Management Systems
in
Production Engineering

2024, Volume 32, Issue 3, pp. 419-427

Date of submission of the article to the Editor: 03/2024
Date of acceptance of the article by the Editor: 07/2024

DOI 10.2478/mspe-2024-0039

TROLLEY RACK DESIGN FOR TEA FACTORY WORKERS IN INDONESIA BASED ON ANTHROPOMETRIC APPROACH

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Abstract:
Trolley rack is a material handling that significantly affects production productivity in Indonesian Tea factories. The design of this tool needs to consider the anthropometric approach. This study raises the problem of the dimensions of the trolley racks used in the industry without thinking about the anthropometric approach. Of the twenty-two trolley rack operators, 92.5% of workers experienced back pain when operating the equipment. This problem has an impact on musculoskeletal disorders (MSDs), which causes a decrease in effectiveness and workers. The REBA and Nordic Body Map Questionnaire methods are used to obtain optimal operator posture analysis related to the redesign of the trolley rack. Five anthropometric dimensions of a comfortable trolley rack were obtained, including shoulder height (SH), standing shoulder width (STW), leg length (FL), foot width (FW), and hand grip width (HGW). The final anthropometric dimensions of this tool are SH = 126 cm, STW = 33 cm, FL = 11 cm, FW = 13 cm, and HGW = 5 cm. Using new trolley racks in this study increased productivity by 80%.

Key words: *design, trolley rack, tea factory, anthropometry*

INTRODUCTION

Anthropometry is a measurement science related to product design by analyzing the human body's physical geometry, mass properties, and abilities [1, 2]. In simple terms, anthropometry can be interpreted as a science that studies the dimensions of the human body, from body size to body shape and work capacity [3]. Some of the purposes of using anthropometry are (1) evaluating body dimensions and their relationship to posture; (2) determining the best distance for workers with surrounding equipment hazards; (3) identifying objects or elements that limit workers; (4) assisting in the analysis of biomechanical data. Human [2, 4].

The trolley racks in the tea factory (Figure 1) are used as material handling equipment between departments. However, the trolley rack design must be ergonomically designed with an anthropometric approach. This is because research on standardizing dimensions based on the anthropometry of workers in Indonesian tea factories has yet to be carried out. The reason is that there are many variations in the body size of workers. This is evidenced by the dimensions of the trolley rack height exceeding the height of the worker's body and the width of the trolley rack exceeding the width of the worker's shoulders. As a result, workers' vision can be disturbed and threaten safety. Anthropometric studies also conducted by the author are shown that the braking pedal on the trolley, which is designed too small, causes the risk of injury to the soles of workers' feet. In addition, the design of the trolley rack handles for pushing needs to pay attention to the anthropometric rules of the hand grip size.

One worker in a tea factory alone operates at least 25 trolley racks during one day at a distance of about 25 meters. Repeated use can cause MSDs [5]. Anthropometric measurements on the trolley rack help tea factory workers achieve comfort in operating the trolley rack, reduce the risk of MSDs, and improve worker performance [6]. In addition, anthropometric design is also used for the safety of workers [5].

(a) (b)

Fig. 1 Current condition of the Trolley Rack: (a) Being pulled, (b) Being pushed

MSDs is a condition of injury to bones, muscle joints, connective tissue, nerves, tendons, and spinal discs [7]. This disorder can cause pain in the body and is the most common condition in Indonesia [8]. The prevalence of MSDs in Indonesia that health workers have done is 11.9% [5]. This disorder causes worker productivity to decrease by 15% [9].

Research on dimensional standardization with an anthropometric approach in Indonesia has been conducted [8]. However, research on dimensional standardization of material handling equipment still needs to be improved. This is based on the author's observations at the National Standardization Agency (BSN). In this study, anthropometric data is limited to the number of trolley rack operator workers, which is 22. The data must be standardized because BSN also underlines standardized updating for specific reasons [8].

REBA is an ergonomic assessment tool to evaluate posture related to MSDs risk. Researchers usually use this assessment in evaluating workers' postures because it is relatively easy to use during research [10]. This assessment indicates an assessment of 5 severity levels of risk for MSDs [11]. This assessment is carried out in 3 parts with 13 steps. The final REBA score is obtained by summing the C score with the activity score. After getting the final score, the score is categorized into five levels [10, 12]. The first level, with a score of 1, has a negligible risk statement. The second level, with a score of 2-3, states low risk, but changes may be needed. The level with a score of 4-7 states medium risk, requires further investigation and needs to be changed immediately. The fourth level, with a score of 8-10, states that high risks must be investigated and changes implemented. The fifth level, with a score of 11 and above, represents a very high risk and must implement changes now[13].

