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Optimizing ergonomic work facilities in distribution logistics to prevent manual lifting injuries

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Abstract: This study aims to improve ergonomic conditions for box-lifting operators in bottled drinking water companies. Operators handling small packaging sizes (600 ml) report significant pain, as revealed by the Nordic Body Map Questionnaire. Addressing this issue is crucial for preventing manual lifting injuries and ensuring worker safety in logistic distribution. A combination of biomechanical analysis, anthropometric data, and the Nordic Body Map Questionnaire was used to assess operator complaints and evaluate ergonomic hazards. The study utilized Catia software to simulate work facility designs, focusing on the development of an adjustable-height hydraulic pallet to optimize operator posture during lifting tasks. Key metrics included compressive and shear force calculations to evaluate injury risks. Operators reported pain in the shoulders, lower back, buttocks, and thighs over the past year. Initial evaluations showed excessive compressive forces (up to 19,778.2 N) and shear forces (over 500 N), indicating a high risk of injury. After ergonomic interventions, simulations recorded compressive forces of 3,350 N and shear forces of 185.31 N, demonstrating a significant reduction in risk and safe operational conditions. This study offers a novel, comprehensive approach to ergonomic optimization in logistics, combining operator feedback, biomechanical analysis, and technological tools like Catia for facility design. The findings provide a blueprint for improving worker safety and efficiency in manual lifting tasks. The study's outcomes benefit safety engineers, ergonomic specialists, and logistics managers, offering insights into improving worker well-being and operational efficiency. Future research could explore further technological enhancements in facility design and their impact on worker ergonomics.

1 Introduction

To maximize income, manufacturing organizations must minimize losses while meeting client requests effectively. Discrepancies between activities and equipment may result in idle time, lowering labor productivity, product quality, and cost savings. Ensuring compliance across all locations and activities is crucial to increasing manufacturing process efficiency and customer satisfaction. This emphasizes the significance of excellent ergonomics and well-designed workstations for decreasing inconsistencies, increasing productivity, and ensuring worker safety [1].

Workers' postural and manual material handling are critical components in determining the risk of musculoskeletal injury in the workplace [2]. Ergonomics is a physical feature that deals with employee working postures in the workplace. Awkward postures and repetitive movements are primarily performance factors and difficulties in the workplace [3].

PT X is a company engaged in bottled drinking water in several sizes. The company found that lifting work on the SPS 600 ml box was done by standing up when taking it from the conveyor, then the operator made a bending motion when storing the boxes onto the pallet according to the number of piles that were conducted repeatedly and continuously. As a result of these conditions, workers at the company face various problems in the industry such as fatigue, discomfort, and back pain due to non-ergonomic machine or equipment design which causes stress to the musculoskeletal system [4]. Poor work posture reduces productivity by increasing health issues, musculoskeletal ailments, and physical stress [5,6]. Ergonomic difficulties are caused by improper work posture, bending, raising, and lowering an object, twisting, pushing, and pulling [7]. Further examination of the issues at risk of further and extensive investigations. To estimate work risk using Recommended Weight Limit (RWL) and Lifting Index (LI) for work physiology are used to calculate the energy produced so that work limits can be estimated.

Several studies indicate that obese workers are a contributing factor to musculoskeletal disorders, and these findings also suggest that additional weight in obese workers has a significant impact on the musculoskeletal structures of the back, increasing the risk of musculoskeletal disorders during load-handling [8].

Logistics activities present unique ergonomic challenges that are significantly different from traditional manufacturing processes. Research indicates that incorporating ergonomic principles into logistics can enhance worker well-being and operational efficiency. For instance, the use of double-back support frameworks has shown promise in reducing the risk of musculoskeletal disorders, improving posture, and decreasing perceived exertion during manual tasks in logistics environments. Additionally, training programs aimed at enhancing logistics personnel’s understanding of efficient practices have demonstrated significant improvements in knowledge and performance, which are crucial for optimizing logistics operations. Furthermore, integrating Lean Six Sigma with ergonomic principles can boost internal logistics efficiency, address warehouse management complexities, and improve productivity. Overall, a comprehensive approach that considers physical, mental, and social health, along with effective training and ergonomic design, is essential for fostering a productive logistics environment while minimizing hazard [9].

