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A Feasibility Study on the Conversion from Manual to Semi-Automatic Material Handling in an Oil and Gas Service Company

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Abstract: In manufacturing companies, manual material handling (MMH) involves lifting, pushing, pulling, carrying, moving, and lowering objects, which can lead to musculoskeletal disorders (MSDs) among workers, resulting in high labor costs due to excessive overtime incurred for manual product preparation. The aim of this study was to show how ergonomic measures were used to reduce the risk of MSDs and to reduce operating costs in the warehouse department of an oil and gas service company. A preliminary study using the Nordic Body Map survey showed that the workers experienced pain in various parts of the body, indicating the presence of MSDs. The researchers then used methods such as the Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and National Institute for Occupational Safety and Health (NIOSH) assessments to verify whether the MMH activities had an acceptable level of risk. The results revealed that certain manual material handling (MMH) activities were assessed as low–very high risk, with RULA scores ranging from 3 to 7 and REBA scores ranging from 4 to 11. An immediate solution was to replace the manual process with a semi-automatic process using a vacuum lifter. A feasibility study was conducted using the net present value (NPV), internal rate of return (IRR), and payback period to justify the economic viability of the solution. The analysis indicated that implementing the vacuum lifter not only mitigated the risk of MSDs but also reduced the operating costs, demonstrating its viability and profitability. Overall, this study suggests that implementing a vacuum lifter as an assistive device in the warehouse would be a beneficial investment for both the workers and the company, improving both well-being and finances.

Keywords: manual handling; musculoskeletal diseases; risk assessment; ergonomics; feasibility studies; occupational health; workplace; occupational exposure; occupational injuries

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1. Introduction

Manual material handling (MMH) is the process of moving goods or items from the point of origin to the point of destination (or vice versa) using muscle power [1]. In many companies, MMH is used to support various activities, including the loading and unloading of heavy items, which can cause muscle strains or musculoskeletal disorders (MSDs) in workers. As it consists of manual activities, MMH depends on the performance of the workers, resulting in a slower process compared to automatic or even semi-automatic processes supported by automatic machines or tools. The result is often not satisfactory, especially when a company is faced with high demands and a tight schedule.

Several studies have investigated the conversion from manual to semi-automatic material handling in different industries [2–6]. However, few studies have assessed the ergonomic risk and economic feasibility of such a conversion from manual to semi-automatic material handling.

This study was conducted on an oil and gas service company in Indonesia. The main activity of the company is to provide services to other companies for oil and gas projects. The company has several departments, including a storage department. In this department, the workers mainly take care of the management of the warehouse products, and the two main activities are shipping and receiving. There are only four warehouse workers, and all four of these workers are male. Products are delivered from international and domestic suppliers to be stored in the warehouse before being prepared and sent to oil and gas project sites. Before a product is delivered to the customer, it must be prepared by the warehouse workers to meet the customer's requirements. MMH is needed for such activities to move the products from the warehouse to the packaging center. Currently, the product preparation process is carried out manually, without any tools, which has resulted in workers experiencing pain and the risk of developing MSDs [7,8].

Ergonomic tools and techniques such as the RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment), and the NIOSH (National Institute for Occupational Safety and Health) lifting equation are used to assess current work practices [9]. The NIOSH lifting equation is a tool developed to assess the risk of lifting tasks in terms of lower-back injuries, and it is widely accepted and used throughout industry in setting acceptable lifting limits for workers [10,11]. The RULA is a survey approach designed for use in workplace ergonomics investigations where work-related upper-limb disorders are reported [12]. The REBA is a tool designed to facilitate the measurement and assessment of risks associated with work posture in the context of ergonomic workload [13,14].

In addition, the company sees high labor costs due to overtime and low productivity [15]. Therefore, the company needs to explore the possibility of investing in equipment to reduce the workload of the workers. By investing in equipment and changing the current manual process to a semi-automatic process, the company could improve product preparation and possibly reduce the risk of MSDs.

The sub-objectives of this study were as follows: to identify risks in MMH warehouse activities that need to be addressed due to the high risk of MSDs, to find a solution that can reduce the risk of MSDs while improving worker performance for the benefit of the company, and to re-evaluate the risk.

The following assumptions were made in this research: all workers were assumed to be working at their normal pace, posture, and workload, and to adhere to work procedures. The data and information on the price and performance of the equipment used in this research were based on the market conditions at the time of the study.

1.1. Musculoskeletal Disorder

A musculoskeletal disorder (MSD) is a type of long-term injury that affects the human musculoskeletal system, which includes muscles, ligaments, and nerves [16]. MSDs can occur in any part of the body, depending on the activity, and can be caused by incorrect sitting posture, heavy lifting, and repetitive movements [17–22]. MSD symptoms that are ignored can worsen and lead to disability, causing physical strain, discomfort, and psychological stress [16,23].

Work-related MSDs (WMSDs) can be caused by poor workplace design that is inappropriate, unsafe, and non-ergonomic [24]. To prevent WMSDs, an ergonomically designed workplace is important, which eliminates tasks, the use of tools or machines, and workloads that cause physical strain and affect the health of workers [25,26]. Work activities that can lead to WMSDs include manual material handling, repetitive movements, awkward and static postures, sitting or standing in the same position for long periods, high-force use, and the use of tools with strong vibration [25]. It is important to note that workplace events responsible for trips, falls, or slips are not WMSDs but accidents, which are different because WMSDs do not occur immediately.

1.2. Manual Material Handling (MMH)

Manual material handling (MMH) involves lifting, carrying, and moving objects, and can lead to musculoskeletal disorders (MSDs) if not properly managed [27,28]. Workers engaged in MMH are often exposed to multiple tasks, increasing their risk of injury [29]. Proper workplace design is crucial in preventing MMH-related injuries and requires consideration of factors such as mass and ergonomics [30]. MMH tasks can be repetitive and performed with awkward postures, leading to muscle and nerve fatigue [30]. It is important for companies to assess the risks of MMH and implement appropriate restrictions and policies to prevent accidents and MSDs.

1.3. Ergonomic Assessment Tools

Ergonomic assessment tools evaluate the risk levels for workers performing tasks in their work environment. Ergonomic assessment tools aim to identify risk factors and reduce them, promoting a safe and comfortable workplace that benefits workers' well-being. Based on the tools' findings, a company can implement changes such as providing aids, correcting awkward postures, or modifying the workplace to improve its ergonomics.

Various ergonomic methods are used for assessing the risk of MSDs, including self-reports, simple observational methods, advanced observational techniques, and direct methods [31]. Simple observational methods are inexpensive and easy to use in various workplaces. Common tools in this category include the RULA, the REBA, and the NIOSH lifting equation.

The RULA assesses the ergonomic conditions of work positions that use the upper limbs of the human body. The result includes a RULA score that indicates the level of risk and may require intervention to prevent injury in the work area [32,33].

The REBA is useful for analyzing the whole body in various movements and is very sensitive to sudden or unpredictable postures [34,35]. It accounts for several factors that influence the work process, including posture, force/load, coupling/handling, and repetitive actions, to determine a representative score for each factor [13].

The NIOSH lifting calculation tool estimates risks based on lifting weights, distance, multipliers, angles, coupling, and work duration, and provides a weight limit result for MMH activity [27,36,37]. The calculation helps prevent the risk of MSDs—particularly for the lower back and back due to lifting weights—and helps determine the need for additional aids to support workers during the activity in question.

Assessment of MMH activities should include all related activities—not just lifting [27].

1.4. Engineering Economics Analysis

Ergonomics interventions have been found to improve productivity, quality, and profitability while reducing rejection costs [38–40]. To evaluate the effectiveness of such interventions, it is essential to track costs, revenues, and benefits over time. Engineering economic analysis, which considers costs, revenues, and benefits at different points in time, can be used to identify worthwhile projects for investment, prioritize projects, and make decisions about investments [41]. Commonly used metrics for such analysis include the net present value (NPV), internal rate of return (IRR), and payback period [41–43].

NPV is a method of valuing all cash flows related to an investment over a given period to calculate its economic value, while IRR calculates the return on investment and is profitable if it is greater than the minimum attractive rate of return (MARR) used in NPV analysis. The payback period determines the time it takes for the total benefits to equal the total costs of the investment, and a shorter payback period is generally preferable [41].