The Nordic Body Map Questionnaire is an ergonomic assessment system in the form of a questionnaire to measure the location of pain in the body by reviewing 27 body parts, from the tip of the neck to the feet[14]. The Nordic Body Map Questionnaire is usually combined with the REBA method to get insights into the location of body parts that feel pain in certain posture conditions [15]. Researchers often use the Nordic Body Map Questionnaire in reviewing the location of discomfort in workers' body parts. This questionnaire has also been standardized and neatly arranged according to the order of the human body parts [16]

Both methods have advantages in producing a standardized value of the optimal trolley rack size dimensions [17]. Umar et al. mentioned that material handling design needs to be done by considering RULA or REBA studies as needed and anthropometric approaches to get accurate dimensions of the trolley rack [18]. The anthropometric approach has yet to be carried out on previously used trolley rack designs. So far, material handling design has only relied on RULA or REBA analysis [13].Thus, if the analysis is only carried out by the RULA or REBA observation method, specific problems regarding MSDs can only partially be determined [19].

Although redesigns use an anthropometric approach to REBA and Nordic Body Map Questionnaire observation procedures, designers often choose to use ready-made data without considering the research approach [20]. The anthropometric dimensions contained in the PEI (Indonesian Ergonomics Association) data bank are also ten years old. In addition, in the data bank, two body dimensions are not measured, such as standing shoulder width and hand grip width. So, in conducting this research, it is necessary to re-measure and create new dimensions as units to describe anthropometric data.

This study aims to describe anthropometric data related to trolley racks in tea factories in Indonesia based on anthropometric data of trolley rack operationalization workers in Indonesian tea factories. This paper comprehensively describes redesigning trolley rack dimensions in the factory to avoid MSDs and increase the productivity of grinding department workers. The main work of this study includes an anthropometric survey and implementation of standardization of trolley rack size with an anthropometric data approach in the Indonesian Tea Factory.

MATERIALS AND METHOD

Participants

The study included 22 workers at the Tea Factory with a mean age of 25.6 years and a standard deviation (SD) of 2.1 years; all were male. They were 22-29 years: 2 workers aged 22. 2 workers aged 23.3 workers aged 24.4 workers aged 25.4 workers aged 26.3 workers aged 27.2 workers aged 28.1 worker aged 29 and 1 worker aged 30.

The dimensions of trolley racks in the market are generally divided into three types, namely, the capacity of 9 trays, 18 trays, and 36 trays [21]. The dimension that is often used in trolley racks in tea factories in Indonesia is a capacity of 9 trays [21]. This is because the dimensions of trolley racks with a capacity of 9 trays are considered the most effective and efficient in transporting tea between departments. In addition, this type of trolley rack is also considered proportional and not too tall to avoid the trolley rack toppling over on the damp and slippery production floor.

Participants were selected as a whole at one of the tea factories in Wonosobo, central Java. All participants were from the Javanese ethnic group, the largest ethnic group in Java. Ethnic restrictions were applied because ethnicity has an essential role in analyzing anthropometric approaches [8]. The selection of participants as a whole is due to the standard deviation that is quite good and below the mean value [22, 23]. Permission for anthropometric measurements along with posture research using the REBA and Nordic Body Map Questionnaire methods was obtained from the head of the factory after an observation submission letter regarding the purpose and procedure of anthropometric observation. The research was carried out during factory breaks to avoid disturbing the factory working hours. The sample size is the whole of the total population in the milling department.

Procedure and Equipment

REBA and Nordic Body Map Questionnaire are used to analyze posture and determine pain's location in body parts [19]. Researchers fill and analyze REBA by paying attention to the details of the 13 steps of determining the REBA score [10]. A Nordic body map questionnaire was given to the workers to fill out to validate the researchers' evaluation of the REBA scores. This is intended to match the results of filling out the Nordic Body Map Questionnaire, namely the location of the painful body parts in workers, with the results of the REBA score assessment with the highest number in a body part. After finding the part of the body that experiences pain, the anthropometric approach is used to re-measure the dimensions of the trolley rack related to the pain experienced by workers.