This research endeavors to fill a critical gap by spotlighting the significance of ergonomics in logistics operations, with a particular focus on distribution logistics environments. It underscores the importance of operator welfare—a pivotal element of the work environment—by addressing the health and safety concerns of individuals engaged in physical tasks. Through a comprehensive approach that incorporates the Nordic Body Map, Biomechanics, and Anthropometry methods, this study aims to enhance the comfort and safety of operators, ensuring they can perform their duties in an environment that supports their overall well-being.

The Nordic Body Map technique is a subjective valuation approach, which means that the effectiveness of its use is heavily dependent on the settings and scenarios encountered by employees at the time of the research, as well as the competence and experience of the observer in question [10]. In the domain of logistics, the use of the Nordic Body Map questionnaire is a relatively recent method. It gives researchers a deep insight into the hassles and disadvantages that operators face, allowing them to more accurately pinpoint issue areas. The use of the Nordic Body Map questionnaire provides a highly effective method for measuring the physical discomfort and pain experienced by the operator. This allows research to identify exactly the location and type of ergonomic problems that need to be fixed. Workers in the parts assembly industry have a high rate of musculoskeletal pain [11]. As a result, it is vital to enhance the workplace amenities that are utilized to maintain appropriate body posture.

The biomechanical method is the application of Newtonian mechanics to the neuromuscular and skeletal systems to calculate the amount of force occurring in each part of the worker's body as well as the internal forces acting within the body [12]. Implementing biomechanical and anthropometric methodologies in this study aids in the scientific and detailed assessment of occupational hazards. It serves as a solid foundation for building ergonomic work environments. The biomechanical and anthropometric technique enables researchers to properly quantify the occupational hazards associated with manual lifting jobs. This offers a firm foundation for ergonomic improvements by verifying that suggested modifications fit the physical features of the operator.

Catia software is used to support the design of work facilities by enabling the visualization of ergonomic solutions before implementation. This allows for adjustments and refinements to be made effectively, contributing to the research with practical recommendations to improve work conditions and operator welfare in distribution logistics.

The study makes a significant contribution to the field of ergonomic solution development in distribution logistics through its focused examination of logistical ergonomics, the adoption of sophisticated evaluation methodologies, and the presentation of evidence demonstrating the beneficial impact on worker well-being.

2 Literature review

2.1 *Ergonomics*

Ergonomics is a scientific subject that enhances human and overall system performance by studying the interactions between humans and other system elements. The profession applies ideas, principles, data, and methodologies [13]. Ergonomics is a systematic approach to evaluating and developing the relationship between individuals and the systems they interact with. Its primary objective is to optimize the quality of life for the particular group of individuals who engage with the system, taking into consideration their attributes, capabilities, requirements, anticipations, tasks performed, and the collection of factors (technological, environmental, organizational, and cultural) that impact them [14]. Ergonomics is a concern in all manual handling jobs, and automation is one of the primary methods for overcoming such issues. Because automation raises expenses such as installation and maintenance, it is impossible to implement. Utilizing ergonomic assessment instruments to ascertain the level of risk associated with one's work and work posture, it is subsequently necessary to devise a workable resolution to surmount such obstacles [15].

2.2 *Musculoskeletal disorder*

Work-related musculoskeletal disorders (WMSDs) are prevalent occupational illnesses that predominantly impact the upper and lower limbs, the lower back, and the neck [16]. Material handling activities that are conducted manually and inappropriately can cause losses to work accidents and result in complaints of musculoskeletal disorders. Complaints of musculoskeletal disorders can be complained of with pain ranging from very mild to very painful in the skeletal muscle. Complaints regarding joint, ligament, and tendon injury are the result of extended and repetitive static load application to muscles.

2.3 Biomechanics

Biomechanical risk variables such as articular positions, efforts, repetitive work, static posture, and vibrations have been extensively studied, and it is well understood that the effects of biomechanical risk are determined by the duration of exposure, the duration of recovery, and temperatures [17]. These studies show a relationship between risk factors, particularly their combined effects, and the development of upper limb MSDs [18]. While correlations have been drawn between the intensity of biomechanical risk factors at work and the risk of MSD development, Lanfranchi and Duveau pointed out that certain low physiological demand tasks, such as working in front of a computer and assembling electronic components, resulted in significant stress and mental load [19].

