure the level of risk based on the criteria for occurrence, severity, and detection values so that a Risk Priority Number (RPN) value can be obtained. The results of the RPN values are based on interviews conducted with experts. Identification of RPN FMEA values is carried out on the five components that contribute to the biggest problems. Each of the biggest problem components will be identified using the FMEA process mainly the water tube, burner, force draft fan, furnace, and BFW pump.

1. Water tube

Water tube component analysis is shown in Table 3. From FMEA there are shown that the corroded tube has the highest score of RPN score after that ineffective maintenance strategy. All the score RPN to be accumulative after that the average is shown the critical problems.

Table 3. FMEA of Water tube

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
|---|---|---|---|---|---|---|---|---|
| F1 | Corroded tube | • The level in the steam drum is critical <br> • The pressure of steam dream increases <br> • An explosion occurred | 8 | • Lifetime <br> • High silica content | 8 | Inspection thickness of a tube | 5 | 320 |
| F2 | BFW off spec | Tube scaling | 8 | Bad-quality Chemical treatment | 6 | Controlling ph quality | 5 | 240 |
| F3 | Gas overheating | The operation control device is faulty | 8 | Recalibrate | 4 | calibration once a year | 5 | 160 |
| F4 | Rework plug tube process | Long repair duration | 8 | Incompetent of welder | 6 | Inspection thickness of the tube | 5 | 240 |
| F5 | Safety devices are broken | Boiler trip | 8 | Poor operating controls | 5 | Alarm condition panels in the control room and local indications | 5 | 200 |
| F6 | Ineffective maintenance strategy | A repeated failure occurred | 6 | Renewable equipment is not done | 7 | History mode of failure | 7 | 294 |
| F7 | Incompetent welder | Rework | 4 | Lack of experienced | 6 | Choosing the right welder | 7 | 168 |
| F8 | Incompetent operators | Operation parameter upset | 4 | Lack of experienced | 6 | Supervision from chief | 7 | 168 |

After obtaining the RPN for each problem, critical problems can then be identified. Critical problems are problems that have an RPN above the average value. The average RPN value is 223.75 so there are 4 critical problems. The problem is, a corroded tube, Ineffective maintenance strategy, BFW off-spec, and rework plug tube process.

2. Burner

The next problem to be analysed is FMEA analysis for burner components that have failed. RPN score and problems in the component burner are shown in Table 4.

Table 4. FMEA of Burner

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
|----|------------------------|------------------------------|----------|-----------------------------|------------|-------------------------|-----------|-----|
| F9 | Deformation of the nozzle tip | Operators had difficulty controlling the direction of the fire | 5 | Lifetime | 3 | Measure nozzle dimensions | 8 | 120 |
| F10 | Instrumentation cables often error | A false alarm appears | 5 | Instrumentation cables are thin and break quickly | 5 | Perform manual checks | 4 | 100 |
| F11 | The nozzle and pipe materials do not match | Difficulty setting the direction of the fire | 5 | No original material data was found on the nozzle | 6 | Checking the material | 8 | 240 |
| F12 | The air is dusty | Visual inspection is not optimal | 4 | Lots of burning dust | 6 | Visual check | 7 | 168 |
| F13 | Burner ignition failure | Delayed steam production | 7 | There is no manual / SOP | 6 | Inspection of the lighter tool | 7 | 294 |
| F14 | Ineffective maintenance strategy | A repeated failure occurred | 6 | Renewable equipment is not done | 7 | History mode of failure | 7 | 294 |
| F15 | The mechanic did not check the nozzle tip | Deformation at the nozzle orifice is not detected | 3 | There is no request from the operator | 4 | Supervision from chief | 3 | 36 |
| F16 | Incompetent operator | Upset operating parameters | 4 | Lack of experience | 6 | Supervision from chief | 7 | 168 |

After obtaining the RPN for each problem, critical problems can then be identified. Critical problems are problems that have an RPN above the average value. The average RPN value is 182.75 so there are 3 critical problems. The problems are, The nozzle and pipe materials do not match, the Burner ignition fails, and Ineffective maintenance strategy.

3. Force Draft Fan

The next problem to be analyzed is the FMEA analysis for the failed force draft fan component. RPN score and problems in the component force draft fan are shown in Table 5.

Table 5. FMEA of Force Draft Fan

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
|----|------------------------|------------------------------|----------|-----------------------------|------------|-------------------------|-----------|-----|

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
|---|---|---|---|---|---|---|---|---|
| F17 | The damper cannot be opened | Blocked airflow | 5 | The shaft is rarely operated | 3 | Check the action of shafts | 4 | 60 |
| F18 | Impeller unbalance | High vibration | 6 | The impeller is wearing out | 5 | Check vibration | 5 | 150 |
| F19 | Offspec impeller quality | The impeller is easily unbalanced which can disrupt the operating rate | 5 | The impeller does not meet material specifications | 4 | Check the material | 4 | 80 |
| F20 | Bearings wear out | High vibration | 5 | The material has not been replaced for a long time | 5 | Check vibration | 6 | 150 |
| F21 | The air is dusty | Interrupted flow | 3 | Near the raw material conveyor area | 4 | Visual inspection | 5 | 60 |
| F22 | The security system doesn't work | FD Fan trip | 8 | The module is broken | 4 | Check vibration | 4 | 128 |
| F23 | Ineffective maintenance strategy | A repeated failure occurred | 6 | Renewable equipment is not done | 7 | History mode of failure | 7 | 294 |
| F24 | The mechanics are less competent in maintenance | rework | 4 | Using inexperienced outsourcing personnel | 5 | Supervision from chief | 4 | 80 |
| F25 | Incompetent operator | Upset operating parameters | 4 | Lack of experience | 6 | Supervision from chief | 7 | 168 |

After obtaining the RPN for each problem, critical problems can then be identified. Critical problems are problems that have an RPN above the average value. The average RPN value is 130 so there are 4 critical problems. The problems are, ineffective maintenance strategy, incompetent operator, impeller unbalance, and bearing wear out.

4. Furnace

The next problem to be analyzed is the FMEA analysis for the furnace component. RPN score and problems in the component force draft fan are shown in Table 6.

Table 6. FMEA of Furnace

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
|---|---|---|---|---|---|---|---|---|
| F26 | Instrumentation problems | A false alarm appears | 5 | Not yet calibrated | 4 | Check manually | 5 | 100 |
| F27 | The wall has a hot spot | The combustion system leaks into the environment | 7 | Affected by a water tube leak | 6 | Check manually | 4 | 168 |

| F28 | The gas supply is jammed | Boiler trip | 5 | Control valve jammed | 3 | Check the control valve | 4 | 60 |
| F29 | There is no SOP for the cement mixing process | Poor cement quality | 4 | Lost notebooks | 6 | Input on the central computer | 4 | 96 |
| F30 | Ineffective maintenance strategy | A repeated failure occurred | 6 | Renewable equipment is not done | 7 | History mode of failure | 7 | 294 |
| F31 | Inexperienced handyman | Poor quality | 4 | Civilians are less competent | 4 | Supervision from chief | 4 | 64 |
| F32 | Incompetent operator | Upset operating parameters | 4 | Lack of experience | 6 | Supervision from chief | 7 | 168 |

After obtaining the RPN for each problem, critical problems can then be identified. Critical problems are problems that have an RPN above the average value. The average RPN value is 135.7 so there are 3 critical problems. The problem is, an ineffective maintenance strategy, the wall has a hot spot, and an incompetent operator.

5. BFW Pump

The next problem to be analyzed is the FMEA analysis for the BFW pump component. RPN score and problems in the component force draft fan are shown in Table 7.

Table 7. FMEA of BFW Pump

| ID | Potential Failure Mode | Potential Effect of failure | Severity | Potential Cause of Failure | Occurrence | Current Design Control | Detection | RPN |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| F33 | Low pump efficiency | The amount of steam generated is reduced | 8 | Spare parts are not original | 8 | Monitoring flow at the pump | 5 | 320 |
| F34 | The electric motor burned out | BFW Pump trip | 6 | Bearings are broken | 4 | Visual monitoring | 6 | 144 |
| F35 | Worn impellers | High vibration | 5 | Poor casting results | 4 | Check vibration | 5 | 100 |
| F36 | Leaking mechanical seals | Bfw water is leaking into the environment | 5 | Carbon seal face worn | 6 | Visual inspection | 5 | 150 |

| F37 | Control switch jammed | Unable to perform pump switch | 5 | Broken instrumentation cable | 4 | Operator manual check | 4 | 80 |
|-----|-----|-----|---|-----|---|-----|---|----|
| F38 | The air is dusty | Bearings ingress of dust | 3 | Near the raw material conveyor area | 4 | Visual observation | 5 | 60 |
| F39 | The repair method utilizes impeller reuse | The pump flow cannot be maximized | 6 | Impeller blades are repaired by the welding method | 7 | Flow monitoring BFW | 4 | 168 |
| F40 | Ineffective maintenance strategy | A repeated failure occurred | 6 | Renewable equipment is not done | 7 | History mode of failure | 7 | 294 |
| F41 | The mechanics are less competent in maintenance | rework | 4 | Using inexperienced outsourcing personnel | 5 | Supervision from chief | 4 | 80 |
| F42 | The operator does not check the stand-by pump | Pump switch failure | 4 | Operators don't care | 6 | Supervision from chief | 7 | 168 |

After obtaining the RPN for each problem, critical problems can then be identified. Critical problems are problems that have an RPN above the average value. The average RPN value is 156.4 so there are 4 critical problems. The problem is, Ineffective maintenance strategy, The repair method utilizes impeller reuse and The operator does not check the stand-by pump.

3.3 Criticality Matrix (FMECA)

The criticality matrix functions to determine the priority of failure modes based on the severity and level of occurrence, if there is the same RPN value then to determine the priority of failure mode is based on the severity and occurrence values. In the previous analysis, critical problems have been obtained for follow-up. The next step is to reassess by taking into account the severity and occurrence values. By using the criticality matrix, it will be clear if there are two or more failure points that have the same RPN value. This problem is an example of the Corroded Tube failure mode (F1) and Low pump efficiency (F33). The two examples above show that each failure mode has the same RPN value. The priority of boiler failure modes can be seen in Table 8.

Table 8. Boiler B 03 Failure Mode Priority

| No | ID | Potential Failure Mode | RPN |
|----|-----|-----|-----|
| 1 | F1 | Corroded tube | 320 |
| 2 | F33 | Low pump efficiency | 320 |
| 3 | F6 | Ineffective maintenance strategy | 294 |
| 4 | F13 | Burner ignition failure | 294 |
| 5 | F14 | Ineffective maintenance strategy | 294 |
| 6 | F23 | Ineffective maintenance strategy | 294 |
| 7 | F30 | Ineffective maintenance strategy | 294 |
| 8 | F40 | Ineffective maintenance strategy | 294 |
| 9 | F2 | BFW off spec | 240 |
| 10 | F4 | Rework plug tube process | 240 |
| 11 | F11 | The nozzle and pipe materials do not match | 240 |

| 12 | F25 | Incompetent operator | 168 |
|---|---|---|---|
| 13 | F27 | The wall has a hot spot | 168 |
| 14 | F32 | Incompetent operator | 168 |
| 15 | F39 | The repair method utilizes impeller reuse | 168 |
| 16 | F42 | The operator does not check the stand-by pump | 168 |
| 17 | F18 | Impeller unbalance | 150 |
| 18 | F20 | Bearings wear out | 150 |

Of all the potential failure modes, it is done in Pareto to get priority repairs to get priority problems that will be the focus of improvement so that boiler 03 performance can increase. By the Pareto principle, 80% of problems will be solved with 20% of solutions. The result of the Pareto of the percentage of failure modes is shown in figure 3. The next step is to re-prioritize the failure modes using the criticality matrix as shown in Figure 4.
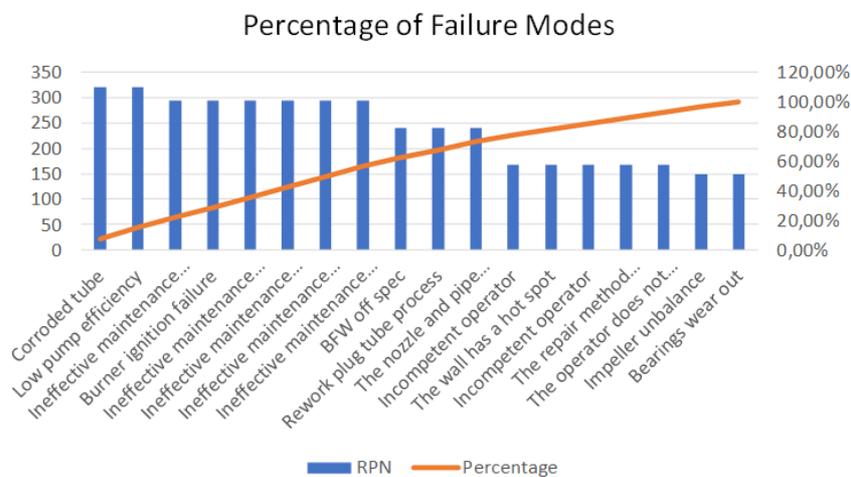


Figure 3. Percentage of Failure Modes

From the graph of the criticality of the failure modes in Figure 4, 13 failure modes are a priority for corrective action. Failure modes will be a priority for boiler B 03 repairs and recommended actions that can be taken to improve boiler B 03 system performance.
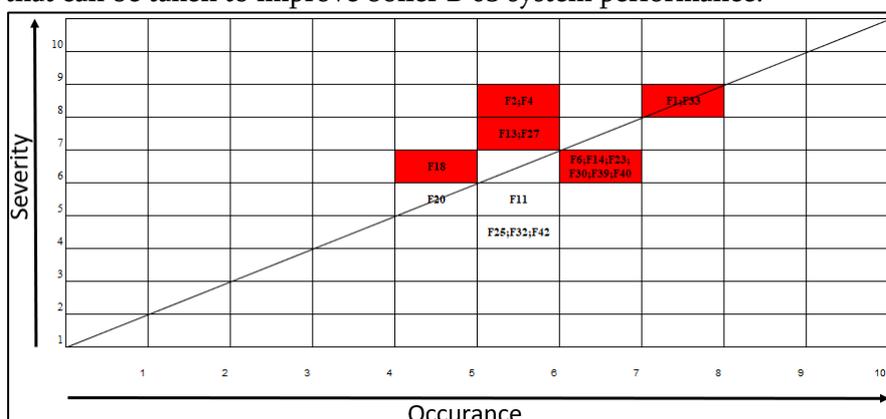


Figure 4. Criticality Matriks

After all the problems are visible from the criticality matrix, recommendations are immediately sought to deal with these problems. Recommendations that can be made to deal with problems can be seen in Table 9.

Table 9. Priority of Boiler B 03 Failure Mode Based on Criticality Matrix and recommended actions

| ID | Potential Failure Mode | RPN | Recommended action |
|---|---|---|---|
| F1 | Corroded tube | 320 | Retubing on corroded tubes |
| F33 | Low pump efficiency | 320 | Replace the new pump unit with the Original Manufacture |
| F6 | Ineffective maintenance strategy | 294 | Create an equipment digitization system based on risk factors |
| F13 | Burner ignition failure | 294 | Replace lighters every 6 months and keep records of replacements |
| F14 | Ineffective maintenance strategy | 294 | Create an equipment digitization system based on risk factors |
| F23 | Ineffective maintenance strategy | 294 | Create an equipment digitization system based on risk factors |
| F30 | Ineffective maintenance strategy | 294 | Create an equipment digitization system based on risk factors |
| F40 | Ineffective maintenance strategy | 294 | Create an equipment digitization system based on risk factors |
| F2 | BFW off spec | 240 | Make long-term contracts with chemical treatment suppliers that are used as boiler control water |
| F4 | Rework plug tube process | 240 | Conduct welder training and certification |
| F27 | The wall has a hot spot | 168 | Make repairs to the wall according to specifications |
| F39 | The repair method utilizes impeller reuse | 168 | Prepare a new impeller |
| F18 | Impeller unbalance | 150 | Perform impeller balancing |

## 4. Conclusion

Based on the initial objectives of conducting this research and the results of the analysis and discussion that have been carried out in the previous chapter, the conclusions that can be drawn include:

- Based on the Pareto results, the components that are the dominant cause of the decline in boiler system performance so that it cannot operate according to design capacity include water tubes, burners, force draft fans, furnaces, and BFW pumps.
- The water tube component has 4 critical problems out of 8 root causes based on the cause-effect diagram and FMEA.
- The burner component has 3 critical problems out of 6 root causes based on the cause-effect diagram and FMEA.
- The force draft fan component has 4 critical problems out of 9 root causes based on the cause-effect diagram and FMEA.
- Furnace components have 3 critical problems out of 7 problems based on FMEA.
- Boiler feed water pump components have 4 critical problems out of 10 problems based on the cause-effect diagram and FMEA.
- Some critical problems that occur in several components have the same RPN value so a more in-depth analysis is carried out using the Failure Mode Effect and Criticality Analysis (FMECA) method to be prioritized for corrective actions, including:
  a. Corroded tube
  b. Low pump efficiency
  c. Ineffective maintenance strategy

d. BFW quality off spec

e. Rework plug process

f. The wall has a hot spot

g. The repair method utilizes impeller reuse

h. Unbalanced impellers

- Proposed improvements to improve boiler system performance include:

a. Retubing on corroded tubes

b. Replacing a new pump unit with the original manufacturer

c. Create an equipment digitization system based on risk factors

d. Replace burner lighters every 6 months and record replacements

e. Make long-term contracts with chemical treatment suppliers that are used as boiler control water

f. Conduct welder training and certification

g. Make repairs to walls that have hot spots

h. Prepare a new impeller

## 5. Acknowledgment

The Author would like to thank all parties for their support in the completion of this research. Hopefully, the research can give benefit any parties, particularly for Operation management as an alternative improvement of the boiler. Moreover, criticism and suggestion are very welcome and it is expected that there will be further research on broader and deeper implementation.

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# Analyzing the Effectivity of Android-Based Application to Increase Physical Performance and Reduce Injuries Potentials During Fitness Training

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**Abstract.** Fitness centers are the favorite place for most urban communities to do physical fitness training activities. However, among the millions who practice fitness in the gym, only certain people know how to exercise using gym equipment correctly. One alternative solution to overcome the problem is using a personal trainer application based on android. Android-based applications are used in this research because it is easier to use than the physical fitness guidebook and cheaper than hiring a personal trainer. This research recruits ten people to prove increased physical performance after using an android-based application by doing fitness training with and without an android-based application. The test will measure at two conditions. The first condition is that right after fitness training, the respondent will measure physical performance analysis using Nordic Body Map (NBM) Questionnaire and maximum oxygen volume. Second, twenty-four hours after fitness training, the respondent's physical performance was measured again using NBM and Mc Gill Pain questionnaire to measure Delayed Onset Muscle Soreness (DOMS). After fitness training activities with the android-based application, there is an increase in physical performance and reduced injury potential, which can be seen from a significantly reduced DOMS score from Mc Gill Pain questionnaire. However, NBM score and maximum oxygen volume result are insignificant.