Four body dimensions were measured. These dimensions were chosen based on the standardized consideration of Indonesian anthropometric data from the Indonesian Ergonomics Association. Of the four dimensions, two are upper body dimensions, and the other is lower body dimensions. Height and weight are also control [8, 23]. These control dimensions play an important role in obtaining essential uniformity and normality in data testing. Anthropometric data measurements are carried out using a Martin anthropometer calibrated before measurement. This manual measurement is unlike sophisticated, automatic measurements (such as body scanners). The choice of this method is considered more practical because measurements are taken in several places in the tea factory where workers who operate the trolley rack are located.

Four people carried out anthropometric data collection. Measurements need to be done repeatedly to minimize errors in measuring. Errors in the measurement are divided into two types: intra-observer and inter-observer. Intra-observer error is a repeated measurement error by the same observer. While inter-observer errors are repeated measurement errors when done by different observers [24]. The three researchers measured twenty-two trolley rack operators simultaneously, while one recorded on paper and checked the results obtained. Random checks were also conducted to ensure that the data taken were valid.

Statistical Analysis

Descriptive statistics are presented to examine the anthropometric data. In addition to the control dimensions already mentioned, anthropometric data from PEI is also used as a reference in reviewing the size. The reference dimensions are not critical for material handling sizes but as a comparison in redesigning trolley racks. To determine the appropriate dimensions, twenty-two data covering four dimensions were tested for normality. The normality test is a test to determine whether the data taken is normally distributed [25]. The normality test was carried out using Shapiro-Wilk because the amount of data is below 50. From the data normality test, it will be seen whether the data distribution is normally distributed or not [26].

Research Methodology

The study began with problem identification. The results of problem identification are followed by data collection. The data that has been collected is then processed. The results of data processing are analyzed, and a dimensional improvement redesign is carried out. The last step in the research flow is to evaluate. Figure The stages of the research flow can be seen in Figure 2.

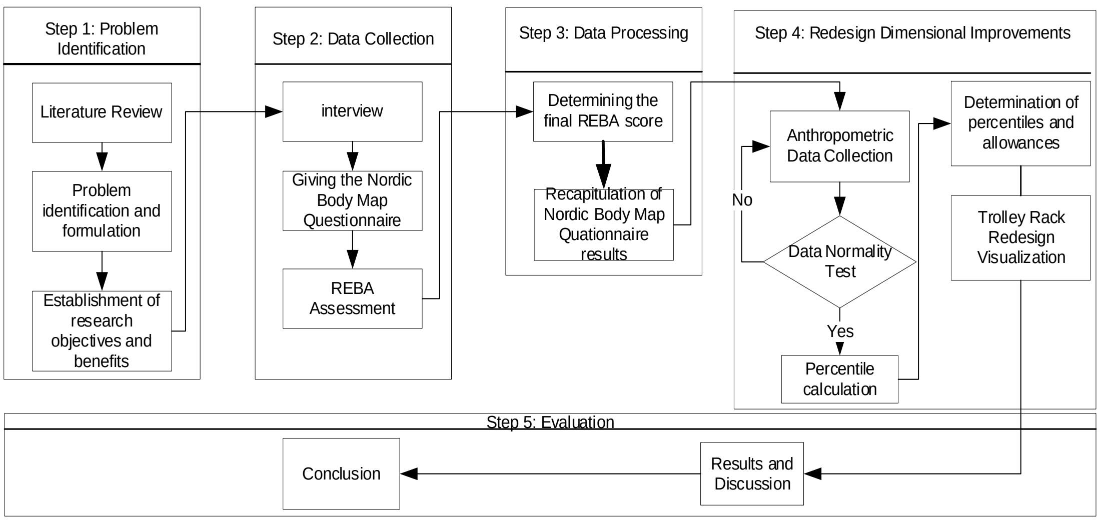


Fig. 2 Research Flowchart

RESULTS

The research results from the operation of the trolley rack with the REBA method get a score of 6. In the REBA assessment category, a score of 6 is a moderate risk. This risk requires further investigation, and changes must be made immediately. Furthermore, the Nordic Body Map Questionnaire analysis found that 85% of the workers experienced pain in the back and pelvis, right leg, left hand, and right hand.

Anthropometric data was recorded on a paper that had been prepared, including four columns of anthropometric dimensions. After data entry, data filtering was carried out using the outlier test. The outlier test results show that no values in the data are extreme or far from the data set. Outliers were determined based on the plus and minus three standard deviations. The data was also tested for normality as indicated by a p-value above the 5% level of accuracy ($p > 0.05$). These results follow previous research [8].

Determination of ergonomic anthropometric trolley rack dimensions is obtained by dividing the data into three percentile groups. The three percentile groups are the 5th, 50th, and 95th percentiles. The 5th percentile is the population size with a small body size, the 50th percentile is the population size with a medium body size, and the 95th percentile is the population size with a large body size (Table 1).

