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Ergonomic Design of Hydraulic Trolley Table Based on Biomechanical Assessment in Briquette SMEs

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Abstract. A biomechanical assessment is essential for reducing the physical workload in MSMEs that rely on manual material handling. Repetitive lifting tasks in briquette-producing MSMEs in Medan cause musculoskeletal complaints and reduce work efficiency. This study aims to design an ergonomic hydraulic trolley table using a multimethod approach. This approach integrates biomechanical analysis, postural assessment and anthropometric design. Data were collected through direct observation, using the Nordic Body Map (NBM) and the Rapid Entire Body Assessment (REBA) method, as well as through anthropometric measurements. These were then complemented by biomechanical simulation using Ergoniza. NBM results revealed dominant discomfort in the waist, shoulders and arms, while REBA scores of 9–11 indicated consistently high-risk postures requiring immediate intervention. Ergoniza simulations showed that applying the proposed design reduced spinal load. The trolley table was developed using 50^(th) percentile anthropometric data and was adjusted to standing elbow height. It is equipped with a hydraulic lift and wheel system to eliminate the need for manual lifting. This integrated design, which combines biomechanical, anthropometric, and ergonomic simulation close to real conditions, is expected to reduce musculoskeletal disorders while improving productivity and comfort among briquette production workers in Medan SMEs.

Keywords: *Biomechanics; Ergoniza; Hydraulic Trolley Table; Musculoskeletal, Nordic Body Map, REBA.*

1. Introduction

Rumah Briket Medan is a Small and Medium Enterprise (SME) that has been producing environmentally friendly briquettes since 2015. The production process utilises wood waste and coconut shells, which are collected from industrial and household sources in the vicinity. Despite the sequential nature of the production stages, material collection, burning, grinding, molding, and packaging, the process remains heavily reliant on manual labour. A significant concern has been identified in the context of material transfer, wherein workers continue to engage in manual lifting and carrying activities without the assistance of tools. Repetitive activities over long working hours lead to frequent complaints of back, waist, neck, shoulder, and hand pain, indicating potential long-term health risks.

Ergonomics, as defined by Sirikasemsuk et al. (2024) and Anindhita (2024), aims to create safe, comfortable, and efficient working conditions. Improper Manual Material Handling (MMH),

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particularly in the domains of lifting and carrying, has been demonstrated to have a significant correlation with increased risks of injuries and musculoskeletal complaints (Fauzi, 2024). Musculoskeletal disorders (MSDs) are the most prevalent work-related disorders worldwide, accounting for approximately 60% of all occupational illnesses (Safithry et al., 2023; Hita-Gutiérrez et al., 2020). In an effort to comprehend the underlying causes of workers' discomfort and to identify potential risk factors, this study employs a multifaceted approach that incorporates the Nordic Body Map (NBM) questionnaire (Adiyanto et al., 2022), the REBA posture assessment (Han et al., 2023; Imdam et al., 2024), a biomechanical analysis (Maharani et al., 2024), and the Ergoniza platform for multi-factor ergonomic evaluation (Izaguirre et al., 2020). Anthropometric data are also collected to ensure proper ergonomic design (Rodríguez et al., 2021; Septian et al., 2023; Perdana et al., 2020; Kurnia, 2024).

However, previous ergonomic studies in similar SMEs have largely focused on identifying symptoms of musculoskeletal disorders (MSD) without integrating multi-method risk assessment or translating findings into ergonomic simulation as a practical engineering control. Moreover, the majority of research has not yielded a design solution tailored to workers' anthropometric dimensions. The present study addresses the aforementioned issue by evaluating physical workload during manual material transfer and by designing an ergonomic hydraulic trolley table based on a comprehensive multi-method ergonomic assessment. This assessment employs Ergoniza software to reduce the risk of musculoskeletal disorders (MSDs) and to improve productivity, and is as close to a real-world condition as is feasible.

2. Methods

2.1. Research Location and Time

This study was conducted at a micro, small, and medium enterprise (UMKM) that produces briquettes, located on Jl. Kanal Raya, Marindal Satu, Medan Amplas District, Medan City, North Sumatra Province, with the postal code 20148. This location was chosen due to reports from workers complaining about work activities that were monotonous, repetitive, and physically demanding. These activities mainly occur in the process of transferring raw materials and production outputs, which are still carried out manually without the aid of adequate work tools. Transportation activities are carried out by lifting, carrying, and bending, which have the potential to cause musculoskeletal disorders. This research was conducted directly at the work site on June 23, 2025, to enable real observation of workers' activities.

