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Manual material handling analysis using biomechanics at repair department workers

Huki Chandra*

* Industrial Engineering, Institut Teknologi Telkom Surabaya, Indonesia. Jl. Ketintang No. 156, Surabaya 60231, Indonesia

* Email: hukichandra@ittelkom-sby.ac.id

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ABSTRACT

The use of manual labor in production process activities in a company is still required, especially in the process of moving materials or products to the next workstation. This activity is often referred to as Manual Material Handling (MMH). Lifting weights that are not according to standards and MMH activities that are not properly carried out by workers have a risk of accidents and diseases such as low back pain. The analysis used in this study is using biomechanical calculations. Based on the load and lifting posture carried out by the worker, it resulted in 3,885 N of compression force, it can be concluded that the lifting level is included in the cautious category. Through the same calculation, it is obtained that the maximum load that may be lifted in the safe category is 11.28 kg. Lifting with two hands can reduce the load on Fc L5/S1 to 2,423 N, this can be done by changing the diameter of the two-handle bucket.

Keywords: Manual material handling; low back pain; biomechanical

1. INTRODUCTION

The use of manual labor in production process activities in a company is still required, especially in the process of moving materials or products to the next workstation. This activity is often referred to as Manual Material Handling (MMH), where the activities carried out include handling, moving, packaging, storing, and monitoring materials or products.

Nowadays, in modern industry, machines have been widely used as aids in material transfer, however, manual material transfer activities are still needed because it has several advantages compared to using tools, such as manual material transfer can be carried out in a limited space. When carrying out activities, workers rely heavily on their physical ability to lift goods, but moving materials manually if not done ergonomically will cause work accidents. The flexibility of movement is the reason why human power is still used in the industry. Improper posture can cause a dangerous injury to the safety of a worker. This is exacerbated by the lack of knowledge of workers and some employers ignore the job risks of their employees. In addition, there are many manual material handling activities that exceed the recommended lifting limits [1].

The ability to assess physical work aims to prevent musculoskeletal disorders (MSDs) due to work. Some manual work done in a dangerous way can cause complaints commonly called musculoskeletal disorders (MSDs). Improving working conditions to prevent the occurrence of MSD in workers is a problem that must be resolved through an assessment of manual material handling (MMH) activities. This physical work can be assessed by biomechanical analysis. Biomechanical analysis can assess MSD risk factors, namely muscle forces and compressive forces on the lower back of workers [2].

Many workers who carry out activities of lifting and moving goods manually complain about their health. Biomechanics is the science related to factors of human movement. When working,

it is necessary to pay attention to the position of the limbs and the direction of movement while working [3]. Manual material handling is a work activity that can cause physical effects on workers. A risk analysis of the work activity needs to be done. Based on the level of risk faced by workers when lifting manually, it is necessary to reduce the risk so that injuries do not occur to workers [4].

When MMH activities take place, the load that is lifted or moved and work attitude or posture have an important role. Inappropriate lifting of weights, as well as inappropriate MMH activities carried out by workers, have a risk of accidents and illnesses, such as low back pain. The work of lifting objects can cause spinal injuries. Lifting loads that are not appropriate or reasonable can also reduce process efficiency, besides that financially the company can also cause losses due to decreased work productivity.

Manual work done in a dangerous way can cause complaints of musculoskeletal disorders (MSDs). Lifting weights beyond capacity can cause spinal injuries. The location of the L5/S1 is a vulnerable point because there is a fluid membrane that dampens movement between the lumbosacral joint. If a worker lifts a load that exceeds the Maximum Permissible Limit (MPL), the disc can rupture and cause musculoskeletal disorder [5].