Table 1
Anthropometric Dimensions of Tea Factory trolley Rack Operators in Indonesia

Dimension	Man				
	Mean	**SD**	**P5**	**P50**	**P95**
SH	134.70	7.35	125.01	134.60	146.57
STW	37.80	3.88	32.09	37.95	43.19
FW	4.10	0.50	7.90	9.05	10.08
FL	24.00	1.55	21.81	23.80	25.99
HGW	8.90	2.55	3.25	4.15	4.80

Table 2
Final Anthropometric Dimensions of Tea Factory trolley Rack Operators in Indonesia

Dimension	Man			
	Percentile Selection	**Dimension**	**Allowances**	**Final Dimension**
SH	P5	125.010	0.990	126
STW	P5	32.085	0.915	33
FW	P95	10.080	0.920	11
FL	P95	25.990	12.990	13
HGW	P95	4.80	0.20	5

The dimensions for each part of the reviewed shelf size are SH with a 95th percentile of 126 cm, STW with a 95th percentile of 33 cm, FL with a 95th percentile of 11 cm, FW with a 95th percentile of 13 cm, and HGW with 5th percentile of 5 cm. Finally, the proposed sizing system for trolley rack dimensions at tea factories in Indonesia can be seen in Table 2.

DISCUSSION

A trolley rack is one of the material handling equipment (MHE) used to move materials from one department to another. In a tea factory, a trolley rack (Figure 1) transfers tea powder from the grinding department to the drying department [21]. During the operation of the trolley rack in the tea factory, it was suspected that workers experienced MSDs. The height of the trolley rack exceeds the height of the worker's body (Figure 1a), and the width of the trolley rack exceeds the width of the worker's shoulders (Figure 1b). In addition, the braking pedal also does not have ergonomic dimensions because it is too small for the worker's feet. The dimensions of the trolley frame used as a handle are also too large (Figure 1b). Please note that the dimensions for HGW do not exist based on PEI data. This results in the worker's hand not being able to grip correctly, which can pose an MSDs risk in this study. In addition, the work of pushing the trolley rack in the tea factory itself is at least done by each operator 25 times during one day with a total track length of 1250 meters with a weight of 450 kg. The initial hypothesis developed based on the information above is whether it is true that the dimensions of the initial trolley rack based on REBA and Nordic Body Map Questionnaire analysis are suspected of causing MSDs disorders. A Nordic body map questionnaire was given to the workers to complete in order to validate the researchers' evaluation of the REBA scores. REBA is used to analyze posture by looking at the level of MSDs risk score. In addition, REBA can also be reviewed at which stage will provide the highest score value to see the body parts most vulnerable to MSDs. REBA analysis is only done from the researcher's side, so to match the operator's experience, it is necessary to analyze the Nordic body map questionnaire to see the operator's response [19]. A Nordic body map questionnaire is used so that the results of the REBA analysis conducted by the author match what the operator feels. This follows previous research results [17]. Currently, research on MSDs risks carried out with a combination of REBA or RULA with a Nordic body map questionnaire needs to be done. In addition, research on MSDs analysis in tea factories is still rare.

The REBA calculation carried out in this study focuses on workers' posture in the grinding department at the tea factory. In the REBA analysis, there are 13 steps with three assessment sections: A, B, and C. Section A is an assessment of the neck, trunk, and leg, plus the value of the force/load lifted with a score of 5 (Figure 3).

Furthermore, the score of section A is added with a force/load score of 2 because the worker pushes a load of more than 22 lbs; thus, the total score of A is 5. Section B analyzes the arm and wrist with a score of 5, referring to Table B (Figure 1b). Furthermore, part B is added with a coupling score of 1 because the handle used is not ideal and requires improvement, so the total score of B is 6. Score C results from a combination score between A and B of 7. After getting the score C, the score is added to the activity score of 0, and the final REBA score is 7 (Figure 3). This score implies that the risk of activities performed by workers has a medium risk of MSDs occurrence. Further investigation and improvement should be implemented immediately. In this study, the improvement made is the redesign of the dimensions of the trolley rack.

Nordic Body Map Questionnaire analysis conducted in this study is used to see the discomfort felt by operators in the milling department. This method is qualitative in the form of a questionnaire given to workers. With this method, the location of discomfort at specific points of the worker's body can be known. In the Nordic Body Map Questionnaire analysis, 27 body parts were analyzed (Figure 4).