**Keywords**: android application, fitness training, Nordic Body Map, Mc Gill Pain questionnaire, maximum oxygen volume

## 1. INTRODUCTION

In cities, most fitness centers are necessary and one of favorite places for citizens. Nowadays, more people are aware of the importance of exercising (1). Several motivations make gym members do fitness exercises, based on recent research (2) the survey results, 72.1% of respondents had internal motivation, for example, for personal pleasure and the need to be healthy and fit. In addition, 65.23% have the external motivation to do fitness. People need appreciation, need to make money from fitness competitions, and awards from the environment.

Weight training exercise in fitness centers is to increase a person's ability to exert force with the aim of increasing strength, muscle endurance, hypertrophy, athlete performance, or a combination of these goals. Sports training uses the right weight and gradually with the aim that the muscles develop stronger. Regular weight training will provide many benefits, including increasing muscle strength, preventing injury, being able to control weight, and improving appearance (3). Millions of people practice fitness at the fitness center or gym, however only a few know how to do the right exercises. Most people go to the gym for physical training and don't get maximum results, maximum results mean weight loss or muscle building (4). Three problems cause the lack of achievement of these maximum results. The first is the lack of understanding of how to use the correct fitness equipment, the second is the lack of

knowledge about proper exercise management, and the third is the failure of the diet program with irregular eating patterns and inappropriate food nutrition.

Fitness exercises using tools often cause pain or soreness in the muscles. Usually, pain is not felt immediately when finish doing fitness exercises. Pain or soreness occurs 24-48 hours after doing the exercise. This situation is called Delayed Onset Muscle Soreness (DOMS). DOMS is delaying muscle pain caused by damage to muscle tissue. Pain or pain that arises is a form of the inflammatory response of the body's immune system to injuries caused by muscle damage (5). Based on these conditions, DOMS is used as a pain assessment parameter to see how far the impact of position and movement errors are when doing fitness exercise movements. Apart from DOMS, the Nordic Body Map (NBM) questionnaire can be used to assess musculoskeletal complaints in people who practice fitness. NBM is a data collection technique on complaints on the part of the worker's body and determines the level of work risk, and there are twenty-eight body parts to measure the pain level. The bigger the NBM shows, the more pain and decreased physical performance (6). Maximum oxygen volume (VO$_2$max) is usually used to measure cardio-respiratory fitness, expressed as O$_2$ per liter in one minute for each kilogram of body weight. VO2max is an indicator of aerobic endurance performance. Individuals with higher VO$_2$max will tend to perform better in endurance activities compared to people with lower VO$_2$max for aerobic endurance activities (7).

The problem of safe position and movement when doing fitness exercises is an ergonomic sport. The goals of ergonomics in sports are anticipating the risk of damage to the musculoskeletal system during sports related to the physical and psychological attributes of performing physical activities and supporting increased physical performance during exercise. An ergonomic approach can provide practical evidence for future research focusing on the prevention of sports injuries (8).

Many android-based personal trainer applications have been developed to manage fitness training. The application can also be downloaded for free on the Google Play Store via smartphone. Nevertheless, most of today's apps focus solely on exercise and nutrition management. Meanwhile, applications focusing on safe positions and movements when using tools are still minimal. Position and movement when using fitness equipment are crucial because errors in position and movement can result in abnormalities in body posture, injuries, muscle disorders, and even body shape. Another advantage of the application designed in this research compared to other applications is that the guide in the form of a video contained in the application is more detailed than other applications. In this application, a breakdown of movements and positions is carried out in detail, accompanied by essential explanations in the video. Whereas in other applications, most of them only display fitness exercise movements without any breakdown of positions and movements, so the angles of the body when doing fitness exercises are hard to understand for application users. In this research, an android-based application develops to inform the correct movements and positions using fitness equipment, health, and safety standards when practicing, and the number of exercise repetitions to optimize the exercise.
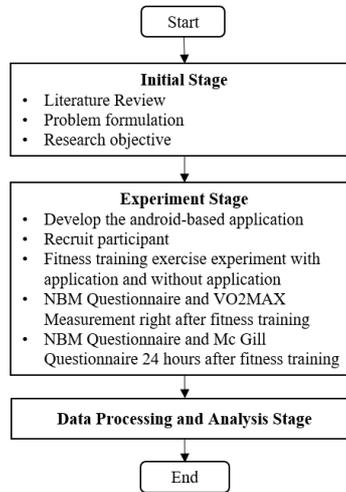
## 2. METHODS



**Figure 5.** Methods of Research

### 2.1. Initial Stage
This stage is the initial stage for starting research which consists of starting from the formulation of the problem and determining the research objectives, literature study, and field studies. The formulation of the problem related to the problem of correct position and movement when doing fitness exercises is summarized in the research objectives. In the literature study, the authors collect various sources that will be used related to the research being conducted. These sources can come from journals, books, scientific articles, or other sources.

### 2.2. Experiment Stage
The interface design of the application the main page contains the logo of the safety workout application along with the application version. The following shows the main page of the safety workout application. If the navigation on the main page is selected, a menu in the safety workout application consists of the menu profile, workout, tips, and contacts. The login menu contains application user information which contains the user's username and email address.
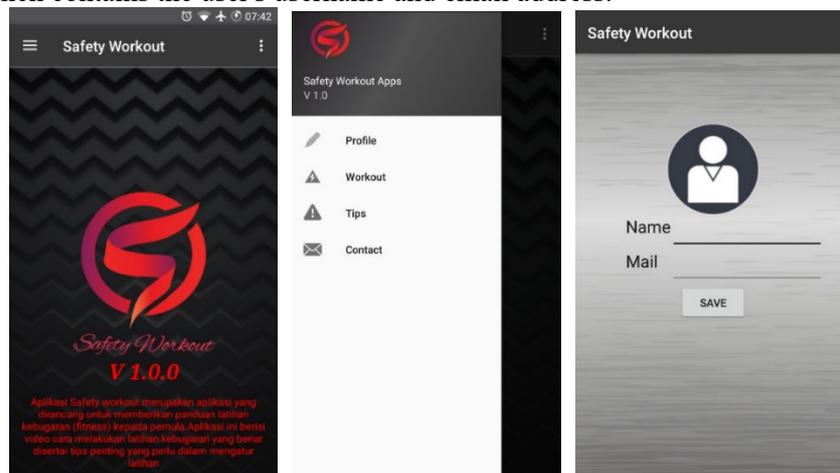


**Figure 6.** Android Application Interface Design of Main Page

The workout menu contains ten videos on how to use fitness equipment. The video will be played automatically when one of the submenu menus on the workout menu is selected. The tips menu contains

information about the number of repetitions in doing fitness movements, fitness equipment, appropriate supplements, and other information.
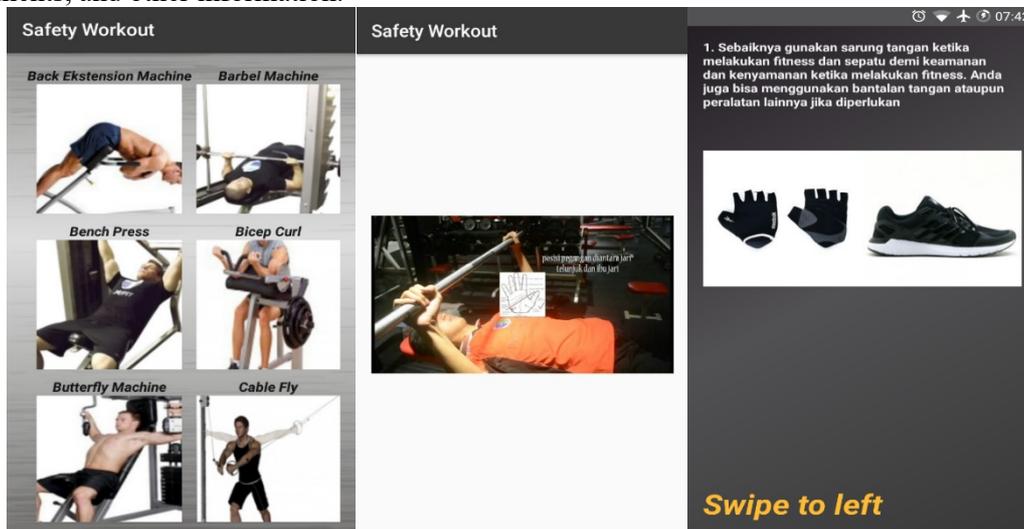


**Figure 7.** Android Application Interface Design of Work Out Menu

Ten respondents were recruited to participate in the experiment. The selected respondents must meet several criteria: male with a fitness training period of fewer than two months. The reason for choosing this respondent is because the targets in this study are users of fitness equipment who are still beginners. There are two treatments for conducting experiments. The first treatment was that all respondents practiced fitness using an application, and the second was that all respondents practiced fitness without using an application. Each respondent will practice fitness training for thirty minutes using ten pieces of equipment: pull down, cable fly, bench press, butterfly machine, rowing machine, chest press machine, barbell machine, squat hack machine, bicep curl, and triceps machine. The order of the equipment is used in the same way. The mobile phone used to support the application is an Android phone with a minimum Android 4.2 Jellybean operating system.
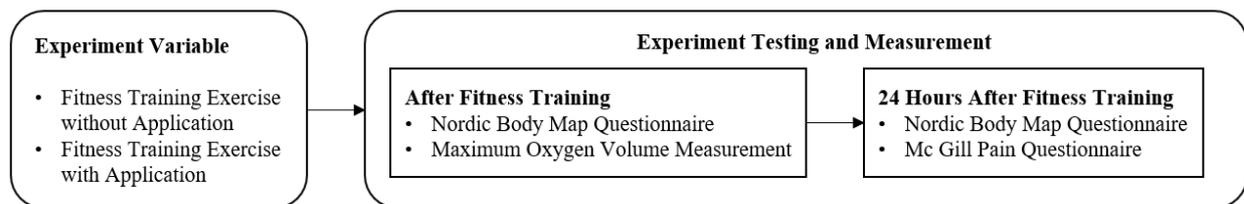


**Figure 8.** Experiment Variable and Measurement

After thirty minutes of fitness training, the Nordic body map questionnaire was asked and measured maximum oxygen volume. NBM questionnaire consist of pain questionnaire in Bahasa Indonesia. The respondent will fill twenty-eight body segments with A (no pain = 1 point), B (moderate pain = 2 points), C (pain = 3 points), D (very painful = 4 points). The oxygen maximum level measurement begins with weighing each respondent first, then using a device to measure the participant's heart rate, so then it counts to be maximum oxygen volume. After twenty-four hours of fitness training, the respondent filled in the NBM questionnaire for the second time, and the participant filled in Mc Gill

pain questionnaire to measure DOMS. This measurement proves the researcher's hypothesis that the position of pain in the body is affected by the effect of DOMS.
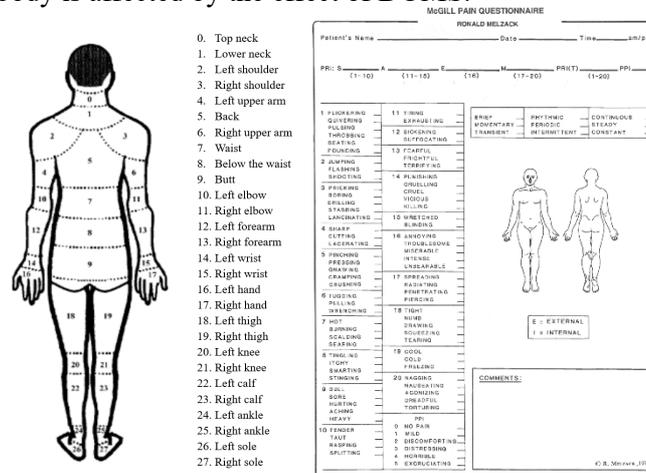


**Figure 9.** Nordic Body Map (9) and Mc Gill Pain Questionnaire (10)

The NBM questionnaire will compare the score from the respondent's answers with and without an android-based application after fitness training and after twenty-four hours. The NBM result will compare using one-way ANOVA. For the McGill Pain Questionnaire, test results from respondents who practice fitness using the application and those who do not use the application compare using paired t-tests. The test result of oxygen maximum volume measurement will also be compared by paired t-test. The conclusion stage is based on the data analysis interpretation results, and suggestions and recommendations are considered when doing fitness exercises.

3. RESULT AND DISCUSSION

*3.1. Nordic Body Map (NBM) Questionnaire*

**Table 1.** NBM Questionnaire Result on Average

|  | Without Application | With Application |
|---|---|---|
| After fitness training | 6.07 | 5.29 |
| 24 hours after fitness training | 22.14 | 20.21 |

The score counts from the weight of each point asked in the NBM questionnaire. The difference in NBM scores after fitness and 24 hours after fitness decreases. The score for the NBM questionnaire right after doing fitness activities was 6.07 on average, while the score for the NBM questionnaire 24 hours after doing fitness activities was 22.14 on average. The difference in this score was due to the Delayed Onset Muscle Sorrowness (DOMS) effect, where pain occurs 24 hours after doing activities. The result of the NBM questionnaire with the application after doing fitness activities was decreased to 5.29 on average, while the score for the results of the NBM questionnaire 24 hours after doing fitness activities was 20.21 on average. The NBM score of respondents who did fitness exercises without the application was higher than the NBM score using the application. The experiment result shows that NBM calculates decreased pain after the respondents did fitness activities using the application. Then the result was analyzed using a Two-Way ANOVA test. The result shows no significant effect with and without application and the interaction between factors.

**Table 2**. NBM Two Way ANOVA Analysis

| Source of Variation | F | P-value | F crit | Conclusion |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| After Exercise - After 24 Hours Exercise | 27.4616 | 0.0000 | 3.9290 | Significant |
| Columns | 0.2105 | 0.6473 | 3.9290 | Not Significant |
| Interaction | 0.0373 | 0.8472 | 3.9290 | Not Significant |

### 3.2. Mc Gill Pain Questionnaire

Table 3 shows data collection for Mc Gill Pain Questionnaire to measure Delayed Onset Muscle Pain (DOMS). The questionnaire asked twice to see the effect of using and without using the application on the presence of DOMS. Questionnaires are given with variables doing fitness activities without the application and with the application.

**Table 3.** Mc Gill Questionnaire Result

| | Without Application | With Application |
|---|---|---|
| Average | 63.8 | 61.4 |
| Standard Deviation | 4.917 | 4.087 |

The data shows that the score reduced after using the android-based application. However, statistical analysis of the Mc Gill Pain questionnaire data using the paired T-test. The hypothesis in this study is formulated as follows.

$H_0 : \mu 1 - \mu 2 = 0$ ; there is no significant difference in the questionnaire results without and with the application.

$H_1 : \mu 1 - \mu 2 \neq 0$ ; there is a significant difference in the questionnaire results without and with the application.

$$t = \frac{\bar{d} - \mu_d}{\frac{s_d}{\sqrt{n}}}, \qquad df = (n-1)$$

(1)

From the calculation, there are 10 data. However, one participant has an outlier result, so we exclude him from the calculation. The result shows the value of t = 2.975617881 with t table with alpha 0.05 is 1.8595. Therefore, it can be concluded that the decision obtained is rejected $H_0$, which means that there is a significant difference in doing fitness activities with application and without the application.

### 3.3. Maximum Oxygen Volume Test Results

Data collection and processing are to calculate the maximum volume of oxygen (VO2 max) with and without using the application.

**Table 4.** Maximum Oxygen Volume Test Result

| | Without Application | With Application |
|---|---|---|
| Average | 58.41 | 58.59 |
| Standard Deviation | 0.62 | 0.79 |

Based on the results of calculating the maximum oxygen volume before using the application, the average maximum oxygen volume value was 58.41 ml.Kg.min. In contrast, after using the application, the average maximum oxygen volume is 58.941 ml.Kg.min. In this case, there is an increase in the average maximum oxygen volume. Then it is analyzed using paired t-test with the same hypothesis as 3.2. The results show the value of t=0.677791105 with t table 1.83311. Therefore, it can be concluded to accept $H_0$, which means there is no significant difference in maximum oxygen volume with and without the application.

## 4. CONCLUSION

This research uses an Android-based application to guide people to practice fitness correctly. The safety workout application features consist of a profile menu, a workout menu containing guide videos on using fitness equipment, tips on fitness, and information on application makers. The result from the Nordic Body Map questionnaire can be concluded that complaints of pain are decreasing after doing fitness activities using the application; however, it is not significant. Using the Mc Gill Pain questionnaire, the result shows there is a decrease in the DOMS score. With the statistical analysis, the result is that $H_0$ is rejected. It can be concluded that there is a significant difference in pain complaints experienced after carrying out fitness activities using the application from Mc Gill Pain Questionnaire. The average maximum oxygen volume before using the application is 58.41 ml.Kg.min. While the average maximum oxygen volume after using the application was 58.941 ml.Kg.min, it is increasing; however, paired t-test results show no significant effect in performance using the maximum oxygen volume measurement after doing fitness activities using the application.

**Table 5.** Research Results

| Measurement Tools | Results |
|---|---|
| Nordic Body Map Questionnaire | Not Significant |
| Mc Gill Pain Questionnaire | Significant |
| Maximum Oxygen Volume | Not Significant |

The research uses three measurements to prove an increase in physical performance. In contrast, only one out of three measurements show there is a significant effect. To see the effect of using the application significantly cannot be done just by doing one experiment. The application function is to give the correct instruction to use the gym equipment because fitness exercises with the correct movements and positions bring pain reduction effects and more extensive performance. The NBM and Oxygen volume are measured after thirty minutes of exercise using ten different pieces of equipment. It can be the cause that the result shows no significant effect because the experiment period is short, the equipment variation is ten, and only once. It also there is effect that every individual stamina is not the same.

This research limitation studied only ten male respondents with a maximum duration of fitness training of two months. The number of tools tested in the experiment was ten tools. Suggestions for further research to see the effect of using the application significantly cannot be done just by doing one experiment because the factors that cause pain when doing fitness activities cannot be defined with certainty. We recommend doing experiments longer to see the application's effect significantly. We recommend that the application made is equipped with a BMI calculation feature, ideal body weight calculation, and other supporting fitness features.