2.2. Data Collection

Data collection in this study used a combination of complementary quantitative and qualitative approaches to obtain a comprehensive understanding of working conditions at Rumah Briket Medan. The methods applied included direct observation in the workplace, distribution of the Nordic Body Map (NBM) questionnaire, assessment of work posture using the Rapid Entire Body Assessment (REBA) method, biomechanical analysis using Ergoniza software, and measurement of workers' body dimensions using an anthropometric approach. Direct observation was conducted to see firsthand how the work process took place, particularly in the transfer of materials from the combustion station to the grinding station and other stations. This activity included observing body posture when lifting loads, how materials were carried, and the interaction between workers and their work environment. The observation process was conducted without the workers' knowledge so that they would continue to work naturally, thereby ensuring that the data obtained accurately reflected the actual working conditions.

Next, the Nordic Body Map (NBM) questionnaire was distributed to identify the parts of the body that most often experience complaints or pain. This questionnaire was given directly to workers in the production area, who were asked to mark the parts of their bodies that they felt pain in, whether mild or severe, while carrying out their daily work activities. The questionnaire consists of 28 body parts, and the results are used to analyze patterns of complaints and determine the areas of the body that are most prone to disorders. A total of ten workers participated in the direct measurement process, consisting predominantly of male workers aged between 19 and 45 years who were actively involved in the material handling process. To ensure that the anthropometric data obtained could be used as a valid reference for ergonomic design, additional anthropometric data from laboratory measurements were used. This combination aimed to provide a more comprehensive and representative dataset reflecting the physical characteristics of workers in general. In addition, work posture assessments are conducted using the REBA (Rapid Entire Body Assessment) method to determine the ergonomic risk level of workers' postures when performing their main activities. Documentation in the form of photos or videos is taken when workers perform activities such as lifting, moving, or carrying loads. Each part of the body from the neck, back, arms, to the legs is analyzed and scored based on the criteria set out in the REBA method. A higher score indicates a greater level of ergonomic risk and requires immediate corrective action.

Biomechanical analysis was conducted to assess the physical workload on workers' bodies during production activities, particularly during the furnace filling and emptying processes. This analysis used Ergoniza software to calculate the compressive force on the L5–S1 spine, load bearing conditions, and the percentage of the body's joints' ability to support the workload. Work posture data was obtained through photo and video documentation of field observations, then analyzed based on the phases of work activity. The analysis results were presented in tabular form to illustrate the distribution of biomechanical loads on each part of the worker's body. To support the design of work facilities, workers' body dimensions were measured using field anthropometry methods. The parameters measured included standing elbow height, shoulder width, and hand width, as these are directly related to the comfort of using worktables and trolleys. Measurements were taken using a tape measure and anthropometric ruler on several workers representing the population. The data obtained was then statistically processed to determine the mean, standard deviation, BKB, BKA, and 50th percentile as the basis for ergonomic design.

By combining these various data collection methods, this study is expected to produce comprehensive, accurate findings that reflect actual working conditions in the field. Each method plays a complementary role: observation provides a realistic picture of work behavior, the NBM questionnaire reveals workers' subjective perceptions of physical complaints, the REBA method objectively assesses posture risks, biomechanical analysis using Ergoniza software measures mechanical loads on the body, while anthropometric measurements provide a basis for designs that are appropriate for the physical characteristics of workers at the research site.

2.3. *Data Analysis*

The data obtained from field collection was systematically analyzed to provide a comprehensive picture of workers' working conditions and to serve as the basis for designing ergonomic work facilities. The analysis process was carried out in stages according to the type of data collected, including the results of the Nordic Body Map (NBM) questionnaire, observation data and scores from the Rapid Entire Body Assessment (REBA) method, and anthropometric data measured directly from workers at the Medan Briquette House. The NBM questionnaire data from each respondent was summarized and classified based on the body part experiencing pain. Each body part was given a score according to the severity or intensity of the pain reported. The higher the frequency of complaints in a body part, the more attention needed to be given to that area. The processed data was then presented in the form of frequency tables and bar charts to show the body parts that experienced the most complaints. This analysis aimed to identify critical points that were the center of excessive physical workload.

Work posture data was analyzed using the REBA method based on photographs and videos of workers' main activities, such as lifting and moving materials. Each body part was evaluated and scored according to the guidelines, covering Segment A (neck, back, legs) and Segment B (upper arms, forearms, wrists), taking into account the load, frequency, and type of grip. The analysis results produced a total REBA score that indicated the level of ergonomic risk. In addition, anthropometric data such as standing elbow height, shoulder width, and hand width were processed to obtain the mean, standard deviation, BKB, BKA, and 50th percentile as the basis for designing work tools that were suitable for the workers' body characteristics. Biomechanical evaluations were conducted using Ergoniza software to assess the physical load on workers' bodies during work activities. This analysis included calculations of compression forces on the spine (L5–S1), body load conditions, and the capacity of major joints to support loads, such as the shoulders, elbows, hips, knees, and ankles. Work posture data obtained from photo and video documentation was then entered into Ergoniza to produce quantitative values that describe the level of biomechanical load and potential ergonomic risks in each work activity.