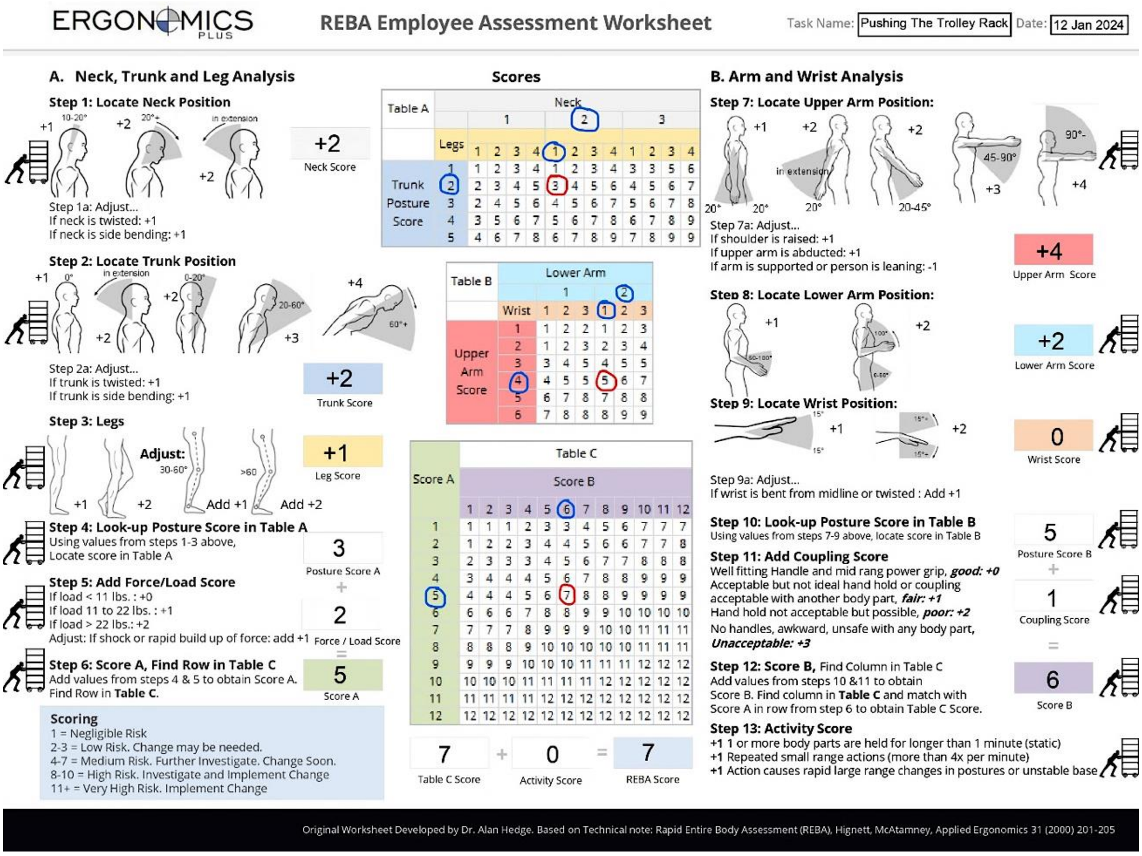
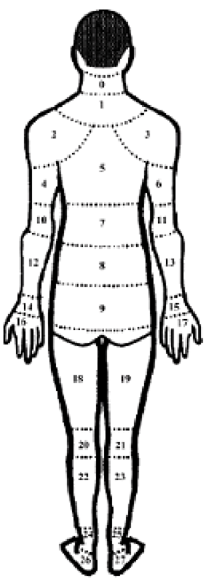


Fig. 3 Output REBA Assessment



No	Location	Grade of complaints			
0	Pain/stiff in the upper neck	A	B	C	D
1	Pain in the lower neck	✓			
2	Pain in the left shoulder			✓	
3	Pain in the right shoulder			✓	
4	Pain in the left upper arm		✓		
5	Pain in the back		✓		
6	Pain in the right upper arm		✓		
7	Pain in the waist		✓		
8	Pain in the buttock				✓
9	Pain in the bottom	✓			
10	Pain in the left elbow	✓			
11	Pain in the right elbow	✓			
12	Pain in the left lower arm	✓			
13	Pain in the right lower arm	✓			
14	Pain in the left wrist	✓			
15	Pain in the right wrist				
16	Pain in the left hand			✓	
17	Pain in the right hand			✓	
18	Pain in the left thigh	✓			
19	Pain in the right thigh	✓			
20	Pain in the left knee	✓			
21	Pain in the right knee	✓			
22	Pain in the left calf	✓			
23	Pain in the right calf	✓			
24	Pain in the left ankle		✓		
25	Pain in the right ankle		✓		
26	Pain in the left foot			✓	
27	Pain in the right foot			✓	

