Product design of upper sandal fabric cutting machine using ergonomic function deployment method

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Abstract. *In the production process, the upper sandal cutting of KUB Mampu Jaya is still done manually using scissors one by one for each mold. The purpose of this research is to create an ergonomic upper sandal cutting machine. The method used in this research is Ergonomic Function Deployment (EFD). Direct data collection involved observing the production stages and activities carried out by workers through interviews and surveys. The results show that this sandal upper cutting machine has been designed by adjusting user needs so as to minimize production time and the cutting process becomes more efficient. Previously, the production or cutting time took 2 minutes per one upper sandal mold, but with this new cutting machine, the cutting process only takes 1 minute per upper sandal mold, saving up to 1 minute. The results of this study will provide a better solution in designing a sandal upper fabric cutting machine that prioritizes ergonomic aspects and can reduce musculoskeletal complaints.*

Keywords: product development, ergonomic function deployment, anthropometry

1. Introduction

Sandals are one of the popular types of footwear and have become an integral part of people's culture and daily lives. In modern times like today, shoes and sandals have become products that play an important role in improving individual appearance, especially among teenagers (Abidin et al., 2022). Over time, the sandal or shoe industry in Indonesia began to innovate in design and materials, creating a wide variety of sandals with diverse styles.

One of the industries that produce footwear is KUB Mampu Jaya located in Surabaya City. Currently, KUB Mampu Jaya produces upper sandals to fulfill the demand from the Barnett sandal company with a production volume of around 6,000 pairs per month. The production process of upper sandals begins with preparing raw materials in the form of mold sheets that already have upper sandal patterns. Furthermore, the mold sheet is cut and punched according to the mold pattern. After that, the buckle installation and locking of the buckle on the upper sandal are carried out and then enter the finishing stage, namely the installation of the upper sandal. In a day, the number of upper sandal productions that can be made is around 200 to 300 pairs.

Based on observations at KUB Mampu Jaya, it was found that at the slipper upper mold cutting workstation, workers use fabric cutting tools, namely scissors, to manually cut the fabric one by one. This process takes quite a long time and has a negative impact on workstation productivity, and can cause complaints of pain and aches in the employee's body. The average time needed to cut one upper sandal mold is about 2 minutes. Musculoskeletal complaints and fatigue can lead to decreased work productivity, lost work hours, increased medical costs and material usage, and decreased work quality. At a global level, musculoskeletal disorders (MSDs) account for approximately 42% to 58% of total work-related illnesses and account for approximately 40% of total work-related health costs (Dwiseli et al., 2023). If muscles receive repetitive loads over a long period, it can cause problems such as damage to joints, ligaments, and tendons (Sumigar, 2022). Productivity plays a central role in influencing the development and decline of a company (Syahputra et al., 2021).

Then data was collected through the Nordic Body Map (NBM) questionnaire. The NBM questionnaire is a form of questionnaire that is often used in the field of ergonomics to identify discomfort in workers. The distribution of this questionnaire aims to assess the discomfort felt by the workforce (Adiyanto et al., 2022). Based on data collection from the results of the Nordic Body Map questionnaire, all workers experience complaints of pain in the left shoulder, right and left upper arm with the average result obtained of 58 indicating that the scale is categorized as "moderate" which means that action at the workstation may be taken in the future (Wandiyanto et al, 2022). In addition, to analyze work postures, the Rapid Upper Limb Assessment (RULA) method can be used because this method can identify work postures that are at risk of causing injury due to repetitive movements. Using the RULA method in the initial data collection resulted in a score of 5, which means it shows that inspection and changes need to be made immediately in the process of cutting the upper sandal mold. A low RULA score does not guarantee that the workplace is free of ergonomic hazards, and a high score does not guarantee the presence of serious problems. It was developed to detect work postures that require special attention

Existing fabric cutting tool products on the market have relatively high prices and are difficult to find in many places. New product development has the potential to affect the continuity and future of the company. By creating replacement products, it is expected to increase sales value and have a positive impact on the company (Nurhayati, 2022). By designing and developing products, it is hoped that new product innovations will be created and can provide special advantages in the face of competition from competing products. To achieve the desired comfort in product design, it is necessary to pay attention to the size that is in accordance with user anthropometry (Pratama & Perdana, 2020). If the product is not designed with ergonomic aspects in mind, its use can cause discomfort. Ergonomics is a principle that must be applied primarily in product design, where products must be adjusted to the capabilities and limitations possessed by humans (Suryatman & Linayah, 2021).