This study aims to demonstrate the use of ergonomic techniques—such as the RULA, REBA, and NIOSH assessments—to minimize the risk of musculoskeletal disorders and reduce the operating costs associated with MMH operations.

2. Research Method

The sub-objectives of this study were as follows: to identify risks in MMH warehouse activities that need to be addressed due to the high risk of MSDs, to find a solution that can reduce the risk of MSDs while improving worker performance for the benefit of the company, and to re-evaluate the risk. The study size was limited by the number of available participants, as only four male workers were employed in the warehouse department of the oil and gas company. These workers were responsible for incoming and outgoing products as well as administrative tasks, and they were the only ones working in the warehouse at the time of the study. Therefore, the study included all four available workers in the warehouse department. All subjects were aged between 30 and 40 years, with a mean age of 35 years.

The study was conducted at a warehouse of an oil and gas service company in Cikarang, Bekasi, Indonesia. The data collection took place over a period of 3 months, from 10 January 2022 to 10 April 2022.

Recruitment took place during the first month of data collection, where workers in the warehouse were approached and provided with information about the study. Workers who met the eligibility criteria and provided their informed consent were then included in the study.

The exposure period was the entire duration of the study, during which the participants were observed during manual material handling activities. The follow-up period was not applicable in this study, due to the cross-sectional study design.

Data collection involved the use of multiple tools, including the Nordic Body Map questionnaire, RULA, REBA, and the NIOSH lifting equation. Data were collected at the warehouse during regular working hours. The study team ensured that the participants were not interrupted during their regular work routines and that the observations did not interfere with their work tasks.

The eligibility criteria for the participants in this study included being currently employed at the warehouse and having at least 6 months of experience in manual material handling tasks. In addition, the participants were required to be healthy, without any pre-existing physical or mental illnesses or severe injuries that could potentially affect their musculoskeletal system or performance during manual material handling activities. The selection of the participants involved obtaining consent from the company and selecting the four workers in the warehouse who met the eligibility criteria.

The diagnostic criteria for the selection of participants in this study included the absence of pre-existing physical illnesses (such as high blood pressure, heart disease, diabetes, or asthma), pre-existing mental illnesses (such as depression, anxiety disorders, bipolar disorder, schizophrenia, or post-traumatic stress disorder (PTSD)), and severe pre-existing injuries (such as spinal cord injury or amputation). These criteria were used to ensure that the participants did not have any underlying health issues that could affect the study's results. A survey was conducted using the Nordic Body Map questionnaire (Appendix A). This questionnaire was used to identify workers' complaints about their physical discomfort during work. The data were analyzed using descriptive statistics such as cumulative scores and averages, which served as indications of the pain levels experienced by the workers in order to verify the presence of the problem (i.e., MSD) and provide support for the next course of action, which included further data collection for the RULA, REBA, and NIOSH assessments. This questionnaire has been used successfully in several studies of workers in the teaching industry [44,45], the metalworking industry [46], the waste collection industry [47], and the semi-automatic packaging industry [48].

The next step was to collect data on MMH activities in the warehouse. Data collection included taking photos of each activity, as well as measuring the weight of material loads, distance, repetition, and other necessary information for data analysis. Once the data were ready, the analysis was performed using the tools to determine the severity of each activity in the warehouse operation. The RULA, REBA, and NIOSH lifting calculations were used to analyze the work activities. These tools are ergonomic assessment tools that can be used to assess workers' activities. The RULA and REBA final scores indicate the levels of risk to which workers are exposed in each activity. As defined by previous studies [49,50], the interpretation of the RULA and REBA scores based on the level of MSD risk can be found in Table 1.

Table 1. The interpretation of the RULA and REBA scores by level of MSD risk.

Score	Level of MSD Risk
RULA	
1–2	Negligible risk, no action needed
3–4	Low risk, change might be required
5–6	Medium risk, further investigation, change soon
6+	Very high risk, implement change immediately
REBA	
1	Negligible risk, no action needed
2–3	Low risk, change might be required
4–7	Medium risk, further investigation, change soon
8–10	High risk, investigate, implement change
11+	Very high risk, implement change

The MMH activity associated with lifting was assessed using the NIOSH lifting equation, which calculates whether the current weight lifted exceeds the recommended load. The formulation of the recommended weight limit (*RWL*) used for the NIOSH lifting equation is as follows:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

where

LC: Load constant;
HM: Horizontal multiplier;
VM: Vertical multiplier;
DM: Distance multiplier;
AM: Asymmetric multiplier;
CM: Coupling multiplier.

The formulation for the lifting index (*LI*) is as follows:

$$LI = \frac{Load\ Weight}{RWL} \quad (2)$$

After the analyses were performed, a recommendation for improvement was suggested to recover the energy spent on the current activity so that it complied with ergonomic principles. Even if there was more than one activity that required improvement, a priority list of improvement activities was drawn up to solve the problem efficiently. This priority list was used to select which of the problems should be solved.

The next step was to determine the right equipment to reduce the risk of MSDs. The selection of alternative equipment was based on availability in the market. The price, maintenance, and service life information were based on the information received from the suppliers.

The feasibility study was carried out using NPV, IRR, and payback time. From an ergonomic point of view, the improvement in the form of a specific tool is necessary, but the feasibility of the investment is important to justify that the improvement will actually have a positive impact on the company as a whole [42].

Figure 1 shows the research framework for this study. The first step in conducting the research was observation. The first observation was conducted in the warehouse department by observing the activities of the workers. The main activities of the warehouse department were divided into two categories, i.e., shipping and receiving products. These two activities are carried out and processed by the workers through various tasks related to warehouse management.

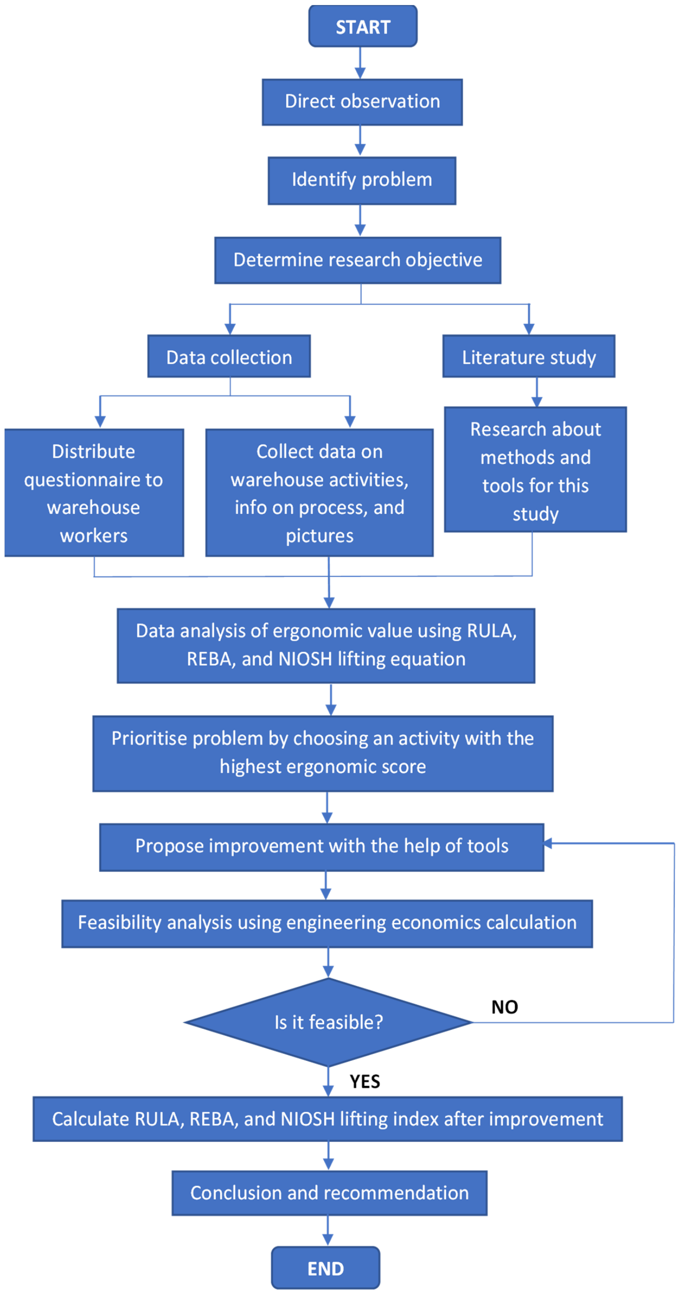


Figure 1. Research framework.