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# Technical Requirements Definitions of Welding Enclosure for Natural Gas Processing Facility Using DMADV

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**Abstract.** New product development required a comprehensive method to avoid any misinterpretation of customer requirements, miscalculation as well as any errors during design conceptual stages. Through a five phase of DMADV method, which accommodates several six-sigma tools in terms of quality management framework, design concept a Welding Enclosure product development has been generated. The use of DMADV tools has succeeded in obtaining a series of research results consist of several things such as mapping the main causes of fire/gas explosion incidents, aligning customer needs with technical and safety requirements, issuing product concept and product feature design recommendations, creating a series of analyses to predict system failures and issuing recommendations in the form of process improvements that must be carried out before the product enters the operational stage. Outline of this paper is, through DMADV, the development of Welding Enclosure products can be carried out to obtain a concept design that's in accordance with customer requirements so that it can be used to carry out hot work in areas with zone-1 hazard classification.

**Keywords**: Welding, Natural Gas, Technical, DMADV, DFMEA

## 6. Introduction

As one of industry segment with high potential risk of any accident related with fire and explosion, Oil and Gas industry was fulfilled by series of safety standard [1] with several technical safety requirements that must be completed before work commencement [2]. Company was decided to develop specific equipment of Welding Enclosure, an equipment that will allow any naked flame present such as performing hot works e.g. welding activity in the middle of oil and gas processing facility. Hot work, as known as an activity that has a high risk if it is carried out in a hazard area with a zone-1 classification and without additional equipment that can eliminate the formation of fire triangles as well as fire tetrahedron. Through a DMADV method or know as Design for Six Sigma (DFSS), Welding Enclosure product will develop or radically redesign from existing through several phase consisting of "Define" phase, "Measure" phase, "Analyse" phase, "Design" phase and "Verify" phase [3].

## 7. Methods

Data enrichment and analysis process started from the Define till Verify stage using several six-sigma tools as can see in Table 1 [3] and the entire of DMADV series can be seen in Figure 1. The author uses internal data of company in the form of tender documents originating from customer requests. The author does not carry out specific survey stages to the customers because the customer requirements have been listed in the tender documents, although they are still general in nature and the need for Welding Enclosure equipment is limited to only 4 or 5 companies within the country.

**Table 1.** DMADV Tools [3]

| Phase | Six Sigma Tools |
| --- | --- |

| | |
|---|---|
| Define | - Determine hypothesis of event |
| | - Cause and Effect Analysis |
| Measure | - Safety criteria analysis |
| | - Technical criteria analysis |
| | - Critical to Quality (CTQs) |
| | - Quality Function Deployment (QFD) |
| |     o   House of Quality (HOQ) |
| Analyse | - Critical to Process (CTPs) |
| | - CTPs target analysis |
| Design | - Design Concept |
| | - Risk Assessment – Fault Tree Analysis |
| Verify | - Design Failure Mode and Effect Analysis (DFMEA) |
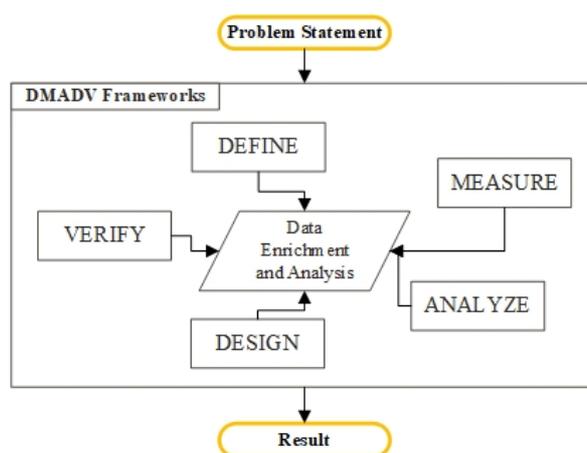


**Figure 1.** Flowchart of DMADV

## 8. Results and Discussion

### 8.1. Define

*8.1.1.* Cause and Effect Analysis. From the process of Cause-and-Effect analysis, the authors have obtained the primary and secondary causes of the occurrence of explosions and fires, which can be seen in the Figure 2. The causes contained in the diagram do not stand alone, there are a series of causes that can or have been trigger these problems, all of which have been summarized in the 4M hypothetical model including Machines, Measurement, Methods, and Manpower. The results of the Cause-and-Effect analysis will be further analyzed to obtain a summary of the hypotheses.

*8.1.2.* Hypothetical Summary. Several hypotheses that can be used by the companies as a basic reference for the development of Welding Enclosure products consist with:

- *No isolation chambers* / There is no chambers with isolation function on the machines scope.
- *Lack of Sensor Device* / There is no sensor equipment to support an isolation chamber function on the measurement scope.
- *Anomaly function* / There is a potential of equipment failure/error on the measurement scope.
- *No Periodical Check* / There is a potential absence to perform periodical check on the measurement scope.
- *No proper method* / There is no proper work procedure on the method scope.
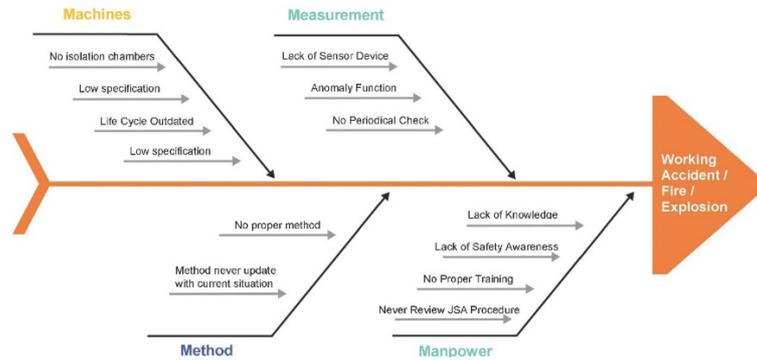
**Figure 2.** Cause and Effect Analysis

Through the concept of new product development using DMADV framework. All the mentioned items will be converted into a technical requirement that will be analysed on the next phase.

*8.2. Measure*

*8.2.1. Safety Criteria and Dangerous Zone*. The occurrence of an explosion or fire caused by a gas leak occurs through several stages and definitions. Not every gas leak will convert into a process of fire or explosion, a process of enrichment of flammable gas material is needed to reach a certain point by ending the ignition process from the heat source and according to predetermined criteria [4], which is related to the *Lower Explosive Limit*/LEL and *Upper Explosive Limit*/UEL. Hazard, as anything that has the potential to cause harm to ill health or risk of injury to humans, damage to property, products, or the environment, has several classifications that can be used by companies to determine which areas to enter into the category of safe or dangerous [5]. Within this basis, several official boards (such as CENELEC, IEC and NEC), which have the responsibility to set a safety standard, have made classification area guidelines which can be seen in Table 2. A simple illustration of LEL and UEL represent in Figure 3.

**Table 2.** Hazard Zone Classification Table (CENELEC/IEC)

| ZONE | DEGREE or RISK |
|---|---|
| 0 | Explosive gas atmosphere is **present continuously or for long periods (typically >1000 hours/year)** |
| 1 | Explosive gas atmosphere is **likely to occur under normal operating condition** |
| 2 | Explosive gas atmosphere is **not likely to occur in normal operation and if it occurs, will only exist for a short period** (typically >10 hours/year) |
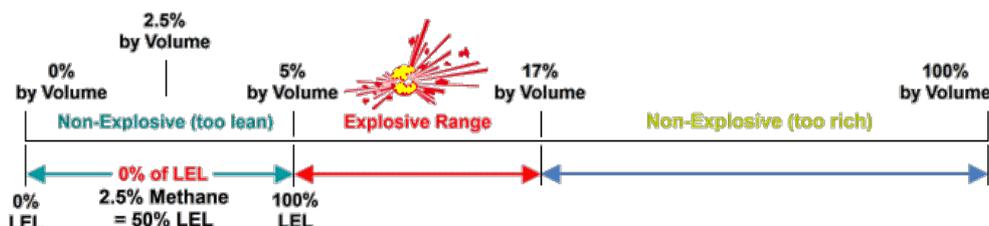


**Figure 3.** LEL UEL Methane material illustration (wermac.org)

*8.2.2. Technical Criteria*. As a product development main reference, another Point-of-View from technical perspective are required to ensure the end-product can meet with customer requirements. Referring to the technical documents that have been obtained from the previous tender process, there

are several technical criteria which's converted to the minimum requirements of Welding Enclosure equipment. Technical criteria can be seen in Table 3.

**Table 3**. General Criteria Welding Enclosure Equipment

| Items | Description |
|---|---|
| Product Name | Welding Enclosure |
| Features | As an isolation chamber that can provide a safe work environment for hot work (welding work or other work that causes hot spots above normal limits) amid the risk of exposure to flammable gases. |
| Main Criteria | • Can provide positive isolation inside the chambers (as a positive barrier between welding activities (source of fire) and exposure of flammable gas |
| | • Can localize heat sources and sparks |
| | • Can be modified |
| | • Zone 1 (explosion proof) classification |
| | • Equipped with LEL and H2S gas detector |
| | • Equipped with emergency beacon and siren |
| | • Adopt stand-alone automatic shutdown system |

*8.2.3. Critical to Quality (CTQs).* Moving on from customer requirements that have been confirmed using the advanced hypothesis from the cause and effect diagram, the authors have obtained the CTQs aspect as the basis for making a House of Quality (HOQ). The CTQs diagram can be seen in Figure 4 with the output in the form of several needs in the measure aspect that have been adjusted to safety and technical requirements.
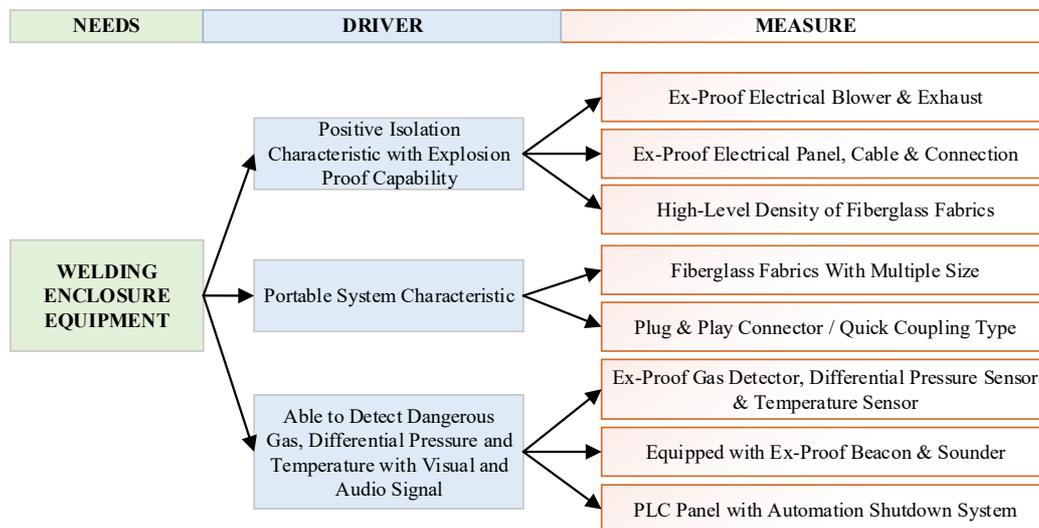


**Figure 4.** Critical To Quality (CTQs)

*8.2.4. Quality Function Deployment (QFD) with House of Quality (HOQ).* Through data result from the VOC, data processing has been carried out originating from customer needs complete with their scale of importance. To align technical criteria with customer needs, each matrix in HOQ has an interrelationship, as well as an evaluation of interrelationships which has a link to technical response, as well as a matrix of customer needs. Evaluation of the relationship between the two matrices has also been carried out using a significance scale of 1 to 9. The higher the number, the stronger the relationship between the items of concern. HOQ results were represented in Figure 5.
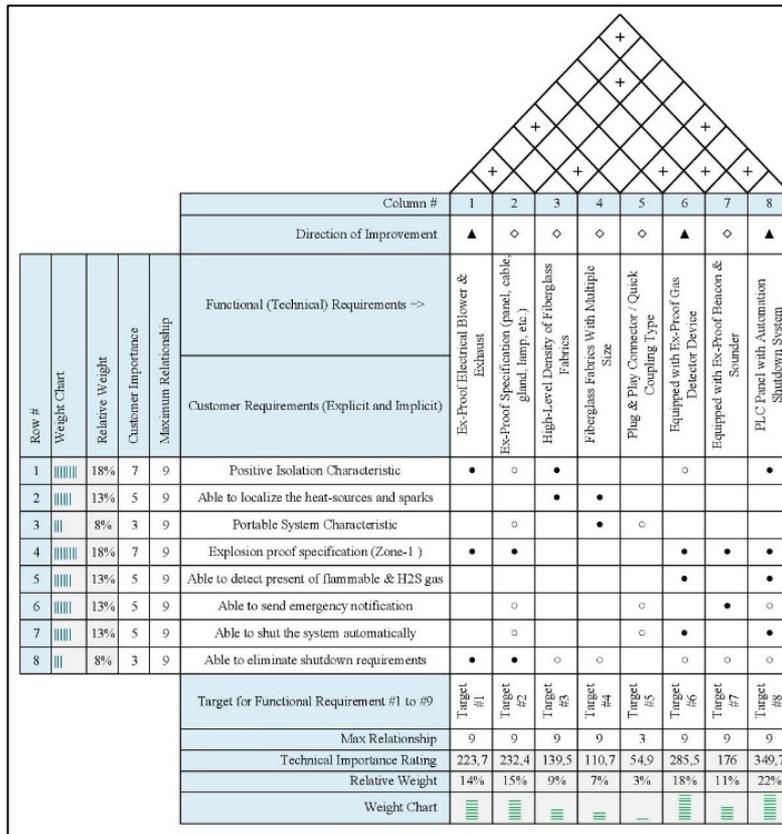
**Figure 5.** House of Quality (HOQ) Matrix

As can be seen in Figure 5, it shows that the PLC panel function with automatic shutdown system is a function that must receive main attention apart from the explosion proof function, etc. Details of technical important rating can be seen in Table 4.

**Table 4.** Technical Importance Rating of HOQ

| Serial Number | Functional (Technical) Requirements | Technical Importance Rating | Relative Weight |
|---|---|---|---|
| 1 | PLC Panel with Automation Shutdown System | 349,7 | 22% |
| 2 | Equipped with Ex-Proof Gas Detector Device | 285,5 | 18% |
| 3 | Ex-Proof Specification (panel, cable, gland, lamp, etc.) | 232,4 | 15% |
| 4 | Ex-Proof Electrical Blower & Exhaust | 223,7 | 14% |
| 5 | Equipped with Ex-Proof Beacon & Sounder | 176 | 11% |
| 6 | High-Level Density of Fiberglass Fabrics | 139,5 | 9% |
| 7 | Fiberglass Fabrics With Multiple Size | 110,7 | 7% |
| 8 | Plug & Play Connector / Quick Coupling Type | 54,9 | 3% |

*8.3. Analyse*

*Critical to Process (CTPs).* After becoming the main reference in determining Voice of Customer in the QFD method, the CTQs method will reused in this phase to be converted to Critical to Process (CTPs) diagram. The purpose of converting data from CTQs to CTPs is so that the product development process can still accommodate customer needs and requirements that are not specifically conveyed but

will become detailed criteria that are quite important in developing product features [3]. The results of product feature development from the CTPs process that have been carried out can be seen in Figure 6.
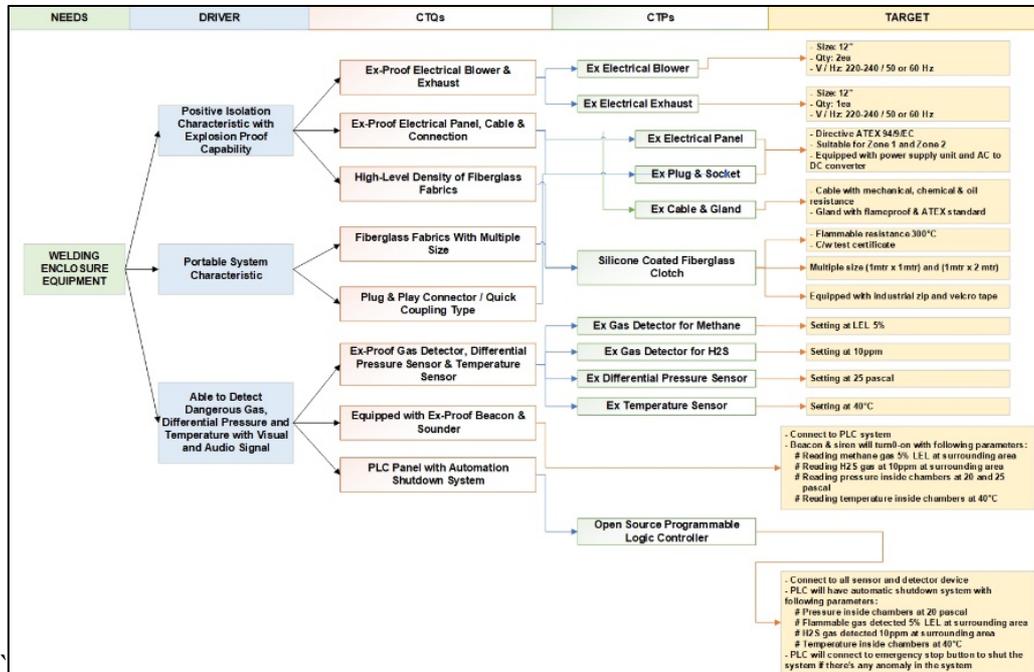


**Figure 6.** Critical to Process (CTPs) Diagram

*8.4. Design*

*8.4.1. Design Concept.* As a result of the CTPs analysis process. The design concept of the Welding Enclosure product will be displayed which refers to the target criteria as shown in Table 4. The design concept will be displayed in the form overall block diagram of Welding Enclosure which can be seen in Figure 7.