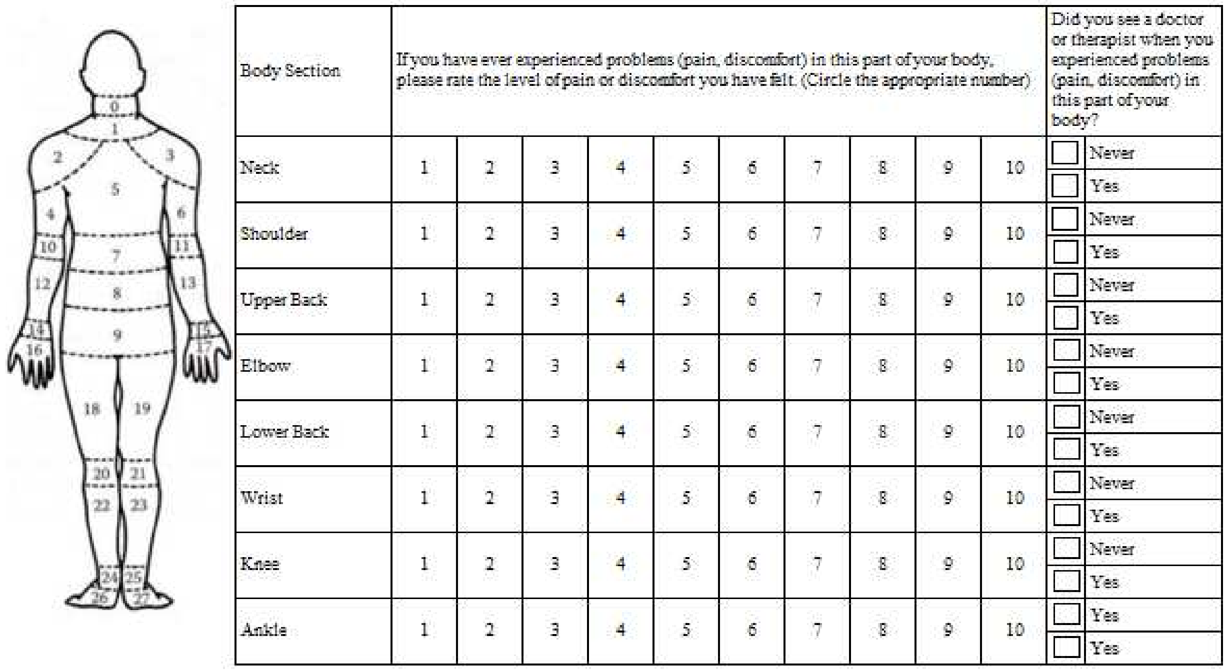
Biomechanics, particularly occupational biomechanics, studies how workers interact with their physical environment, including equipment and materials, to enhance safety and efficiency. This sub-discipline applies mechanical principles to understand human movement and the forces acting on the body, aiming to reduce the risk of musculoskeletal disorders. Research in biomechanics covers a range of applications, from sports performance to clinical contexts, where understanding mechanical forces is crucial for designing medical devices and surgical techniques [20]. Additionally, biomechanics integrates principles from engineering and biophysics to analyze the structural and functional aspects of living organisms, which is essential for designing ergonomic tools and workspaces that alleviate stress on the musculoskeletal system [21].

2.4 Manual material handling

Manual Material Handling (MMH) is the leading cause of weariness, waist pain, and spinal cord damage. Lifting activity was found to be one of the causes of a high level of injury in some manual material handling activities. In light of the risks associated with manual material handling, it is necessary to implement an intervention or enhance ergonomics to mitigate the potential for worker injuries [22].

2.5 Nordic body map questionnaire

The Nordic Body Map (NBM) is a tool used to pinpoint areas of muscle or joint discomfort experienced by workers. It categorizes body parts using numbers from 0 to 27, ranging from the neck to the feet. Six factory workers were provided with and completed the NBM questionnaire [23]. Figure 1 is the questionnaire from the Nordic Body Map [24].