In the efforts to address potential bias, the workers were informed about the study and its purpose, and they were assured that their participation was voluntary and anonymous. To reduce the potential for measurement bias, the members of the research team who conducted the assessments were trained in the use of the assessment tools prior to conducting the assessments. Finally, to minimize the potential for observer bias, the research team members were blinded to the study's potential outcomes and were not involved in the development of the study intervention. These measures were taken to ensure the integrity and validity of the study's results.

3. Results and Discussion

3.1. Data Analysis

The first step in this research was to identify the level of risk experienced by workers. The Nordic Body Map questionnaire responses, completed by all four workers working in the warehouse (a response rate of 100%), were collected as an indication of the level of pain experienced by the workers. Further analysis of the work activities included the RULA, REBA, and NIOSH lifting calculations. The final RULA and REBA scores were used to infer the degree of risk to which workers were exposed in each activity, and the NIOSH lifting calculation determined whether the current weight lifted exceeded the recommended load. Table 2 shows the results of the Nordic Body Map questionnaires. The table shows the scores in descending order to indicate who had the highest scores. An example of the Nordic Body Map questionnaire can be found in Appendix A.

Table 2. Nordic Body Map results.

Body Part	Nordic Score	Average Score	Body Part	Nordic Score	Average Score	Body Part	Nordic Score	Average Score
Right shoulder	12	3.75	Left shoulder	10	3.00	Left hand	7	1.75
Left upper arm	12	4.00	Left knee	10	2.50	Lower neck	6	1.75
Right upper arm	12	4.50	Back	9	2.50	Left elbow	6	2.00
Waist	12	4.75	Left ankle	9	2.25	Buttock	5	3.25
Right lower arm	12	3.75	Right ankle	9	2.25	Left foot	5	1.25
Upper neck	11	2.75	Right hand	8	2.00	Right foot	5	1.25
Left lower arm	11	2.75	Left calf	8	2.00	Bottom	4	3.25
Left wrist	11	2.75	Right calf	8	2.00	Left thigh	4	1.00
Right wrist	11	2.75	Right elbow	7	2.00	Right thigh	4	1.00
Right knee	11	2.75						

The Nordic score denotes the cumulative score of all four warehouse workers. The average score denotes the average of the scores given by all four warehouse workers. With a cumulative score of 12, the right shoulder (average score = 3.75), left upper arm (average score = 4.00), right upper arm (average score = 4.5), waist (average score = 4.75), and right lower arm (average score = 3.75) received the highest ratings, as shown in Table 1. The upper neck, left lower arm, left wrist, right wrist, and right knee received cumulative scores of 11. These findings revealed that additional analyses were required to support and choose the best course of action.

3.2. Workers' Overtime Hours and Cost

Further observations revealed that there was a lot of overtime in the warehouse department. The work routines in the warehouse were not only detrimental to the workers in terms of overtime, but also detrimental to the company, as the wages for overtime are higher than for regular working hours. This situation increased the company's expenses, as management had to meet the product preparation schedule. Data on workers' overtime were collected from the September–October 2021 schedule report (see Table 3).

Table 3. Average overtime hours per month.

	Warehouse Worker 1	Warehouse Worker 2	Warehouse Worker 3	Warehouse Worker 4
Overtime (hours)	34	33	34	31
	Total overtime hours			132

A total of 132 h of overtime were recorded for the four workers per month. The cost per hour was IDR 35,000.00, the total cost per month was IDR 4,620,000.00, and the total cost per year was approximately IDR 55,440,000.00. The company spent IDR 55,440,000.00 per year on overtime payments because the necessary amount of work could not be completed during regular working hours, due to the need for manual procedures.

3.3. Ergonomic Analysis

In the analysis section, the activities of the workers were examined using RULA and REBA analyses. The main focus of the RULA and REBA analyses was on the ergonomic value of the working position, the load, the coupling, and the repetitive or static movements. The most common activities or operations in the warehouse itself are shown in Table 4. The results show the processes of the product preparation activities. These processes start with the following operations:

- Take out new cardboard;
- Place cardboard in pallet;
- Place plastics inside cardboard;
- Place product into new packaging;
- Pull up plastics;
- Take another piece of cardboard for the upper cover;
- Place upper cover;
- Product labeling;
- Product covering process;
- Take plastic cover;
- Banding process;
- Wrapping process.

Table 4. Workers' working positions.

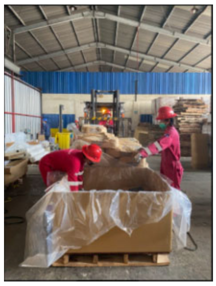
Product Preparation Activity			
 1. Take out new cardboard.	 2. Place cardboard in pallet.	 3. Place plastics inside cardboard.	 4. Place product into new packaging.
 5. Pull up plastics.	 6. Take another piece of cardboard for the upper cover.	 7. Place upper cover.	 8. Product labeling.

Table 4. *Cont.*

Product Preparation Activity			
			
9. Take plastic cover.	10. Product covering process.	11. Banding process.	12. Wrapping process.

The overall results of the RULA and REBA analyses can be seen in Table 5. An example of how the RULA assessments were carried out can be found in Appendix B. An example of the REBA assessment can be found in Appendix C.

Table 5. RULA and REBA results.

	Activity/Task	RULA Score		REBA Score	
Product preparation	Take out new cardboard	5	Medium risk	6	Medium risk
	Place cardboard in pallet	3	Low risk	5	Medium risk
	Place plastics inside cardboard	6	Medium risk	8	High risk
	Place product into new packaging/cardboard	7	High risk	11	Very high risk
	Pull up plastics	4	Low risk	5	Medium risk
	Take another piece of cardboard	4	Low risk	5	Medium risk
	Place upper cover	6	Medium risk	7	Medium risk
	Product labeling	6	Medium risk	6	Medium risk
	Take plastic cover	4	Low risk	5	Medium risk
	Product covering process	6	Medium risk	7	Medium risk
	Bending process	3	Low risk	5	Medium risk
	Wrapping process	3	Low risk	4	Medium risk

The highest-risk activities included decanting the product into new packaging for product preparation, with a RULA rating of 7 and a REBA rating of 11. The ergonomic assessments identified the following reasons for these high-risk ratings:

1. Heavy load in MMH: workers had to move materials or products with a heavy load of 20–25 kg from the old packaging to the new packaging every day.
2. Lack of utilities: workers performed MMH every day and had to lift heavy loads without proper aids to reduce the weight load.
3. Repetitive activities: when packing a product, many bags of products had to be moved, and the workers packed not just one pallet but dozens of pallets per day, resulting in repetitive actions.
4. Unfavorable posture: workers had to move their bodies from a bent position to a straight position and back to a bent position several times per day, which caused pain due to the rapid changes in movement.

The pain felt by the workers was related to their work concerning the movement of heavy loads. The amount of load and the repetitiveness required the workers to use their shoulders, upper arms, forearms, and waists frequently. Therefore, it is suggested that the company should invest in more tools to reduce the workers' strain and repetitive activities as much as possible.

3.4. NIOSH Lifting Calculation

A NIOSH lifting calculation was carried out to determine the risk of injury—particularly to the lower back and back areas—due to the lifting activity. A high risk of injury due to the lifting activity can lead to WMSDs if the workers' lifting activity exceeds the maximum capacity. A NIOSH lifting calculation was applied to the activity of placing the product in new packaging for product preparation. The desired results included the recommended weight limit (*RWL*) and the lifting index (*LI*). An example of the calculation of the NIOSH lifting index can be found in Appendix D.