All analysis results from the three methods, namely NBM, REBA, and anthropometry, were used in an integrated manner as the basis for designing ergonomic hydraulic trolley tables. By combining subjective data from pain complaints, objective data from work posture assessments, and physical data from workers' body measurements, the resulting design is expected to address existing work problems, improve comfort, and reduce the risk of musculoskeletal disorders in the work environment of the Medan Briquette House MSME.

2.4. Work Facility Design

Based on the results of the data analysis obtained, a hydraulic trolley table was designed as a work facility to replace the manual material transfer process. Findings from body complaint analysis using NBM, assessment of work posture risk levels through the REBA method, and worker body dimension data obtained from anthropometric measurements formed the main basis for determining the specifications and design of the tool. The trolley table is designed with a work surface that can be adjusted in height using a hydraulic system, allowing workers to adjust their working position to elbow height to avoid bending over and reduce pressure on the back and shoulders. In addition, the trolley is equipped with wheels at the bottom so that materials can be moved by pushing rather than lifting, significantly reducing the physical strain on workers. This design is not only focused on improving comfort and occupational health, but also considers functionality and efficiency in the MSME work environment. The presence of hydraulic trolley tables is expected to make the process of moving materials safer and more efficient, as well as reducing excessive physical strain on workers.

3. Results and Discussion

3.1. Results of physical complaint identification using the Nordic Body Map (NBM)

This subsection presents the physical complaints reported by workers using the Nordic Body Map (NBM) questionnaire. The results obtained facilitate the identification of body regions most affected by manual material handling activities and provide a foundation for the implementation of ergonomic interventions. The distribution of complaints is illustrated in Figure 1 and detailed in Table 1.

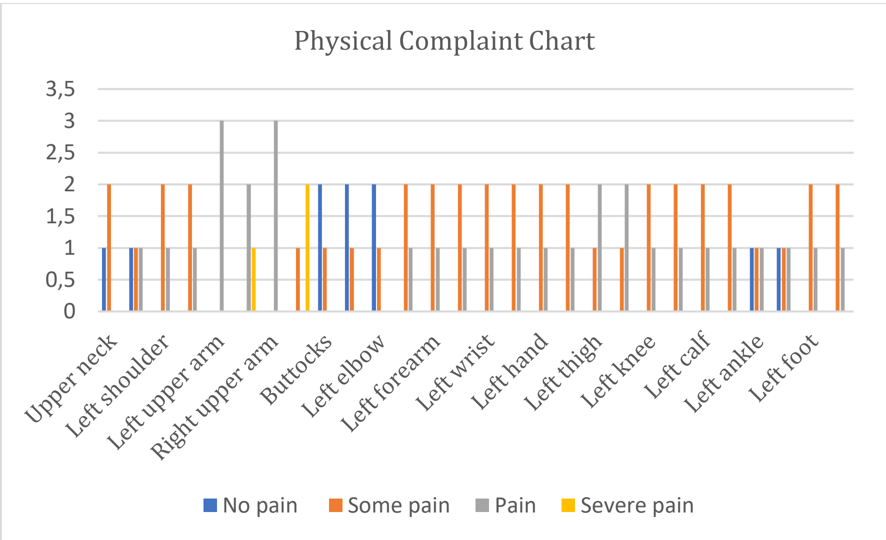


Figure 1. Physical Complaint Chart

The results of the NBM indicate that the waist is the body part that experiences the highest level of discomfort, categorised as being in the painful to very painful category. It is also notable that a significant number of complaints are reported in relation to the shoulders, lower neck, upper arms, forearms, and wrists. This finding suggests that the upper body is under excessive strain due to repetitive lifting, carrying, and forward-bending postures. Meanwhile, complaints in the knees, calves, or ankles are indicative of prolonged standing, squatting, or load-bearing during furnace operations. In contrast, body parts such as the elbows, hips, and buttocks demonstrate low discomfort levels, indicating that these areas are less involved in the primary material-handling tasks. The distribution of complaints over the waist and shoulders is consistent with the manual transfer of heavy loads and frequent bending, suggesting significant ergonomic risks in current work practices. It is evident from the findings that the design of ergonomic work facilities is of crucial importance in minimising bending, reducing manual lifting, and lowering pressure on both the upper and lower body.