Body Section	If you have ever experienced problems (pain, discomfort) in this part of your body, please rate the level of pain or discomfort you have felt. (Circle the appropriate number)									Did you see a doctor or therapist when you experienced problems (pain, discomfort) in this part of your body?
Neck	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Shoulder	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Upper Back	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Elbow	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Lower Back	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Wrist	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Knee	1	2	3	4	5	6	7	8	9	10	☐ Never ☐ Yes
Ankle	1	2	3	4	5	6	7	8	9	10	☐ Yes ☐ Yes

Figure 1 Questionnaire Nordic Body Map

2.6 Gaps from the previous research studies

This investigation aims to enhance the ergonomics of work facilities for operators in a bottled water production line by employing a comprehensive methodology. This method entails the identification of operator complaints, the assessment of work hazards using biomechanical and anthropometric methods, and the application of design through Catia to create more ergonomic work facilities. In contrast, a previous study titled "Work Posture Analysis of Manual Material Handling Using the OWAS Method" investigated a small-scale maize chip facility. The objective of the investigation was to quantify injury risk indexes and offer precise suggestions for improving worker safety. The WinOWAS software was employed to analyze work posture and evaluate injury risks based on specific postures and loads, while the Nordic Body Map (NBM) questionnaire was employed to identify worker complaints. In contrast to the previous research, which was more focused on enhancing posture and burden in a specific factory environment, the current study provides a more comprehensive and integrated solution for enhancing workplace safety [23].

A decision matrix was employed to emphasize ergonomic procedures at a coal mining site in South Kalimantan, Indonesia, in another study. To ascertain which workgroups necessitated additional evaluation in light of ergonomic risks identified from physical distress and burden, this matrix combined incident data, responses from the Nordic questionnaire, and interviews with supervisors [25]. Musculoskeletal disorders (MSDs) were the subject of another study, which concentrated on the prevalence of MSDs in Indonesia's informal sector and across industries. The study employed quantitative data, including the Nordic Body Map (NBM) and Rapid Entire Body Assessment (REBA), to investigate the prevalence of MSD complaints and work posture among textile workers. They identified risk factors, including gender, age, work environment, and poor posture, that could contribute to MSDs. The purpose of this investigation was to ascertain the prevalence and risk factors of MSDs and to devise comprehensive preventive strategies. Compared to the previous study, which was more comprehensive and focused on the analysis of MSD risk across a variety of industries, the current study is more focused on the ergonomic issues in bottled water production facilities and integrates the most recent technology to enhance ergonomic design [26].

In a previous study on seafarers, the incidence of MSDs was also investigated by investigating the effects of age, years of service, and smoking behaviors. The Nordic Body Map questionnaire and health examination data of fishermen were the primary instruments utilized in this cross-sectional study, which also employed statistical analysis methods such as Chi-square. Musculoskeletal disorders were not significantly associated with age, according to the results. However, years of service were. Nevertheless, this research procedure was deemed to be restricted by its dependence on questionnaires rather than comprehensive medical examinations [27].

Previous research has generally focused on specific evaluations, such as identifying musculoskeletal risks based on factors like age and work environment or analyzing work posture in specific factory settings using tools such as the Nordic Body Map and REBA. While these methods were effective in certain contexts, they were limited in scope and lacked a comprehensive, integrated approach. In contrast, the present research offers a more holistic and integrated methodology. It includes hazard evaluations using biomechanical and anthropometric methods, develops ergonomic interventions tailored to the facility's design, and addresses operator complaints through the use of advanced software like Catia. This ensures more effective implementation of ergonomic solutions, significantly enhancing the well-being of workers in logistics distribution environments.

Moreover, while previous studies often focused on specific industries or individual risk factors, the current research takes a more comprehensive approach by combining multiple assessment methods and cutting-edge technology. As a result, this research provides a more robust, technology-driven solution for improving ergonomic work facilities, which not only fills the methodological gap left by earlier studies but also offers practical, evidence-based improvements. By addressing both the physical and operational aspects of ergonomics, this study surpasses previous research, providing a new standard for ergonomic interventions in distribution logistics.