The calculation of the recommended weight limit (*RWL*) is as follows:

$$RWL = 23 \text{ kg} \times 0.42 \times 0.955 \times 0.91 \times 0.90 \times 0.65 \times 0.95 = 4.66 \text{ kg}$$

The calculation of each multiplier can be found in Appendix D. After the result of the *RWL* has been determined, the lifting index (*LI*) is calculated as follows:

$$LI = \frac{25}{4.66} = 5.36 \quad (3)$$

Based on the results of the NIOSH lifting calculation, the current weight load of the workers was found to be far above the *RWL*. In comparison, the current weight of the lifted object was 25 kg, while the *RWL* was only 4.66 kg. This result shows that the workers' lifting load is 5.36 times higher than the recommended limit and is not ergonomic. Moreover, the result of the lifting index *LI* is greater than one, which means that it is not safe and may lead to WMSDs due to overloaded manual handling.

3.5. Proposed Improvement

From the RULA and REBA analyses, it appears that the activity involving the placement of the product into new packaging has the highest scores—7 (for RULA) and 11 (for REBA). Furthermore, based on the NIOSH lifting equation, this activity exceeds the allowable *RWL* and *LI* (*RWL* = 4.66 kg and *LI* = 5.36). These indicators show that immediate action is required on the part of the company. The improvement to reduce worker strain or injury and to fix the worker's working position in the form of assistive devices included the use of a device known as a vacuum lifter. This study aims to consider whether the proposal to use the vacuum lifter device can reduce the RULA and REBA scores, and whether it is economically viable. Figure 2 shows the proposed equipment used. This equipment is available on the market. A vacuum lifter is a tool that allows workers to easily lift and move objects using a suction method. The vacuum lifter was chosen as a tool for product preparation for the following reasons:

- During product preparation, paper bags containing powder need to be moved carefully to minimize the risk of tearing the bags and spilling the product. The vacuum lifter is specifically designed for this type of activity to prevent paper or plastic bags from being opened during transport.
- Less physical strain results in less risk of injury to the musculoskeletal system—especially the muscles.
- Faster handling and less labor required.
- Minimal learning required, as use depends on the intuitive control of the user.
- Ergonomic handle to improve working position.

Figure 2. Vacuum lifter.

Vacuum lifting allows the worker to move bags quickly and accurately without having to use a lot of force. The suggested working position for workers using the vacuum lifter is shown in Figure 3.

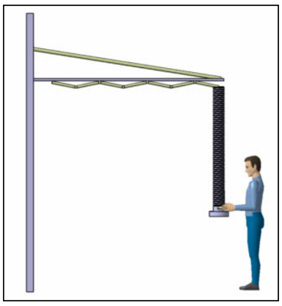


Figure 3. Proposed working position.

3.6. Benefits of the Vacuum Lifter

Installing a vacuum lifter in the product preparation process will not eliminate the need for workers, because the vacuum lifter is not a fully automatic machine, as it still needs to be operated by workers, which makes it a semi-automatic process. The current time for placing the product in the new packaging is 490 s for 48 bags (one pallet); i.e., an estimated 10 s to move one bag from the starting point to the destination. The authors assumed that the vacuum lifter can reduce this time by at least 30–50%, taking 7 s per bag. This means that only 336 s are needed for one pallet. The current cycle time for product preparation is 1085 s (18 min and 5 s). Assuming this, it can be reduced to 931 s (15 min and 31 s), saving 154 s in the entire process. Table 6 shows the time savings for each activity before and after using the vacuum lifter.

To calculate the benefit in terms of time saved, the demand in the last three months was used to predict future demand. The demand in the last three months was as follows: August, 2411 pallets; September, 2173 pallets; October, 2219 pallets. The average/month was 2268 pallets.

If the cycle time for product preparation of one pallet can be reduced by 154 s by using a vacuum lifter, then a total of 349,272 s or 97.02 h per month—or 1164.24 h/year—can be saved by using a vacuum lifter.

The time saved per month was assumed to be 97.02 h, and from the calculation of overtime based on the data collected, the overtime would be 132 h, so the cost would be reduced by 97.02 h when calculating the overtime cost by reducing the current 132 h of overtime. Table 7 shows the savings. A time saving of 66.78 h means a saving of IDR 40,748,400.00 per year.

Table 6. Benefits of the vacuum lifter.

No.	Activity	Before		After	
		Time (s)	Percentage	Time (s)	Percentage
1	Taking out new cardboard	35	3%	35	4%
2	Place cardboard in pallet	15	1%	15	2%

Table 6. *Cont.*

No.	Activity	Before		After	
		Time (s)	Percentage	Time (s)	Percentage
3	Place plastics inside cardboard	25	2%	25	3%
4	Place product in new packaging	490	45%	336	36%
5	Pulling up plastics	50	5%	50	5%
6	Taking more cardboard for the upper cover	30	3%	30	3%
7	Place upper cover	35	3%	35	4%
8	Product labeling	45	4%	45	5%
9	Take plastic cover	20	2%	20	2%
10	Product covering process	45	4%	45	5%
11	Banding process	175	16%	175	19%
12	Wrapping process	120	11%	120	13%
	Total	1085	100%	931	100%

Table 7. Time-saving benefits.

Total hours/month	97.02 hours/month
Cost/hour	IDR 35,000.00
Total cost/month	IDR 3,395,700.00
Total cost/year	IDR 40,748,400.00

3.7. Investment Analysis

The total cost of the investment for a vacuum lifter was IDR 81,000,000. This included the cost of purchase and installation for a useful life of 15 years. To calculate the depreciation of the vacuum lifter, a depreciation rate of 15% per year was assumed based on the original investment cost. The rate of 15% was used as a general rate for the depreciation of machinery (see Table 8).

Table 8. Machine depreciation for 15 years with a depreciation rate of 15%.

Year	Salvage Value	Year	Salvage Value
1	IDR 68,000,000.00	9	IDR 18,529,355.70
2	IDR 57,800,000.00	10	IDR 15,749,952.35
3	IDR 49,130,000.00	11	IDR 13,387,459.50
4	IDR 41,760,500.00	12	IDR 11,379,340.57
5	IDR 35,496,425.00	13	IDR 9,672,439.49
6	IDR 30,171,961.25	14	IDR 8,221,573.56
7	IDR 25,646,167.06	15	IDR 6,988,337.53
8	IDR 21,799,242.00		

At the end of year 15, the vacuum lifter would have a residual value of IDR 6,988,337.53. For the energy consumption of the vacuum lifter, the assumed calculation was based on kWh for the average consumption and the price per kWh. The vacuum lifter consumed an average of 2.6 kWh at a price of IDR 1440.47/kWh and was assumed to operate for 23 working days per month, with 8 working hours per day (see Table 9).

Table 9. Energy consumption every year for 15 years.

Energy Consumption per Year		Energy Consumption per Year	
Year 1	IDR 8,269,450.18	Year 9	IDR 17,726,300.86
Year 2	IDR 9,096,395.19	Year 10	IDR 19,498,930.95
Year 3	IDR 10,006,034.71	Year 11	IDR 21,448,824.04
Year 4	IDR 11,006,638.18	Year 12	IDR 23,593,706.45
Year 5	IDR 12,107,302.00	Year 13	IDR 25,953,077.09
Year 6	IDR 13,318,032.20	Year 14	IDR 28,548,384.80
Year 7	IDR 14,649,835.42	Year 15	IDR 31,403,223.28
Year 8	IDR 16,114,818.97		

The energy consumption price increased by 10% every year due to the price change per kWh. In addition, the total cost of maintenance was IDR 1,750,000.00 per year, taking into account the changing of air cushions, cleaning of the air filter, and replacement of screws/bolts. It was assumed that the maintenance costs increased by 10% each year (see Table 10).

Table 10. Maintenance costs every year for 15 years.

Maintenance Cost per Year		Maintenance Cost per Year	
Year 1	IDR 1,750,000.00	Year 9	IDR 2,585,547.03
Year 2	IDR 1,837,500.00	Year 10	IDR 2,714,824.38
Year 3	IDR 1,929,375.00	Year 11	IDR 2,850,565.60
Year 4	IDR 2,025,843.75	Year 12	IDR 2,993,093.88
Year 5	IDR 2,127,135.94	Year 13	IDR 3,142,748.57
Year 6	IDR 2,233,492.73	Year 14	IDR 3,299,886.00
Year 7	IDR 2,345,167.37	Year 15	IDR 3,464,880.30
Year 8	IDR 2,462,425.74		

All of the above data and calculations were used to calculate the NPV, IRR, and payback period.

