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Ergonomic Design of a Paving Block Transport Tool Using Anthropometry and Design Thinking Approaches

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ABSTRACT

This study aims to design an ergonomic paving block transport tool using an anthropometric and design thinking approach to reduce musculoskeletal risk among workers. The research began by assessing worker postures through the Rapid Entire Body Assessment (REBA) method and measuring relevant anthropometric dimensions to inform the tool's ergonomic specifications. The design process applied a human-centred design thinking framework, incorporating user needs and physical data. REBA analysis showed that Worker 1 had a score of 8 (high risk, requiring immediate intervention), while Worker 2 had a score of 5 (moderate risk). The recommended lifting index was calculated at 0.71, indicating an acceptable workload. Anthropometric data determined key design parameters, including tool height (136 cm), grip height (94 cm), tool width (68 cm), and reach length (73 cm), based on the 5th and 50th percentiles of worker measurements. The selected tool design utilized steel materials for strength and durability and incorporated a rack and lifting mechanism to accommodate up to five paving block boards per transfer. Field testing demonstrated a 257% increase in production capacity and a 33% reduction in transport time. The tool design successfully addressed key ergonomic risks, enhanced operational efficiency, and supported safer manual material handling practices. The study concludes that combining anthropometric data with design thinking can lead to effective ergonomic interventions in construction environments.

Keywords: *REBA, ergonomics, anthropometry, design thinking, lifting trolley, manual material handling*

Introduction

The industrial sector, especially construction, has experienced rapid development, as indicated by data from the Central Statistics Agency [1][2] which recorded an increase in the construction value index from 150.03 in the first quarter of 2023 to 162.16 in the first quarter of 2024. This condition encourages manufacturing companies, including those engaged in construction, to continue to improve quality and develop products to meet consumer demand [3]–[5]. However, in the production process, many companies still rely on manual methods, which have the potential to cause the risk of fatigue and muscle injuries (musculoskeletal disorders) [6]. This is in line with research stating that manual work involving continuous lifting or moving of heavy objects can hurt workers' health, especially in the long term [7]. Repetitive manual work can worsen musculoskeletal problems, which have the potential to cause long-term disability [8][9]. PT Beton Lawang, which produces paving blocks and precast, emerged as a response to changes in the paradigm of society, such as switching from the use of asphalt and river stones to products such as paving stones and precast (such as u-ditch or box culvert). Based on observations, it was found that workers in the production process still manually moved the moulded concrete bricks to the drying area. This process is known as manual material handling, which includes activities such as lifting, placing, pushing, carrying, and holding materials [10][11]. Manual material handling activities can increase the risk of musculoskeletal disorders if carried out without assistive devices or without considering proper ergonomic factors. The application of ergonomic design in the production process can reduce the risk of injury and increase work efficiency. The application of ergonomic aids to support workers is also very important to reduce the physical burden they bear during the manual production process [12].

Figure 1 Body Posture of Paving Block Arrangement Workers

Figure 1 illustrates the activities of workers in the process of manually moving paving blocks from the printing process to the drying place. In one printing process, the machine can produce 12 pieces of products, where the weight of one paving block is approximately 3 kg, so that in one printing process the weight is 36 kg, and the distance required by workers to the drying place is 8 meters and takes 1 minute and its arrangement. With a production target that must be met by workers in a day of 800 pallets, the process is repeated 800 times. In addition, to identify the risk of work activities in moving paving blocks using the REBA method [13][14].

Companies in maintaining or developing their productivity cannot be separated from the existence of workers [15]. Workers who do not get support from work facilities to increase productivity experience obstacles [16]. One of the supporting facilities in the process of moving paving blocks is the existence of paving block moving aids. Designing paving block moving aids, is based on an ergonomic approach, anthropometric calculations and design thinking methods to facilitate and reduce the burden on workers [17][18]. The purpose of this study is to design an ergonomic paving block moving tool based on worker anthropometry to reduce musculoskeletal risks, with a structured thinking approach.

Research Methods

This study uses a combined approach between quantitative and qualitative research. Quantitative research focuses on theory, design, hypothesis, and research subjects, while qualitative research includes human interaction and related objects, as stated by Creswell [19], who emphasized the importance of combining these two approaches to obtain more comprehensive results. Data were collected, processed, and analyzed to obtain conclusions with an ergonomic approach and structured thinking. The study was conducted at PT Beton Lawang located in Malang, East Java, from October to November 2024. The objects of the study were workers involved in the process of moving paving blocks, with a sample of 14 male workers aged 22-55 years.