*8.4.2. Fault-Tree Analysis.* One of the features that received the main attention in the process of developing of Welding Enclosure equipment is the automatic shutdown system feature and this turned out to be in line with the results of the HOQ analysis which placed this function as the main criterion with an importance level of 22%. Even so, it is still necessary to map the potential for faulty systems using the *Top-Down Fault-Tree Analysis* (FTA) method, a method introduced by Watson from Bell Laboratories in 1962 which will be able to analyse potential failure of a product or system caused by a malfunction and/or due to human error [6][7]. The results of the analysis can be seen in Figure 8.
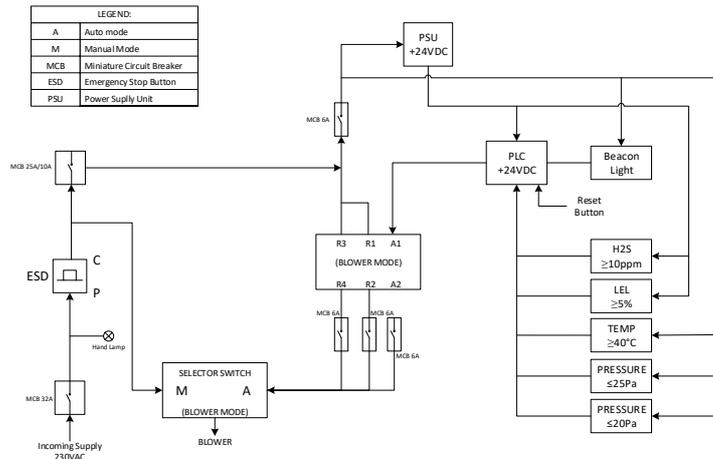
**Figure 7.** Overall Block Diagram
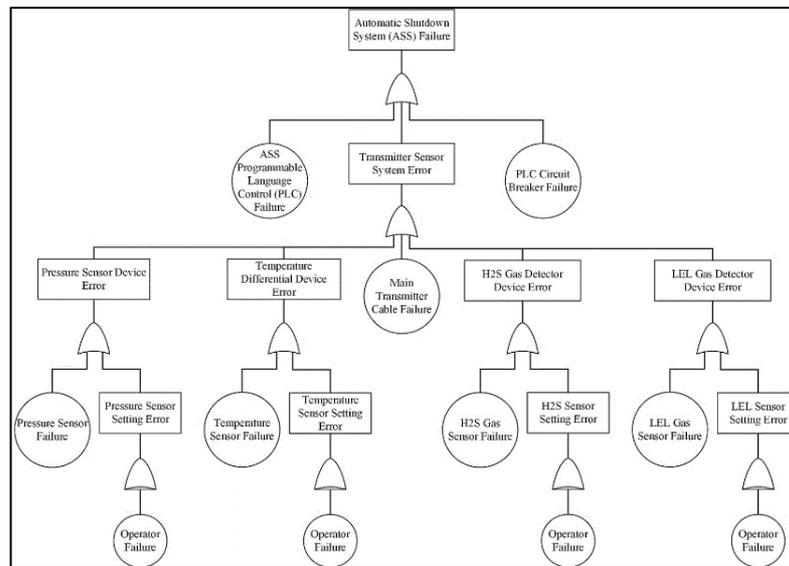


**Figure 8.** Fault-Tree Analysis Diagram

*8.5. Verify*

To ensure the results at each stage still in line with the main criteria, a final verification was carried out by using the Design Failure Mode and Effect Analysis (DFMEA). All potential items will have individual ranking (severity, occurrence, and detection) with result of Risk Priority Number (RPN). RPN calculation will using following equation [3][8]. Result of DFMEA analysis for *Welding Enclosure* equipment are represent in Figure 9 with vary RPN value.

$$RPN = Severity \; x \; Occurence \; x \; Detection \qquad (1)$$

RPN         : *Risk Priority Number*
Severity   : *How severe are the effects of the failure on the system*
Occurrence          : *The likelihood that the failure will occur*
Detection : *The chance that the failure will be detected*

| Function | Potential Failure Mode | Potential Failure Effect | Severity | Potential Causes / Mechanism of Failure | Occurrence | Current Controls | Detection | RPN | Recommended Action | Responsibility Due Phase | Action Result | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Action Taken | Severity | Occurance | Detection | RPN |
| Automatic Shutdown System | Failure on Programmable Language Control (PLC) system | Automatic Shutdown System fail to operate | 9 | Error in PLC system setting (program error) | 3 | Perform system testing | 6 | 162 | Generate PLC system setting procedure | Prior of final setting for PLC setup | To perform recommended action | 9 | 2 | 3 | 54 |
| | Failure on Programmable Language Control (PLC) circuit breaker device | Automatic Shutdown System fail to operate | 6 | Malfuntion on circuit breaker device (MCB Broken) | 3 | Purchase parts with warranty terms | 6 | 108 | Perform electric current testing | During construction stage | To perform recommended action | 6 | 2 | 3 | 36 |
| PLC Transmitter Sensor System | Failure in main transmitter cable | PLC System fail to operate | 6 | Cable broken/short | 3 | Purchase parts with warranty terms | 6 | 108 | Perform electric current testing | During construction stage | To perform recommended action | 6 | 2 | 3 | 36 |
| | Failure in pressure sensor device | PLC error in reading of pressure inside the chambers | 6 | Parts of pressure sensor broken | 6 | not available | 6 | 216 | Perform parts FAT test | During construction stage | To perform recommended action | 6 | 3 | 3 | 54 |
| | Failure in pressure sensor device | PLC error in reading of pressure inside the chambers | 6 | Fault during system setup | 3 | not available | 3 | 54 | Generate sensor setting procedure | Before construction stage | To perform recommended action | 6 | 2 | 2 | 24 |
| | Failure in temperature sensor device | PLC error in reading differential temperature | 6 | Parts of temperature sensor broken & fault during system setup | 6 | not available | 6 | 216 | Perform parts FAT test | During construction stage | To perform recommended action | 6 | 3 | 3 | 54 |
| | Failure in temperature sensor device | PLC error in reading differential temperature | 6 | Fault during system setup | 3 | not available | 3 | 54 | Generate sensor setting procedure | Before construction stage | To perform recommended action | 6 | 2 | 2 | 24 |
| | Failure in H2S gas sensor device | PLC error in reading presence of H2S gas | 6 | Parts of H2S gas sensor broken & fault during system setup | 6 | not available | 6 | 216 | Perform parts FAT test | During construction stage | To perform recommended action | 6 | 3 | 3 | 54 |
| | Failure in H2S gas sensor device | PLC error in reading presence of H2S gas | 6 | Fault during system setup | 3 | not available | 3 | 54 | Generate sensor setting procedure | Before construction stage | To perform recommended action | 6 | 2 | 2 | 24 |
| | Failure in LEL gas sensor device | PLC error in reading presence of LEL gas | 6 | Parts of LEL gas sensor broken & fault during system setup | 6 | not available | 6 | 216 | Perform parts FAT test | During construction stage | To perform recommended action | 6 | 3 | 3 | 54 |
| | Failure in LEL gas sensor device | PLC error in reading presence of LEL gas | 6 | Fault during system setup | 3 | not available | 3 | 54 | Generate sensor setting procedure | Before construction stage | To perform recommended action | 6 | 2 | 2 | 24 |

**Figure 9.** Design Failure Mode and Effect Analysis (DFMEA)

Unlike the commonly known FMEA, DFMEA is a six-sigma method that is specifically intended to carry out advanced analysis regarding the use of hardware that is integrated with the system at all. The analysis carried out is to determine the possibility of a failure mode in the designed system [3][9]. From the DFMEA analysis, it was found that several sub-functions shall receive more attention due of highest RPN value, consist of potential failure in pressure differential sensor, temperature sensor, LEL gas and H2S gas sensor device with similar RPN at 216 point. All of these potential failures can be caused by sensor parts that are damaged since the purchase stage or errors during the system setting process by the operator (human error). Through recommended action by the author, all the RPN number of those potential failure shall be able to reduce from 216 to become 54 point. If refer to Boeing company recommendation for the recommended action requirement, 120 RPN value is the limit, >120 RPN value will required recommended action and vice versa. Therefore, by following recommended action as shown inside the DFMEA table, Welding Enclosure equipment will be having less risk of failure during operational stages.

9. Conclusion

Through DMADV framework, technical requirement definitions of Welding Enclosure products have been generated in the form of design concept data along with Fault-Tree-Analysis and Design Failure Mode Effect Analysis. By following the results of this analysis, authors believe that Welding Enclosure products can be produced in accordance with safety and technical standards in accordance with related industries. The application of recommended actions as listed in the DFMEA table will also be able to eliminate any potential failure of the Welding Enclosure system so that the product can meet the minimum standards of product reliability before being used in the operational stage.

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# The Effect of Noise on Potential Work Accidents and Analysis of the Application of Occupational Safety and Health in Glass Manufacturing

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**Abstract.** PT. MGC is a manufacturer of products made of glass in the form of glass packaging and Glass Blocks. The production process uses machines that cause noise that is not in accordance with Occupational Safety and Health. This study aims to evaluate Occupational Safety and Health in the Department of Forming Glass Block to anticipate the occurrence of work accidents. Occupational Safety and Health Analysis to identify hazards using the Job Safety Analysis (JSA) method then risk assessment using Semi-Quantitative analysis methods by considering Probability, Consequences and Exposure based on Australia / New Zealand AS/NZS 4360:2004 standards and conducting questionnaires regarding noise and safety in the work environment. The respondents in this study were production operators in the Department Forming Glass Block C3. The results of the risk analysis using the Job Safety Analysis method have the highest potential risk at the Very High-risk level is noise and the calculation of noise intensity using the Decibel X: dB Sound Level Meter application is at a noise level above The Recommended Exposure Limits (REL).
**Keywords**: Noise; Occupational Safety and Health; Job Safety Analysis

## Article I.        Introduction

[1] noted, the number of accidents in Indonesia was 116,411 cases in 2019. This number is up 6.59% from the previous year of 109,215 cases and up 11.58% from 2017 with 104,327 cases. This means that accident cases increase every year. Work Safety is a condition where workers are guaranteed safety when working, be it using machines, aircraft, work tools, processing processes as well as the workplace and the environment is also guaranteed. Occupational Health and Safety is very important to be implemented in all fields of work without exception, because the application of Occupational Health and Safety can prevent and reduce the risk of accidents and diseases due to doing work [2].

PT. MGC is a manufacturer of products made of glass in the form of glass packaging and Glass Blocks. In the Department Forming Glass Block, it is known that the production machine is run automatically without stopping using a pneumatic system that utilizes air pressure as a driving force by the compressor. Glass Block production machines include Press Machines and sealing machines where each machine has its own control panel. The role of workers in this part is needed to control the smooth running of the machine and ensure that the product is in good condition during the production process. Some improvements to the mechanics of the machine and the quality of production are carried out without stopping the running machine by means of making settings on the control panel and or on the machine. In the repair process, workers who control the machine panel and those who make arrangements on the machine must understand each other's repair stages so that there are no machine operational errors that have the potential to cause accidents. The sound of the compressor machine greatly interferes with the hearing and activity of workers when they have to be close to the production machine. Most workers in the production area complained about the difficulty of communicating between workers until they had misrepresented the information received. From the measurement results, the amount of noise value around the engine was obtained by 90dB – 108dB. It is also feared that this will affect the level of focus of workers, long-term hearing health and the potential for work accidents due to the difficulty of communicating well in these work areas. The influence of noise must be overcome immediately so that communication between workers can be

effective so that machine operational errors can be avoided and make efforts to control the risk of potential work accidents.

*Article II.*        **Methods**
This study was conducted with the aim of identifying and analyzing the risks of the production process with the ultimate goal of measuring each risk of each work in the production area of the C3 Glass Block Forming Department. The type of research used is Semi-Quantitative Analysis by considering Probability, Consequences and Exposure from hazard identification, risk assessment and risk control in production operators in the Forming Glass Block C3 Department. Hazard identification is carried out using a JSA (Job Safety Analysis) form sheet then conducting a risk assessment using a semi-quantitative analysis method based on [3] about Risk Management to determine the level of occupational safety risk in the work process carried out by the production operator in the Department of Forming Glass Block C3.

*Article III.*       **Questionnaire**
According to *[4]*, the questionnaire, it is a data collection technique that is carried out by giving a set of questions or written statements to respondents to be answered. At this stage, 40 questionnaires were distributed online questionnaires or a number of production operators in the Forming Glass Block C3 Department. Then data processing is carried out using IBM SPSS Statistics with an ordinal scale and a Likert Scale, which is a scale containing 5 levels of answer preference.

*Article IV.*       **Validity Test**
According to *[5]*, the validity test is tool used to measure the legitimate or validity of a questionnaire.  In this test, a data is said to be valid if the instrument can test what it wants to measure. This test uses Karl Pearson product moment formula. The basis for making the decision is that if r count > r table with significance (Sig.) 0.05 then it is considered valid and even if r count < r table is considered invalid, it will be continued with reliability testing.

*Article V.*        **Reliability Test**
This test aims to understand the accuracy of the instrument in measuring the same symptoms even though at different times. If the data is measured twice or more under the same conditions using the same measurement tool, both externally and internally measured, the results will remain the same. According to *[6]*, Cronbach's Alpha indicates the overall reliability of a questionnaire, and values around 0.8 are good.

*Article VI.*       **Noise Observation**
According to *[7]*, Noise is all unwanted sounds that come from the tools of the production process and or work tools that at some level can cause hearing loss. Loud, excessive or prolonged sounds can damage sensitive nerve tissue in the ear, causing temporary or permanent hearing loss. It is often overlooked as a health problem, but it is one of the major physical hazards. The exposure limit to noise was set a threshold value of 85 dB for 8 hours a day. Observations were made to determine the intensity of noise in the production area of the Forming Glass Block C3 Department. Observation and direct measurement of noise intensity can be done using a Sound Level Meter or the like, in this study a noise measurement instrument using a smartphone application, namely Decibel X: dB Sound Level Meter.

*Article VII.*      **Job Safety Analysis**
Job Safety Analysis (JSA) is one of the most important instruments to reduce injuries and accidents in the workplace and eliminate hazards *[8]*. Job Safety Analysis is one of the most important steps in analyzing hazards and incidents to improve safety in the workplace. Once the threat is identified, management measures such as physical changes or improvements in work practices can be implemented to reduce occupational hazards. The occupational safety analysis method requires training, monitoring, and creating job descriptions known as JSA in order for workers to understand work procedures *[9]*. The information collected from field observations and interviews was analyzed and then calculated the risk value using the William T. Fine method, namely by looking for three parameters including probability, exposure, and consequences from the Robinson Matrix. The risk score is determined by the formula:

$$RS = E \; x \; C \; x \; P$$

Information: RS = Risk Score, E = Exposure, C = Consequences, P = Probability. The results of these calculations are then classified into classifications, namely: [3]

Very High  : (>350)
Priority 1    : (181-350)
Substantial  : (71-180)
Priority 3    : (20-70)
Acceptable  : (<20)

*Article VIII.*  **Results and Discussion**

*Article IX.*  **Questionnaire Research Results**

This research was conducted at the Department of Forming Glass Block C3 located at PT. MGC. The respondents who participated in the study were production operators working in the C3 Glass Block Forming Department. Data collection was carried out through the dissemination of research questionnaires directly to respondents who worked as production operators in the Forming Glass Block C3 Department. The research questionnaire is distributed through Google Form in link form. The number of respondents obtained from the results of the distribution of questionnaire was 24 respondents. Table 1 is a summary of the answers from respondents with the following Likert scale information: 1. Strongly disagree, 2. Disagree, 3. Hesitation, 4. Agree, 5. Strongly agree.

Table 6. Summary of Respondents' Answers

| Statement | Scale | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| 1. Noise in the production area interferes with me in communicating effectively with colleagues. | 0 | 2 | 0 | 17 | 5 |
| 2. I once found it difficult to convey information to colleagues when in the production area. | 0 | 0 | 1 | 16 | 7 |
| 3. I once misrepresented the information provided by colleagues when I was in the production area. | 0 | 0 | 1 | 17 | 6 |
| 4. I better understand oral information assisted by gestures when in the production area. | 0 | 1 | 1 | 12 | 10 |
| 5. I know well all potential hazards or hazard actions when in the production area. | 1 | 0 | 3 | 11 | 9 |
| 6. I know well the control functions of the machine (valves, buttons) that are in the production area. | 0 | 0 | 6 | 10 | 8 |
| 7. I have had work accidents / almost wretched either due to personal actions or other people. | 3 | 2 | 3 | 14 | 2 |
| 8. If there is an abnormal condition on the production machine that cannot be handled by myself, I can easily and quickly ask for help from related parties who understand better (Engineering, Instruments). | 1 | 1 | 5 | 9 | 8 |

Figure 1 and Figure 2 are the results of the answers to the questionnaires made into the diagram.
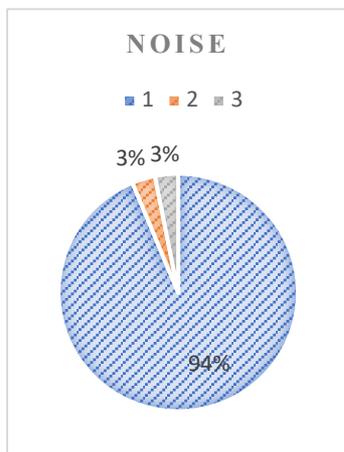


**Figure 1.** A statement about noise shows that 94% of workers agree that noise interferes with communication in the production area
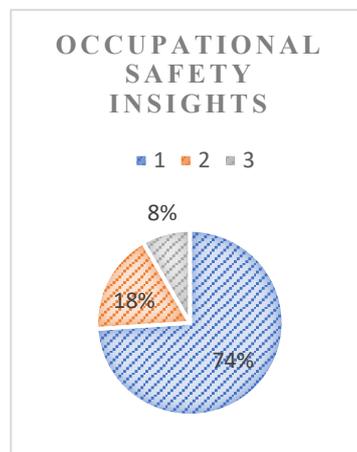


**Figure 2.** A statement on occupational safety insights shows that 74% of workers agree to know about potential work accidents but have or are close to experiencing a wretched condition.

*Article X.*        **Validity Test Results**

Table 7.  Validity Test Results

| No. Item | Pearson Correlation | Sig. | Information |
|---|---|---|---|
| 1 | .870** | 0,000 | valid |
| 2 | .859** | 0,000 | valid |
| 3 | .830** | 0,000 | valid |
| 4 | .929** | 0,000 | valid |
| 5 | .949** | 0,000 | valid |
| 6 | .905** | 0,000 | valid |
| 7 | .881** | 0,000 | valid |
| 8 | .978** | 0,000 | valid |

Based on Table 2, it can be seen that all statements are at a signification level that is below 0.05, so it can be concluded that the statements in the study are valid.

*Article XI.*        **Reliability Test Results**

Table 8.  Reliability Test Results

| Reliability Statistics | |
|---|---|
| Cronbach's Alpha | N of Items |
| 0,957 | 8 |

Based on Table 3, you can see all the statements that have been reliable. Because the reliability test results get Cronbach's Alpha value greater than the critical value (0.957 > 0.060).