Table. 1 Nordic Body Map Questionnaire Results

No	Body Part	No pain	Some pain	Pain	Severe pain
0	Upper neck	1	2	0	0
1	Lower neck	1	1	1	0
2	Left shoulder	0	2	1	0
3	Right shoulder	0	2	1	0
4	Left upper arm	0	0	3	0
5	Back	0	0	2	1
6	Right upper arm	0	0	3	0
7	Waist	0	1	0	2
8	Buttocks	2	1	0	0
9	Buttocks	2	1	0	0
10	Left elbow	2	1	0	0
11	Right elbow	0	2	1	0
12	Left forearm	0	2	1	0
13	Right forearm	0	2	1	0
14	Left wrist	0	2	1	0
15	Right wrist	0	2	1	0
16	Left hand	0	2	1	0
17	Right hand	0	2	1	0
18	Left thigh	0	1	2	0
19	Right thigh	0	1	2	0
20	Left knee	0	2	1	0
21	Right knee	0	2	1	0
22	Left calf	0	2	1	0
23	Right calf	0	2	1	0
24	Left ankle	1	1	1	0
25	Right ankle	1	1	1	0
26	Left foot	0	2	1	0
27	Right foot	0	2	1	0

3.2. Work Posture Assessment Using the REBA Method

Following the identification of physical complaints, the postures of workers were evaluated using the Rapid Entire Body Assessment (REBA) method. Figure 2 and Table 2 provide a summary of the REBA scores for the five primary material-handling postures.

Table 2. REBA Score

No	Working Posture	Skor
1	Lifting charcoal while bending over	11
2	Lifting charcoal while standing	10
3	Lifting flour paste while standing	10
4	Lifting charcoal grinder while bending over	10
5	Lifting flour paste while bending over	9

The postures which have undergone evaluation are all found to be within those which are categorised as high or very high risk, with a range of scores from 9 to 11 being demonstrated. It is evident that postures involving bending while lifting charcoal and flour paste result in the highest scores. These movements require forward flexion, asymmetric loads and unsupported trunk positions, all of which contribute to increased musculoskeletal strain. These findings are highly congruent with the NBM results, in which waist and shoulder complaints were predominant. Crucially, the high REBA scores indicate an urgent need for improvements in ergonomic design.

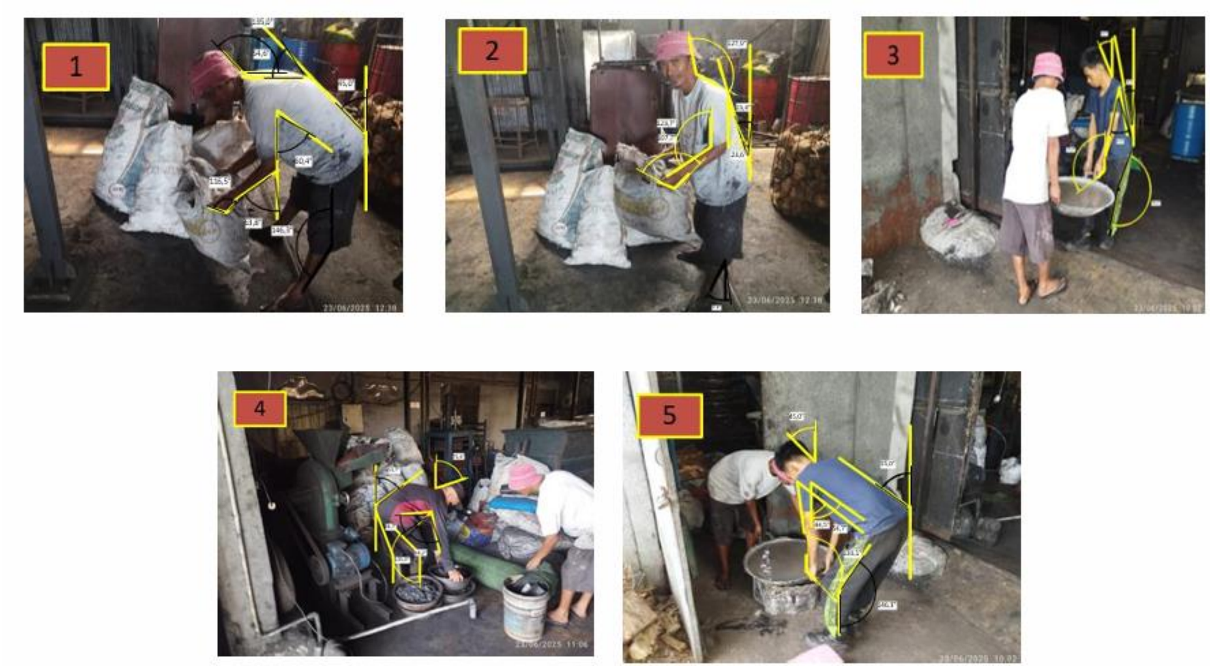


Figure 2. Posture Analysis using REBA

The significant discomfort experienced in the waist, shoulders, and neck, as indicated by the NBM assessment, corresponds with the findings reported by Oesman et al. (2019). These researchers observed a strong correlation between trunk flexion and unsupported lifting with increased lower-back and upper-body complaints. In addition, the elevated REBA scores (9–11) documented in this study corroborate the conclusions of Han et al. (2023), who underscored that lifting tasks involving substantial loads and unnatural postures invariably fall into the high–very high risk categories and necessitate immediate ergonomic intervention.