Data collection techniques include observation, interviews, and documentation. Observation is carried out to observe worker activities directly without disturbing the natural conditions of the company. According to Sugiono [20], observation is an effective method for obtaining valid data because it allows researchers to directly see events that occur without intervention. Interviews were conducted with paving block removal workers to collect anthropometric data. Documentation collects company archives related to worker injuries and photos of non-ergonomic work activities.

Data processing techniques are carried out by analyzing the worker's body posture, calculating the recommended load limits to help determine the load lifting limits [21][22], and anthropometric measurements using Microsoft Excel software, for the design of paving block moving tools using Autodesk Inventor 2021. As stated by Nurmianto [23], the use of software for anthropometric analysis is very helpful in optimizing work designs that are more on the physical characteristics of workers. The research stages began with a direct survey at PT Beton Lawang, identification of paving block moving work activities, and determination of research objectives. Furthermore, the collected body postures were analyzed using the REBA method and calculated the recommended load limits. The next process was to design assistive devices using the structured thinking method. According to Brown [24], the structured thinking approach allows for more human-centred and efficient innovation in designing ergonomic solutions [25]. The study ended with limitations to a deeper analysis of the durability and cost of assistive devices by providing conclusions and suggestions.

Results and Discussion

Rapid Body Assessment (REBA)

The REBA method as an analysis of the worker's body posture covers the upper to lower body of the worker. This is because the activity for both paving blocks moving workers uses the entire body to carry out the handling. The posture of the two workers can be presented in Figure 2.

Figure 2 Worker's Body Posture

Based on the body posture images of the two workers, the REBA assessment results are presented in the following table.

Table 1 Recapitulation of REBA Data for Paving Block Moving Workers

Criteria	Worker 1 (Left)	Worker 2 (Right)
Neck	2	1
Trunk	3	2
Leg	2	1
Total A	**5**	**2**
Load	2	2
Score A	**7**	**4**
Upper Arm	1	1
Lower Arm	1	1
Wrist	3	3
Total B	**2**	**2**
Coupling	1	1
Score B	**3**	**3**
Score C	**7**	**4**
Activities	1	1
Total REBA	**8**	**5**

The result of the REBA calculation for worker 1 is 8, from the total A, has a value of 5 added to the load so that the Score A is 7. In Score B calculated from the total value of B is 2 with a coupling value of 1 so that the score B is 3. Score C as the final REBA for worker 1 is 8. The difference between Worker 1 and Worker 2 lies in the value of Score A which is 4, so the final REBA for Worker 2 is 5.

Recommended Weight Limit (RWL)

Horizontal Multiplier

The horizontal multiplier factor is the horizontal distance of the load to the worker. It is known that the initial and target horizontal distances are 30 cm. Then continue by calculating the initial horizontal multiplier (HM) and the target horizontal multiplier (HM) as follows:

Initial HM Calculation

HM Origin = 25/30 = **0.83**
HM Calculation Goal
HM Goal = 25/30 = **0.83**

Vertical Multiplier

The vertical multiplier factor comes from the distance of the height of the load to the floor by the worker. Based on the initial vertical distance of the worker from the floor position to the load is 100 cm, while the target vertical distance is 15 cm to 147 cm. For the calculation of the initial multiplier factor, namely:

VM = 1-(0.003 |100-75|)
= **0.93**

Meanwhile, the calculation of the VM Objective is:

1. VM = 1-(0.003 |15-75|) = **1.18**
2. VM = 1-(0.003 |27-75|) **= 1.14**
3. VM = 1-(0.003 |39-75|) = **1.11**
4. VM = 1-(0.003 |51-75|) = **1.07**
5. VM = 1-(0.003 |63-75|) = **1.04**
6. VM = 1-(0.003 |75-75|) = **1**
7. VM = 1-(0.003 |87-75|) = **0.96**
8. VM = 1-(0.003 |99-75|) = **0.93**
9. VM = 1-(0.003 |111-75|) = **0.89**
10. VM = 1-(0.003 |123-75|) = **0.86**
11. VM = 1-(0.003 |135-75|) = **0.82**
12. VM = 1-(0.003 |147-75|) = **0.78**

Distance Multiplier

The displacement multiplier factor comes from the displacement distance which is expressed as the difference in vertical distance between the initial location and the destination location. The furthest displacement distance has a higher risk. To find out the displacement distance, the calculation is carried out by subtracting the vertical distance from the destination from the initial vertical distance. After the displacement distance is known, it will be continued by processing the displacement multiplier factor with the formula DM = 0.82 + (4.5/D). The following is the calculation process for the initial displacement multiplier factor:

DM = 0.92 + (4.5/100) = 0.865

Meanwhile, the process for calculating the destination transfer multiplier factor is as follows:

1. DM = 0.82 + (4.5/85) = 0.873
2. DM = 0.82 + (4.5/73) = 0.882
3. DM = 0.82 + (4.5/61) = 0.894
4. DM = 0.82 + (4.5/49) = 0.912
5. DM = 0.82 + (4.5/37) = 0.942
6. DM = 0.82 + (4.5/25) = 1,000
7. DM = 0.82 + (4.5/13) = 1.166
8. DM = 0.82 + (4.5/-1) = 5,320
9. DM = 0.82 + (4.5/-11) = 0.411
10. DM = 0.82 + (4.5/-23) = 0.624
11. DM = 0.82 + (4.5/-35) = 0.691
12. DM = 0.82 + (4.5/-47) = 0.724

Based on the calculation results, the furthest displacement multiplier factor was obtained at the destination location of 5.320.

Asymmetric Multiplier Factor

The asymmetric angle is formed by a triangular line (straight asymmetric line) indicating the shift of the worker's body. The worker is directly facing the paving block board with an initial asymmetric angle to the destination location of 90 degrees. The calculation of the asymmetric angle multiplier factor manually obtained the following results:

AM = 1-(0.032 A)
AM = 1-(0.032 * 90) = 0.712

Frequency Multiplier

The frequency multiplier factor is obtained from the results of the number of loads lifted in a period. In one day, on average, workers move paving blocks in one board as many as 800 boards with the contents of paving per board being 12 pcs. Each board has a weight load of 36 kg, while the duration of the move is 20 seconds. The duration of workers in a day is 8 hours with a break time of 1 hour. By using the frequency multiplier table, the following frequency multiplier results are obtained:
FM = 60 boards / 60 minutes = 1
FM = **0.75** (Based on FM V ≥ 75 table)

Coupling Multiplier

The coupling multiplier factor is obtained through the Coupling Multiplier table. Based on the field conditions of the paving block moving process, workers move with both hands and without special grips and there is a working duration of 8 working hours. The decision-making of the initial and objective clutch multiplier conditions, free object control with dimensions wide enough to obtain a value of 1.

Recommended Weight Limit (RWL) & Lifting Index (LI)

After the multiplier factors are known, all recommended weight limit (RWL) data processing is carried out at the initial location and destination location. to determine the load restrictions carried out by paving block moving workers. For the calculation process with the manual formula as follows:

1. **Calculation of *Recommended Weight Limit* (RWL)**

   The following is the initial RWL calculation process:
   RWL = 23 x 0.83 x 0.93 x 0.865 x 0.712 x 0.75 x 1
   RWL = 8,189
   The following is the calculation process for RWL Destination:

Table 2 Recommended Weight Limit Purpose

No	LC	HM	VM	DM	AM	FM	CM	RWL	LI
1	23	0.83	1.18	0.873	0.712	0.75	0.9	10,543	3.41
2	23	0.83	1.14	0.882	0.712	0.75	0.9	10,323	3.49
3	23	0.83	1.11	0.894	0.712	0.75	0.9	10,136	3.55
4	23	0.83	1.07	0.912	0.712	0.75	0.9	10,005	3.60
5	23	0.83	1.04	0.942	0.712	0.75	0.9	9,984	3.61
6	23	0.83	1.00	1,000	0.712	0.75	0.9	10,235	3.52
7	23	0.83	0.96	1,166	0.712	0.75	0.9	11,506	3.13
8	23	0.83	0.93	5,320	0.712	0.75	0.9	50,530	0.71
9	23	0.83	0.89	0.411	0.712	0.75	0.9	3,751	9.60
10	23	0.83	0.86	0.624	0.712	0.75	0.9	5,470	6.58
11	23	0.83	0.82	0.691	0.712	0.75	0.9	5,803	6.20
12	23	0.83	0.78	0.724	0.712	0.75	0.9	5,812	6.19

After knowing the RWL value, continue with the calculation of the lifting index. The lifting index of each paving removal worker weighs 3 kg, each board contains 12 pcs weighing 36 kg. The calculation of the lifting index at the initial location is as follows:

LI = 36 / 8,189= 4,440 (High Risk)

The following is the lifting index calculation process objective :