The existence of burdens exceeding capacity can cause spinal injuries (musculoskeletal disorders) and other muscle disorders. This lumbosacral joint (L5/S1) is the point most prone to work accidents. In the spine, there is a disk (fluid-filled membrane) that functions to dampen the movement between the lumbosacral joint (L5/S1). This disc will break if the pressure caused by lifting workloads exceeds the Maximum Permissible Limit [5]. Incorrect working posture and lifting loads that exceed the carrying capacity can be fatal and serious [6]. Musculoskeletal disorder (MSD) problems can cause various levels of severity from minor injuries to disabling injuries [7].

In developing countries, a job often involves manual material handling activities. Measurement of workload is important to identify the level of workload, especially on unduly heavy tasks, and to make work methods more efficient. Biomechanical methods can quantify and minimize the risk of Musculoskeletal Disorders (MSDs) in material handling work by reducing physical stress and reducing fatigue [8]. Musculoskeletal Disorders are conditions that interfere with the function of the joints, ligaments, muscles, nerves and tendons, and the spine [9].

The wrong lifting method can cause very high compression and has the potential to cause spinal injury. The activity of moving materials is an important thing to pay attention to improve work safety [10]. Spinal cord injuries can cost you financially and cause decreased productivity. Ergonomic risk analysis can be used to determine strategies to reduce the risk of Musculoskeletal Disorders [11].

Manual material handling work is a job that has a high risk of causing low back pain. As many as 25% of respondents who came from manual handling workers felt low back pain for at least one week, as many as 14% needed medical treatment and as many as 10% had to rest from work (lost time) [12]. To reduce the risk of work accidents, it is necessary to evaluate manual work such as lifting and moving materials [13]. The tension in the muscles of the body will be dangerous if workers continue to lift heavy loads. When lifting materials, lifting load restrictions can reduce worker fatigue [14]. Manual lifting activities are the most common cause of fatigue and injury to the spinal cord and waist [15].

Body tissue can be damaged by lifting excessive loads (over-exertion-lifting and carrying). When workers lift weights, the whole body receives stress. If the muscles receive an excessive load, the muscles will tighten and the blood vessels constrict, thus making workers feel tired. The muscles of the body will receive a higher tension if the weight being lifted is heavier. This should not be allowed because it will potentially endanger the safety and health of workers [16]. Manual material handling activities include: lifting, lowering, pushing, and pulling [17]. Analysis of human movement and muscular activity in manual material handling work can be done using biomechanical analysis [2]. The measured activity consists of two sets of activities. The first set of activities is lifting, lowering, and carrying objects. The second activity is arm movement.

Analysis of Manual Material Handling in lifting raw materials using a biomechanical approach has been carried out in previous studies [3]. The purpose of the research is to propose a working system for manual material handling activities. The activity assessed is the transfer in the warehouse department. The method used in this research is biomechanics. The results of the study indicate that the lifting conditions at the time of measurement have the potential to cause spinal cord injury (musculoskeletal disorder). Understanding knowledge related to work safety is important so that workers are aware of the impacts and risks of the work.

Previous research analyzed Manual Material Handling in manual piano production work [4]. Assessment is carried out when workers carry out lifting activities manually and when using hand lifts. Workload assessment was also carried out on lifting goods from porters who work in traditional markets [5]. The workload of lifting goods is measured using a biomechanical method to prevent the risk of spinal cord injury. While the measurement condition, the force compression value is greater than the maximum permissible limit value. When carrying out lifting work, you should use assistive devices to prevent the risk of spinal cord injury.

Manual activity loads are also measured at printing companies [6]. The manual activities carried out at the company are filling machine ink, moving raw materials, lifting goods, carrying out the finishing goods, and storing. The measurement results obtained that the level of risk in the job has the potential to cause spinal cord injury.

The results of the calculation of the moment of force showed that the average moment of force is very high which will make the worker feel pain in the spine and posture may bend [10]. Proposed work system improvements are needed so as not to cause injury to the L5/S1 vertebrae. Analysis of lifting activity was also carried out on pine oleoresin harvesting [11]. This study uses biomechanics to identify the risk of injury to the spine. The results show that there is excessive compression so there is a risk of injury at L5/S1. In that study, a smaller oleoresin bucket was recommended to significantly reduce compression at L5/S1.