3.7.1. NPV (Net Present Value)

In the NPV analysis, a discount rate of 15% was used as a standard interest rate for investments. Figure 4 shows the calculation.

From the result of the calculation using NPV analysis, the NPV was found to be positive, with a value of IDR 64,616,079.59, indicating that the investment in the vacuum lifter was profitable because it reaped more benefits than costs.

3.7.2. Payback Period

To calculate the payback period, a net cash flow was calculated (see Table 11).

The payback period was as follows:

$$Payback\ period = 2 + 0.29 = 2.29\ years$$

The payback period of 2.29 years is acceptable because it is far below the useful life of the vacuum lifter. This indicated that the investment costs were already amortized in year 2.29, which is considered to be a short time.

Discount Rate	15%						
Year	COST			BENEFIT		Discount Factor	Present Value
	Initial Investment	Energy Consumption	Maintenance	Savings	Salvage Value		
0	-Rp 81,000,000.00						-Rp 81,000,000.00
1		Rp 8,269,450.18	Rp 1,750,000.00	Rp 40,748,400.00		0.870	Rp 26,720,825.93
2		Rp 9,096,395.19	Rp 1,837,500.00	Rp 40,748,400.00		0.756	Rp 22,544,049.00
3		Rp 10,006,034.71	Rp 1,929,375.00	Rp 40,748,400.00		0.658	Rp 18,945,008.82
4		Rp 11,006,638.18	Rp 2,025,843.75	Rp 40,748,400.00		0.572	Rp 15,846,666.11
5		Rp 12,107,302.00	Rp 2,127,135.94	Rp 40,748,400.00		0.497	Rp 13,182,125.10
6		Rp 13,318,032.20	Rp 2,233,492.73	Rp 40,748,400.00		0.432	Rp 10,893,304.42
7		Rp 14,649,835.42	Rp 2,345,167.37	Rp 40,748,400.00		0.376	Rp 8,929,781.83
8		Rp 16,114,818.97	Rp 2,462,425.74	Rp 40,748,400.00		0.327	Rp 7,247,789.99
9		Rp 17,726,300.86	Rp 2,585,547.03	Rp 40,748,400.00		0.284	Rp 5,809,343.60
10		Rp 19,498,930.95	Rp 2,714,824.38	Rp 40,748,400.00		0.247	Rp 4,581,480.70
11		Rp 21,448,824.04	Rp 2,850,565.60	Rp 40,748,400.00		0.215	Rp 3,535,603.30
12		Rp 23,593,706.45	Rp 2,993,093.88	Rp 40,748,400.00		0.187	Rp 2,646,904.24
13		Rp 25,953,077.09	Rp 3,142,748.57	Rp 40,748,400.00		0.163	Rp 1,893,869.10
14		Rp 28,548,384.80	Rp 3,299,886.00	Rp 40,748,400.00		0.141	Rp 1,257,843.32
15		Rp 31,403,223.28	Rp 3,464,880.30	Rp 40,748,400.00	Rp 6,988,337.53	0.123	Rp 1,581,484.14
NPV							Rp 64,616,079.59

Figure 4. NPV calculation.

Table 11. Payback period for 4 years.

Year	Net Cash Flow	Payback Period
1	IDR 30,728,949.82	IDR 50,271,050.18
2	IDR 29,814,504.81	IDR 20,456,545.37
3	IDR 28,812,990.29	−IDR 8,356,444.92
4	IDR 27,715,918.07	−IDR 36,072,362.98

3.7.3. IRR (Internal Rate of Return)

To determine the IRR, a trial-and-error method was used. By applying different discount rates, the researchers tried to bring the NPV to zero to determine the IRR. In the first attempt, at 34% (see Figure 5), the value was −IDR 1,101,433.67. Then, the researchers tried an IRR of 33%. From the calculation at 33% (see Figure 6), the net present value was positive, at IDR 923,694.63, indicating that the IRR was between 34% and 33%. Interpolation was used to approximate the exact IRR value.

$$i = 33 + \frac{923,694.63}{923,694.63 - (-1,101,433.67)} \times (34 - 33)$$

$$i = 33 + \frac{923,694.63}{2,025,128.3} \times (1)$$

$$i = 33.45$$

The IRR was eventually found to be 33.45%. As the IRR was higher than the discount factor used in the NPV analysis, the project was considered to be feasible and profitable.

Discount Rate	34%						
Year	COST			BENEFIT		Discount Factor	Present Value
	Initial Investment	Energy Consumption	Maintenance	Savings	Salvage Value		
0	-Rp 81,000,000.00						-Rp 81,000,000.00
1		Rp 8,269,450.18	Rp 1,750,000.00	Rp 40,748,400.00		0.746	Rp 22,932,052.11
2		Rp 9,096,395.19	Rp 1,837,500.00	Rp 40,748,400.00		0.557	Rp 16,604,201.83
3		Rp 10,006,034.71	Rp 1,929,375.00	Rp 40,748,400.00		0.416	Rp 11,974,956.31
4		Rp 11,006,638.18	Rp 2,025,843.75	Rp 40,748,400.00		0.310	Rp 8,596,270.55
5		Rp 12,107,302.00	Rp 2,127,135.94	Rp 40,748,400.00		0.231	Rp 6,136,922.50
6		Rp 13,318,032.20	Rp 2,233,492.73	Rp 40,748,400.00		0.173	Rp 4,352,290.67
7		Rp 14,649,835.42	Rp 2,345,167.37	Rp 40,748,400.00		0.129	Rp 3,061,908.04
8		Rp 16,114,818.97	Rp 2,462,425.74	Rp 40,748,400.00		0.096	Rp 2,132,799.04
9		Rp 17,726,300.86	Rp 2,585,547.03	Rp 40,748,400.00		0.072	Rp 1,467,115.96
10		Rp 19,498,930.95	Rp 2,714,824.38	Rp 40,748,400.00		0.054	Rp 992,970.35
11		Rp 21,448,824.04	Rp 2,850,565.60	Rp 40,748,400.00		0.040	Rp 657,638.14
12		Rp 23,593,706.45	Rp 2,993,093.88	Rp 40,748,400.00		0.030	Rp 422,527.26
13		Rp 25,953,077.09	Rp 3,142,748.57	Rp 40,748,400.00		0.022	Rp 259,453.48
14		Rp 28,548,384.80	Rp 3,299,886.00	Rp 40,748,400.00		0.017	Rp 147,886.71
15		Rp 31,403,223.28	Rp 3,464,880.30	Rp 40,748,400.00	Rp 6,988,337.53	0.012	Rp 159,573.39
NPV							-Rp 1,101,433.67

Figure 5. IRR calculation at 34%.

Discount Rate	33%						
Year	COST			BENEFIT		Discount Factor	Present Value
	Initial Investment	Energy Consumption	Maintenance	Savings	Salvage Value		
0	-Rp 81,000,000.00						-Rp 81,000,000.00
1		Rp 8,269,450.18	Rp 1,750,000.00	Rp 40,748,400.00		0.752	Rp 23,104,473.55
2		Rp 9,096,395.19	Rp 1,837,500.00	Rp 40,748,400.00		0.565	Rp 16,854,827.75
3		Rp 10,006,034.71	Rp 1,929,375.00	Rp 40,748,400.00		0.425	Rp 12,247,104.12
4		Rp 11,006,638.18	Rp 2,025,843.75	Rp 40,748,400.00		0.320	Rp 8,857,735.44
5		Rp 12,107,302.00	Rp 2,127,135.94	Rp 40,748,400.00		0.240	Rp 6,371,129.40
6		Rp 13,318,032.20	Rp 2,233,492.73	Rp 40,748,400.00		0.181	Rp 4,552,362.50
7		Rp 14,649,835.42	Rp 2,345,167.37	Rp 40,748,400.00		0.136	Rp 3,226,742.02
8		Rp 16,114,818.97	Rp 2,462,425.74	Rp 40,748,400.00		0.102	Rp 2,264,514.97
9		Rp 17,726,300.86	Rp 2,585,547.03	Rp 40,748,400.00		0.077	Rp 1,569,433.28
10		Rp 19,498,930.95	Rp 2,714,824.38	Rp 40,748,400.00		0.058	Rp 1,070,207.17
11		Rp 21,448,824.04	Rp 2,850,565.60	Rp 40,748,400.00		0.043	Rp 714,120.87
12		Rp 23,593,706.45	Rp 2,993,093.88	Rp 40,748,400.00		0.033	Rp 462,266.71
13		Rp 25,953,077.09	Rp 3,142,748.57	Rp 40,748,400.00		0.025	Rp 285,989.80
14		Rp 28,548,384.80	Rp 3,299,886.00	Rp 40,748,400.00		0.018	Rp 164,237.88
15		Rp 31,403,223.28	Rp 3,464,880.30	Rp 40,748,400.00	Rp 6,988,337.53	0.014	Rp 178,549.17
NPV							Rp 923,694.63

Figure 6. IRR calculation at 33%.