This study aims to design a sandal upper mold fabric cutting tool that can increase the productivity of workers and evaluate the operator's work posture at the cutting workstation. In designing this upper mold fabric cutting machine, the dimensions and sizes will be adjusted to the anthropometric size of the users or operators, so that the tool can be used more comfortably and safely.

2. Method

This research was conducted at KUB Mampu Jaya located in Surabaya city and conducted research at the upper sandal cutting workstation. Direct data collection involved observing the production stages and activities carried out by workers through interviews and surveys. In these interviews, Nordic Body Map (NBM) and RULA (Rapid Upper Limb Assessment) questionnaires were used to identify problems and discomfort during work. This approach was also utilized to understand the needs in the product design of the sandal upper mold cutting machine. This research is descriptive and uses the Ergonomic Function Deployment (EFD) method in product design. The Ergonomic Function Deployment (EFD) method is a development of Quality Function Deployment (QFD) that will involve the addition of new ties between consumer preferences and ergonomic aspects of the product (Sukma et al., 2022). The inclusion of this relationship will fill the House of Quality (HOQ) matrix with elements related to ergonomics desired by consumers (Ningsih et al., 2022).

The steps of the ergonomic function deployment (EFD) method are as follows:

1. The selected attributes based on ergonomics aspects include Effective, Comfortable, Safe, Healthy, and Efficient (abbreviated as ENASE).
2. The questionnaire was designed to assess the needs of consumers to gain an in-depth understanding of their preferences.
3. The formation of the House of Ergonomics involves the formation of a matrix that corresponds to the needs and desires of consumers, in line with the principles of ergonomics. This matrix is

used as the basis for designing the product attributes of rubber harvesting tools and their technical specifications. (Anwardi et al., 2019).

Anthropometric data is needed so that the design of a product can be adapted to the person who will operate it. To design ergonomic products, it is necessary to adjust the anthropometry of people in the environment, because if it is not appropriate, it will cause problems, short term and in the long term. Data was taken from the body dimensions of workers at the upper sandal cutting station of KUB Mampu Jaya Surabaya. The anthropometric dimensions used are height in a sitting position, upper arm length, forearm length, forward hand span length.

1. Sitting Position Height

In the design of this sandal upper cutting machine, the sitting position height is used to determine the height of the machine according to the operator's sitting height so that it can work with the correct posture and avoid tension or injury, therefore the dimensions of the sitting position height use the 5th percentile. For the height size with the 5th percentile is 65 cm.

2. Upper Arm Length

In the design of this upper sandal cutting machine, the length of the upper arm is used to adjust the length of the machine and arm motion space so that when working the operator's arm can move freely and without obstacles when cutting the fabric material to be cut besides that the operator can work comfortably, safely and maintain a good working posture, therefore the dimensions of the lenfa length use the 5th percentile. For the size of the upper arm length of the tool with the 5th percentile, which is 40 cm.

3. Forearm Length

In the design of this sandal upper cutting machine, the length of the forearm is used to estimate the space for the operator's forearm to have enough space when using controls and cutting tools in addition to considering the size of the design of the material support tool to be cut so that the operator can hold the material in a comfortable and safe position without having to overload or force the forearm, therefore the dimensions of the forearm length use the 5th percentile. For the size of the forearm length of the 5th percentile tool is 47 cm.

4. Length of Forward Hand Span

In the design of this sandal upper cutting machine, the length of the forward hand span is used for the distance of machine controls such as the power button which must be placed at a distance that allows the operator to operate it easily using the forward hand span, therefore the dimensions of the length of the forward hand span use the 5th percentile. For the length of the forearm, the 5th percentile tool is 47 cm.

In the Nordic Body Map questionnaire, the use of a "4 Likert scale" was applied, with a score range of 1 to 4 representing the indicators TS (No Pain), AS (Somewhat Pain), S (Pain), and SS (Very Pain). Participants were asked to rate the level of discomfort in their body parts while performing work tasks using the predefined Likert scales. In using this Likert scale, each score or value must have a clear operational definition and be understood by the respondent (Megawati, 2021).