Previous researchers developed a physical load assignment classification scheme for manual material handling work [18]. Physical loads are the effect of input forces during material handling activities and from the interaction of material handling equipment with material [18]. Other researchers measured workload on the activity of loading mineral water cups [1]. The loading process is done manually from the warehouse into the truck. The results show that the calculation of the moment force in the study is greater than the limit, so the proposal offered is to reduce the lifting load to 24 kilograms.

Physical activity is also often carried out by workers in building shops [9]. Physical load is measured in manual material handling activities in lifting and moving bricks that are done manually [9]. This work causes injury because the weight of the load exceeds the permissible lifting limit. Previous researchers measured the workload on the activity of lifting raw materials at companies that produce interiors for housing and companies [13]. The analytical method in the study uses biomechanics principles by comparing the compressive force with the maximum permissible lifting load.

Observation of manual material handling activities has been carried out in previous studies [14]. Observations were made to analyze the risk of spinal cord injury in manual material handling activities in raw material warehouses and finished goods warehouses using biomechanical methods.

Analysis of manual material handling was also carried out on the activities of workers in flour producers [15]. Many lifting activities are not ergonomic [15]. This can cause work accidents, and reduce work productivity and worker health. The given recommendation is that it is necessary to reduce the workload. Ergonomic work environment design focuses on reducing hazard exposure to the musculoskeletal system. The application of ergonomic principles in the work environment can balance productivity with worker comfort.

Previous studies have also analyzed material handling activities in textile companies in the spinning department [16]. The results of the study indicate that lifting loads significantly affects the occurrence of low back pain in workers. Previous researchers also identified factors related

to low back pain felt by fishermen [19]. Manual material handling is a risky activity for fishermen. The results of this study indicate that there is a significant correlation between lifting loads and low back pain felt by fishermen.

Low Back Pain is a painful sensation that is felt in the lower back arising from the spine, muscles, nerves, and other structures around it. Low back pain can occur locally, radicular, or both. Factors that cause low back pain are individual factors, work factors, and environmental factors [19]. Compression forces in biomechanics analysis of manual material handling activities in supermarkets have been carried out in previous studies [20]. The results show 8 tasks have compression forces on L5-S1 that exceed the biomechanical tolerance limit. The given recommendation in the study is that boxes should not be lifted manually or by limiting the number and size of boxes lifted.

In a previous study, the activity load on cassava snack production was measured [21]. Work is still done manually using simple equipment. The results of this study are workers in these small and medium enterprises are not at risk of spinal cord injury because they are still below the permissible load limit. A load of lifting spare parts activities in the warehouse at a coal company has been analyzed in previous studies [22]. The results of this study are that workers have a high risk of injury to the L5/S1. If this continues for a long time, it can cause damage to the L5/S1 vertebrae.

Based on previous studies, it was concluded that excessive manual material handling activities can increase the risk of musculoskeletal disorders and other losses. Therefore, this study focuses on Manual Material Handling (MMH) activities carried out in the process of transferring loads in the company's repair department. The experimental results were then analyzed using biomechanics calculations to find out whether the load and posture used fulfilled the standard or whether suggestions for improvement were needed.

2. RESEARCH METHODOLOGY

2.1 The object of this study

The object of this study is the operator in the preparation room who lifts the workload manually with the posture and lifting load according to the workers at the repair department.

2.2 Research stages

The stages of this research were carried out starting with identifying the problem. After identifying the problem, it is found that the problem that this study takes is the evaluation of manual material handling. For the problem of manual material handling evaluation, this study makes a manual material handling evaluation sheet in the form of the required data table. Furthermore, observations and data collection were carried out to analyze the forces and moments on each body segment based on Action Limit and Maximum Permissible Limit calculations. At the time of data collection, the operator will measure body weight with a scale. The operator then carried out the activity of lifting loads with different postures and weights according to the conditions in the repair room. Operator images are taken when carrying out the lifting activity, which is needed to determine the angle of posture and calculate Fc-L5/S1 (compression force) and then compares it with AL (Action Limit) and MPL (Maximum Permissible Limit).