3.8. Comparison

In this section, a comparison was made between the situations before and after the RULA and REBA analyses. We also observed the practices in product preparation when the proposed tools were used. This comparison for the proposed improvement was presented using a simulation (see Table 12).

Table 12. RULA and REBA comparison.

	Before Improvement		After Improvement	
RULA	7	High risk	4	Low risk
REBA	11	Very high risk	4	Medium risk

The RULA score before improvement was seven, indicating a high risk to the workers' position in performing their job. After the improvement, the score dropped significantly to four (low risk). For REBA, the score also dropped significantly, from 11 to 4 (medium risk). As with most studies on industries involving manufacturing [51], steel [52], "batik" [53], women's bags [54], and chemicals [55], a RULA score of four and a REBA score of four means that further research and changes are needed. Nevertheless, a significant improvement of ~40% (for RULA) and 60% (for REBA) suggests that the ergonomic intervention was successful to some extent. From the RULA and REBA analyses, it can be concluded that the vacuum lifter is suitable as an aid.

There was also a comparison using the NIOSH lifting calculation to see whether the *RWL* and *LI* had decreased (see the calculations below). After using the vacuum lifter, the weight of the load was reduced from 25 to 1 kg.

$$RWL = 23\text{ kg} \times 0.63 \times 0.78 \times 0.91 \times 0.90 \times 0.45 \times 1 = 4.17\text{ kg} \quad (4)$$

$$LI = \frac{Load\ Weight}{RWL} = \frac{1}{4.17} = 0.24 \quad (5)$$

Based on the results of the NIOSH lifting calculation after the improvement, the *RWL* decreased to 4.17 kg. Based on the NIOSH lifting calculation, the result of *LI* after the proposed improvement decreased compared to the previous calculation and was well below one, indicating that the lifting activity could be considered safe and did not exceed the recommended limit. According to the NIOSH, lifting is not considered to be a risk for all workers if the *LI* is well below 3.0 [11,37,56]. Moreover, the loads that the workers had to carry did not exceed the *RWL* value. This result proves that the lifting activity with the vacuum lifter is beneficial and ergonomic.

3.9. Summary of Key Results

This study's first sub-objective was to identify MMH risks in the warehouse activities that required addressing due to the high risk of MSDs. The Nordic Body Map scores showed that the right shoulder, left upper arm, right upper arm, waist, and right lower arm had the highest scores. This led to further analysis to determine the best course of action. Additionally, observations revealed that overtime was prevalent in the warehouse department, which had negative effects on workers' health and company expenses. The highest-risk activities included decanting the product into new packaging, with RULA and REBA ratings of 7 and 11, respectively. The NIOSH lifting calculation revealed that the workers' current lifting load was 5.36 times higher than the recommended limit and was not ergonomic, which may lead to WMSDs due to overloaded manual handling.

The second objective was to find a solution that can reduce the risk of MSDs while improving worker performance for the benefit of the company. The use of a vacuum lifter was proposed as a solution, which would reduce the physical strain on workers and improve their working position. It was found that the vacuum lifter could reduce the time needed for product preparation by 30–50%, saving an estimated 97.02 h per month and resulting in a cost saving of IDR 40,748,400.00 per year. NPV analysis showed that the investment in the vacuum lifter was profitable, with a positive NPV value of IDR 64,616,079.59 and an acceptable payback period of 2.29 years. The IRR was found to be 33.45%, indicating that the project was feasible and profitable.

As for the third sub-objective—to re-evaluate the risk of the solution—we evaluated the risk of the solution by using the RULA, REBA, and NIOSH lifting calculations. Before the intervention, the RULA score was 7 and the REBA score was 11, indicating high risk; however, after the intervention, the scores dropped significantly to four (low–medium risk). Although further research and changes are needed, the ergonomic intervention was successful, as the scores improved by ~40% (for RULA) and 60% (for REBA). The NIOSH lifting calculation also showed that the lifting activity with the vacuum lifter was safe and beneficial, with an *RWL* of 4.17 kg and an *LI* well below 1, which was below the recommended limit of 3.0.

In summary, all sub-objectives were achieved, demonstrating that this study successfully achieved its aim of showing how ergonomic measures could be used to reduce the risk of MSDs and to reduce operating costs in the warehouse department of an oil and gas service company. A cautious overall interpretation of this study's results is necessary, taking into account the objectives, results from similar studies, and other relevant evidence. Although this study provides valuable insights into the effectiveness of ergonomic interventions in reducing the risk of MSDs and operating costs in the warehouse department of an oil and gas service company, there are limitations that must be considered. These limitations include the study's single-industry and single-company focus, small sample size, and lack of a control group. While this study's results are consistent with the findings of previous research, caution should be exercised when generalizing these findings to other industries and companies. Additionally, potential sources of bias should be considered, including the self-reported nature of the data and the possibility of social desirability bias. Nonetheless, this study highlights the importance of ergonomic interventions in reducing the risk of MSDs and improving worker performance, and future research should aim to replicate and build upon these findings in a variety of contexts.

4. Conclusions

This study examined the risks associated with manual material handling (MMH) in a warehouse setting and evaluated the potential benefits of implementing a vacuum lifter as an assistive device to reduce those risks. Our findings indicate that MMH activities in the warehouse were associated with high levels of pain among workers, which could potentially lead to musculoskeletal disorders. Our analysis using the RULA, REBA, and NIOSH assessment tools identified a need for improvements to reduce scores above four—particularly, for REBA scores above six. In addition, our analysis showed that the current MMH process was associated with high labor costs due to excessive overtime incurred for manual product preparation.

To address these issues, we proposed the implementation of a vacuum lifter as an assistive device to reduce the risk of musculoskeletal disorders among workers and increase efficiency in the product preparation process. Our feasibility analysis using NPV, IRR, and payback period demonstrated that the investment in the vacuum lifter would be feasible and profitable for the company. Our simulation analysis showed that the use of the vacuum lifter would reduce the risk of MSDs by reducing the weight of the load and improving the working position.

Overall, our findings suggest that implementing a vacuum lifter as an assistive device in the warehouse would be a beneficial investment for both the workers and the company, improving both well-being and finances. The proposed solution would transform the current MMH process into a semi-automatic activity, speeding up the product preparation process and significantly reducing overtime.

Limitations and Future Work

One of the limitations of this study is the small sample size of the study. Although all four workers in the warehouse participated in the study, the generalizability of this study to semi-automated material handling could be improved if the types of industries and the number of workers were more diverse. Another limitation is the lack of follow-up of improvements after RULA and REBA scores of four were achieved. Although this study mainly aimed to observe the improvement associated with the process after the simulated ergonomic intervention, it could not confirm whether the process would improve even more with further interventions, let alone whether these further interventions would be economical.

Further research should include the issue of sustainability, incorporating the three pillars of sustainability (i.e., economic viability, environmental preservation, and social equity) into the decision-making process before changing technology or mechanization and automation. This consideration could help the company to speed up the process so that operations could be faster than in manual mode. However, it is also important to observe how the solution affects the balance of other aspects related to sustainability.

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Institutional Review Board Statement: This study was carried out in accordance with the guidelines of the Declaration of Helsinki. All participants gave their written informed consent prior to their involvement in the study. All procedures and protocols were approved by the Research Ethics Committee (REC) of the Research Institute and Community Service (RICS) of President University. Research ethics approval for the project was granted with approval number E409012201 (granted on 9 January 2022), and the approval letter was endorsed by the RICS Director cum REC Secretariat of the university.