3. Result and Discussion

KUB Mampu Jaya carries out the process of making upper sandal parts starting with the preparation of raw materials consisting of basic materials such as cloth or synthetic leather. After the raw material is ready, the next step is to cut the material using manual scissors one by one according to the predetermined design pattern. This cutting process takes quite a long time and can reduce workstation productivity and can cause complaints of pain and aches on the employee's body parts.

Nordic Body Map

The Nordic Body Map questionnaire is an example of an ergonomics checklist questionnaire. By using the Nordic Body Map measurement tool, an evaluation of pain complaints can be carried out through a series of identified assessments (Asih et al., 2022). The upper sandal cutting is currently done manually using scissors while the new cutting uses an upper sandal cutting machine which is faster in the cutting process and can reduce the risk of musculoskeletal disorders in workers. After collecting data through filling out a questionnaire by 8 workers, the following is a comparison of the Nordic Body Map score results from the data collection process as seen as Table 1.

Table 1 Comparison of Nordic Body Map Questionnaire Scores

Workers	Manual Cutting Score	New Cutting Score
1	65	30
2	75	34
3	83	34
4	80	30
5	84	35
6	78	30
7	88	33
8	84	32
Average	79.6	32,25

Based on Table 1 regarding the comparison of the Nordic Body Map questionnaire scores on employees, it is known that the manual cutting score obtained an average score of 79.6 where the score is the risk level in the high category and immediate corrective action is needed in the upper sandal cutting work. Then in the calculation of the new cutting score, an average score of 32.25 is obtained, where the risk level is in the low category and no corrective action has been found in the upper sandal cutting work.

RULA Score Comparison

Table 2 present a comparison table between the Rapid Upper Limb Assessment scores between manual cutting tools and the latest cutting tools.

Table 2 Comparison of RULA Scores

Manual Process			New Process		
No	**Analysis**	**Score**	**No**	**Analysis**	**Score**
1	Upper Arm	2	1	Upper Arm	2
2	Lower Arm	2	2	Lower Arm	1
3	Wrist	4	3	Wrist	1
4	Wrist Twist	1	4	Wrist Twist	1
5	Power	1	5	Power	1
6	Group A Posture	5	6	Group A Posture	3
7	Neck	3	7	Neck	2
8	Trunk	2	8	Trunk	2
9	Legs	1	9	Legs	1
10	Power	1	10	Power	1
11	Group B Posture	4	11	Group B Posture	3
	Grand Score	**5**		**Grand Score**	**3**

Based on Table 2 on the comparison of RULA scores between the manual process using a scissor cutting tool and the new process using the upper sandal cutting machine that has been made, it is known that in the manual process a grand score of 5 is obtained, meaning that the upper sandal cutting work requires investigation and changes that must be made immediately. Then in the calculation of the score of the new process using the upper sandal cutting machine that has been made, a grand score of 3 is obtained, meaning that the upper sandal cutting work requires further investigation and changes may be needed.

Ergonomic Function Deployment

Determining the Level of Importance

The importance questionnaire is used to measure the level of importance of each customer's needs and preferences for the product to be developed. The attribute assessment uses a Likert scale with a value of 1-5, namely very unimportant, not important, quite important, important and very important. There are 8 attribute statements given to each respondent which are then processed and produce the highest score of 4,875 on the attribute "The upper sandal cutting machine can reduce musculoskeletal complaints".

Determining Satisfaction Level

The satisfaction level questionnaire is a consumer response regarding the extent to which a product or service meets their needs, meets their expectations, or not. The statements given have similarities to the importance assessment, where respondents are asked to choose five answer criteria that are weighted using a Likert scale of 1 to 5. There are 8 attribute statements given to each respondent, which are then processed and produce the highest score of 1.75 on the attribute "The upper sandal cutting machine has a maximum production capacity".

Setting Goals

Goal setting is done to show the goals that researchers need to achieve, with the aim of assessing the level of satisfaction of consumer needs based on considerations. The goal value is determined by considering the value of customer importance and satisfaction using a scale of 1 to 5. Based on the results obtained, the highest goal score is 4.7 for the attribute "Upper sandal cutting machine has maximum production capacity". Then for the lowest attribute value, a value of 4.5 is obtained, namely "the upper sandal cutting machine has good product quality".