A is no pain, B is slight pain, C is pain, and D is the most pain

Fig. 4 Output of Nordic Body Map Questionnaire for trolley rack Operator at Tea Factory

Nordic body map questionnaire is done by categorizing workers' pain into 4 levels namely A, B, C, and D. A is no pain, B is slight pain, C is pain, and D is the most pain. Based on the research, 85% of the population experienced discomfort in the shoulders, hands, pelvic joints (buttocks), and legs. The highest level of discomfort lies in the pelvic (buttock) joint (Figure 4). This is because the pelvic joint plays the most critical role in the worker's body to support the load on the trolley rack that the worker pushes. The REBA analysis conducted by the researcher is also appropriate concerning the Nordic body map questionnaire analysis, which shows discomfort in several body parts, just like the REBA analysis.

Based on the Reba and Nordic Body Map Questionnaire analysis, five related body parts were found that need to be improved to lower the REBA score and eliminate discomfort. The five body parts are shoulder height (SH), standing shoulder width (STW), foot width (FW), foot length (FL), and hand grip width (HGW) (Figure 5). The data was measured using anthropometric kits on 22 trolley rack operator workers. After 22 data were obtained, then normality testing was carried out on the data. Data normality testing is done to see if the data is normally distributed. The normality test method used is shapiro wilk.

Testing using Shapiro Wilk is done because the amount of data is relatively small and below 50 data [26]. The Shapiro-Wilk test is a hypothesis test, so a null and alternative hypothesis are needed [27].

The null hypothesis is that the data comes from a normal distribution (p-value > 0.1), and the alternative hypothesis is that the data does not come from a normal distribution (p-value < 0.1). The p-value results of the five data tested, namely SH, STW, FW, FL, and HGW, have a p-value above 0.1 (Figure 6).

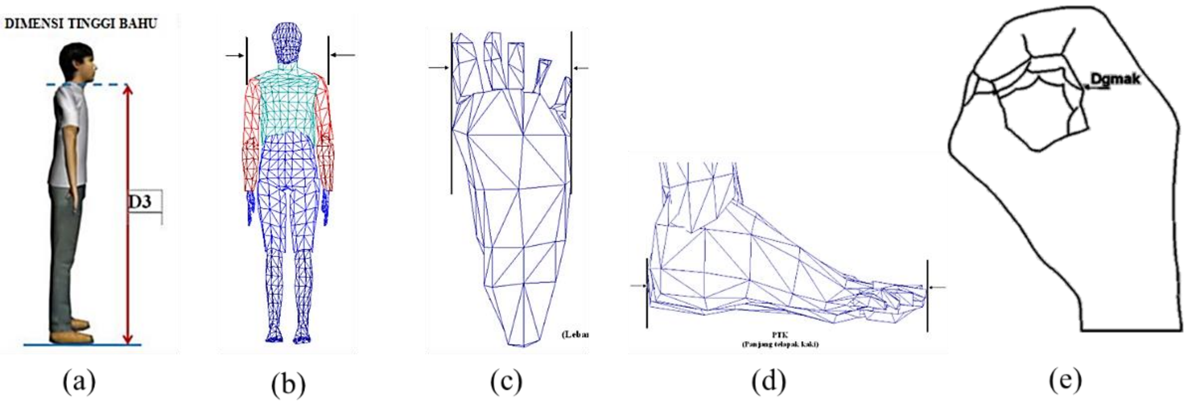


Fig. 5 Anthropometric Dimensions: (a) shoulder height (SH), (b) shoulder weight (STW), (c) leg width (FW), (d) food length (FL), (e) hand grip width (HGW)