*Article XII.*        **Noise Research Results**
The results of measuring the intensity of noise in the Press Area section of the Press Machine between 94-105 dBA and in the Panel Press between 102-109 dBA. Meanwhile, the results of measuring noise intensity in the Sealing Area section of the Sealing Machine are between 90-99 dBA and in the Sealing Panel between 89-93 dBA. In accordance with the Recommended Exposure Limits (REL) within the noise limit in the work environment is 85 dBA or can be described within 8 hours per day or 40 days per week. So that the value of the noise that occurs in the Press Area Machine and Sealing Area Machine in the Department Glass Block C3 is already above the Recommended Exposure Limits. [10]
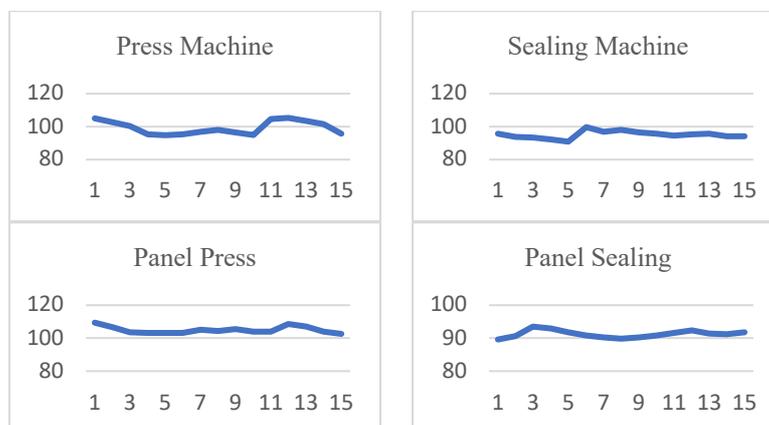In Figure 3 is the intensity of noise in the form of a graph.



Figure 3 Noise Intensity Graph

*Article XIII.*        **Data Analysis Results Using Job Safety Analysis Method**

**After identifying potential hazards in the Press Machine Area and Sealing Machine Area, the next step is to provide recommendations for controlling the source of hazards that can be seen in the table 4 dan table 5.**

Table 9.  Recommendations for Controlling Hazards in the Press Machine Area

| Sequences of Steps | Potential Incidents | Preventative Measures |
|---|---|---|
| 1. Replacing the Plunger | 1) Burns | 1) Using fireproof finger and arm guards |
| | 2) Pinched | 2) Make a pinched red flag |
| 2. Changing / Setting the Cooling Plunger Pipe | 1) Noise | 1) Using Earplugs |
| | 2) Burns | 2) Using fireproof finger and arm guards |
| | 3) Pinched | 3) Make a pinched red flag |
| | 4) Bumped | 4) Using a Helmet |
| 3. Changing the Bottom / Ring | 1) Noise | 1) Using Earplugs |
| | 2) Crushed | 2) Using a good lifting device |
| | 3) Slipping | 1) Ensure oil-free floor area |
| | | 2) Wearing safety shoes |
| 4. Disposing of Molten Gob (Drain) | 1) Fire | 1) Make a small output volume of Molten Gob |
| | | 2) Placing the standby fire extinguisher |
| 5. Troubleshooting Stop Press Table | 1) Fire | 1) Make a small output volume of Molten Gob |
| | | 2) Placing the standby fire extinguisher |
| | 2) Burns | 3) Using tools to retrieve GBH |
| | 3) Communication Disorders | 4) Using body language cues |
| 6. Operating the control button / wind valve | 1) Wrong Control | 1) Create an identity label on the button or valve |

Table 10.  Recommendations for Controlling the Risk of Hazards in the Sealing Machine Area

| Sequences of Steps | Potential Incidents | Preventative Measures |
|---|---|---|
| 1. Replacing the Transfer Loading Equipment | 1) Snapped | 1) Changing by closing the wind supply |
| | 2) Burns | 2) Using fireproof finger and arm guards |
| 2. Rocky Offset Setting | 1) Noise | 1) Using Earplugs |
| | 2) Bumped | 2) Done by experts |
| | | 3) Setting the nut closing on the 1st and 2nd section burners |
| | 3) Pinched | 4) Using a helmet |
| 3. Issue GBH at the bottom position (Lower Block) | 1) Snapped | 1) Using the GB getter tool |
| | 2) Burns | 2) Using fire retardant gloves |

| | 3) Using body language cues | |
|---|---|---|
| 4. Troubleshooting Desk Sealing Stop | 1) Snapped | 1) Using the GB getter tool |
| | 2) Burns | 2) Using fire retardant gloves |
| | 3) Communication Disorders | 3) Using body language cues |
| 5. Operating the control button / wind valve | 1) Wrong Control | 1) Create an identity label on the button or valve |

**After analysis and knowing all the risks contained in each stage of work, calculations are carried out using the semi-quantitative method of William T. Fine. By determining the value of consequences, probability, exposure to determine risk assessment. The risk assessment can be seen in table 6 and 7.**

Table 11. Risk Assessment of Hazards in Area Press Machines

| Sequences of Steps | Potential Incidents | E | P | C | Value Risk | Risk Level |
|---|---|---|---|---|---|---|
| 1. Replacing the Plunger | 1) Burns | 3 | 3 | 5 | 45 | Priority 3 |
| | 2) Pinched | 1 | 3 | 5 | 15 | Acceptable |
| 2. Changing / Setting the Cooling Plunger Pipe | 1) Noise | 10 | 10 | 25 | 2500 | Very High |
| | 2) Burns | 3 | 3 | 5 | 45 | Priority 3 |
| | 3) Pinched | 1 | 3 | 5 | 15 | Acceptable |
| | 4) Bumped | 2 | 3 | 5 | 30 | Priority 3 |
| 3. Changing the Bottom / Ring | 1) Noise | 10 | 10 | 25 | 2500 | Very High |
| | 2) Crushed | 3 | 3 | 5 | 45 | Priority 3 |
| | 3) Slipping | 2 | 3 | 5 | 30 | Priority 3 |
| 4. Disposing of Molten Gob (Drain) | 1) Fire | 1 | 1 | 1 | 1 | Acceptable |
| 5. Troubleshooting Stop Press Table | 1) Fire | 1 | 1 | 1 | 1 | Acceptable |
| | 2) Burns | 1 | 3 | 5 | 15 | Acceptable |
| | 3) Communication Disorders | 6 | 10 | 25 | 1500 | Very High |
| 6. Operating the control button / wind valve | 1) Wrong Control | 2 | 6 | 5 | 60 | Priority 3 |

Table 12. Hazard Risk Assessment in Area Sealing Machine

| Sequences of Steps | Potential Incidents | E | P | C | Value Risk | Risk Level |
|---|---|---|---|---|---|---|
| 1. Replacing the Transfer Loading Equipment | 1) Snapped | 1 | 3 | 5 | 15 | Acceptable |
| | 2) Burns | 3 | 3 | 5 | 45 | Priority 3 |
| 2. Rocky Offset Setting | 1) Noise | 10 | 10 | 25 | 2500 | Very High |
| | 2) Bumped | 2 | 3 | 5 | 30 | Priority 3 |
| | 3) Pinched | 1 | 3 | 5 | 15 | Acceptable |

| 3. Issue GBH at the bottom position (Lower Block) | 1) Snapped | 1 | 3 | 5 | 15 | Acceptable |
|---|---|---|---|---|---|---|
| | 2) Burns | 3 | 3 | 5 | 45 | Priority 3 |
| 4. Troubleshooting Desk Sealing Stop | 1) Snapped | 1 | 3 | 5 | 15 | Acceptable |
| | 2) Burns | 1 | 3 | 5 | 15 | Acceptable |
| | 3) Communication Disorders | 10 | 10 | 5 | 500 | Very High |
| 5. Operating the control button / wind valve | 1) Wrong Control | 2 | 6 | 5 | 60 | Priority 3 |

**After the risk is analyzed using the Job Safety Analysis method against the risk of danger in the Press Machine Area and Sealing Machine in the Forming Glass Block C3 Department. Of the 6 work processes in the Press Machine Area, there are jobs that are included in the risk with the Acceptable category of 5, the risk with the Priority 3 category of 6 and the risk with the Very High category of 3. Meanwhile, of the 5 work processes in the Sealing Area Machine, there are jobs that are included in the risk with the Acceptable category as many as 5, risks with the Priority 3 category as many as 4 and risks with the Very High category as many as 2.**

*Article XIV.      Conclusion*

Based on the results of the Job Safety Analysis Method, of the 6 work processes in the Press Area section, there are jobs that are included in the risk with the Acceptable category of 5, the risk with the Priority 3 category of 6 and the risk with the Very High category of 3. Meanwhile, of the 5 work processes in the Sealing Area Machine, there are jobs that are included in the risk with the Acceptable category as many as 5, risks with priority category 3 as many as 4 and risks with the Very High category as many as 2. Noise has the highest potential risk with the Very High category in the Press Machine Area and Sealing Machine Area.

Based on the results of noise intensity measurements using the Decibel X: dB Sound Level Meter Application in the Press Area section of the Press Machine between 94-105 dBA and in the Press Panel between 102-109 dBA. Meanwhile, the results of measuring the intensity of noise in the Sealing Area section of the Sealing Machine between 90-99 dBA and on the Sealing Panel between 89-93 dBA. The impact that occurs due to noise is in the form of communication disorders, hearing loss and psychological disorders. This is supported by the results of the questionnaire obtained from 24 respondents. Where if there is a communication disorder in the work environment, it can result in a potential risk of work accidents.

Based on the results of the analysis in this study, it is necessary to have Management Engineering by controlling the risk of communication disturbances due to noise by making non-verbal communication procedures using gestures and socializing these rules to workers in the Forming Glass Block production area. Regulate the portion of the operator's working hours when in the area around the machine in accordance with the noise exposure limit time that has been determined by the Regulation of the Minister of Labor. Make Engineering to apply a safety sensor system to the machine so that the machine cannot move when there is contact with workers.

*Article XV.      Reference*

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# Proposed Design Development Trolly Overhaul Cylinder Hydraulic by Quality Function Deployment (QFD) and Anthropometric Approach Method

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**Abstract.** One of the systems for moving production machines is the hydraulic system. Hydraulic system is a system that utilizes fluid/liquid pressure as a source of energy to produce mechanical power. The auxiliary tool used to perform maintenance on the hydraulic cylinder part is the cylinder overhaul trolley. The trolley used today is uncomfortable because when the worker overhaul has to be slightly lowered, so it can cause waist injury. Based on these problems, it is necessary to plan a proposal for the development of an existing hydraulic cylinder overhaul trolley so that it gets good and comfortable performance in accordance with the conditions of the workers. The Quality function of deployment (QFD) method is a methodology for translating the consumers' wants and needs into a product design that has certain technical requirements and quality characteristics. Then, it is strengthened using Anthropometry Analysis which analyzes the design of the hydraulic cylinder overhaul trolley as a reference in the design of the work tool to be made. The results obtained in the analysis of Quality Function Deployment (QFD) are an ergonomic design, which the addition of height features can be adjusted. There are also additional tools for draining residual oil, the tools are available in the trolley and those tools can be used for unloading and installing. Anthropometric data processing for the development of tool designs in the form of trolleys with tool dimensions to be made, namely Length, width, and height. The result of the design of this cylindrical overhaul trolley also shows several advantages including the height can be adjusted, there is a tool holder available and a tool for oil draining.
**Keywords**: Quality Function Deployment (QFD), Anthropometry, Ergonomics and Hydraulic.

## Introduction

Basically, machine movement in the production process use the pneumatic system and the hydraulic system[1]. Fluid power system using air as a medium for developing, transmitting, controlling and utilizing power is commonly referred to as Pneumatics [2]. While the hydraulic system is a form of change or transfer of power by using a conducting medium in the form of liquid fluid to obtain greater power than the initial power released [3].

In the treatment process, one part of the hydraulic machine, namely the cylinder using a tool in the form of a trolley to disassemble, clean, seal replacement, and reinstall the cylinder. The currently used trolly's height is still fixed so that the cylinder must be lifted to the trolley when unloading it from the machine. That situation makes the position when overhaul is not comfortable since the worker must be slightly bent, and that position can cause waist injury. This can be seen based on the results of observations and interviews that have been conducted, it is known that the trolleys used for overhauling hydraulic cylinders still cause discomfort during work and result in complaints of pain in the workers' limbs. The working position is meant when the worker disassembles and installs the cylinder from the machine and when the cylinder is overhauled.

Based on the existing problems, the researchers proposed the development of a hydraulic cylinder overhaul trolley product design the researchers propose development a product design for the Hydraulic

cylinder overhaul trolley. Using a combination model of Quality Function Deployment (QFD) method and anthropometric approaches. QFD method is applied in this study is focused on the House of Quality (HOQ) matrix. Meanwhile, the anthropometric approach to evaluate the product designs so that they are in accordance with the principles of ergonomics. Evaluation in the design of the Hydraulic cylinder overhaul trolley is shown through anthropometric dimension.

Product design using the QFD-Ergonomics combination as applied in this study has been widely applied by several researchers to redesign products. For example, it used QFD to identify and define critical components for redesigning Texon cutting tools. Ergonomic aspects are also used for the development of this new product which is obtained from input anthropometric dimensions. The end result of the design of this texon cutting tool can reduce musculoskeletal complaints, on the back, waist, neck, as well as improve quality and make it easier to use texon cutting tools [4].

The purpose of this research is to redesign the auxiliary tool in the form of a hydraulic cylinder overhaul trolley to suit the needs of workers and an ergonomic design so as to increase the productivity and comfort of workers.

Methods
## 2.1 Quality Function Deployment
The QFD method is used in the process of designing and developing products to determine the specifics of consumer needs and desires, as well as systematically evaluating the capability of products or services in meeting consumer needs and desires [5]. Based on the completion of QFD, it is a practice to design a process in response to customer needs (Voice of Customer). QFD translates what the customer needs into what the designer produces. The focus of QFD is to involve customers in the product balancing process as early as possible. The underlying philosophy is that customers will not be satisfied with a product even if a product has been produced perfectly if they do not want or need it. To implement the QFD method there are several steps and processes that must be done in order to obtain results in the form of product needs specifications that are in accordance with the needs and desires of consumers. Steps in QFD that must be done such as identification of consumer needs, calculation of importance rating, calculation of product position value and so on. These steps will be used to build the House of Quality (HOQ). House of Quality (HOQ) is a tool in the form of a matrix diagram used as a connecting tool to the needs of consumers contained in the left cystic matrix and technical response contained in the upper part of the matrix. in which there are several sections consisting of customer requirements, planning matrix, technical and correlation matrix [6].

## 2.2 Anthropometry
Anthropometry comes from the Latin word Anthropos which means human and metron which means measurement; thus, anthropometry has the meaning of measuring the human body [7]. In general, anthropometry for anatomical measurement variables is divided into general and application surveys. General surveys are used to explain the hand variation of large populations. Their main purpose is to describe populations. By contrast, application surveys are used to gather data for a specific product. Therefore, an application survey often uses few individuals but with strictly defined populations such as occupational groups [8]. Percentile is the value of an anthropometric dimension that represents the percentage of the population that has a certain dimension size. This information is very important in the design stage because it can help to estimate the percentage of the user population that can be accommodated by a particular design.

## 2.3 Ergonomics
Ergonomics is defined by the International Ergonomics Association (IEA) as "the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system in order to optimize human well-being and overall system performance [9]. The focus of the science of ergonomics is the consideration of human elements in the design of objects, work procedures and work environments. The goal of ergonomics is to achieve the highest possible productivity and

efficiency. This is related to the use of appropriate technology, appropriate and compatible with the type of work. The application of ergonomics is generally a product design (design) or redesign (redesign). In addition, ergonomics also plays an important role in improving occupational safety and health factors, for example to apply ergonomic rules and principles by redesigning work tools and processes [10].

## 3. Result And Discussion

In this study the researchers focused on the QFD data processing stage and anthropometric data processing. QFD data processing stages include (1) Identification Customer Need, (2) Define The Customer Importance, (3) Identification The Technical Response, (4) Define The Relationship Matrix, (5) Define The Correlation Matrix, (6) Calculation of Priority Identification, (7) House of Quality (HoQ), Stage 8. Determine the anthropometric measurement (8), and Desain Product (9). Type of this study is survey research. A questionnaire and interview method were used as a tool to acquire these data. Population and sample in this study were the maintenance operators who use hydraulic cylinder overhaul trolleys.

*3.1 Stage 1. Identification Customer Need.*

At this stage, conducted direct interviews with workers, by asking questions in response. From the results of interviews with maintenance operator workers, a list of worker needs was obtained, namely safe trolleys for overhauling hydraulic cylinders, trolleys that can be used to disassemble and install cylinders to machines, there is a place for tools for cylinder overhauls, there is a place to drain excess oil in the cylinder tube, The trolley is not easy to rust; The color of the trolley must be attractive, the trolley is not easily damaged, the ergonomic design of the trolley, and the ease of use of the trolley. Then the list of workers' needs is used as the first draft questionnaire to look for importance rating values and the second questionnaire to look for comparisons of the trolley developed with the previous trolley. Summary of the first and second questionnaires Table 1 and Table 2.

**Table 1.** The results of the first questionnaire to determine the value of the importance rating

| No | Questions | Importance Rating | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | Safe trolley for hydraulic cylinder overhaul | 0 | 1 | 11 | 3 | 0 |
| 2 | The trolley can be used to load and install cylinder to the machine | 0 | 0 | 5 | 4 | 6 |
| 3 | There is a tool place for cylinder overhaul | 0 | 0 | 6 | 5 | 4 |
| 4 | There is place for the draining of oil residue in cylinder rubes | 0 | 1 | 8 | 2 | 4 |
| 5 | The trolley is not easy to rust | 0 | 5 | 8 | 2 | 0 |
| 6 | The trolley color should be attractive | 0 | 10 | 5 | 0 | 0 |
| 7 | The trolley is not easily damaged | 0 | 4 | 5 | 5 | 1 |
| 8 | The trolley design is ergonomic | 0 | 0 | 2 | 6 | 7 |
| 9 | Ease of use of the trolley | 0 | 3 | 6 | 5 | 1 |

**Table 2.** The results of the second questionnaire which is a comparison of the trolley that was developed with the previous trolley, these results are used to determine the position of the product to be developed against the previous product.

| No | Questions | Comparation Trolley Before | | | | | Comparation Trolley After | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| 1 | Safe trolley for hydraulic cylinder overhaul | 0 | 1 | 11 | 3 | 0 | 0 | 0 | 7 | 6 | 2 |
| 2 | The trolley can be used to load and install cylinder to the machine | 0 | 6 | 5 | 4 | 0 | 0 | 0 | 5 | 4 | 6 |
| 3 | There is a tool place for cylinder overhaul | 5 | 4 | 6 | 0 | 0 | 0 | 0 | 6 | 5 | 4 |
| 4 | There is place for the draining of oil residue in cylinder rubes | 4 | 8 | 3 | 0 | 0 | 0 | 1 | 8 | 2 | 4 |
| 5 | The trolley is not easy to rust | 0 | 5 | 8 | 2 | 0 | 0 | 2 | 8 | 2 | 3 |
| 6 | The trolley color should be attractive | 0 | 10 | 5 | 0 | 0 | 0 | 0 | 5 | 10 | 0 |
| 7 | The trolley is not easily damaged | 1 | 7 | 5 | 2 | 0 | 0 | 4 | 5 | 5 | 1 |
| 8 | The trolley design is ergonomic | 7 | 6 | 2 | 0 | 0 | 0 | 0 | 2 | 6 | 7 |
| 9 | Ease of use of the trolley | 1 | 6 | 6 | 2 | 0 | 0 | 3 | 6 | 5 | 1 |

### 3.2 Stage 2. Define The Customer Importance.

After determining the needs of workers, then the first draft of the questionnaire was prepared. Respondents gave an assessment of the attributes with Likert scale method. The importance rating data is obtained from the distribution of questionnaires containing questions about the level of importance of each attribute based on each respondent. The questions asked to respondents consisted of 9 questions obtained from the recapitulation results of interviews with workers.