1. LI = 36 / 10.543 = 3.41 (High Risk)
2. LI = 36 / 10.323 = 3.49 (High Risk)
3. LI = 36 / 10.136 = 3.55 (High Risk)
4. LI = 36 / 10.005 = 3.60 (High Risk)
5. LI = 36 / 9.984 = 3.61 (High Risk)
6. LI = 36 / 10.235 = 3.52 (High Risk)
7. LI = 36 / 11.506 = 3.13 (High Risk)
8. LI = 36 / 50,530 = 0.71 (Good Condition)
9. LI = 36 / 3.751 = 9.60 (High Risk)
10. LI = 36 / 5,470 = 6.58 (High Risk)
11. LI = 36 / 5.804 = 6.20 (High Risk)
12. LI = 36 / 5.812 = 6.19 (High Risk)

Based on the results of the lifting index calculation at the initial location, the recommended lifting load value at the destination location is number eight with a lifting index of 0.71, while the highest lifting index value is 9.60, which has a high risk.

Design Thinking

Empathize (Empathy)

The results of discussions and observations with workers contained seven statements that describe user needs in the process of moving and transporting paving blocks. First, a statement about carrying a fairly heavy load. Second, a statement about moving which is done manually and the process takes place back and forth. Third, a statement about transporting paving block boards, which can only be transported one board at a time. Fourth, a statement stating that when arranging high parts, extra energy is needed. Fifth, a statement about the need for tools that provide comfort. Sixth, a statement about the need for multifunctional tools. Seventh, a statement about the need for practical tools. In the results of the user needs component, it is described that tools are expected to reduce the workload where initially the process of moving paving blocks manually will be assisted by paving block moving equipment. Tools can be used easily on paving block moving tools some wheels help the transfer to run easily and make workers more comfortable. The tool can accommodate a lot when moving paving blocks, and has dimensions and loads that can accommodate more paving block boards, so it helps workers move paving not manually with a manual transport capacity of only one board. When workers move paving manually by carrying out arrangement activities, there are problems when the position is higher, so multifunctional performance, it helps workers to be more effective in moving paving that is positioned higher than the body dimensions or recommended loading limits.

Define (Definition)

Paving blocks or concrete bricks are non-structural products made from aggregate, type I Portland cement, and water [26] The production process begins by inserting the material into a mixer for a mixing process that takes 3 minutes. After being mixed evenly, the material is transferred to a press machine with a conveyor, and the molding is done by pressing for 1 minute, producing 12 pieces of paving per pressing. The paving that is still wet is then transferred to a drying place to dry for 12 hours. Based on interviews, the transfer of paving blocks is done manually with material handling. Workers lift 12 pieces (36 kg) per lift, with a daily production target of 800 pallets. The results of the analysis of user needs components identify the components that must be present in the tool, which are then explained in the functional requirements as a benchmark for designing the tool.

The following are the functional criteria with statements and technical responses required in the development of tools for moving paving blocks. In the first statement, related to carrying quite heavy loads, the technical response indicates that the tool can reduce the workload. Second, for manual transfers and back-and-forth processes, the tool is expected to be easy to use. Third, regarding the transportation of paving block boards that can only be transported one board at a time, the tool should be able to accommodate many. Fourth, when arranging high parts that require extra energy, the tool is expected to be able to adjust the dimensions of the material or product. Fifth, regarding the need for tools that provide comfort, the tool must have dimensions that are by the anthropometry of the worker. Sixth, the tool needed must be multifunctional, allowing various functions to be performed in one tool. Finally, related to practical tools, the tool is expected to be practical in installation.

Each of the criteria of the function mentioned will be measured to determine its success capability. The tool has a drive system that can be measured from the user's loading brick in regulating the load being transported. Easy moving arrangements can be measured by the worker's ability to control the goods. In tools that can adjust to materials or products, it is measured from the tool's ability to adjust the dimensions of the product being transported. Safe and comfortable tools can be measured when workers move goods using tools.

Idea

paving block moving tool in the form of a trolley that can facilitate and provide safety in moving goods. The tools to be designed have 2 types of choices that are per the wishes of the workers, the tool is designed in a lifting mechanism and a mechanism that has lifting and safety. The dimensions of the tool are adjusted to the anthropometric dimensions of the paving block moving worker. The following are the stages of determining the mechanism of the tool before designing a design based on user needs. The components of user needs for alternative designs can be explained for the first component, namely the ability of the tool to reduce the workload, the first mechanism with a trolley shape gets 7 respondents and the second mechanism with a rack shape gets 3 respondents. For ease of use of the tool, the first mechanism using wheels is desired by 6 respondents, and the second mechanism using a lift is desired by 4 respondents. In the component of the tool that can accommodate a lot, the first mechanism with a shelf gets 3 respondents, and the second mechanism with a wide board gets 4 respondents. Adjusting the dimensions of the material or product, the first mechanism that can move vertically is chosen by 8 respondents, and the second mechanism that can be extended by 4 respondents.