Determining the Improvement Ratio

The improvement ratio illustrates the level of effort the company must make to achieve the goal. A higher value indicates a greater level of change that needs to be made. Based on the results obtained, the highest improvement ratio score is 3.9 for the attribute "Upper sandal cutting machine can reduce musculoskeletal complaints". Then for the lowest attribute value obtained a value of 2.64, namely "Upper sandal cutting machine is easy to operate".

Determining Sales Point

Sales Point indicates the extent to which the satisfaction of consumer needs affects the value of the product. Determination of point-of-sale value based on point-of-sale valuation includes:

1 = No selling point
1,2 = Medium selling point
1.5 = Strong selling point

From the sales point value, it can be seen that this upper sandal cutting machine is needed by workers to cut the upper sandals to facilitate and speed up workers in the production process, while reducing the risk of musculoskeletal disorders. This could be based on the sales value of this sandal upper cutting machine with a value of 1.5 and this result shows a very strong sales value.

Determining Raw Weight

The Raw Weight value represents the overall importance of consumer demand. The weighted value is obtained by multiplying the consumer importance level, improvement ratio, and sales point. The greater the raw weight value, the more important the need is to fulfill. Based on the results obtained, the highest raw weight score is 28.5 for the attribute "Upper sandal cutting machine can reduce musculoskeletal complaints". Then for the lowest attribute value obtained a value of 18.3, namely the attribute "Upper sandal cutting machine is easy to operate".

Calculating Normalized Raw Weight

Calculation of normalized raw weight is the process of changing the raw weight value on a scale of 0 to 1 or in percentage form. Based on the results obtained, the highest normalized raw weight score is 0.16 for the attribute "Upper sandal cutting machine can reduce musculoskeletal complaints". Then for the lowest attribute value obtained a value of 0.1, namely the attribute "Upper sandal cutting machine is easy to operate".

Defining the Technical Response

This technical response describes the engineering plan or design proposed to meet consumer needs. The list of relevant specifications in this study can be seen in Table 3 presented below.

Table 3 Technical Response

No	Level of Importance	Technical Characteristics
1	Upper sandal cutting machine has maximum production capacity	Fast working process
2	The upper sandal cutting machine is easy to operate	Simple way of working
3	The upper sandal cutting machine has an ergonomic design	Tool design in accordance with the normal posture of the operator
4	The upper sandal cutting machine has a good level of safety	Does not cause injury to the operator
5	The upper sandal cutting machine can reduce musculoskeletal complaints.	Reduce soreness in the body parts used during the cutting process
6	The upper sandal cutting machine has good product quality	Pay attention to the K3 aspects of workers
7	The upper sandal cutting machine is easy to maintain	The cutting machine is easy to clean and maintain
8	The upper sandal cutting machine has strong and durable raw materials	Machine material is made of strong material

Relationship between Technical Response and Consumer Needs

In the EFD method, the House of Ergonomic Matrix is used, which is a matrix that systematically describes the approach to designing quality products that are easy to use and meet consumer needs in a comprehensive and measurable manner. This matrix helps in determining the right specifications to meet consumer needs. The relationship between technical response and consumer demand is depicted with symbols that reflect the strength of the relationship between the two. The more elements in the technical features that relate to the elements of customer needs, the greater the impact of the technical features in meeting customer needs. After knowing the relationship between specifications and customer needs, the contribution value of each technical characteristic is then calculated. Based on the results obtained, the highest contribution calculation value and priority order is 4.32 for the attribute "Tool design in accordance with the normal posture of the operator". Then for the lowest attribute value obtained a value of 1.2, namely "Cutting machine easy to clean and maintain".

Target Specification

This specification target is the result of the development of technical characteristics obtained from the identification of consumer needs. Product specifications are a collection of individual specifications of metrics, which indicate whether the needs are met or not. In Table 4 there is an explanation of the product specification target.

Table 4 Target Product Specifications

No	Technical Characteristics	Speciation Target
1	Fast working process	The cutting machine can cut the upper sandal mold quickly and neatly.
2	Simple way of working	The way to use the machine is only by moving and following the upper sandal mold pattern
3	Tool design in accordance with the normal posture of the operator	Tool dimensions use Indonesian anthropometric data
4	Does not cause injury to the operator	The cutting machine will not hurt the operator
5	Reduce soreness in the body parts used during the cutting process	The machine is designed with ergonomics in mind so that the operator's working position is comfortable and does not cause excessive fatigue
6	Pay attention to the K3 aspects of workers	The machine is equipped with an effective protective system to protect the operator from the risk of injury during operation.
7	The cutting machine is easy to clean and maintain	The machine is designed with a design that allows users to easily disassemble the main components.
8	Machine material is made of strong material	The machine is designed using strong and durable materials

Based on the table above, the designer can form a specification goal that will be the basis for designing a successful product in the market. These specifications will be used as guidelines to determine the specifications of the sandal upper cutting machine. Simple initial specifications are then developed using the House of Ergonomics method, so that the relationship between consumer demand and product features and needs can be clearly seen consumer requirements and specifications.