3.3. Anthropometric Data Processing for Designing Hydraulic Trolley

Anthropometric data processing was conducted to obtain worker body measurements relevant to the design of work facilities. In this study, the body dimensions measured included standing elbow height, shoulder width, and hand width, as these three dimensions are directly related to the height, width, and operational area of the hydraulic trolley table to be designed. The data was obtained through direct measurements of a number of workers at the research site. Additional dimensions were also measured to assist in biomechanical analysis. The results of the anthropometric data calculations are as follows.

- Data Normality Test, Mean and Standard Deviation Calculation

  The anthropometric data obtained from measurements taken from craftsmen was then processed by calculating the mean, standard deviation, maximum value, and minimum value for each dimension required in the tool design. The data can be seen in Table 3.

Table 3. Average Value and Standard Deviation of Each Body Dimension

Description	D4	D14	D17	D20	D19	D22	D23	D29
N	68	68	73	69	68	68	72	68
Average	74,02	44,34	42,58	19,37	33,03	33,12	42,16	11,33

Standard Deviation	2,52	7,94	4,12	2,88	3,95	2,67	4,88	0,58
Min	65	37	34	14	24,8	27,5	32,9	11
Max	80	51	50	25	41,5	39	50,9	16

Based on Table 3, which shows the mean and standard deviation of each body dimension, it can be concluded that the anthropometric data obtained is normally distributed. This is supported by the proportional comparison between the mean and standard deviation for each variable, as well as the minimum and maximum value ranges that are symmetrical around the mean value. These values can be seen in Figure 3.