Informed Consent Statement: Informed consent was obtained from all of the subjects involved in the study.

Data Availability Statement: Not applicable.

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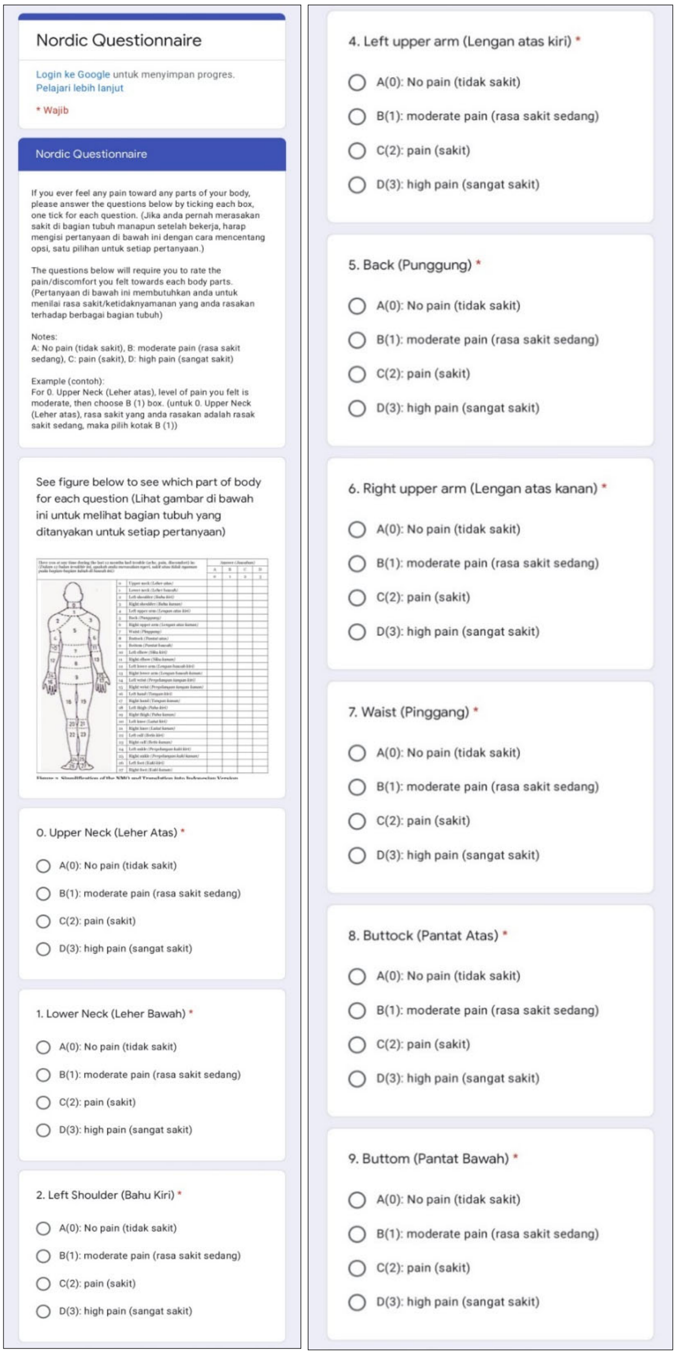
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A


Nordic Questionnaire

Login ke Google untuk menyimpan progres.
Pelajari lebih lanjut

* Wajib

Nordic Questionnaire

If you ever feel any pain toward any parts of your body, please answer the questions below by ticking each box, one tick for each question. (Jika anda pernah merasakan sakit di bagian tubuh manapun setelah bekerja, harap mengisi pertanyaan di bawah ini dengan cara mencentang opsi, satu pilihan untuk setiap pertanyaan.)

The questions below will require you to rate the pain/discomfort you felt towards each body parts. (Pertanyaan di bawah ini membutuhkan anda untuk menilai rasa sakit/ketidaknyamanan yang anda rasakan terhadap berbagai bagian tubuh)

Notes:
A: No pain (tidak sakit), B: moderate pain (rasa sakit sedang), C: pain (sakit), D: high pain (sangat sakit)

Example (contoh):
For 0. Upper Neck (Leher atas), level of pain you felt is moderate, then choose B (1) box. (untuk 0. Upper Neck (Leher atas), rasa sakit yang anda rasakan adalah rasak sakit sedang, maka pilih kotak B (1))

See figure below to see which part of body for each question (Lihat gambar di bawah ini untuk melihat bagian tubuh yang ditanyakan untuk setiap pertanyaan)

0. Upper Neck (Leher Atas) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

1. Lower Neck (Leher Bawah) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

2. Left Shoulder (Bahu Kiri) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

4. Left upper arm (Lengan atas kiri) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

5. Back (Punggung) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

6. Right upper arm (Lengan atas kanan) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

7. Waist (Pinggang) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

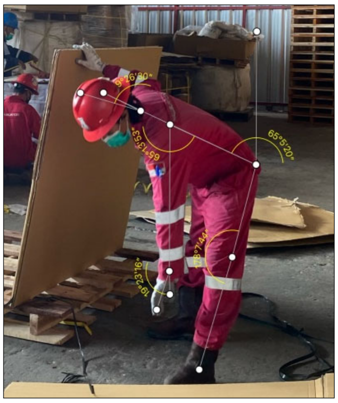
8. Buttock (Pantat Atas) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

9. Buttom (Pantat Bawah) *
- A(0): No pain (tidak sakit)
- B(1): moderate pain (rasa sakit sedang)
- C(2): pain (sakit)
- D(3): high pain (sangat sakit)

Figure A1. Example of the Nordic Body Map Questionnaire.

Appendix B

Table A1. Example of the RULA assessment.

Activity	Picture	Assessment
Taking out new cardboard		Score A: Arm and Wrist Upper arm position is between 45 and 90°, scoring +3 Lower arm position is 0–60°, scoring +2 Wrist movement is 15°+; thus, the wrist position score is +3 Wrist twist score is +1 because it is twisted in the mid-range Score from Table A in Figure A2 is 4 There is no added muscle or added force, so the score remains 4 Score B: Neck, Trunk, and Leg Neck position is at 0–10°, scoring +1 Trunk position is at 60°+, scoring +4 Legs and feet are supported, scoring +1 Score from Table B in Figure A2 is 5 There is no added muscle or added force, so the score remains 5 Score C/Total Score Looking at Table C in Figure A2, the RULA score of taking cardboard is 5 (meaning further investigation, change soon)

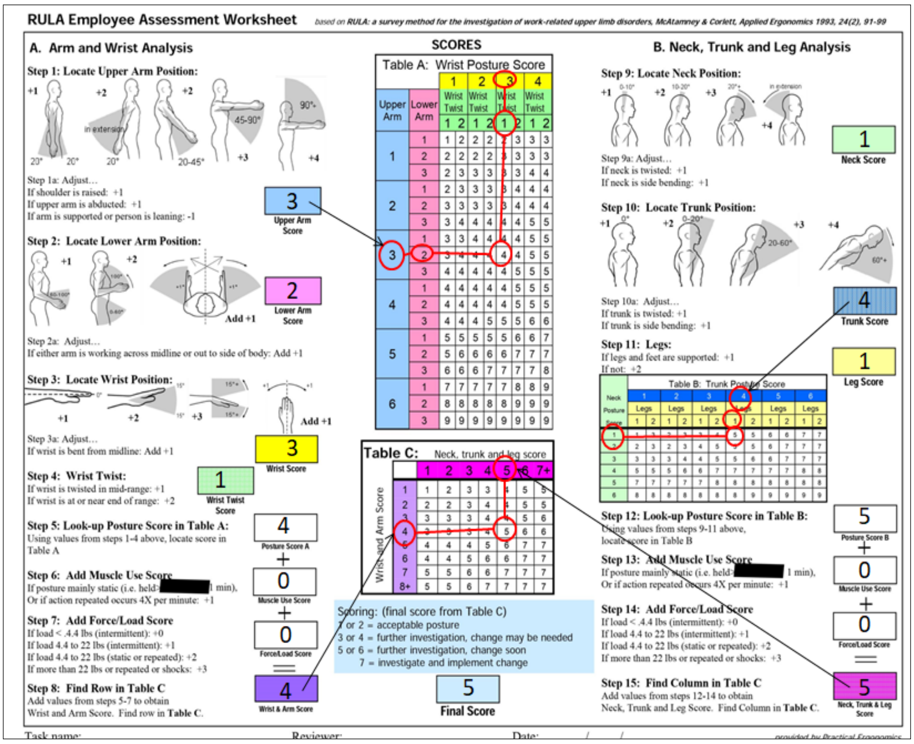
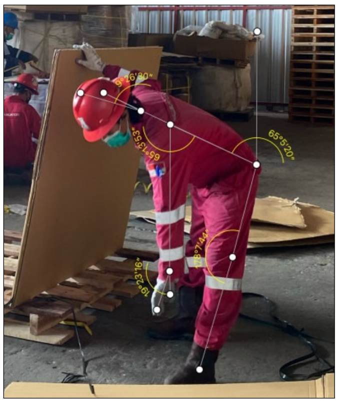


Figure A2. RULA employee assessment worksheet.