### 3.3 Stage 3. Identification the Technical Response.

Technical requirements are translators of worker needs in a technical form so that a product can be formed directly. In this section there are specific targets that will be set based on the company's capabilities that have been set through customer needs.

### 3.4 Stage 4. Define The Relationship Matrix.

At this stage an analysis of the relationship between consumer needs is carried out (Customer Needs) and technical characteristics (technical requirements), so they are known whether consumer needs have a strong, moderate or weak relationship with technical characteristics. Strong relationship is if a certain technical characteristics is a direct interpretation of consumer needs. While the relationship is and weak is if the technical characteristics are not a direct interpretation of consumer needs.

### 3.5 Define The Correlation Matrix.

The next step is to identify the relevant interactions between each of the technical characteristics. The correlation matrix is a triangular table that is used for shows the relationship between one technical characteristic with another technical characteristic other.

### 3.6 Stage 6. Calculation of Priority Identification.

At this stage there are several calculations that can be used to assist the process of determining priorities, including:

a. Goal: is the level of performance to be achieved by the company to meet the needs of workers.
b. Sales Point: is information on the ability to sell products based on how well consumers' needs can be met and affects the competition used for marketing.
c. Improvement Ratio: is a comparison of goal scores with customer competitive evaluation values.
d. Row Weight is obtained by multiplying the importance rating, improvement ratio and sales point. The results of the row weight are used to determine the actions that can be taken by the company, these actions consist of 3 categories, namely category A improves product quality, category B

maintains product quality and continuously innovates products, and category C maintains product quality.

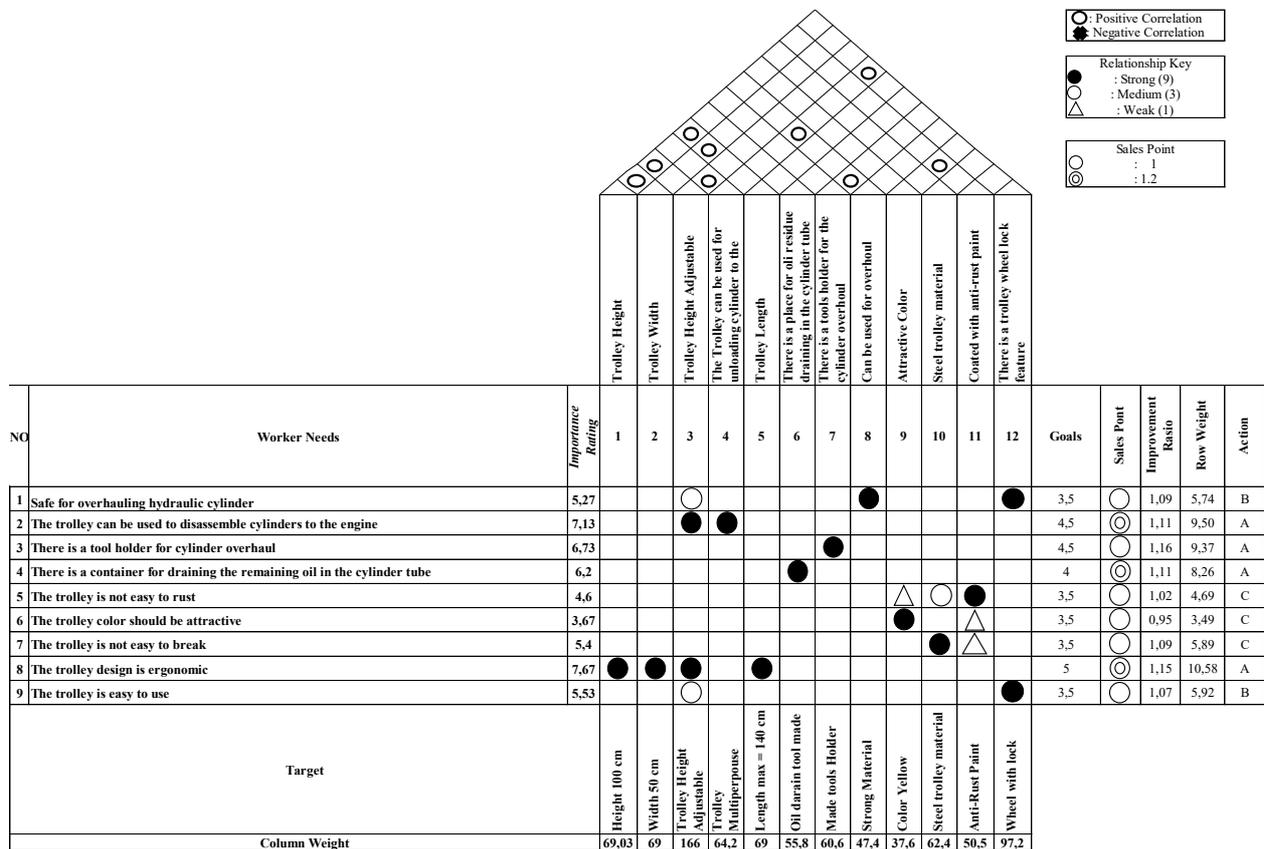*3.7 Stage 7. House of Quality (HoQ).*



**Figure 1.** House of Quality.

From the HoQ results in Figure 3, it can be analysed several things, as follows:

1  The level of importance: very important criteria is the trolley design is ergonomic and the trolley can be used to load and install cylinder to the machine. Meanwhile, there is a place for tools for cylinder repairs and there is a place for draining the remaining oil in the cylinder tube which is at a moderate level.

2  Row Weight: the results obtained on the raw weight for the trolley can be used to disassemble cylinders to the engine, here is a tool holder for cylinder overhaul, there is place for the draining of oil residue in cylinder rubes, and The trolley design is ergonomic get a high value so that it gets the action category A, namely the need to improve product quality.

*3.8 Stage 8. Determine the anthropometric measurement.*

After obtaining anthropometric data for maintenance operators, the 5th, 50th and 95th percentile values will be calculated. The 5.50 and 95th percentile values for all anthropometric dimensions can be seen in Table 2.

### Table 3. Percentiles value of 5, 50 and 95

| No | Dimension | $\bar{x}$ | σ | $P_5$ | $P_{50}$ | $P_{95}$ |
|----|-----------|-----------|---|-------|----------|----------|
| 1 | Side Hand Reach Dimensions | 43.87 cm | 2.00 | 40.58 cm | 43.87 cm | 47.15 cm |

| 2 | Front Hand Reach Dimensions | 74.60 cm | 1.72 | 71.76 cm | 74.60 cm | 77.44 cm |
|---|---|---|---|---|---|---|
| 3 | Shoulder Height In Standing Position | 143.73 cm | 1,67 | 140,99 cm | 143.73 cm | 146.48 cm |

Data processing to determine the dimensions of work facility design using the principle of extreme anthropometric data with the purpose of the design can be used comfortably with a normal size. The results of data processing to determine the dimensions of work facility design are as follows:

1. Hydraulic cylinder overhaul trolley width: is designed for anthropometric dimensions of side hand reach dimensions with a percentile value of 95%. The purpose is that when the operator performs a cylinder overhaul it is more flexible and can be reached by all operators. The calculation as follows: Dimensions of the width of the hydraulic cylinder overhaul trolley: 47.15 cm.
2. Hydraulic cylinder overhaul trolley length: is designed for anthropometric dimensions of front hand reach dimensions with a percentile value of 95%. The purpose is that when the operator performs a cylinder overhaul more freely. And coupled with the length of the tool for overhaul of about 20 cm. The calculation as follows:
Dimensions of the length of the hydraulic cylinder overhaul trolley: 77.44 + 20 = 97.44 cm.
3. Hydraulic cylinder overhaul trolley height: is designed for anthropometric dimensions of shoulder height in standing position with a percentile value of 95%. The purpose is for operators with higher dimensions can use the trolley comfortably. And so that the trolley can be used by operators with short dimensions, the trolley is designed with an adjustable height. The calculation as follows:
Dimensions of the height of the hydraulic cylinder overhaul trolley can be adjusted in height with a minimum height of 43.87 cm and a maximum of 146.48 cm.

*3.9 Desain Product.*

Analysis of the results of the product development design of the hydraulic cylinder overhaul trolley based on the results research using QFD and anthropometry can be seen in Figure 2.
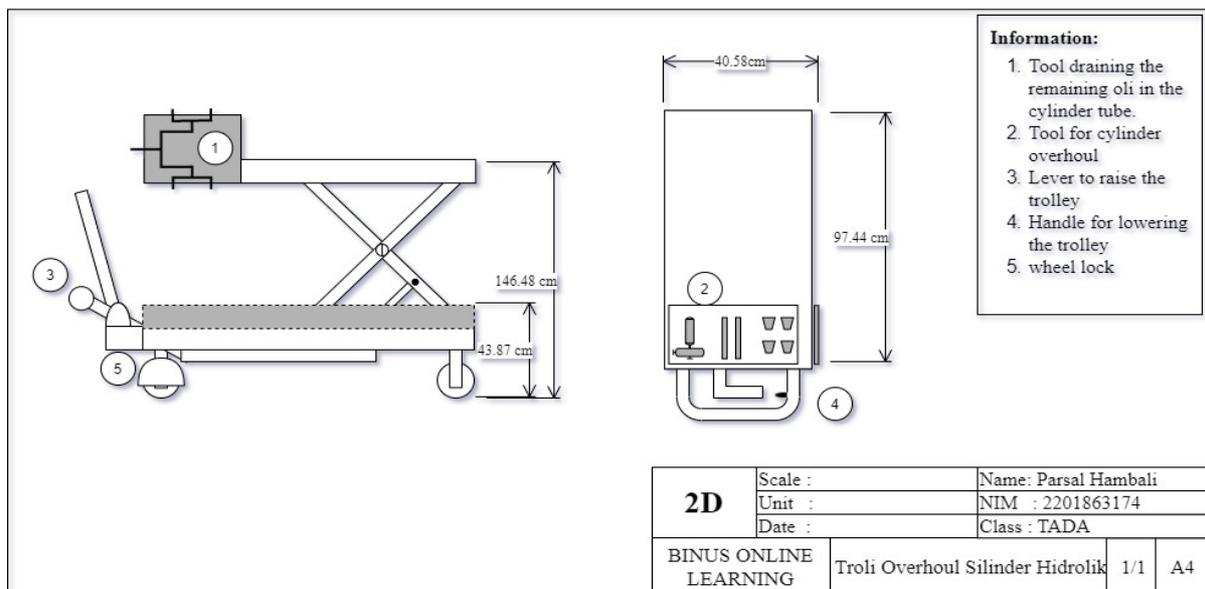


**Figure 2.** Design Trolley Overhaul Cylinder Hydraulic

From figure 4 several differences of hydraulic cylinder overhaul trolleys with the previous trolleys are obtained. Table 5 lists the overall comparison of trolley designs.

**Table 4.** Difference: The overhaul trolley has a new hydraulic cylinder with an old one.

| No | Old Hydraulic Cylinder Overhaul Trolley | New Hydraulic Cylinder Overhaul Trolley |
|----|------------------------------------------|------------------------------------------|
| 1 | The trolley can not be used for unloading cylinders to the machine | The trolley can be used for unloading cylinders to the machine |
| 2 | There is a tool holder for the cylinder overhaul | There is a tool holder for the cylinder overhaul. |
| 3 | There is a place for oil residue draining in the cylinder tube | There is a place for oil residue draining in the cylinder tube |
| 4 | Non-ergonomic trolley design | Ergonomic trolley design |
| 5 | Height cannot be adjusted | Trolley height adjustable |

## 4. CONCLUSION

This study succeeded in redesigning the hydraulic cylinder overhaul trolley by identifying user needs and using anthropometric data to determine the dimensions of the trolley so that the operator is comfortable when used, with dimensions of the width of the hydraulic cylinder overhaul trolley: 47.15 cm, length of the hydraulic cylinder overhaul trolley: 97.44 cm, and the height of the hydraulic cylinder overhaul trolley can be adjusted in height with a minimum height of 43.87 cm and a maximum of 146.48 cm.

The level of importance: very important criteria is the trolley design is ergonomic and the trolley can be used to load and install cylinder to the machine. Meanwhile, there is a place for tools for cylinder repairs and there is a place for draining the remaining oil in the cylinder tube which is at a moderate level. Row Weight: the results obtained on the raw weight for the trolley can be used to disassemble cylinders to the engine, here is a tool holder for cylinder overhaul, there is place for the draining of oil residue in cylinder rubes, and The trolley design is ergonomic get a high value so that it gets the action category A, namely the need to improve product quality.

The results obtained are several differences between the overhauled hydraulic cylinder trolley and the previous trolley. Old hydraulic cylinder overhaul trolley that is the trolley cannot be used for unloading cylinders to the machine, there is a tool holder for the cylinder overhaul, there is a place for oil residue draining in the cylinder tube, non-ergonomic trolley design, and height cannot be adjusted. Meanwhile, the new hydraulic cylinder overhaul trolley that is the trolley can be used for unloading cylinders to the machine, there is a tool holder for the cylinder overhaul, there is a place for oil residue draining in the cylinder tube, ergonomic trolley design, and trolley height adjustable.

For future recommendation, For future recommendations, this research still requires further refinement, because there are still deficiencies in the ergonomic design of the hydraulic cylinder overhaul trolley, namely the limited strength of the trolley and the material used to make this hydraulic cylinder overhaul trolley.

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# Determinants of Consumer Purchase Intentions in Cleaning Product Refill Facilities as an Alternative to Reducing Single-use Plastic Packaging Waste

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**Abstract.** Single-use plastic packaging is widely used in FMCG (Fast Moving Consumer Goods) to pack products. The use of single-use plastic packaging has become a daily habit and triggers an increasement of the amount of plastic waste. Nowadays, a linear economy has been swift into a circular economy to save the environment. One of the best solutions is by providing household cleaning product refill facilities in several areas. Also, this research wants to find the influence of household cleaning product refill facilities in order to reduce single-use plastic packaging waste. The Theory of Planned Behaviour (TPB) is used in this research to analyse and estimate people's behavior. The questionnaire helps to identify the impact of environmental consciousness, environmental knowledge, subjective norms, and green marketing on the purchase intention to refill cleaning products at filling facilities. The result of this research shows that the purchase intention to refill cleaning products at filling facilities is influenced by each variable of the research. Therefore, innovative refill cleaning products at filling facilities can be a solution to reduce the increase in plastic waste.
**Keywords**: Plastic packaging, Circular economy, Refill facilities, Environmental consciousness, Subjective norms, and Green marketing.

## Introduction

Single-use plastic packaging is only used once before being recycled or disposed of (Vimal 2020). It is widely used in FMCG (Fast Moving Consumer Goods) to pack shampoo, soap, household cleaners, food, etc. Due to its convenience when storing and transporting things, single-use plastic is commonly used to provide consumers daily needs [1]. In Jakarta (Indonesia), the use of single-use plastic packaging has become a daily habit for its citizens. The number of plastic waste also increases along with the high consumer demand [2]. This causes an increase in the amount of waste that pollutes the environment [3]. Therefore, Indonesia became the second-largest contributor to plastic waste, which is also among the 10 nations that manage plastic waste the worst globally [4]. According to research by Waste4Change in 2021, 87.52%, or more than 279.63 tons of single-use plastic packaging waste per day will be disposed of in final disposal sites but only 2.99% that be recycled [5].

Currently, a linear economy (take-make-dispose economy) that relies on resources to continuously produce products and ultimately dispose of waste without thinking twice has become a major cause of climate change and ecological degradation [6]. However, this economic system starts to transform into a more sustainable way to tackle issues such as pollution, waste, biodiversity loss, and environmental issues, called a circular economy. The circular economy is a theory that encourages the repairing, enhancing, and redistributing of used products [7]. The 3Rs—Reduce, Reuse, and Recycle—are conceptually used to characterize the circular economy concept [8]. In addition, this concept has become a method to cut down and prevent human behaviours that can trigger environmental issues [9]. It is clearly meant that by using the circular economy concept, plastic packaging waste may be turned into something beneficial that can be reused [7].

In order to accomplish this circular economy, the Indonesian government has legalized Law Number 18 of 2008 concerning Waste Management. This policy states that manufacturer is required to manage the packaging and/or goods they produce which cannot or are difficult to decompose by natural processes. One of the famous FMCG industries in Indonesia has implemented a circular economy to solve the single-use plastic packaging waste in Jakarta. The solution is by provide household cleaning product refill facilities at several points in Jakarta. This business innovation was designed as a new technique for reusing and refilling household cleaning product containers. Also, could reduce the waste burden and may contribute to the development of more sustainable solutions.

The public awareness to refill cleaning products is very important to achieve this program. It is because environmental problems can be the reason why people are becoming more aware of their living environment [10]. Consumer purchase intention can be greatly influenced by consumer understanding of green purchasing which is related to environmental sustainability. Single-use plastic packaging waste can be reduced with the consumer awareness to have a sustainable consumption pattern by using environmentally friendly products, commonly referred to as "Green Purchasing". This consumption pattern refers to consumer actions to save resources and protect the environment [11][12][13].

Several studies have discussed the relationship between environmental consciousness and environmental knowledge with customer purchase intention [10,14,15]. In addition, green marketing has attracted public attention since it can lead to boost customer purchase intention [16–18]. However, the customer purchase intention can also be caused by subjective norms from people support [15,19]. All of these factors can influence the customers purchase intention to refill cleaning products at the refill point. Thus, this study is to figure out the customer purchase intention toward the relationship between environmental consciousness, environmental knowledges, subjective norms and green marketing. Moreover, this research wants to find the influence of household cleaning product refill facilities in order to reduce single-use plastic packaging waste.