The dimensions of the aids that match the anthropometry of the workers were chosen by 10 respondents the first mechanism has dimensions according to anthropometry, while the second mechanism with dimensions according to the material. For the ability of the aids to work multifunctionally, the first mechanism with dimensions according to anthropometry received 10 respondents, while the second mechanism with dimensions according to the material. In the components of the aids that are practical in installation, the first mechanism with permanent safety was chosen by 2 respondents and the second mechanism with flexible safety by 8 respondents.

1. **Alternative Design 1**

In Alternative 1, the design of a simple tool with a movement mechanism using a wheel drive. The front wheels can rotate 360 degrees, but the part with fixed wheels, in addition, the dimensions used are the anthropometric dimensions of paving block moving workers based on the results of uniformity tests and data adequacy obtained percentile results 5, 50, and 95. The design is designed in 3D to help researchers in simplifying design selection. Which is described as follows.

Figure 3 Design Alternative 1

2. **Alternative Design 2**

In alternative design 3, there is a fairly detailed combination, namely a tool using an adjuster pad wheel, a lifting function using a hand winch with a lifting capacity of 350 kg, having a fork with a length that can be adjusted to the dimensions of the pallet, having a safety on the side, and dimensions according to the anthropometry of the paving block moving worker. In addition, the trolley drive mechanism is done manually, if each paving block board has a load of 36 kg with a lifting capacity of 350 kg, then the trolley can move as many as 5 boards each time it is moved. The design is in 3D form with the following image:

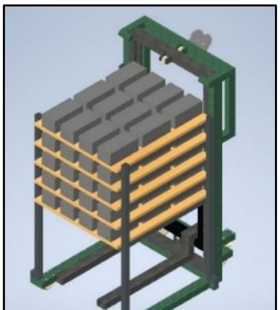

Figure 4 Alternative Design 2

The design alternatives that have been described will be processed. product design concept selection to determine the product concept. The next process is to give a score to each alternative or what is called the scoring method according to the criteria that have been determined by giving a check mark (✓) for better criteria. The scoring process for the paving block moving tool is as follows.

Table 3 Scoring Method

No	**User Requirements Components**	**Alternative**	
		1	**2**
1	Carrying quite a heavy load	✓	✓
2	The transfer is done manually and the process goes back and forth.	✓	✓
3	Transporting *paving block boards* at a time is only one board.	✓	✓
4	When arranging high parts requires extra effort		✓
5	Need a tool that provides comfort	✓	✓
6	Need a multi-function tool		✓
7	Requires practical tools	✓	✓
	Amount ✓	5	7

In the table above, the determination of the value is done using the brainstorming method between researchers and paving block removal workers. based on the alternative selection criteria, the highest value is obtained in the second design alternative which is 7 points, the difference with the first design alternative is in the user needs component when the height of arranging requires extra energy and requires multifunctional tools, so that the first design alternative has a value of 5. the final design selected is the second alternative and continues to the next stage which is the prototype stage.

Prototype

Table 4 Determination of Dimensions of Assistive Devices

No	**Design Dimensions**	**Percentile**	**Dimensions (cm)**	**Information**
1	Tool height	TBB (P50)	136	Adapting worker anthropometry and goals to product height characteristics
2	Tool handle height	TSB (P5)	94	Adjust worker comfort according to standing elbow height anthropometric data
3	Tool width	JRS (P50)	68	Adjusting worker anthropometry for flexibility in operating assistive devices
4	Tool length	JRD (P50)	73	Adjusts the worker's hand reach forward to control, carry, and grasp
5	Fork length	-	67	Board characteristics
6	Side guard	-	100	Board characteristics
7	*Hand winch*	-	136	Vertical movement mechanism regulator for aids

After all dimensions have been determined and described in the table, it will be continued with visual interpretation as a point in the design and manufacture of the following aids:

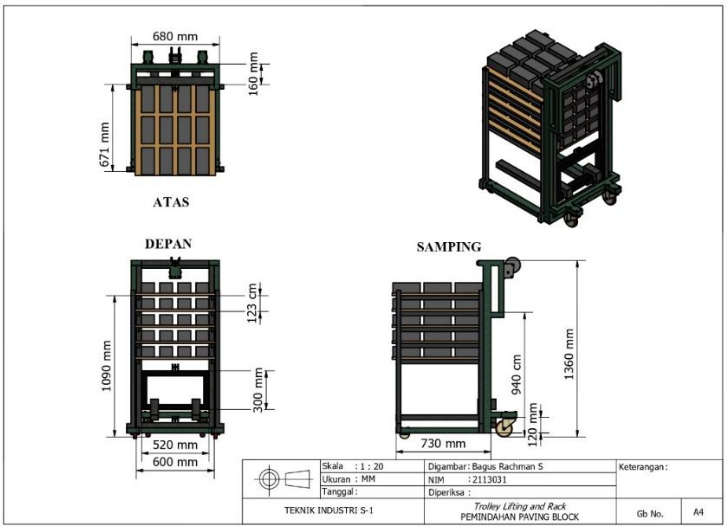

Figure 5 Technical Drawing of Paving Moving Tool

With the existence of predetermined dimensions, it can facilitate the design process of 2-dimensional and 3-dimensional aids. The design process that has been described in Figure 4.8 contains several components with different material and volume specifications.

Test

At the final stage of designing the aids, the aim is to find out the evaluation of the aids for workers who operate them to move paving blocks. Based on the following test results.

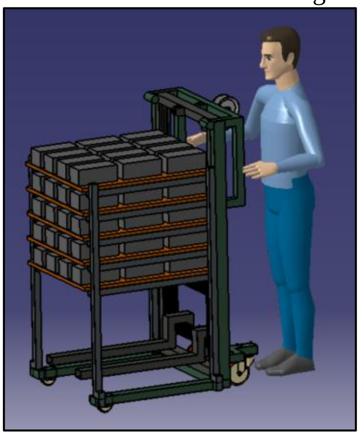

Figure 6 Trolley lifting and rack testing

In the picture above, with the aids, workers can operate the tool comfortably according to the worker's anthropometry along with supporting components according to user needs. Workers who previously had to manually move each paving block after being printed, with the aids can accommodate as many as 4 to 5 paving boards so that the frequency required by workers to move 800 boards or 9600 pcs of paving blocks in a day is 180 repetitions. This can reduce the risk of fatigue due to repeated transportation.

Evaluation of the Assistive Devices Before and After

Table 5 Evaluation of Assistive Devices

Criteria	Before Repair	After Repair	Efficiency	Percentage Increase
Effective Working Time	7 hours	7 hours		
Transfer Time	60 seconds	40 seconds	20 seconds	33%
Carrying Capacity	1 board	5 boards	4 boards	400%
Production per day	420 boards	1500 boards		257%

Based on the evaluation results after the presence of the aids with an effective working time of 7 hours (420 minutes) workers in one transfer can accommodate 5 paving block boards and the transfer time is 40 seconds, so that the production capacity that can be produced in one day is 1500 boards. The increase resulting from the evaluation before and after the presence of the lifting and rack trolley aids increased by 257%.

Conclusion

The overall research results can be concluded as follows. The results of the processing of musculoskeletal risk identification data on the first worker have a final REBA score of 8, including high risk requiring immediate investigation and change, while for the second worker, the final REBA score is 5, which is included in the medium category requiring investigation for future changes, and the calculation of the lifting index for the recommended workload for paving block removal workers at a value of 0.71. In the anthropometric data of paving block removal workers, the standing shoulder height as a consideration of the height of the assistive device using the 50th percentile is obtained at 135.43 cm rounded to 136 cm, the standing elbow height as a consideration of the height of the grip using the 5th percentile is obtained at 94 cm, the range of elbow to elbow span as a consideration of the width of the assistive device using the percentile calculation is obtained at 68 cm, and the reach of the hand forward as a consideration of the length of the assistive device using the 50th percentile is obtained at 73 cm.

By using the design thinking method, the design of the paving block moving aid is designed according to the needs of the selected user is the third alternative design in the form of a trolley and has a mechanism in the form of a rack and lifting system. In addition, the aid is made of sturdy but not heavy iron material, has wheels that can rotate to make it easier and provide security, there is a safety rack that functions to protect the board. In addition, the evaluation after the design of the aid can help and increase production capacity per day by 257% with a transport capacity in one transfer of the aid can accommodate as many as 5 paving block boards. Sustainability in the same study, it can be continued by calculating the durability of the ergonomic paving block moving aid and structured training to reduce musculoskeletal.

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