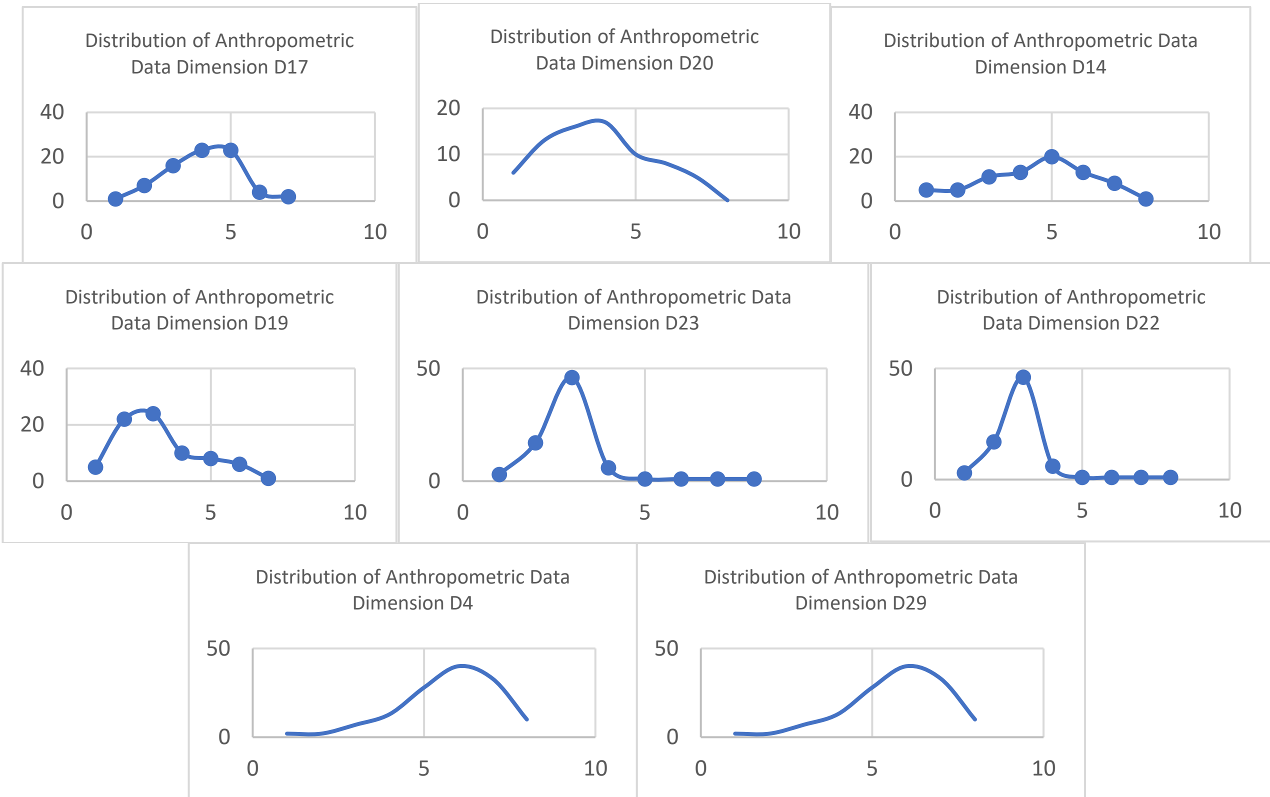


Figure 3. Graph of Anthropometric Dimension Data Distribution

- Data Uniformity Test
  Data uniformity tests are used to determine whether the collected data has a homogeneous distribution to ensure consistency and reliability in statistical analysis. In data uniformity tests, data that is outside the control limits will be discarded, then the calculations are repeated until the data becomes uniform. Data uniformity tests can be seen in the Figure 4.

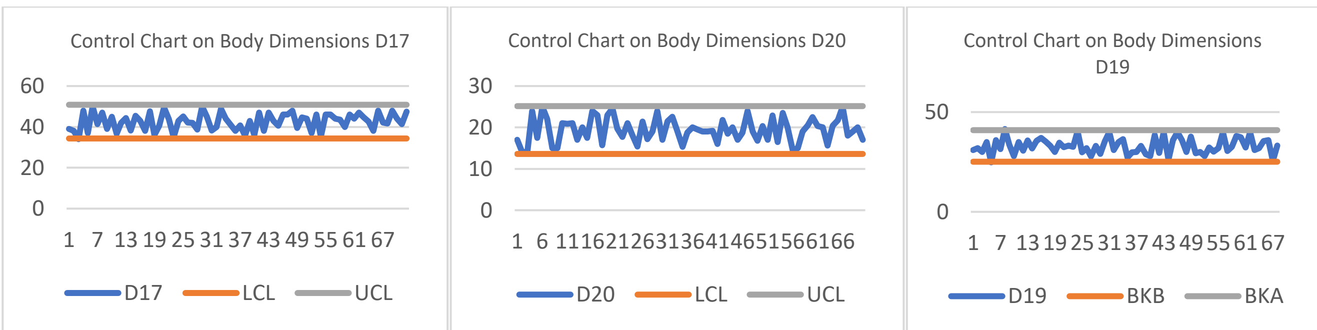


Figure 4. Graph of Control Chart on Body

After obtaining uniform anthropometric data, anthropometric data processing was carried out. Anthropometric data processing was carried out to obtain worker body measurements relevant to the design of work facilities. In this study, the body dimensions measured included standing elbow height, shoulder width, and hand width, as these three dimensions are directly related to the height, width, and operational area of the hydraulic trolley table to be designed. The data was obtained through direct measurements of a number of workers at the research site. The measurement results were then processed using descriptive statistical analysis to obtain the mean, standard deviation, lower limit (LCL), upper limit (UCL), and 50th percentile. The 50th percentile was used as the main reference in the design, as it was considered to best represent the body size of the majority of the worker population in general. The results of the anthropometric data processing used in the design of the hydraulic trolley table work facility can be seen in Table 4.

Table 4. The results of anthropometric data processing used in the design.

Body Dimensions	**Persentil 50th**
D4	74,02
D14	44,34
D17	42,58
D20	19,37
D19	33,03
D22	33,12
D23	42,16
D29	11,33

3.4. Biomechanics Analysis

Biomechanical analysis was performed using Ergoniza software to evaluate the physical load on workers' bodies during production activities, particularly during the filling and emptying of furnaces. Work posture data obtained through photo and video documentation was analyzed based on the phases of work activities. Before performing biomechanical angle analysis, 50th percentile anthropometric data is first mapped into body image dimension variables (link length) that will be used in the calculations. Based on Table 3, the 95th percentile value for each dimension is calculated and entered into the variables as follows: Height (D14) is allocated to the Lf variable, sitting height (D20) is allocated to the Lc variable, upper arm length (D19) is allocated to the Lt variable, and lower arm length (D22) is allocated to the Lp variable. Furthermore, lower leg length (D23) is also allocated to the variable Lp, while shoulder width or arm span (D17) is mapped to the variable La or Lma. Thus, all key anthropometric variables have been filled in and are ready for use in further biomechanical modeling.