Appendix C

Table A2. Example of the REBA assessment.

Activity	Picture	Assessment
Taking out new cardboard		Score A: Neck, Trunk, and Leg Neck position is at 0–20°, scoring +1 Trunk position is at 60°+, scoring +4 Legs' position shows a bilateral weight bearing, scoring +1 Score from Table A in Figure A3 is 3 There is no added force/load score, so the score remains 3 Score B: Arm and Wrist Upper arm position is between 45 and 90°, scoring +3 Lower arm position is 0–60°, scoring +2 Wrist movement is 15°+; thus, the wrist position score is +2 Score from Table B in Figure A3 is 5 Coupling is considered to be fair, scoring +1; score B becomes 6 Score C and Activity Score Looking at Table C in Figure A3, the score is 5. There is no additional activity score, such that the final REBA score is 5 (meaning medium risk, further investigation, change soon)

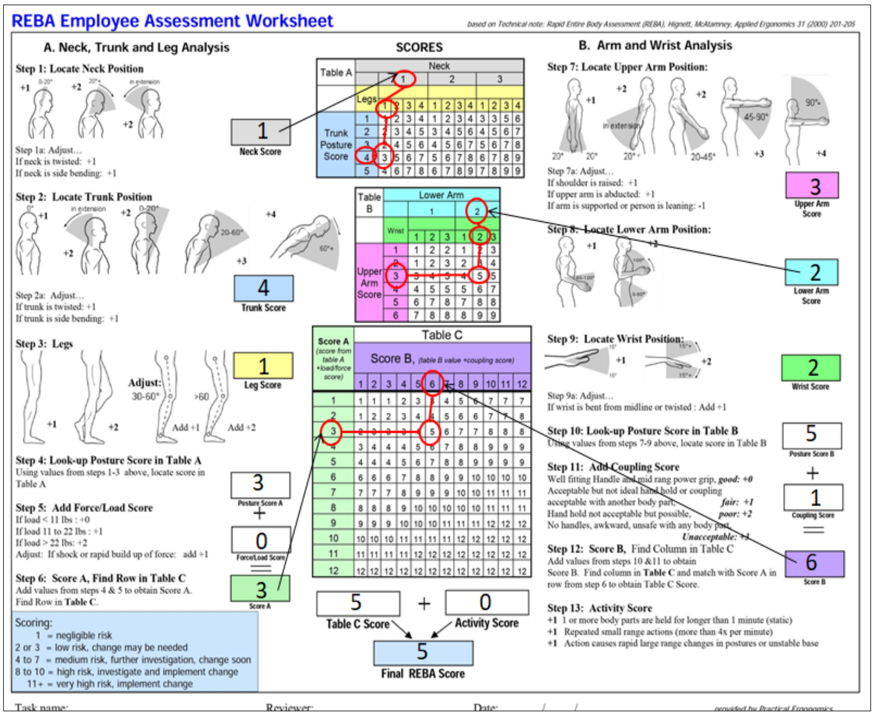


Figure A3. REBA employee assessment worksheet.

Appendix D

Example of the NIOSH lifting assessment:

In the NIOSH lifting calculation, there will be two results:

1. *RWL* (recommended weight limit): Gives results about the appropriate amount of weight workers should perform in a certain period of time without any risk of developing any pain. If the current lifting weight exceeds the *RWL*, then it is suggested that the company should reduce the load by providing tools or some other action. The formula for calculating the *RWL* is as follows:

$$RWL = LC\ (Load\ Constant) \times HM \times VM \times DM \times AM \times FM \times CM$$

Each multiplier can be determined through the following calculations:

Table A3. NIOSH data before improvement.

NIOSH Lifting Calculation		
Parameter	**Data**	**Multipliers**
Horizontal location (H), cm	60 cm	$HM = \frac{25}{60} = 0.42$
Vertical location (V), cm	Average = 90 cm	$VM = 1 - (0.003\lvert 90 - 75\rvert) = 0.955$
Travel distance (D), cm	Average = 50 cm	$DM = 0.82 + (4.5/50) = 0.91$
Angle of asymmetry (A)	30°	$AM = 1 - (0.0032(30)) = 0.90$
Coupling (C)	Fair (score = 2)	CM = 0.95
Frequency (F), lifts/min	2 lifts/min	FM = 0.65
Load (L)	Average = 25 kg	
Duration	Long (2–8 h)	

Table A4. NIOSH data after improvement.

NIOSH Lifting Calculation		
Parameter	**Data**	**Multipliers**
Horizontal location (H), cm	40 cm	$HM = \frac{25}{40} = 0.63$
Vertical location (V), cm	Average = 80 cm	$VM = 1 - (0.003\lvert 80 - 75\rvert) = 0.78$
Travel distance (D), cm	Average = 50 cm	$DM = 0.82 + (4.5/50) = 0.91$
Angle of asymmetry (A)	30°	$AM = 1 - (0.0032(30)) = 0.90$
Coupling (C)	Good (score = 1)	CM = 1
Frequency (F), lifts/min	4 lifts/min	FM = 0.45
Load (L)	Average = 1 kg	
Duration	Long (2–8 h)	

2. *LI* (lifting index): Estimation of physical stress; if the result is *LI* > 1, it means that the current weight lifted is not recommended and should be improved by reducing the lifting weight, whereas if it is $LI \leq 1$, it is a recommended weight for lifting activity. The formula used to calculate *LI* is as follows:

$$LI = \frac{Load\ Weight\ (L)}{RWL}$$

To be able to determine the results of *RWL* and *LI*, there are several data that must be collected/measured. The explanation of each of the data needed can be found in the figure below.

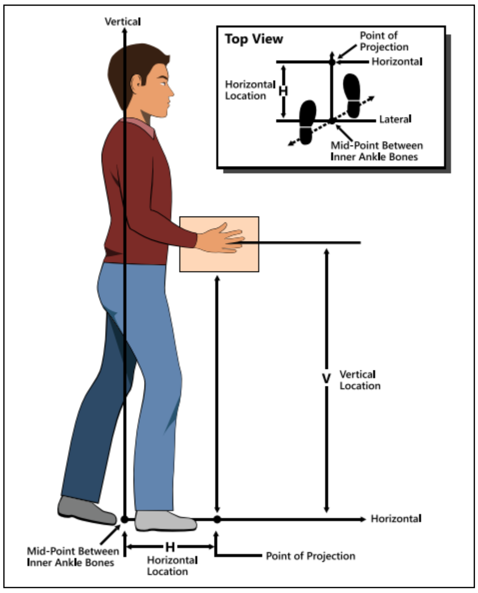


Figure A4. NIOSH lifting parameters.

- H (horizontal location): distance between a body point projected to the floor and the midpoint of the hands that hold the object;
- V (vertical location): the height of the hands that grasp the object from floor;
- D (vertical travel distance): The distance between the initial vertical location and the object's destination;
- A (angle of asymmetry): The angle of body movement in degrees during the task;
- C (coupling): The level of hold exerted by the workers to grasp the object. Coupling has three levels—good (1), fair (2), and poor (3);
- F (lifting frequency): Average lifts per minute;
- L (load weight): Object's weight;
- Dur (lifting duration): The time that the workers spend performing the task. The duration is grouped into three categories: short (1) is less than or equal to 1 h; moderate (2) is 1–2 h, and long (3) is 2–8 h.

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