Literature Review
*10.1. Theory of Planned Behavior*
The Theory of Planned Behavior (TPB) has been widely utilized to analyze human behavior, particularly pro-environmental conduct [20]. Therefore, this theory is used in this research to analyze and estimate people behavior. TPB is a social psychological theory and one of the most well researched models in the area of study. The theory presents a comprehensive psychological theory that discovers an original way of describing a wide range of individual behavior [21]. Behavior might be generally or specifically defined, depending on the theoretical or practical purposes of the researcher. This current research conceptualized the behavior of customer of household cleaning product refill facilities regarding the environmental consciousness, environmental knowledges, subjective norms and green marketing.

*10.2. Hypothesis Development*
Consumers' environmental consciousness and knowledge have been evaluated by green products [22]. Subjective norms are described as seeing society pressure from others to perform certain behaviors [20]. When buyers are unfamiliar with the product, packaging and label may be a powerful marketing strategy. Also, advertising is an effective strategy for modern marketers to persuade customer choice and decision-making [23]. In this study, researcher proposed the hypothesis:
H1. Environmental consciousness influences the purchase intention to refill cleaning products at filling facilities.
H2. Environmental knowledges influence the purchase intention to refill cleaning products at filling facilities.
H3. Subjective norms influence the purchase intention to refill cleaning products at filling facilities.
H4. Green marketing influence the purchase intention to refill cleaning products at filling facilities.

i.**Figure 1.** *Research Framework*
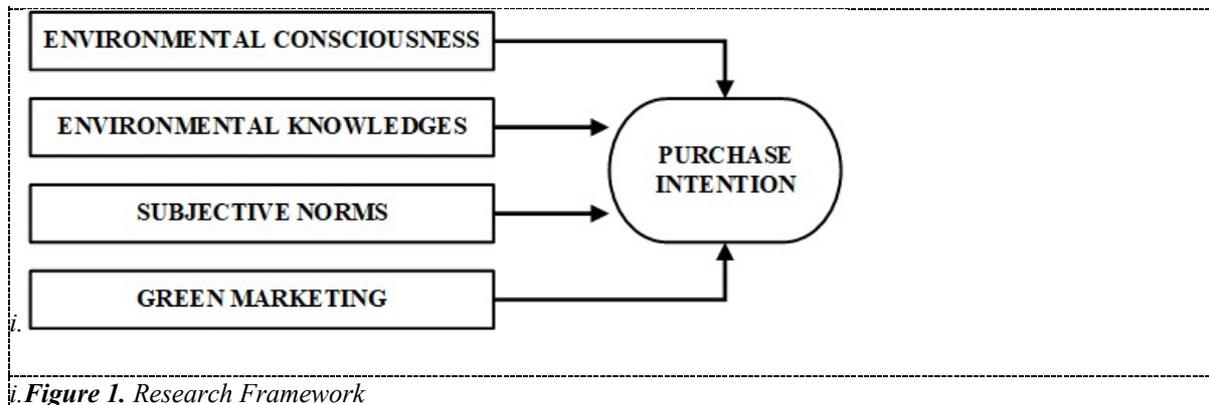
Methodology

In investigating the customer purchase intention, this research using quantitative method to identify the impact of environmental consciousness, environmental knowledges, subjective norms and green marketing on the purchase intention to refill cleaning products at filling facilities. The primary target for the online questionnaire is potential buyers of refill cleaning products in Jakarta. Questionnaires were distributed via messaging applications and personal social media. The sampling technique used Isaac and Michael technique with significance level 5%. A total of 407 respondents were asked to answer various questions such as gender, age, education, occupation, income and 15 research questions. The research question using a survey method with Likert-type scales with five possible responses, ranging from 1 (strongly disagree) to 5 (strongly agree). Table 1 shows the variables and question list.

**Table 1.** Variables and Question List

| | Variables | | Question |
|---|---|---|---|
| $X_1$ | Purchase Intention (PI) | $(Q_1)$ | I prefer to refill cleaning products instead of buying new packs |
| | | $(Q_2)$ | I will buy a cleaning container or bottle to refill the product |
| | | $(Q_3)$ | I am willing to refill the cleaning products at refill facilities |
| $X_2$ | Environmental Consciousness (EC) | $(Q_4)$ | I am responsible for protecting the environment |
| | | $(Q_5)$ | I avoid using products that are harmful to the environment |
| | | $(Q_6)$ | I am aware that refill facilities can be a solution to reduce pollution |
| $X_3$ | Environmental Knowledges (EK) | $(Q_7)$ | I know the risks of using single-use plastic packaging for the environment |
| | | $(Q_8)$ | I know the positive impact refilled products have on the environment |
| | | $(Q_9)$ | I am aware of information regarding refill facilities for cleaning products |
| $X_4$ | Subjective Norms (SN) | $(Q_{10})$ | I was influenced to buy green products because of my acquaintances |
| | | $(Q_{11})$ | I will consider the advice of people around me when buying eco-friendly products |
| | | $(Q_{12})$ | I got support from relatives regarding my decision to refill cleaning products at a refill facility |
| $X_5$ | Green Marketing (GM) | $(Q_{13})$ | I am interested in eco-friendly labels on cleaning products |
| | | $(Q_{14})$ | I am motivated to buy eco-friendly products because of influencer marketing |
| | | $(Q_{15})$ | I was interested in refilling cleaning products at the refill station because of the advertisement |

j.
v.*Figure 2.* Research Design
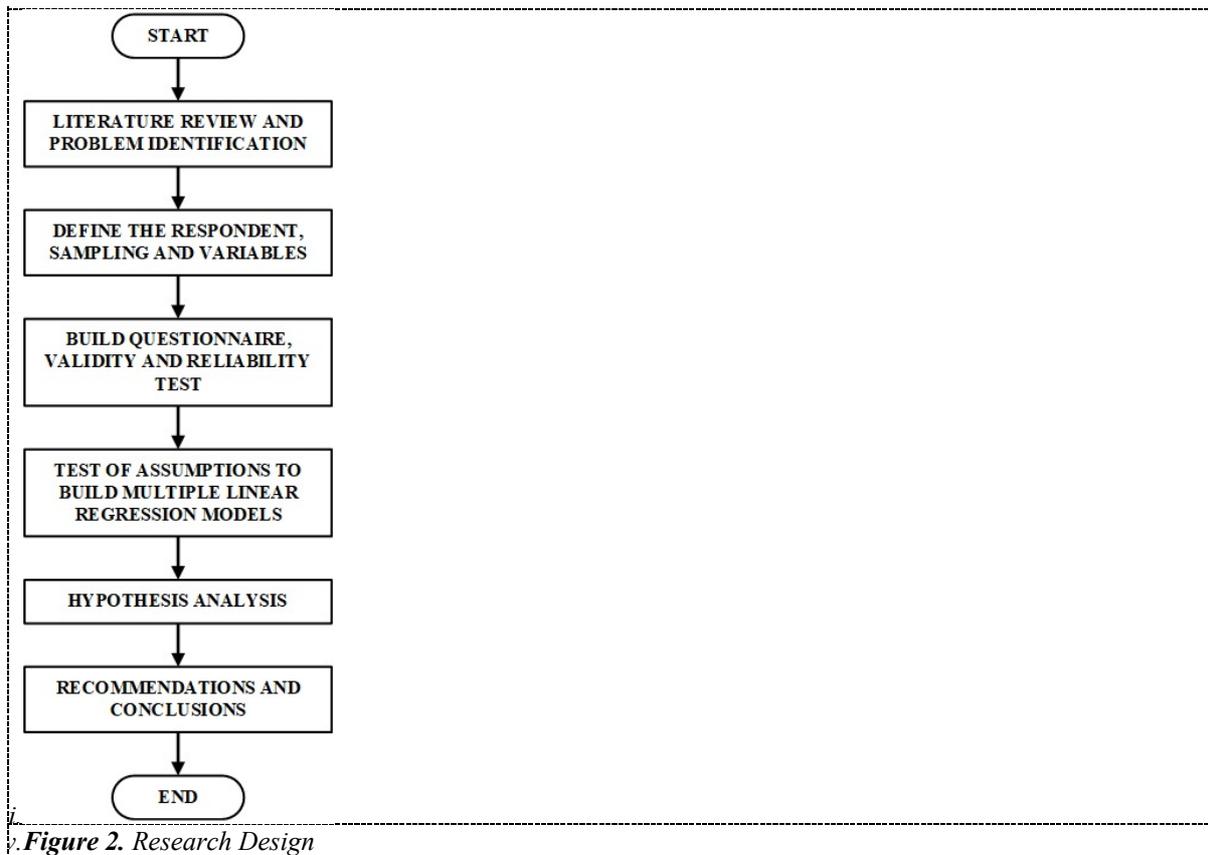
Result and Discussion
*4.1. Demographic Characteristics of Respondents*
The data were collected from 70 potential consumers of refill cleaning products with different demographic information. Female respondents completed the questionnaire more than the male, 62.9% and 37.1% respectively. Most respondents aged in the range of 20-29 years old (52.9%) with the latest education in bachelor's degree (81.4%). Moreover, mostly the respondent's occupation is a Bachelor's degree with an income level in the range of Rp 7,600,000 – Rp 10,000,000 for each month. Table 2 shows the demographic profile of respondents (N = 70) that were used in this research.

**Table 2.** Demographic Characteristics of The Respondents

|  | **Frequency(s)** | **Percent (%)** |
|---|---|---|
| Gender: |  |  |
| Male | 184 | 45 |
| Female | 223 | 55 |
| Total | 407 | 100 |
|  |  |  |
| Age: |  |  |
| < 20 years old | 41 | 10 |
| 20 – 29 years old | 205 | 50 |
| 30 – 39 years old | 97 | 24 |
| 40 – 49 years old | 47 | 12 |

|  |  |  |
|---|---|---|
| > 50 years old | 17 | 4 |
| Total | 407 | 100 |

|  |  |  |
|---|---|---|
| Latest Education: |  |  |
| Senior High School | 115 | 28.3 |
| Vocational degree | 44 | 10.8 |
| Bachelor's degree | 203 | 49.9 |
| Master's degree | 18 | 4.4 |
| Others | 27 | 6.6 |
| Total | 407 | 100 |

|  |  |  |
|---|---|---|
| Occupation: |  |  |
| Student | 86 | 21 |
| Civil servant | 42 | 10 |
| Private employee | 158 | 39 |
| Entrepreneur | 66 | 16 |
| Others | 55 | 14 |
| Total | 407 | 100 |

|  |  |  |
|---|---|---|
| Income level (per month): |  |  |
| < Rp 2,500,000 | 97 | 24 |
| Rp 2,500,000 – Rp 4,900,000 | 115 | 28 |
| Rp 5,000,000 – Rp 7,500,000 | 105 | 26 |
| Rp 7,600,000 – Rp 10,000,00 | 51 | 13 |
| > Rp 10,000,000 | 39 | 10 |
| Total | 407 | 100 |

### 4.2. Validity of Measurement Model

The validity test was carried out using the product moment correlation technique by correlating each question with the total score for each variable. The correlation figure obtained statistically is compared with the critical value of the correlation table for the $R$ value with a significant level of 90%. $R_{Table}$ is obtained by using equation (1).

$$D_f = N - 2 \qquad (1)$$

Where $D_f$ is the degrees of freedom and $N$ is the number of respondents. With $N = 407$, then $R_{Table} = 0.0978$ and must be smaller than $R_{Count}$. The tests of the variables are shows in Table 2. Furthermore, a reliability test was carried out to find out whether the data collection tool basically showed the level of precision, accuracy, stability or consistency of the tool in expressing certain symptoms from a group of individuals, even though it was carried out at different times and carried out on valid statements. A question is considered reliable if it has a Cronbach's Alpha value of more than 0.7 [24]. The Cronbach's Alpha of this test is 0.901, means that the test is reliable because greater than 0.7.

**Table 3.** Validity Test Results

| Variables | Question | Validity | |
| | | $R_{Count}$ | Valid/No |
| --- | --- | --- | --- |
| PI | $(Q_1)$ | 0.442 | VALID |
| | $(Q_2)$ | 0.371 | VALID |
| | $(Q_3)$ | 0.444 | VALID |
| EC | $(Q_4)$ | 0.418 | VALID |
| | $(Q_5)$ | 0.443 | VALID |
| | $(Q_6)$ | 0.327 | VALID |
| EK | $(Q_7)$ | 0.464 | VALID |
| | $(Q_8)$ | 0.500 | VALID |
| | $(Q_9)$ | 0.483 | VALID |
| SN | $(Q_{10})$ | 0.500 | VALID |
| | $(Q_{11})$ | 0.565 | VALID |
| | $(Q_{12})$ | 0.529 | VALID |
| GM | $(Q_{13})$ | 0.392 | VALID |
| | $(Q_{14})$ | 0.473 | VALID |
| | $(Q_{15})$ | 0.419 | VALID |

The Spearman's Correlation test will be carried out to find out the relationship between the two variables is significant or not. Also, determine the direction of the relationship between two variables. In this test, the correlation value is start from 0 until 1. If it is greater than 0.1 means that there is a correlation. However, the intention is depending on the correlation value. The closer the correlation value is to 1, the stronger the relationship between variables will be. Based on table 4, the highest correlation value is between EK and SN with value 0.594. This score means that the correlation is moderate. If the correlation value is smaller than 0.4, so the correlation is weak.

**Table 4.** Spearman's Correlation Test Results

| | PI | EC | EK | SN | GM |
| --- | --- | --- | --- | --- | --- |
| **PI** | | 5.640 | 0.454 | 0.457 | 0.318 |
| **EC** | 0.564 | | 0.485 | 0.434 | 0.396 |
| **EK** | 0.454 | 0.485 | | 0.594 | 0.496 |
| **SN** | 0.457 | 0.434 | 0.594 | | 0.556 |
| **GM** | 0.318 | 0.396 | 0.496 | 0.556 | |

Table 5 shows the result of multiple linear regression test. This method conducted in hypothesis test to determine the direction and how much influence the independent variables with the dependent variable. In estimating consumer behavior based on independent variables, an approximate model is obtained in equation (2).

$$Y = 1.417 + 0.36X_1 + 0.074X_2 + 0.178X_3 + 0.143X_4 \qquad (2)$$

R Square analysis or the coefficient of determination is used to find out how much the percentage of independent variables contributes together to the dependent variable. Where, purchase intention is influenced by 32.5% of Environmental Consciousness, Environmental Knowledges, Subjective Norms, and green marketing.

Moreover, in table 6 gives information about the hypothesis testing result. To support the proposed research hypothesis, the $t_{Value}$ have to be greater than $t_{table}$ ($t_{Value} > t_{table}$) or $p_{Value}$ less than 0.05 ($p_{Value} < 0.05$). The $t_{Table}$ in this research with $df = 405$ is 1.960. The $p_{Value}$ and $t_{Value}$ shows that one of the hypothesis tests (H$_2$) is rejected because the $t_{Value}$ is smaller than $t_{table}$ (1.276 < 1.960) and also $p_{Value}$ greater than 0.05 (0.203 > 0.05). Otherwise, the relationship path between EC and PI (EC -> PI), SN and PI (SN-> PI), also GM and PI (GM-> PI) are interconnected. Its because the $p_{Value}$ is less than 0.05. Negative in $t_{Value}$ did not indicate that there is not significant because the value is absolute.

**Table 5.** Multiple Linear Regression Test Results

| Model Summary $R^2$ | Variables | Coefficient $\beta$ | $t_{Value}$ | $p_{Value}$ |
|---|---|---|---|---|
| | PI (Constant) | 1.417 | 6.216 | 0.000 |
| | EC | 0.36 | 5.688 | 0.000 |
| 0.325 | EK | 0.074 | 1.276 | 0.203 |
| | SN | 0.178 | 3.676 | 0.000 |
| | GM | 0.143 | -2.667 | 0.008 |

**Table 6.** Hypothesis Testing

| Hypothesis | Path | β | $t_{Value}$ | $p_{Value}$ | Decision |
|---|---|---|---|---|---|
| $H_1$ | EC -> PI | 0.36 | 5.688 | 0.000 | Supported |
| $H_2$ | EK -> PI | 0.074 | 1.276 | 0.203 | Rejected |
| $H_3$ | SN -> PI | 0.178 | 3.676 | 0.000 | Supported |
| $H_4$ | GM -> PI | 0.143 | -2.667 | 0.008 | Supported |

In this research used TPB to identify human behavior based on social psychological theory. This research variables focused on customers environmental consciousness, environmental knowledge, subjective norms, and green marketing. Where these variables affect purchase intention based on the construction of the regression model and hypothesis testing. The $t_{value}$ which is greater than $t_{table}$ (1.960) explains that some of the independent variables have an effect on purchase intention. Furthermore, the respondents of this research are 407 citizens of Jakarta based on Isaac and Michael technique with significance level 5%.

Conclusions
The result of this research shows that the purchase intention to refill cleaning products at refilling facilities are influenced by customers environmental consciousness, subjective norms, and green marketing. Moreover, to reduce single-use plastic packaging waste, innovative refill cleaning products at filling facilities can be a solution to reduce the increase in plastic waste. This study could identify variables that influence customer purchase intention to refill cleaning products at filling facilities. For further research, a greater number of participants is needed, so it can lead to more precise results when testing hypotheses. Also, the variable of this research should use design packaging product to know the influence of the customer purchase intention to refill cleaning products at filling facilities.