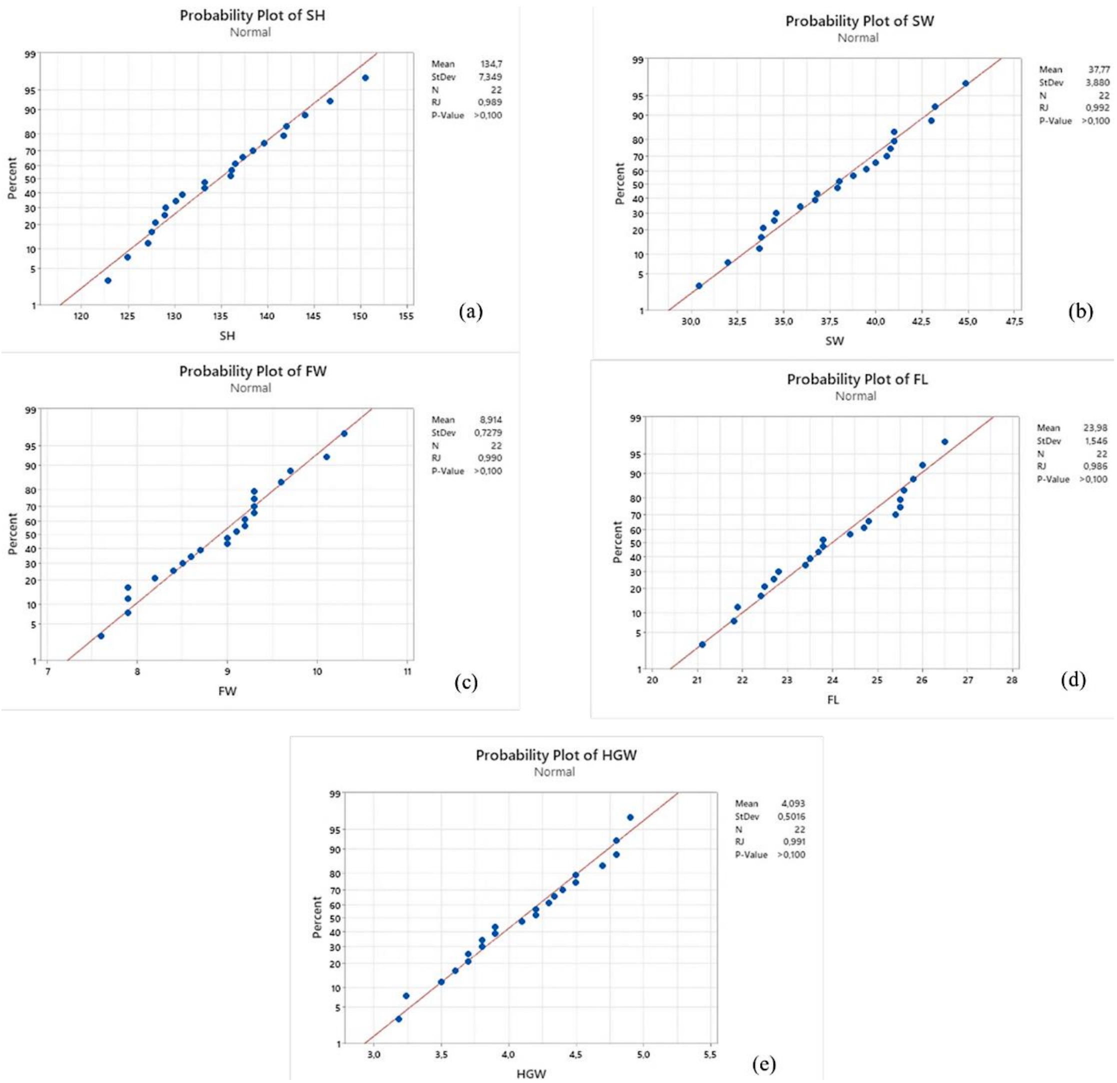


Fig. 6 Output Normality Test: (a) shoulder height (SH), (b) shoulder weight (STW), (c) foot width (FW), (d) food length (FL), (e) hand grip width (HGW).

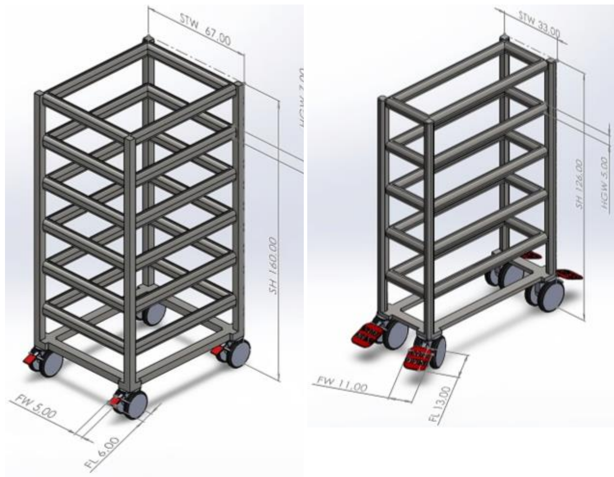
This indicates that to accept the null hypothesis and reject the alternative hypothesis, the data taken comes from a normal distribution. It can be used after the tested data is normally distributed because it has a slight and evenly distributed deviation [26]. The research continued with calculating the 5th, 50th, and 95th percentiles. After obtaining the results of the percentile calculation (see Table 1), proceed with the selection of percentiles following the relevant body dimensions (see Table 2).