After doing calculations and comparisons, this study determines the right posture and load in lifting activities, provides conclusions and recommendations, and then draws conclusions. The stages of this study are as follows:

- Collect data on body weight, arm length, and trunk length of workers
- Calculate moments in the upper arm, lower arm, and trunk (L5/S1)
- Calculate the abdominal force
- Calculate the muscle force
- Calculate the compression force
- Comparing Fc L5/S1 with the action limit and maximum permissible limit

2.3 Manual material handling analysis with biomechanics

Calculation of the pressure at L5/S1 (Lumbosacral joint) it can be done by using the biomechanics approach which consists of several sets of single-segment static models consisting of the lower arm, upper arm, and trunk segments.
Steps to determine the compressive force at L5/S1: Calculate the moment at L5/S1. Then, determine the amount of abdominal pressure. Next is to calculate the abdominal force. Then, calculate the muscle force. The final step is to calculate the compression force at L5/S1 [23].

2.4 Action Limit (AL) and Maximum Permissible Limit (MPL)

MPL or Maximum Permissible Limit is the maximum limit of the compressive force on the L5/S1 segment of the lifting activity in Newton units standardized by NIOSH (National Institute of Occupational Safety and Health). So, if Fc < AL (safe), AL < Fc < MPL (careful), and if Fc > MPL (dangerous). The maximum permissible lifting limit, which NIOSH recommends, is based on a compressive force of 6500 N at L5/S1. The normal lifting force limit (Action Limit) is 3500 at L5/S1 [24].

3. RESULTS AND DISCUSSION

3.1 Preparing Manual Material Handling (MMH) data

The implementation process starts at this stage by directly watching manual material handling operations. The weight of the item being raised is 13.52 kg, and the posture used during the lifting task will be examined. In addition to watching the aforementioned activities, simultaneous shooting is also done to create pictures that reflect the posture and load of the activities being done. The angle of specific body parts will then be determined using the images from each action.

The operator's lower and upper arm lengths were measured after all activity observations and shooting had been finished. Next, a body weight was measured to determine the weight mass center (Wcm), and all data were entered on the worksheet. The biomechanics calculations will be used to analyze all the data to determine whether the operator's action falls under the category of safe (Fc AL) or dangerous (Fc > MPL), and if necessary, recommendations for improvement can be made.

3.2 Manual Material Handling Measurement Data (MMH)

It is essential to calculate Wcm and Lcm values in order to analyze the posture of the observed operators before conducting a manual handling activity analysis at the repair department. measurements of Wcm and Lcm are displayed in **Table 1**.

Table 1. Value of Wcm and Lcm

Body Section	Length (m)	Wcm	Lcm
Lower arm	0.28	6.25878	0.19096
Upper arm	0.3	7.96572	0.1308
Trunk	0.52	80.7951	0.052

It is also referred to as the value of the load being raised in addition to the Wcm and Lcm values. The weight of the cargo is 13.52 kg, or 132.63 Newton. The operator's measured weight is 58 kg, which is equal to 568.98 Newton. The object must be raised because it is 30 cm tall and 32 cm in diameter. The following is **Table 2** regarding the results of biomechanics calculations in actual conditions:

Table 2. Fc load calculation results

Moment/Force	Calculation Results
$M_{L5/S1}$	189.38 Nm
P_A	0.252 N/m2
F_A	117.510 N
F_M	3,529.190 N
F_c	3,885.488 N

The results obtained show that Fc > AL, so it is necessary to be careful when lifting manually.