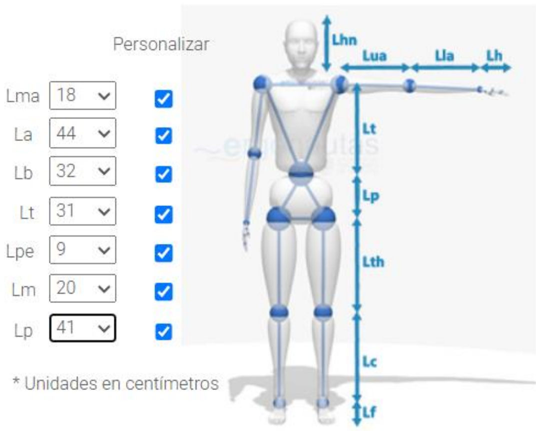
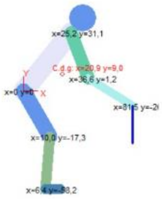
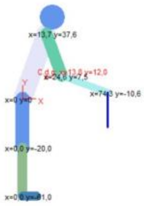
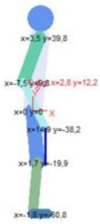
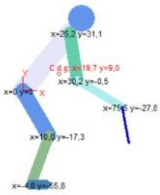
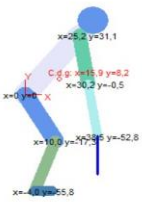


Figure 5. Body Segmentation According To Anthropometric Data

The biomechanical analysis can be seen in Table 5. There are significant variations in the level of stress on the joints of the body during the performance of tasks. The stress on the wrist and elbow joints is still within safe limits, with percentages of 36% and 39% respectively. However, some joints experience stress that exceeds the maximum permissible capacity. The Shoulder joint bears a load of 80%, which is approaching the limit, while the most critical are the loads on the Back/L5/S1 and Hip joints, which have exceeded safe limits with percentages of 111% and 103%, respectively. The graph illustrating these conditions can be seen in Figure 6.

Table 5. Biomechanics Analysis Posture

Angle Assessment	Force Analysis	Description
		Lifting charcoal while bending over
		Lifting charcoal while standing
		Lifting flour paste while standing
		Lifting charcoal grinder while bending over
		Lifting flour paste while bending over

These biomechanical analysis results, demonstrating excessive loading at the L5/S1 joint, further corroborate the conclusions of Hita-Gutiérrez et al. (2020), who identified lumbar compression forces as a significant contributing factor to musculoskeletal disorders in occupations involving repetitive lifting. The pattern of discomfort and joint overload identified in this study bears a strong resemblance to the observations made by Adiyanto et al. (2022), who found that manual material-handling workers exhibited the highest levels of strain in the waist and shoulders.

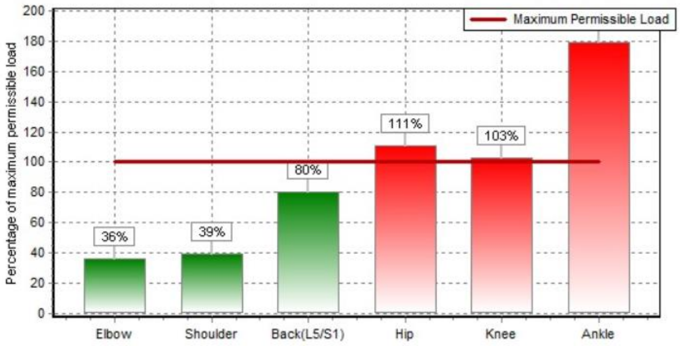


Figure 6. Biomechanical Analysis Result

3.5. Work Facility Design

The development of the hydraulic trolley table was a direct response to the findings from a range of analyses, including NBM, REBA, anthropometry, and biomechanical analysis. The NBM results demonstrated that the waist, shoulders, and arms were the most frequently reported areas of discomfort, consistent with previous findings that manual handling tasks significantly contribute to musculoskeletal complaints (Adiyanto et al., 2022; Safithry et al., 2023). The REBA assessment also revealed high-risk postures, with scores ranging from 9 to 11, emphasising the necessity for immediate ergonomic intervention. This finding is consistent with the conclusions drawn by Hita-Gutiérrez et al. (2020) and Sirikasemsuk et al. (2024), who asserted that elevated REBA scores indicate the imperative for prompt corrective measures.

It was determined that manual material handling, specifically lifting, bending, and carrying, constituted the primary source of physical strain. Consequently, the hydraulic trolley table was designed to address these specific risks by leveraging established ergonomic principles, the resulting hydraulic trolley table design is presented in Figure 7.

1. Minimizing trunk flexion

The height-adjustable hydraulic mechanism is based on the 50th-percentile standing elbow height from anthropometric measurements, ensuring workers maintain neutral postures. As Kurnia (2024) and Rodríguez et al. (2021) have previously highlighted, the importance of ensuring proper dimensional alignment between tools and the body size of the user is paramount in order to prevent musculoskeletal load. These scholars have also emphasised the value of employing anthropometry-based design methods in this regard.