House of Ergonomics

Ergonomic Function Deployment (EFD) is a design method that takes into account user comfort to improve product efficiency. The goal is to incorporate ergonomic principles into the product design process, so that the resulting product is better suited to the needs and comfort of the user. In other words, EFD helps implement ergonomic aspects in product design to ensure a more optimized user experience. After determining the aspects of the EFD, they are then completely arranged in the house of ergonomic matrix as shown in Figure 1.

Product Design

This design is carried out by considering and processing all the data obtained, namely regarding consumer needs, target specifications, and anthropometric data.

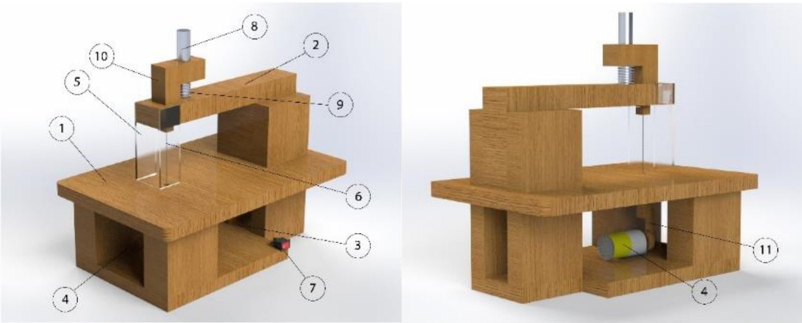

Figure 2 Upper Sandal Cutting Machine Design

Based on Figure 2, it is explained that the upper sandal cutting machine product consists of x components with details of the components can be seen in Table 5.