3.3 Lifting load reduction scenario

This scenario is carried out with the lifting load reduction to 10 kg, while the other variables remain the same. The followings are the results of biomechanics calculations if the lifting load is 10 kg shown in **Table 3**:

Table 3. Fc calculation results with lifting load scenarios

Moment/Force	Calculation Results
$M_{L5/S1}$	155.92 Nm
P_A	0.178 N/m2
F_A	82.804 N
F_M	2,936.139 N
F_c	3,274.583 N

The results obtained show that Fc <AL, so manual lifting activities are in the safe category. By carrying out the same calculation method, it is obtained that the threshold limit of the load that can be lifted in the safe category is 11.28 kg. This limit is used assuming other parameters remain unchanged, such as the worker's posture and weight and the dimensions of the object being lifted.

3.4 Scenarios of reducing dimensions of lifting objects

This scenario is carried out with the diameter of the lifting object by reducing the dimensions to 23 cm, while the other variables remain the same. Following are the results of biomechanics calculations if the dimension is 23 cm in **Table 4**:

Table 4. Fc calculation results by reducing dimension scenarios

Moment/Force	Calculation Results
$M_{L5/S1}$	165.51 Nm
P_A	0.198 N/m2
F_A	92.203 N
F_M	3,107.395 N
F_c	3,400 N

The results obtained show that Fc <AL, so manual lifting activities are in the safe category. By carrying out the same calculation method, it is found that the threshold limit of the load that can be lifted in the safe category is approximately 23 cm.

3.5 Two-hand lifting scenario

This scenario is carried out by changing the method of lifting using both hands at once, while the other variables remain the same. The following are the results of biomechanics calculations when using both hands in **Table 5**.

Table 5. Result of Fc calculation with scenario of lifting method

Moment/Force	Calculation Results
$M_{L5/S1}$	103.89 Nm
P_A	0.086 N/m2
F_A	39.871 N
F_M	1,990.014 N
F_c	2,423.950 N

The results obtained show that Fc <AL, so manual lifting activities are in the safe category.

3.6 Discussion

Based on the calculation of the scenario performed, the action that can be taken is to reduce the lifting load to be below 11.28 kg and change the method of lifting using two hands, where this can be done by replacing a more comfortable grip with two handles on the left and right. Pay attention to the maximum permissible weight, appropriate and comfortable position and posture, and creating a safe work design (for example, as much as possible avoid placing objects on the floor that require the operator to bend or twist the body to lift them), and pay attention to the conditions of the workplace.

Apart from that, it is also recommended to redesign the lifting box by adding a more comfortable hand grip, if possible use aids for handling such as a trolley, or if that is not possible then try to lift the load not exceeding the maximum permissible limit. This can be overcome by doing work rotations and providing sufficient recovery time, for heavy loads you can lift the materials by more than 1 person, so that the load is lighter, lifting as close to the body as possible (if the distance is far it creates a big moment of force). In addition, it is important to distribute a checklist containing complaints and suggestions from workers, for improvement.

4. CONCLUSION

Biomechanics is a manual material handling analysis tool that is used to analyze how much workload is allowed. Based on the lifting carried out by workers at the repair department, a load of 3,885 N has resulted, it can be concluded that the lifting level is in the cautious category, based on the results of biomechanics calculations and NIOSH standards. This is because the force on Fc L5/S1 is above the Action Limit value and below the Maximum Permissible Limit (MPL). Through the same calculation, it is found that the maximum load that may be lifted in the safe category is 11.28 kg. Lifting with two hands can reduce the load on Fc L5/S1 to 2,423 N, this can be done by changing the design of the lift bucket to two lifting handles. When lifting weights manually, pay attention to the lifting posture. To reduce the pressure at Fc L5/S1, you can also do it by limiting the lifting load to under 11.28 kg or changing the lifting using 2 hands by modifying the dimension of the lifting bucket, or you can also do a neutral lifting posture (not bending), and try to lift the object as close to the body as possible.

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