2. Reducing manual lifting by facilitating the adoption of push-pull transport methods.

The substitution of lifting with pushing using a wheeled trolley is consistent with the manual material handling guidelines reported by Fauzi (2024), who observed that excessive lifting and carrying can lead to increased spinal and shoulder loads. This design is also consistent with the findings of biomechanical studies, which demonstrate that a reduction in direct load handling significantly reduces the risk of injury (Han et al., 2023; Maharani et al., 2024).

3. It is important to ensure that the reach and clearance are appropriate, taking into consideration the width of the shoulders and hands.

The design dimensions, derived from anthropometric data, ensure safe reach distances and comfortable working spaces. It is notable that analogous anthropometric-based ergonomic redesign approaches have been successfully implemented in the domain of furniture and workstation design (Septian et al., 2023; Imdam et al., 2024).

The following discussion will consider what the expected ergonomic impact is. The design decisions that have been made are not merely descriptive; rather, they directly respond to quantified ergonomic risks. It is anticipated that the hydraulic trolley table will:

1). The primary goal is to minimize trunk flexion and shoulder loading, as supported by the REBA and biomechanical analysis.

2). As observed in intervention studies involving ergonomic redesigns (Oesman et al., 2019; Anindhita, 2024), there is a concomitant reduction in MSDs prevalence.

3). It is important to reduce the physical burden associated with manual material handling (Fauzi, 2024; Safithry et al., 2023).

Despite the fact that the trolley table has not yet been fabricated, the design offers a strong evidence-based ergonomic concept that can be prototyped and further validated in future research. The integration of NBM, REBA, anthropometry, and biomechanical analysis ensures that the proposed tool directly targets the primary sources of worker musculoskeletal risk identified in the study.

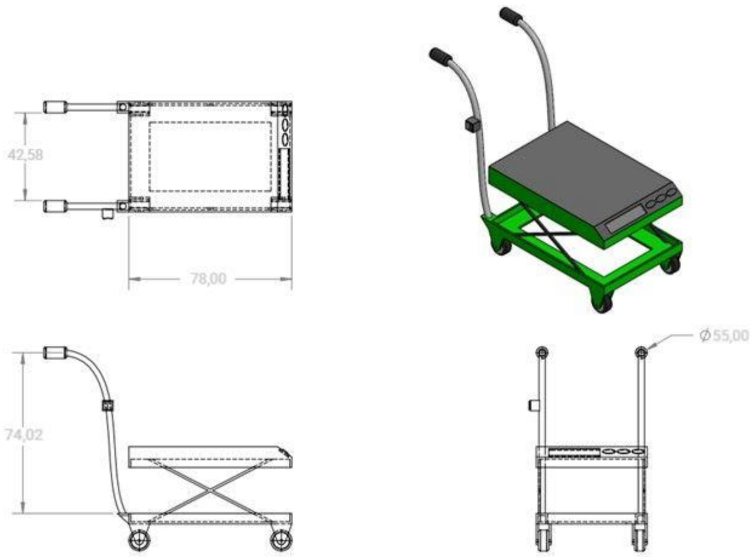


Figure 7. Hydraulic Trolley

4. Conclusions

This study establishes that the primary ergonomic hazards in SMEs like Rumah Briket Medan are attributable to repetitive and force-intensive manual material handling in non-neutral postures during the production of briquettes. The integrated assessment, incorporating the Nordic Body Map, REBA, anthropometric data, and biomechanical simulation, indicates that trunk flexion and manual lifting are the predominant contributors to musculoskeletal strain, with the waist, shoulders, and arms identified as the most affected regions. Biomechanical analysis via Ergoniza further confirms excessive loading on the L5/S1 vertebra and the hip joints, which exceeds the recommended safety thresholds.

The principal conclusion of this research is that an evidence-based ergonomic intervention, specifically a hydraulic trolley table designed according to the 50th-percentile standing elbow height, offers a theoretically sound approach for reducing hazardous postures and biomechanical demands. From a scientific perspective, the present work makes a significant contribution in the form of a structured multi-method evaluation framework. This framework is directly applicable in informing ergonomic design decisions. In practice, it provides a viable strategy for SMEs to mitigate the risks associated with musculoskeletal disorders and to support safer material-handling practices.

The study is constrained by two factors: first, the omission of a prototype implementation, and second, the lack of a post-intervention measurement. It is recommended that future research include the fabrication and field evaluation of the proposed design, as well as its adaptation to other industrial contexts involving similar manual handling characteristics.

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