3 Methodology

The research follows a systematic design, divided into key stages to address the ergonomic risks associated with manual lifting tasks in logistics operations. The stages are as follows:

1. Introduction to the Study: Initial observations were made regarding operator complaints related to fatigue, lifting frequency, and the distances involved in handling SPS 600 ml boxes. These insights guided the identification of ergonomic risks and informed the research direction.
2. Literature Review: A comprehensive review of literature related to ergonomics, biomechanics, and anthropometry was conducted. This review provided the theoretical foundation necessary for formulating the research problem and informed the design of ergonomic interventions.
3. Problem Formulation and Research Objectives: Based on the initial observations and literature, key problems were formulated, including risks associated with manual lifting tasks. The primary research objective was to design ergonomic interventions to mitigate these risks, focusing on reducing musculoskeletal strain through improved work facility design.
4. Data Collection: Data was collected from a sample of 9 operators using the Nordic Body Map questionnaire to assess their physical discomfort during box lifting tasks. Additionally, their work postures and movements were recorded during the transfer of boxes from the conveyor to the pallet. The rationale for selecting 9 operators was based on representativeness and practicality, given the constraints of the workplace environment.

5. Data Processing: The data were processed by analyzing the questionnaire responses and conducting biomechanical calculations, including forces such as compressive (Fcompression) and shear (Fshear) forces. Statistical tests were employed to validate the findings, ensuring the reliability of the data.
6. Analysis: The analysis focused on operator discomfort and the biomechanical forces exerted during lifting tasks. By correlating the Nordic Body Map results with biomechanical data, potential risks were identified, leading to recommendations for ergonomic improvements, including the potential introduction of lifting aids.
7. Design of Work Facilities: Based on the analysis, ergonomic work facilities were designed using anthropometric data and technologies such as AutoCAD and Catia. These designs aimed to minimize operator discomfort and reduce the physical demands of manual lifting tasks.
8. Conclusions and Recommendations: The research culminated in recommendations for the implementation of ergonomic interventions to improve operator well-being and safety. These recommendations were based on both biomechanical assessments and ergonomic design principles.

Illustration of SPS 600 ml Box Lifting Process: The current material lifting procedure involves lifting the 600 ml SPS box from the conveyor onto the pallet, where the operator stands and repeatedly bends while storing the box. Figure 2 illustrates lifting and storing the 600 ml SPS box from the conveyor to the pallet.

Figure 2 SPS box lifting and storage process 600 ml from conveyor to pallet

With these improvements, the research methodology is structured as a clear research flow, with data collection and questionnaire distribution included as integral parts of the methodology.

4 Results and discussion

Figure 3 presents Nordic Body Map graphics, a graph of the operator's specific concerns about the task.

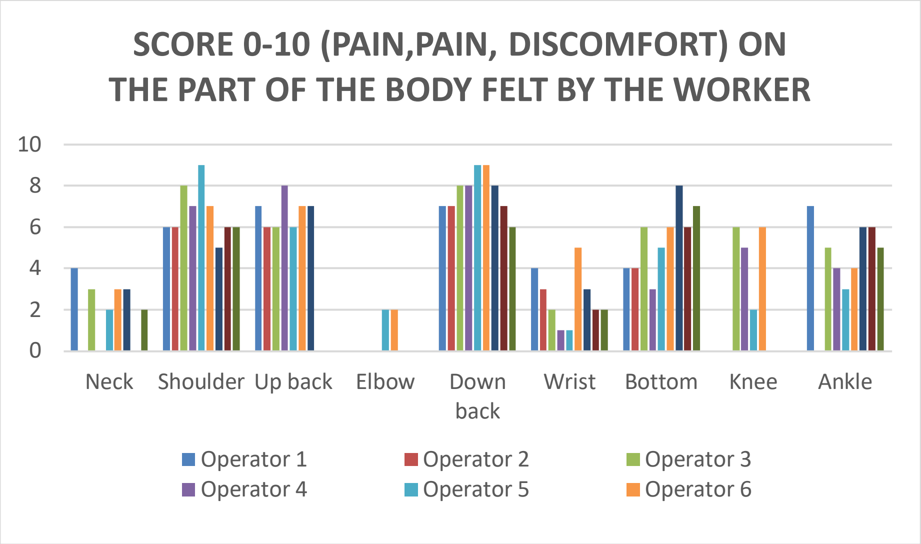


Figure 3 Nordic body map graphics

Complaints about the shoulders, lower back, buttocks, or thighs are felt by the operator when lifting loads above the conveyor and placing them on a pallet that is not at the same height as the operator. This requires the operator to perform repeated bending movements. Prolonged injury effects can occur if no immediate repair or additional work facilities are implemented. It is necessary to design ergonomic aids to facilitate operators and minimize work risks.