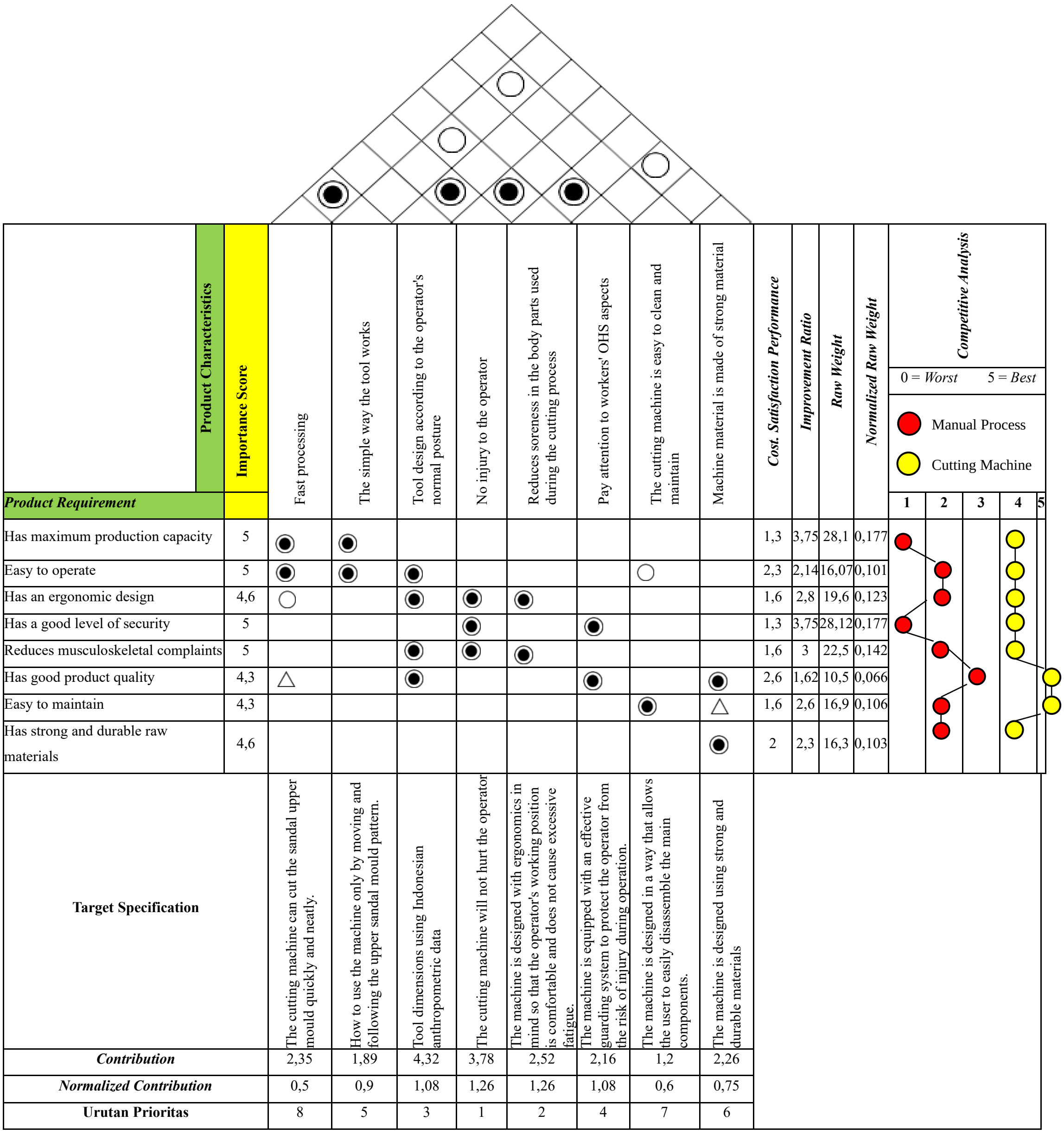

Figure 1 House of Ergonomic

Table 5 List of Product Components

No	Components Name	Specifications
1	Cutting Workbench	Solid Wood
2	Machine Arm	Solid Wood
3	Machine Bottom Room	Solid Wood
4	Dynamo Motor	DC 795
5	Blade Guard	Acrylic
6	Knife Blade	Saw Scroller 130 mm
7	Power Swtich	-
8	Support Pole	Steel
9	Per	32 mm
10	Upper Lock	Solid Wood
11	Lower Lock	Solid Wood

Based on the results obtained, the results of the product design that has been designed in accordance with user needs and anthropometric data that has been obtained previously. The upper sandal cutting machine is then tested to determine the working time in cutting the upper sandal fabric and MSDs work posture analysis. The results of the upper sandal cutting machine test can cut the upper sandal fabric in a faster time so that productivity can also increase. In addition, by using this machine, musculoskeletal complaints can be reduced so that workers can do their work more safely.

4. Conclusion and Suggestion

By integrating ergonomic aspects in the design of the machine, this research results in a more efficient cutting machine and reduces production time to 1 minute per upper sandal mold compared to the previous process using scissors manually with a time of 2 minutes per upper sandal mould. These results show that the design of this machine is able to minimize production time, save time, and increase efficiency in the process of cutting upper sandal fabric. In addition, the use of the Rapid Upper Limb Assessment (RULA) method to evaluate work posture has ensured that workers can work in a more ergonomic position, which can reduce the risk of musculoskeletal injuries and complaints related to improper work posture. Thus, this cutting machine not only increases productivity but also maintains worker health and comfort. Posture evaluation using the RULA method resulted in a grand score of 5 for the manual process, indicating the need to investigate and make immediate changes to the upper sandal cutting task. However, after calculating the score for the new process involving the implemented upper sandal cutting machine, the grand score obtained was 3. This indicates the need for further investigation into the upper sandal cutting task and the possibility of additional changes being required. The design of the sandal upper cutting machine has resulted in increased efficiency in the cutting stage. It has enabled a reduction in the time required for the cutting process, thus having a positive impact on overall productivity.

Based on the results of the research that has been carried out, and in this study there are definitely shortcomings, suggestions that may need to be done are to conduct further research to develop more sophisticated cutting machine technology that can speed up the cutting process and reduce the physical involvement of workers. Then the ergonomics concepts and methods applied in this study can be extended to other industries that require similar cutting or production processes. This can help reduce the risk of injury and improve efficiency in various sectors.

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