Percentile selection is carried out by considering the body conditions of the workers, also added with allowances for the remanufacturing process for redesigning the trolley rack dimensions (see Table 2). After the quantitative calculation process, there are size adjustments of the five dimensions under review (Figure 2). In the SH dimension, the 5th percentile was chosen so that people with small body dimensions can reach the handle grip without causing a large angle in the upper arm, and people with the 95th percentile can still reach it. In the STW dimension, the 5th percentile was chosen so that people with small body dimensions can reach the handle grip without stretching their arms too broad, and people with the 95th percentile can still reach it. The 95th percentile FW dimension was chosen so that people with large body dimensions can step on the brake pedal according to the width of their feet, and people with small body sizes can also step on the brake pedal properly. In the FL dimension, the 95th percentile is chosen so that people with large body dimensions can step on the brake pedal according to the length of their feet, and people with small body sizes can also step on the brake pedal well. In the HGW dimension, the 5th percentile was chosen so that people with small body dimensions can grip the trolley handle well, and people with large body dimensions can also grip it well. This follows previous research on the application of anthropometric material handling [28].

Size adjustments, in addition to eliminating discomfort to workers, also eliminate worker insecurity. Worker insecurity is divided into two conditions: unsafe acts and unsafe conditions. An unsafe act is when workers are aware of unsafe conditions but still choose to do the job. The unsafe act occurs to workers push the trolley rack with limited vision. Meanwhile, an unsafe condition is a condition of the work environment that may or may not have been identified and is harmful to workers. The unsafe condition experienced by workers is pushing the trolley rack with dimensions that are not following the dimensions of the worker's body.

Improvements to anthropometric dimensional redesign increase worker productivity. This is because the dimensions of the trolley rack can be considered ergonomic. After all, they have adjusted to the dimensions of the worker's body so that worker discomfort can be eliminated. In addition, unsafe conditions experienced by workers, such as limited vision, can also be eliminated. When worker discomfort and insecurity are eliminated, the tea production process can be carried out more effectively and efficiently. This results in an increase in worker productivity of up to 85%.

REBA analysis shows moderate risk and needs immediate improvement. This statement is reinforced by the recapitulation of the Nordic body map questionnaire, where 85% of workers were shown to experience pain and discomfort. The safety analysis in this study also indicates that there are workers who, in carrying out their work activities, are in unsafe acts and unsafe conditions [29, 30]. This unsafe act condition can be interpreted as workers consciously pushing the trolley rack with limited vision. While the unsafe condition is that workers work with trolley rack conditions that are not ergonomic. This results in workers often slipping, causing injuries and impacting productivity by 15%. These two conditions ultimately require a redesign of the trolley rack (Figure 7). From the figure, the anthropometric dimensions of a comfortable trolley rack are obtained with specifications SH = 126 cm, STW = 33 cm, FL = 11 cm, FW = 13 cm, and HGW = 5 cm.



a) b)

Fig. 7 3D CAD output model of trolley rack at the Tea Factory (a) before; (b) proposed

CONCLUSIONS

The final results of this study show that the anthropometric data of trolley rack operator workers in tea factories in Indonesia initially showed discomfort and the emergence of MSDs. The following results evidence this:

a. REBA analysis obtained a final score of 6,
b. Nordic Body Map Questionnaire analysis results in 85% of workers experiencing mild to severe pain and discomfort in several body parts such as shoulders, upper arms, back, waist, hands, buttocks (pelvis), ankles, and feet;
c. Safety analysis found that workers work in unsafe acts and conditions.

From the 4 points above, it is evident that the initial product dimensions of the trolley rack in the tea factory are not ergonomic, so they have the potential to generate MSDs and endanger worker safety.

The results of this research are a reference for engineers, tea factory owners, and researchers to design trolley shelves that genuinely follow ergonomics rules. So that it can prevent the risk of MSDs, future research will be more focused on implementing anthropometric dimensions according to ergonomic rules on the trolley rack, and testing of the new trolley rack will be carried out to prove the increased productivity of workers.

ACKNOWLEDGMENTS

We would like to thank the PT Perkebunan Tambi, Wonosobo, Central Java, Indonesia, as well as their help with the writing of this paper.

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