The occupational risk assessment uses the biomechanical method in equations (1) to equations (4) for the calculation of occupational risk assessment using the lower back model static method on the L5/S1 segment on the 600 ml SPS box moving operator. The results of the biomechanical calculation of the L5/S1 static model are the

1st stack to the 6th pile of the 1st load to the 60th load. Figure 4 shows an example of lifting a load of 3 stacks 1 operator 3.

Figure 4 Example of load lifting 3 stack 1 operator 3

Based on the existing issues, research was conducted on six workers involved in lifting the 600 ml SPS box to determine the operator's complaints. The recapitulation of the calculation of the biomechanics of the lower back static model at the L5/S1 point of lifting is shown in Table 1 shows the recapitulation of displacement biomechanics calculations, Table 2 and Table 3 show recapitulation of displacement biomechanics calculations.

Table 1 Recapitulation of lifting biomechanics calculations

Load To-	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
3	1	3	7,166.67	7,934.67	2,616	Risk

Table 2 Recapitulation of displacement biomechanics calculations

Load To -	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
1	1	2	12,390	12,694.2	717.6	Risk
2	1	2	11,460	11,865.6	670.8	Risk
3	1	3	18,283.3	18,547.3	760	Risk
4	1	3	19,300	19,564	760	Risk
5	1	4	17,976.7	18,557.7	581	Risk
6	1	1	9,650	10,124.5	442	Risk
7	1	1	8,933.33	9,342.83	507	Risk
8	1	1	10,100	10,444.5	552.5	Risk
9	1	4	17,473.3	17,971.3	664	Risk
10	1	4	18,410	18,908	664	Risk
11	2	2	10,340	10,925	507	Risk
12	2	2	10,500	11,077.2	522.6	Risk
13	2	3	15,400	15,960	560	Risk
14	2	3	16,616.7	17,128.7	616	Risk
15	2	3	19,600	20.192	536	Risk
16	2	1	8,716.67	9,243.17	383.5	Risk

Table 3 Recapitulation of displacement biomechanics calculations

Load To -	T	O	Muscle (N)	Fc (N)	Fs (N)	Information
17	2	1	8,550	9,031	435.5	Risk
18	2	1	10,650	11,163.5	403	Risk
19	2	6	10,050	10,563.5	403	Risk
20	2	6	12,933.3	13,472.8	364	Risk
21	3	2	11,420	12,090.8	405.6	Risk
22	3	2	14,810	15,519.8	327.6	Risk
23	3	3	11,683.3	12,363.3	424	Risk
24	3	3	11,350	12,078	336	Risk
25	3	3	11,833.3	12,521.3	416	Risk
26	3	1	7,766.67	8,403.67	110.5	Risk
27	3	1	8,516.67	9,153.67	110.5	Risk
28	3	1	9,383.33	10,000.8	214.5	Risk
29	3	6	6,383.33	7,020.33	110.5	Risk
30	3	6	5,866.67	6,497.17	169	Risk
31	4	2	12,916.4	13,535.6	282.83	Risk
32	4	2	12,965.4	13,699.2	214.03	Risk
33	4	6	8,575	9,205.63	101.92	Risk
34	4	6	5,912.67	6,549.67	0	Risk
35	4	6	6,027	6,651.26	108.29	Risk
36	4	1	9,391.67	10,022.3	89.18	Risk
37	4	1	9,212	9,842.63	31.85	Risk
38	4	1	8,575	9,205.63	31.85	Risk
39	4	6	6,141.33	6,771.96	76.44	Risk
40	4	6	6,370	7,000.63	44.59	Risk
41	5	2	12,910	13,651	257.4	Risk
42	5	2	12,700	13,456.6	171.6	Risk
43	5	6	7,300	7,943.5	32.5	Risk
44	5	6	6,683.33	7,326.83	0	Risk
45	5	5	9,683.33	10,376.3	112	Risk
46	5	1	8,000	8,643.5	19.5	Risk
47	5	1	8,150	8,800	0	Risk
48	5	6	7,066.67	7,170.67	0	Risk
49	5	6	5.483,33	6,126.83	0	Risk
50	5	6	6,550	7,193.5	0	Risk
51	6	2	10,133.2	10,706.5	496.86	Risk
52	6	2	10,290	10,855.7	512.15	Risk
53	6	6	15,092	15,640.8	548.8	Risk
54	6	6	16,284.3	16,786.1	603.68	Risk
55	6	6	19,208	19,788.2	525.28	Risk
56	6	1	8,542.33	9,058.3	375.83	Risk
57	6	1	8,379	8,850.38	426.79	Risk
58	6	1	10,437	10,940.2	394.94	Risk
59	6	6	12,142.2	12,784.8	504.308	Risk
60	6	6	16,143.9	16,819	455.50	Risk