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# The Factors of Temperature, Lighting, and Noise for the Accuracy of Answering the Tests Using Experiment Design Factorial 3$^f$ at Ergonomic Laboratory

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**Abstract.** To doing a task, it was surely needing a focus so that a decision can be made with a high accuracy. At least there were 3 factors than can be interfere in a decision making, which were temperature, lighting, and noise. This paper is dealing with those factors whether the factors were significant affecting to doing the task. The tasks were mathematical calculating, memory test, and matching colors. There were 3 conditions for each factor. The conditions for temperature factor were cold, room, and hot, while the conditions for lighting factor were dim, normal, and bright, and the conditions for noise factor were quiet, normal, and noisy. The experiment design was used in this paper to test the significant accuracy for answering the test. The results were there was a significant effect of temperature and noise to the test result, while there was no significant effect of lighting to the test result.
**Keywords**: Experimental Design, 3$^f$ Factorial, ANOVA, Temperature, Lighting, Noise

## INTRODUCTION

A study regarding the effect of temperature to the student's performance was conducted by Wargocki, Pawel at.al. conclude that the drop in classroom temperature from 30°C to 20°C, and optimal performance below 22°C, can improve psychological test and academic performance by an average of 20%. This relationship applies only to temperature climates.[1]

The individual lighting conditions were interpreted based on 4 of 6 factors which were amount of light, spectrum, time, and duration of exposure to light. A large individual difference was observed in sunlight exposure, illuminance, correlated color temperature, and irradiance measured on the blue sensor surface of the dosimeter. The mean daily illumination (all participants and all days) were peaked three times. An analysis of exposure time showed that the participant was only exposed to illumination in excess of 1000 lx for an average of 72 minutes per her day. Interpretation of individual lighting conditions based on four factors provides important information. Because all of these factors may be relevant in triggering beyond-visual effects. The results of the current work provide the first detailed insight into the possibilities of interpreting the personal lighting conditions of office workers.[2]

Students can be disturbed by background noise while working in an open learning environment. To improve the acoustic quality of an open learning environment, a study was conducted on the impact of different noise scenarios on students working on a typical student task and studying for an exam. Three sound scenarios and a quiet reference sound scenario were developed based on the acoustic environment of real large-scale research environments with different numbers of speakers in the background and different reverberation times of the research environments. However, it was found a significant effect of noise on the performance of students working on logic brain exercise. In addition, it was found significant effects of noise scenarios on self-rated performance and perceived impairment for all tasks, with the reading task involving text memory being the most impeded task.[3]

This paper is a study regarding the effect of temperature, lighting, and noise in one test and the objective is to find a significant value for the effect of temperature, lighting, and noise by giving the respondents problems to be solved in calculating simple mathematics, memorizing the manuscripts, and matching colors using ANOVA 3$^f$ factorial.

## METHODS

An experimental design consists of a series of tests using both descriptive and inferential statistics, with the aim of transforming input variables into outputs, which are the responses of the experiment. In one study, responses that were sometimes observed in experiments that were performed multiple times at different times during the study were called repeated measures. Observation time is considered an additional factor, with repeated measures considered a two-factor design with a split-plot pattern. Factors are assigned as major plots and observation times as minor plots. Stepwise analysis to test normality of errors, test homogeneity of variance, determine degrees of freedom, sum of squares and mean square for each factor. The following hypotheses that test both factor a, factor b, and interaction affect the observed response.[4]

An experiment using three factors A, B, and C at levels a, b, and c, respectively, in a fully randomized experimental design. Assume there are $n$ observations for each combination of abc treatments. It is outlined a significance tests for the three main relevant effects and interactions. It can use the explanations given here to generalize the analysis to k > 3 factors.[5]

The model of three-factors experiments is,

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \epsilon_{ijkl} \qquad \text{............ (1)}$$

$i = 1,2,\ldots,a$; $j = 1,2,\ldots,b$; $k = 1,2,\ldots,c$; and $l = 1,2,\ldots,n$, where $\alpha_i$, $\beta_j$, and $\gamma_k$ are the main effects and $(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, and $(\beta\gamma)_{jk}$ are the two factors interaction, and $(\alpha\beta\gamma)_{ijk}$ is the three factors interaction. [6]

The sum of squares for a three factors experiments are,

$$SSA = bcn \sum_{i=1}^{a} (\bar{y}_{i...} - \bar{y}_{....})^2 \qquad \text{.................................…... (2)}$$

$$SSA = acn \sum_{i=1}^{a} (\bar{y}_{.j..} - \bar{y}_{....})^2 \qquad \text{.................................…... (3)}$$

$$SSA = abn \sum_{i=1}^{a} (\bar{y}_{..k.} - \bar{y}_{....})^2 \qquad \text{.................................…... (4)}$$

$$SS(AB) = cn \sum_{i} \sum_{j} (\bar{y}_{ij..} - \bar{y}_{i...} - \bar{y}_{.j..} + \bar{y}_{....})^2 \qquad \text{..........................…... (5)}$$

$$SS(AB) = bn \sum_{i} \sum_{j} (\bar{y}_{i.k.} - \bar{y}_{i...} - \bar{y}_{..k.} + \bar{y}_{....})^2 \qquad \text{........................…... (6)}$$

$$SS(BC) = an \sum_{i} \sum_{j} (\bar{y}_{.jk.} - \bar{y}_{i...} - \bar{y}_{.j..} + \bar{y}_{....})^2 \qquad \text{..........................…... (7)}$$

$$SS(ABC) = n \sum_{i} \sum_{j} \sum (\bar{y}_{ijk.} - \bar{y}_{ij..} - \bar{y}_{i.k.} - \bar{y}_{.jk.} + \bar{y}_{i...} + \bar{y}_{.j..} + \bar{y}_{..k.} - \bar{y}_{....})^2 \qquad \text{............ (8)}$$

$$SST = \sum_{i} \sum_{j} \sum_{k} \sum_{l} (y_{ijkl} - \bar{y}_{....})^2 \qquad \text{.................................…... (9)}$$

$$SSE = \sum_{i} \sum_{j} \sum_{k} \sum_{l} (y_{ijkl} - \bar{y}_{ijk.})^2 \qquad \text{.................................…... (10)}$$

The factors are (A) is temperature, (B) is lighting, and (C) is noise, and the hypothesis for those factors are,
a. Temperature

$H_0: \alpha_1 = \alpha_2 = \alpha_3 = 0$; $\alpha_i$ there is no significant effect on the test result

$H_1$: at least one $\alpha_i$ there is a significant effect on the result

b. Lighting

$H_0: \beta_1 = \beta_2 = \beta_3 = 0$; $\beta_i$ there is no significant effect on the test result

$H_1$: at least one $\beta_i$ there is a significant effect on the result

c. Noise

$H_0: \gamma_1 = \gamma_2 = \gamma_3 = 0$; $\gamma_i$ there is no significant effect on the test result

$H_1$: at least one $\gamma_i$ there is a significant effect on the result

d. Temperature and Lighting interaction

$H_0: (\alpha\beta)_{11} = (\alpha\beta)_{12} = (\alpha\beta)_{13} = \ldots = (\alpha\beta)_{33} = 0$; $(\alpha\beta)_{ij}$ there is no significant effect on the test result

$H_1: (\alpha\beta)_{ij}$ there is a significant effect on the test result

e. Lighting and Noise interaction

$H_0: (\beta\gamma)_{11} = (\beta\gamma)_{12} = (\beta\gamma)_{13} = \ldots = (\beta\gamma)_{33} = 0$; $(\beta\gamma)_{jk}$ there is no significant effect on the test result

$H_1: (\beta\gamma)_{jk}$ there is a significant effect on the test result

f. Temperature and Noise interaction

$H_0: (\alpha\gamma)_{11} = (\alpha\gamma)_{12} = (\alpha\gamma)_{13} = \ldots = (\alpha\gamma)_{33} = 0$; $(\alpha\gamma)_{ik}$ there is no significant effect on the test result

$H_1: (\alpha\gamma)_{ik}$ there is a significant effect on the test result

g. Temperature, Lighting, and Noise interaction

$H_0: (\alpha\beta\gamma)_{111} = (\alpha\beta\gamma)_{112} = (\alpha\beta\gamma)_{113} = \ldots = (\alpha\beta\gamma)_{333} = 0$; $(\alpha\beta\gamma)_{ijk}$ there is no significant effect on the test result

$H_1: (\alpha\beta\gamma)_{ijk}$ there is a significant effect on the test result

# RESULT AND DISCUSSION

Data was collected by distribute the questions to 5 students at Ergonomic Laboratory and were conducted in climatic chamber. The questions were the simple mathematics, the memorizing a manuscript (which were in Bahasa Indonesia), and the matching colors, as shown in Figure 1, Figure 2, and Figure 3.

1. $6 + 6 - 5 + 8 \times 7 = 63$
2. $8 \times 8 + 7 - 6 + 9 = 74$
3. $8 + 7 - 9 + 9 \times 7 = 69$
4. $8 \times 9 - 9 + 8 - 9 = 62$
5. $8 + 8 + 9 \times 8 - 10 = 78$
6. $9 : 3 + 3 - 9 \times 7 = -57$
7. $8 + 9 - 7 + 10 \times 0 = 10$
8. $9 - 8 + 7 + 9^2 - 10 = 79$
9. $10 - 9 - 8 + 9 \times 7 = 56$
10. $9 \times 8 + 8 - 9 \times 7 = 17$
11. $8 \times 8 + 7 - 6 + 9 = 74$
12. $8 + 8 + 9 \times 8 - 10 = 78$
13. $9 : 3 + 3 - 9 \times 7 = -57$
14. $9 - 8 + 7 + 9^2 - 10 = 79$
15. $10 - 9 - 8 + 9 \times 7 = 56$
16. $9 \times 8 + 8 - 9 \times 7 = 17$

**Sejarah Gedung Sate**

Gedung Sate merupakan ikon dari kota Bandung yang sangat populer. Gedung yang satu ini bukan hanya ikon kota semata, namun merupakan tempat bersejarah sekaligus kawasan wisata Bandung yang banyak dikunjungi. Gedung Sate ini memiliki sejarah panjang yang sudah ada sejak masa Kolonial Belanda. Peletakan batu pertamanya dilakukan pada 27 Juli 1920 yang dihadiri oleh Johanna Catherina Coops yang merupakan putri tertua Wali Kota Bandung dan B. Coops serta Petronella Roelofsen yang mewakili Gubernur Jenderal di Batavia. Perancang gedung bersejarah ini dilakukan oleh beberapa arsitek Ir. J. Gerber dari Fakultas Teknik Delft Nederland, Ir. Eh. De Roo, dan Ir. G. Hendriks, dan dari Gemeente vna Bandoeng. Selain menonjolkan unsur tradisional nusantara, Gedung Sate ini juga mengadopsi beberapa aliran arsitek pada beberapa bagian gedung ini. Desain jendela mengusung konsep Moor Spanyol.

1. Kapan peletakan batu pertama untuk pembangunan Gedung Sate ?
   a. 27 Juli 1920      c. 27 Juli 1820
   b. 27 Juni 1920      d. 27 Juni 1820
2. Siapa saja yang menghadiri peletakan batu pertama Gedung Sate? Kecuali . . .
   a. Johanna Catherina Coops   c. B. Coops
   b. J. Gerber                 d. Petronella Roelofsen
3. Pada perancangan gedung sate ini, terdapat beberapa arsitek yang terlibat, diantaranya adalah?
   a. Ir. Eh De Roo    c. Ir. J. Gibsen
   b. Ir. Van Vertee   d. Ir. G. Hendri
4. Kapan gedung sate selesai dibangun?
   a. September 1924   c. Desember 1924
   b. September 1934   d. Desember 1934

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

Pilihlah 3 warna yang berbeda diantara 7 lingkaran dibawah ini
1 2 3 4 5 6 7

**Figure 1**. Example of Simple Mathematics

**Figure 2**. Example of Memorizing a Manuscript

**Figure 3**. Example of Matching Colors

The Temperature factor were conducted in 3 conditions which were cold, room temperature, and hot. The Lighting factor were conducted in 3 conditions which were dim, normal, and bright. The Noise factors were conducted in 3 conditions which were quiet, normal, and noisy and the experimental design as shown in Figure 4.
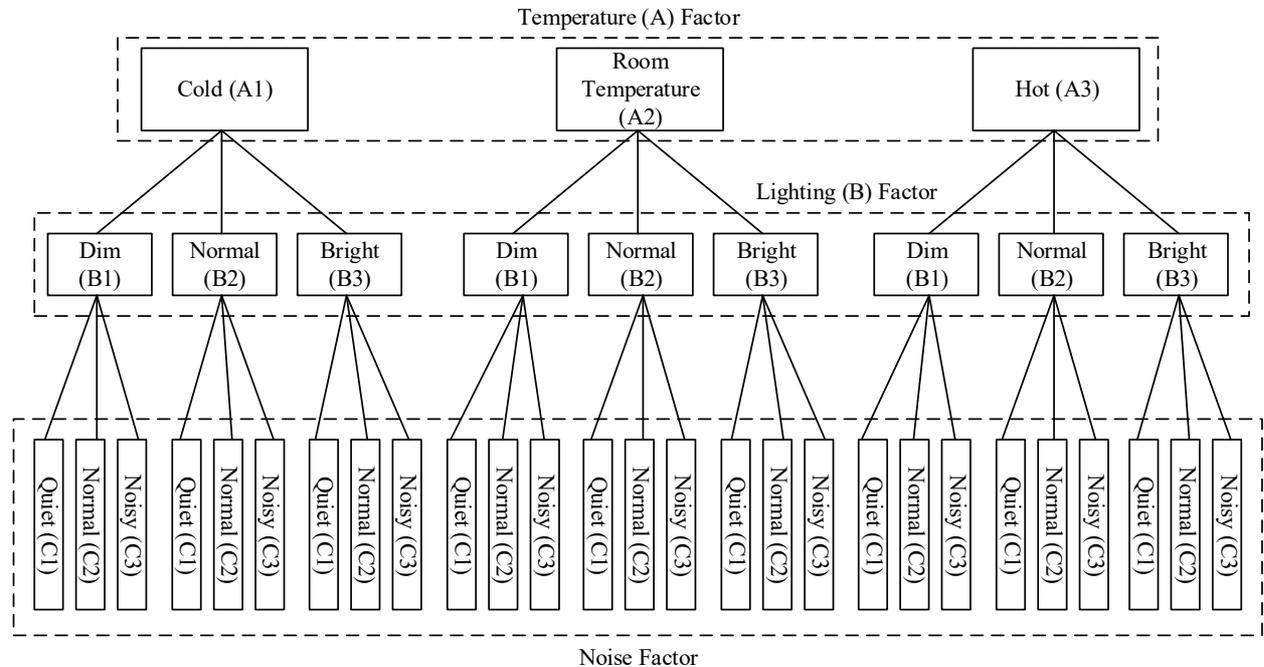


**Figure 4.** The Experimental Design

When the data collecting is completed, then the next step is summarizing the test result with 3 replications into the Table 1.

**Table 1. Summarizing Test Result**

| Temperature (A) | Dim Noise (C) | | | Normal Noise (C) | | | Bright Noise (C) | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Quiet | Normal | Noisy | Quiet | Normal | Noisy | Quiet | Normal | Noisy | |
| Cold | 8 | 9.5 | 9.5 | 8 | 8 | 7.5 | 7.5 | 9 | 7.5 | 74.5 |
| | 3.5 | 5.5 | 5.5 | 8.5 | 8 | 6 | 7.5 | 9.5 | 8 | 62 |
| | 8.5 | 7 | 7 | 7 | 7.5 | 9 | 8 | 9 | 8 | 71 |
| Room Temperature | 8.5 | 8.5 | 7.5 | 9.5 | 9.5 | 9 | 9.5 | 9.5 | 9 | 80.5 |
| | 7 | 9.5 | 9.5 | 8 | 7.5 | 8.5 | 9 | 6.5 | 9 | 74.5 |
| | 7 | 7 | 10 | 7.5 | 6 | 5.5 | 8 | 7 | 6 | 64 |
| Hot | 8.5 | 9.5 | 8 | 7.5 | 8.5 | 8 | 7.5 | 9 | 7.5 | 74 |
| | 9.5 | 6 | 8.5 | 6.5 | 7.5 | 9 | 6 | 6 | 8 | 67 |
| | 8 | 9 | 9 | 8 | 9 | 8 | 7 | 7 | 9 | 74 |
| Total | 68.5 | 71.5 | 74.5 | 70.5 | 71.5 | 70.5 | 70 | 72.5 | 72 | 641.5 |

Several calculations were made to obtain the value of the effects and the interactions, for example, as shown in Table 2, Table 3, and Table 4.

**Tabel 2.** Lighting (Dim) and Noise (Quiet, Normal, Noisy)

| B1 | C | | | |
|---|---|---|---|---|
| A | 1 | 2 | 3 | Total |
| 1 | 20 | 22 | 22 | 64 |
| 2 | 22.5 | 25 | 27 | 74.5 |
| 3 | 26 | 24.5 | 25.5 | 76 |
| Total | 68.5 | 71.5 | 74.5 | 214.5 |

**Tabel 3.** Lighting (Normal) and Noise (Quiet, Normal, Noisy)

| B2 | C | | | |
|---|---|---|---|---|
| A | 1 | 2 | 3 | Total |
| 1 | 23.5 | 23.5 | 22.5 | 69.5 |
| 2 | 25 | 23 | 23 | 71 |
| 3 | 22 | 25 | 25 | 72 |
| Total | 70.5 | 71.5 | 70.5 | 212.5 |

**Tabel 4.** Lighting (Bright) and Noise (Quiet, Normal, Noisy)

| B3 | C | | | |
|---|---|---|---|---|
| A | 1 | 2 | 3 | Total |
| 1 | 23 | 27.5 | 23.5 | 74 |
| 2 | 26.5 | 23 | 24 | 73.5 |
| 3 | 20.5 | 22 | 24.5 | 67 |
| Total | 70 | 72.5 | 72 | 214.5 |

After constructing the data to the table similar to Table 2 to Table 4, then the calculations were made using formula [2] – [10] to obtain the ANOVA table and the result as shown in Table 5.

**Table 5**. ANOVA for Three-factors

| Source of Variation | Sum of Square | Degree of Freedom | Mean Square | Calculated $f$ | $f_{(0.05, v1, v2)}$ | effect |
|---|---|---|---|---|---|---|
| Main Effects | | | | | | |
| A (Temperature) | 2,52 | 2 | 1,26 | 0,74 | 0,05 | significant |
| B (Lighting) | 0,10 | 2 | 0,05 | 0,03 | 0,05 | not significant |
| C (Noise) | 1,34 | 2 | 0,67 | 0,39 | 0,05 | significant |
| Two-factor Interactions | | | | | | |
| AB | 10,72 | 4 | 2,68 | 1,56 | 0,18 | significant |
| BC | 1,12 | 4 | 0,28 | 0,16 | 0,18 | not significant |
| AC | 4,25 | 4 | 1,06 | 0,62 | 0,18 | significant |
| Three-factors Interaction | | | | | | |
| ABC | 10,01 | 8 | 1,25 | 0,73 | 0,33 | significant |
| Error | 92,67 | 54 | 1,72 | | | |
| Total | 122,73 | 80 | | | | |

The significance level was used to obtain the $f$ value was 0.05. From Table 5 shows that there is no significant effect on the test result regarding to the Lighting for main effects and there is no significant effect on the test result regarding to the Two-factors interaction which was the Lighting and Noise interaction. These not significant effects possibly happen when the light equipment was not working properly.

## CONCLUSION

Based on the calculation, it can be concluded that there is a significant effect on the test result for the effect of Temperature (A), Noise (C), Temperature (A) and Lighting (B) Interaction, Temperature and (A) and Noise (C) Interaction, and Temperature (A) and Lighting (B) and Noise (C) Interactions, while there is no significant effect on the test result for the effect for Lighting (B), and for Lighting (B) and Noise (C).

## ACKNOWLEDGEMENT

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