Based on the findings, six operators with weights of 50, 55, 63, 65, and 68 kg were analyzed. The operators lift 60 loads organized into six heaps on a pallet, with 10 loads of the same weight of 15 kg in each pile. The results of the low back model calculation reveal that the compressive force (Fcompression) and shear force (Fshear) do not meet safety standards. The 60 loads exhibit varied results; if one criterion is not met, the operator's task is regarded as unsafe.

The compressive force in the 6th pile, the 55th load handled by the 6th operator, is more than the safety criterion, with the largest Fcompression being 19778.2 N, influenced by the operator's poor body posture when lifting the weight. The smallest Fshear value, 0 N, is observed in the 48th load handled by the 6th operator in the 5th pile. Despite the shear value showing 0 (not risky), the work is declared risky due to a compressive force of 7170.67 N. Recommendations for designing work facilities to reduce work risk during lifting transfers are necessary. Figure 5 shows the facilities before the design, Figure 5 shows current work facilities, while Figure 6 shows Hydraulic Pallet Work Facility Design and Size.

Figure 5 Current work facilities

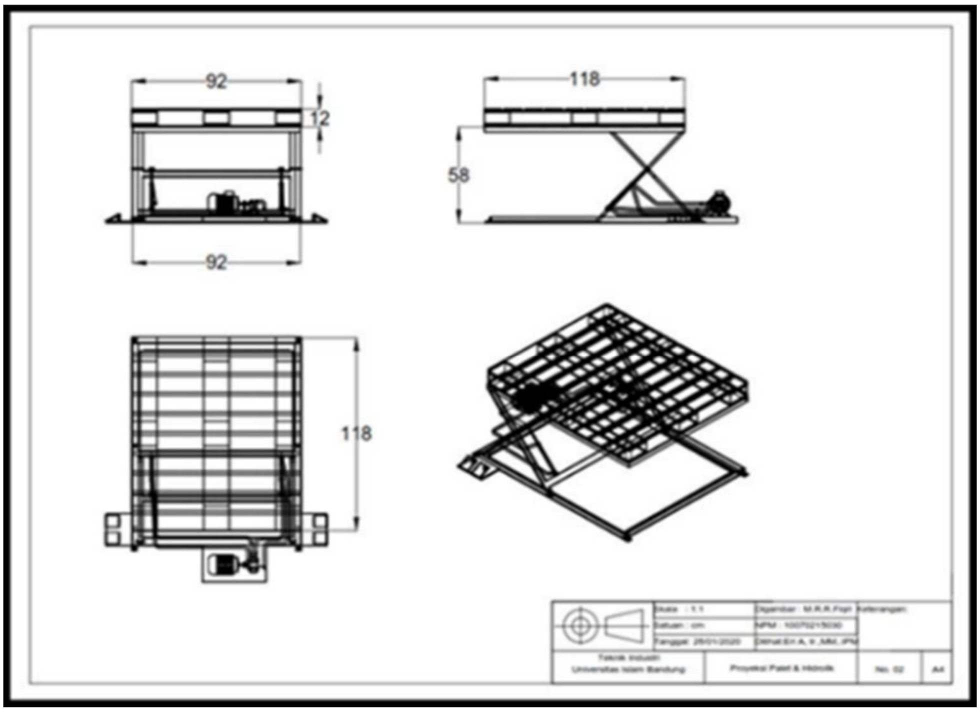


Figure 6 Hydraulic pallet work facility design and size

Determine the needed body proportions initially while developing work facilities. Table 4 displays work dimension facilities, the specified body dimensions, and their applications.

Table 4 Work dimension facilities

No.	Work facilities design	Work facility dimension	Body dimension	Reason
1	Hydraulicpallet	Hydraulic base width	3 x box (2 x boxwidth + 1 x box length)	To determine the maximum length of the hydraulic pallet hydraulic
2		Hydraulic base length	4 x box (1 x boxlength+ 3 x box width)	To determine the maximum height of the hydraulic pallet hydraulic
3		Hydraulic pallet height	Standing elbow	To determine the maximum height of the hydraulic pallet sothe operator can work as comfortable as possible

Figure 7 shows a work facility design in the form of a hydraulic pallet that has been changed to the chosen body dimensions and final facility size. Based on visualization findings in the Catia program, the operator no longer bends while performing tasks, reducing work risk by adding new work facilities since no shear force is created at locations L5/S1. Designing new work facilities using hydraulic pallets that function to raise and lower pallets prevents operators from bending when storing or lifting loads on conveyors.

The simulation of the work facility design, featuring an adjustable-height hydraulic pallet, demonstrated that operators could maintain an upright posture during lifting tasks. The compressive force (Fc) and shear force (Fs) recorded during all box-lifting activities from box 1 to 60 were significantly reduced to 3,350 N and 185.31 N, respectively, which are well within safe ergonomic limits. This represents a marked improvement from the earlier measurements, where compressive forces exceeded 19,778.2 N, indicating a high risk of injury. By allowing operators to maintain proper posture and minimize bending movements, the hydraulic pallet effectively reduces biomechanical risks, ensuring a safer working environment.

The upright standing position of the operator during storage, without continuous and repeated bending movements, minimizes work risks and allows for the implementation of new facilities.

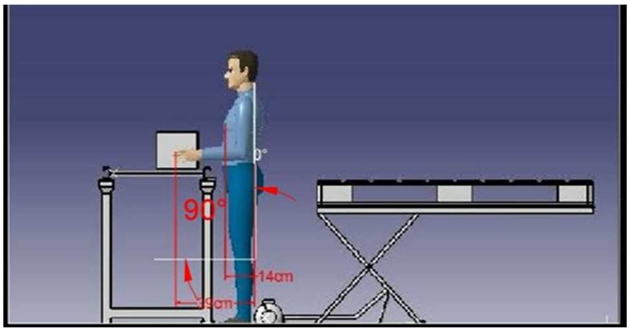


Figure 7 Work facilities design

5 Conclusions

The biomechanical analysis of lifting and transferring 600 ml SPS boxes, focusing on the lower back's static model at the L5/S1 point, has highlighted significant ergonomic concerns. Our findings indicate that the operators' postures during lifting and their positions when storing loads are unsafe. These safety issues are primarily determined by the operator's body angle and the distances between the load's center of mass and the L5/S1 point, as well as between the body's center of mass and the L5/S1 point. Proper manual lifting techniques, which include keeping the load close to the body's center, positioning the feet near the load, maintaining straight back and shoulders, and ensuring load and body position stability, are not currently being followed.

To mitigate these risks, we propose introducing a hydraulic pallet that adjusts in height, allowing operators to store or load items without bending. Simulation results from this intervention indicate a significant risk reduction, with compressive forces (Fcompression) reduced to 3,350 N—within safe criteria—and shear forces (Fshear) eliminated at the L5/S1 point. By enabling operators to maintain an erect posture during storage tasks, the redesigned work environment significantly decreases the risk associated with repetitive bending actions.

This study opens avenues for future research aimed at a deeper and broader understanding of logistical ergonomics and manual lifting. Future work could focus on the deployment and evaluation of ergonomically designed work facilities, examining their impact on operator well-being, productivity, and incidence of work-related injuries. The integration of monitoring technologies, such as motion sensors or wearable devices, in logistics settings presents a promising area for investigation, offering the potential for real-time monitoring of operator behaviors and quicker responses to emerging workplace hazards.

Further research could develop more precise ergonomic guidelines for the distribution logistics environment, providing businesses with the tools needed to create safer and more efficient workspaces. An in-depth biomechanical analysis of operators performing manual lifting tasks could enhance our understanding of the physical impacts of these tasks, including posture and joint stress. Investigating the effects of environmental factors such as temperature, lighting, and noise on operator well-being could yield a comprehensive view of the elements that influence ergonomic conditions in the workplace.

Incorporating psychological aspects of work, including stress levels and job satisfaction, could further elucidate the complex interplay between physical and mental health in occupational settings. Continued research in this field is essential for generating actionable insights into improving logistics ergonomics, leading to safer and more productive work environments that benefit both operator well-being and overall productivity.

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Review process

Single-blind peer review process.